Precision wavelength calibration for radial velocity measurements using uranium lines between 3800 and 6900 Å

Rishikesh Sharma* and Abhijit Chakraborty
Physical Research Laboratory, Astronomy and Astrophysics Division, Ahmedabad, Gujarat, India

Abstract. We present the precise wavelength calibration of a high-resolution spectrum using uranium (U) lines in the wavelength range of 3809 to 6833 Å for precision radial velocity (RV) measurements for exoplanet detection or related astrophysical sciences. We identify 1540 well-resolved U lines from a high-resolution ($R = 67,000$) spectrum of the uranium-argon hollow cathode lamp (UAr HCL) using PARAS spectrograph in the aforesaid wavelength range. We calculate the neutral and first allowed transitions (Ritz wavelength) of U from its known energy levels and compare them with our observed central wavelengths. We measure an offset of $-0.15 \text{ mÅ}$ in our final U line list. The line list has an average measurement uncertainty of 15 ms$^{-1}$ (0.013 pixels or 0.28 mÅ). We included these lines to the PARAS data analysis framework to perform the wavelength calibration and then calculate the multi-order RV of PARAS spectra. The typical dispersion of residuals around the wavelength solution of a UAr spectrum, using U lines, is found to be 0.8 mÅ ($\sim 45 \text{ m s}^{-1}$). With the use of this line list, we present our results for the precision RV of an on-sky source (an RV standard star) and an off-sky source (an HCL) observed with PARAS along with UAr HCL. We measure the dispersion in absolute drift difference between two fibers (inter-fiber drift) for a span of 6.5 h to be 88 cm s$^{-1}$, and the RV dispersion ($\sigma_{\text{RV}}$) for an RV standard star, HD55575 over the course of $\sim 450$ days to be $3.2 \text{ m s}^{-1}$. These results are in good agreement with the previous ones measured using the ThAr HCL. It proves that the ThAr HCL with $\sim 99\%$ pure-Th is replaceable with the UAr HCL for the wavelength calibration of the high-resolution spectrographs such as PARAS ($R \leq 67,000$) to achieve an RV precision of 1 to 3 m s$^{-1}$ in the visible region. © 2021 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: 10.1117/1.JATIS.7.3.038005]

Keywords: hollow cathode lamps; wavelength calibration; high-resolution spectrographs; radial velocity.

Paper 20163 received Nov. 10, 2020; accepted for publication Jul. 27, 2021; published online Aug. 18, 2021.

1 Introduction

The sudden increase in the population of exoplanet candidates in the last decades from various space-based (such as CoRoT,1 Kepler & K2,2 and TESS3) and ground-based transit surveys (such as SuperWASP4 and KELT5) has opened a quest among the scientific community to build the high-precision radial velocity (RV) spectrographs, which can go down to sub-1 m s$^{-1}$ of RV precision and eventually, detect and confirm the exoplanet candidates. One of the main challenging aspects for such instruments is the wavelength calibration technique, which is evolved from the initial and established techniques of iodine cell and hollow cathode lamps (HCLs) to Fabry–Perot etalon and highly precise high-frequency laser combs. The laser frequency combs (LFCs) used in various spectrographs, such as EXPRESS6 ESPRESSO,7 HARPS,8 and HPF,9 are the latest and most precise equipment for the wavelength calibration that have shown up to 2.5 cm s$^{-1}$ of RV precision on HARPS8 over a short term (2 h).10 In addition to being the most advanced system for wavelength calibration, the use of LFCs is limited due to their cost and

*Address all correspondence to Rishikesh Sharma, rishikesh@prl.res.in

2329-4124/2021/$28.00$ © 2021 SPIE

J. Astron. Telesc. Instrum. Syst. 038005-1 Jul–Sep 2021 • Vol. 7(3)
complexity. Alternatively, the conventional system for calibration, such as HCLs\textsuperscript{11} (e.g., ThAr), is widely used in the astronomical spectrographs due to their relatively long life, easy handling, simple structure, and less maintenance. Th metal being a single isotope, having narrow lines and a dense spectrum, is used for the wavelength calibration of the astronomical spectrographs. PARAS (PRL Advanced Radial-velocity Abu-sky Search)\textsuperscript{12,13} is a precision RV fiber-fed, temperature- and pressure-controlled spectrograph connected to a 1.2-m telescope at PRL Mt. Abu Observatory in Gurushikar, Mt. Abu, India. The high-precision RV spectrographs, such as HARPS and PARAS, have used Th-Ar HCL for wavelength calibrations and shown long-term stability up to 0.8\textsuperscript{14} and 1 m s\textsuperscript{12},\textsuperscript{12} respectively. The long-term stability refers to the RV stability achieved over the course of 3 months or more.

The ThAr HCLs from S & J Juniper & Co\textsuperscript{15} are currently used in many precision RV spectrographs. However, these HCLs with a cathode made of pure Th (up to 99% purity) are no more commercially available; instead, they are available with a cathode made of thorium-oxide (ThO). Reference \textsuperscript{16} confirmed that this oxide impurity is responsible for the presence of molecular oxide bands and other unwanted features in the HCL's spectra. Thus, it becomes difficult to identify the faint Th atomic lines in the oxide bands and make them useless for wavelength calibration in some regions, making it tough to precisely characterize and track the Th lines. It degrades the precision of wavelength calibration of high-resolution spectra and, ultimately, the RV precision. It becomes paramount to choose the proper element, which can replace the Th element in the HCLs and equally have a vast number of transitions to provide precise wavelength calibration for the astronomical spectrographs.

We looked into the actinide series of the periodic table and found that U fits closest to the Th, and U HCLs are also readily available in the commercial market. The U HCLs are available with the cathode made of natural U. Unlike Th, the U atom is found in three isotopic forms in nature, namely U\textsuperscript{238}, U\textsuperscript{235}, and U\textsuperscript{234}, with abundances of \textasciitilde99.275\%, \textasciitilde0.720\%, and \textasciitilde0.005\%, respectively. Reference \textsuperscript{17} showed that the second most abundant isotope has a hyper-fine structure, and thus its features spread over many lines with very less intensity and will not cause any significant problem in RV precision. Even, the recent study by Ref. \textsuperscript{18} (here on, S18) showed that the U could replace the Th in ThAr and thorium-neon (Th-Ne) HCLs for the wavelength calibration in the visible and NIR range more precisely, as U has a greater number of lines than Th in both the wavelength regions. However, their line list starts from mid-visible and stretches up to NIR, i.e., in the wavelength range of 5000 to 17000 Å, which does not fully cover the PARAS wavelength range of 3809 to 6833 Å. Reference \textsuperscript{19} (here on, P80) was also previously published the U line list in the wavelength range of 3846 to 9091 Å. We acknowledge both previous works of P80 and S18. The P80 line list covers the whole range, which is used for the wavelength calibration in PARAS spectra and hence, more suitable for comparison with our line list. Despite having more lines than Th in the visible range, U lines have never been checked \textit{a priori} for long-term stability with high-resolution spectrographs.

This work primarily focuses on the precise wavelength calibration of an astronomical spectrograph such as PARAS using the U lines in the visible band (3809 to 6833 Å) for RV precision of 1 to 3 m s\textsuperscript{1} for exoplanet detection, characterization, and related astrophysical sciences. Here, we measure the RVs of a well-known RV standard star HD 55575 over a period of 450 days in order to check the feasibility of using U lines instead of Th lines for precision RV measurements of stars.

We describe the observations with PARAS in Sec. 2, while Sec. 3 focuses on the data reduction and wavelength calibration of the UAr spectrum for identifying the lines. Section 4 elaborates the algorithms used for identifying the line features from a UAr spectrum and various steps involved in selecting the final line list, including those from U I and U II transitions. In Sec. 5, we compare the observed central wavelength of selected lines and the calculated Ritz wavelength and discuss the final line list. In Sec. 6, we incorporate the U line list in the PARAS wavelength calibration framework to do the RV measurements on an RV standard star HD55575 and show the on-sky performance for 450 days for the long-term stability of more than a year. Section 7 describes the possible future work, while Sec. 8 summarizes our results.
2 PARAS Observations with UAr HCL

2.1 Experimental Setup

We acquired the high-resolution spectra of the UAr HCL using the PARAS spectrograph coupled with the 1.2-m telescope at Gurushikhar Observatory, Mt Abu, India. The UAr HCL from Photran Pty. Ltd. is used for the experiment. The spectrograph works at a resolving power of \( \sim 67,000 \) at the blaze peak wavelength of 5500 Å. It is a white-pupil configuration fiber-fed spectrograph kept inside a thermally controlled vacuum chamber. There are two fibers, namely star-fiber (or A fiber) and calibration-fiber (or B fiber) that feed the starlight and calibration lamp light into the spectrograph, respectively. Inside the vacuum chamber, the light beam from both the fibers is collimated by an off-axis parabolic mirror, then dispersed by an R4 echelle grating, and then cross-dispersed by a prism, re-imaged onto the 4k x 4k e2v CCD, which has a pixel size of 15 μm. The details of the spectrograph are given in Ref. 12. The CCD detector has a sampling of \( \sim 4 \) pixels and an average dispersion of 0.021 Å per pixel. It implies that each pixel corresponds to a velocity of 1145 m s\(^{-1}\). The previous study has represented that a HCL’s life and intensity of the emitted lines are strongly dependent on the operating current (OC). The increase in OC increases the line intensities and number of transitions but reduces the HCL’s life. We set the OC to 10 mA to have a sufficient number of U transitions and, at the same time, to increase the HCL’s life. We use the C610 HCL power supply from Cathodeon, which provides the current stability up to 0.05% after the warm-up time of 15 min, throughout the observations. We note here that the HCL was kept switched on throughout the night of observation.

2.2 Off-Sky Observations

Initially, we acquired a spectrum of the UAr HCL by illuminating its light in the star-fiber (or A-fiber) to identify the U emission lines. To do the initial wavelength calibration of the acquired UAr spectrum, a ThAr spectrum was also acquired in the same way just before the UAr spectrum. The spectrograph stability is such that the drift between the ThAr and the UAr spectrum is negligible for our purpose. We did not use a neutral density filter for off-sky observations, and we set the exposure time at 400 s to have the high signal-to-noise ratio (SNR) spectra as well as to make sure that the high-intensity lines should not saturate the CCD.

We also acquired a series of 400-s UAr exposures by simultaneously illuminating the UAr HCL’s light in both the fibers (A and B fibers) for \( \sim 6.5 \) h, to track each line’s stability and calculate the instrumental drifts for the mentioned time interval.

2.3 On-Sky Observations

We observed an RV standard star HD55575, for the span of 450 days, acquiring 27 spectra during the period. These observations were done by illuminating the A-fiber with the starlight and simultaneously illuminating the B-fiber with the UAr light for precise wavelength calibration. The exposure time for these observations was set to 1200 s, and the SNR ranges between 70 and 80 at 5500 Å. We use the neutral density filter (FSQ-OD50 from Newport) with the UAr HCL for these long exposures to ensure that the high-intensity lines should not saturate the CCD. These spectra are used to calculate the RV precision achievable on stars with UAr HCLs (see Sec. 4).

3 Data Reduction and Analysis

We used the custom-designed automated pipeline to extract the U spectra from PARAS two-dimensional images. The pipeline is based on the REDUCE package of Ref. 22, which is an optimal extraction code to extract the cross-dispersed echelle spectra. We use the existing ThAr wavelength calibration process to do the initial wavelength calibration of the UAr spectrum, as described in Ref. 12. The ThAr spectrum, which was acquired just before the UAr spectrum as discussed in Sec. 1, is wavelength calibrated using this existing process in the PARAS pipeline. The pipeline uses a template of Th lines for the wavelength calibration. A template is defined here as an order-wise list of central wavelengths of Th lines to use for wavelength calibration. The template has a total of around 1000 Th lines with at least 8 lines per order. For a particular
order in the ThAr spectrum, the pixel position of the central wavelength for each line is found, and then a Gaussian is fitted to precisely determine the line position in terms of pixels. These fitted pixel positions and the line’s central wavelengths for that order are then fit with a third-order polynomial. The resultant polynomial is used as the wavelength solution for that order. In this way, the wavelength calibration is done for all the 70 orders. This ThAr wavelength solution is applied over the UAr spectrum which was acquired for the line identification process.

4 Identification and Selection of U Lines

The wavelength-calibrated UAr spectrum is now used for the line identification and selection process. The echelle spectra have overlapping wavelength regions over the two consecutive orders. We stitched the UAr spectrum distributed among various echelle orders for line identification and characterization by weighing the overlapping regions in the two consecutive orders according to their SNR. This stitched spectrum is further used for the line identification process.

First, we identified all the line features present in the stitched UAr spectra, based on the slope of the spectra at each point, considering only those features with SNR \( \geq 30 \), to minimize the uncertainties in finding the central wavelength \( \sigma_\lambda < 1 \) mÅ. We characterized each of these identified lines by fitting them with the MPFITPEAK23 Gaussian function, written in IDL, and determined the line parameters. We have identified nearly 4500 emission features in this step. The intensities of these lines spread across the whole dynamic range of the CCD detector, and three high-intensity lines among them falling at 5915.3867, 6449.1625, and 6826.9185 Å are found to be saturated. These lines are not considered for further selection and are excluded from the identified lines.

The lines identified in the last step are supposed to be emitted by either cathode filling metal U or the filling gas Ar. It is well-known that the Ar lines are not suitable for the precise wavelength calibration and can show wavelength drifts of tens of m s\(^{-1}\).24 The next step in the U line selection procedure is to remove the Ar lines. So, we identified the argon lines using the ThAr line list,24 based on the fitted central wavelength of each line’s Gaussian profile and eliminated them for further selection process. Reference 24 used the HARPS spectrograph for their work. Since HARPS has a higher resolution than PARAS, all the argon lines from our spectra must be listed in the cited line list. We could identify 270 Ar lines in the UAr spectrum and removed them from the lines identified in the last step. We plotted the linewidths (FWHM of the Gaussian) of Ar lines in red color in Fig. 1. It can be seen that their linewidths are consistent with the PARAS instrumental resolution. The blended lines present in the UAr spectra can induce the centroid

![Fig. 1](image)

Fig. 1 The FWHM of all the 4500 emission features identified in the first step (see Sec. 4) is plotted here in gray color. Overplotted in red are the widths of 270 Ar lines identified in Sec. 4. The blue dots represent the linewidths of the 1819 lines of the preliminary U line list (see Sec. 4). It can be seen that the selected U lines and identified Ar lines are consistent with the instrumental resolution and have linewidths between 3.75 and 6 km s\(^{-1}\).
shifts much larger than the measurement errors associated with line positions. Therefore, it is better to remove the possible blends from the remaining lines. We used the linewidth of the remaining lines to identify the blends. Since the instrument works at a certain resolution ($R \sim 67,000; 4.5 \text{ km s}^{-1}$), we only considered those lines whose widths are consistent with the instrumental resolution and lie within 3.75 to 6.0 km s$^{-1}$. This eliminates the possible dangerous blends in the UAr spectra to be included in our further selection of the lines. In Fig. 1, we have plotted the linewidths of all the identified lines in gray color. The lines that pass the above selection criteria have been highlighted in blue. In Fig. 1, few lines among 4500 lines with significantly smaller linewidths ($\leq 3.75 \text{ km s}^{-1}$) can be seen, which could be due to some artifacts or bad pixels and hot pixels in the CCD detector. As a precaution, we also removed those lines which appear single in our spectra but have other line features within, listed in the P80 line list, due to a much higher resolution of the instrument used by them ($R = 600,000$).

Since our main aim is to do the precise wavelength calibration of the spectrograph using UAr spectra, we strictly consider the lines that are well-resolved or well-separated from their neighbors to fit a single-peaked one-dimensional Gaussian. This implies that the two neighboring lines with least separation of two-resolution elements are considered for further selection. We have plotted a histogram (see Fig. 2), which shows the distance between two consecutive lines from our final line list. The minimum separation is $\sim 9 \text{ km s}^{-1}$, which is nearly equal to two-resolution elements of PARAS.

In this way, the total number of lines selected after passing through each of the above selection steps was 1819. We call this line list as the preliminary U line list. The instrumental resolution calculated using these lines by measuring their linewidths is plotted in Fig. 3. The median resolution of the spectrograph is 67,000.

### 5 Final U Line List

The preliminary line list possibly contains the lines which are not exactly the U transitions or for which energy levels are unknown. It is also possible that the UAr spectra may contain more Ar lines than the ThAr spectra, which are mentioned in Ref. 24 (see Sec. 4). As stated before, we do not want to include any Ar line in the final line list; therefore, we compared all the lines from the preliminary line list with the possible theoretical transitions. We calculated the Ritz wavelength using the energy levels for the first and the second transitions of U found at actinides database,$^{25}$ considering the selection rule for possible allowed electronic transitions.$^{26}$ With the known energy levels, there are 96,936 possible transitions in the wavelength range of 3809 to 6833 Å. We calculated the difference between all our lines and the closest line from the theoretical line
list, and plotted its distribution in Fig. 4. The median of the distribution is found to be $-0.15 \text{ mÅ}$, with a standard deviation ($\sigma$) of 2.1 mÅ. The standard error of median is 0.061 mÅ, which shows that the offset is considerable. The observed lines that lie within the $3\sigma$ of the median of this distribution from their closest Ritz wavelength are selected for the final line list. The final line list contains a total of 1540 U lines. The remaining 279 lines from preliminary line list are either U lines for unidentified energy levels or atomic lines for other elements that may be present as contamination in U. The identification of these lines is not the scope of this paper, and we simply rejected these lines.

The final selected lines are listed in Table 1, which has seven columns. The uncertainties reported in the table are the errors associated with each line while determining the line position, computed from the covariance matrix using the MPFITPEAK Gaussian function written in IDL. The major contributor in these errors is the photon shot noise corresponding to the line intensities and they range between 0.02 and 0.9 mÅ. The final line list has an average measurement uncertainty of 15 m s$^{-1}$ (0.013 pixels or 0.28 mÅ). The strongest line has a measurement uncertainty of $\sim$1.2 m s$^{-1}$ (0.001 pixels or 0.02 mÅ), while the faintest line has been measured with a precision of $\sim$50 m s$^{-1}$ (0.043 pixels or 0.9 mÅ). It is also observed that the

![Fig. 3](image)

**Fig. 3** The resolution of acquired UAr spectrum in various orders. It can be seen that the spectral resolution is in the range of 60,000 to 80,000. The color coding here represents the resolution and, the median resolution is 67,000.

![Fig. 4](image)

**Fig. 4** The distribution of differences between observed central wavelengths in this work and the Ritz wavelength. The left panel is the scatter plot of the distribution. The median and standard deviation ($1\sigma$) of the distribution are $-0.15$ and 2.1 mÅ, respectively. The right panel is the histogram of the same data. The two black lines represent the $\pm 3\sigma$ limits of the distribution.
median photon noise errors of the lines falling at the edges are 14% higher than the lines falling at the center of the CCD. This is because those lines falling on the edges of the detector, where orders are stitched together, may have slight asymmetric point spread function which lead to higher errors. The various distributions of uncertainties are plotted in Fig. 5. It is to note here that the Th lines used for initial wavelength calibration of the U lines have a median offset of $\sim -1.5 \, \text{mÅ}$ from the absolute wavelength scale of line list, and that offset has been corrected before comparing the U lines (from preliminary U line list) with Ritz wavelengths.

We have also compared our final line list with the P80 line list. The P80 line list is the only previously published line list which covers the whole wavelength range used in our work. They used Fourier transform spectrograph (FTS) for the line identification work and reported around 3700 lines in the PARAS wavelength range. We found that $\sim 90\%$ of the lines in the final line list are from P80, and the remaining are newly identified in this work. These newly identified lines are flagged as “RS21” in the line list, while the remaining has been flagged as “P80” (see Table 1). In 1980s, photo multiplier tubes were generally used as detectors, while we use a CCD as a detector, which has much better quantum efficiency than the former. It results in better sensitivity and thus, we could detect the fainter lines missed in P80 work. Also, new energy levels identified after the P80 work, found at the actinides energy database, are included in this work. The number of lines in our line list is less than the P80 line list as our resolution is much lesser than the FTS ($R = 600,000$), and our line list only contains the lines, which are clearly resolved and their line positions are precisely determined. In addition to that, we have found that there is no significant offset in the absolute wavelength scale in our line list from P80 line list. The main advantage of our line list is that the photon noise uncertainties in determining the line positions are much lesser than the P80. The P80 line list determined the line positions with an average precision of 2 mÅ, while the median error of our line list is 0.28 mÅ, which is $\sim 7$ times better than the P80 line list errors.

6 Results and Discussions

6.1 Performance of the Instrument Using UAr HCL

We measured and found that the fundamental precision achievable with the UAr spectra is 20 cm s$^{-1}$, while it is 18 cm s$^{-1}$ with the ThAr spectra in PARAS, calculated using the algorithm explained in Ref. 29. To check the stability of the UAr HCL with the instrument and to track the instrumental drift, a series of continuous UAr–UAr exposures is acquired for $\sim 6.5$ h as described in Sec. 2. A template of the U lines from the final line list is used for the wavelength calibration of these spectra. The template is created in the same manner as described in Sec. 3. This template is replaced with the previously used Th lines template in the PARAS data analysis framework, and

Fig. 5 The histogram plot for the uncertainties with which we find the positions of each line in the final line list in mÅ is plotted in blue. The mean error is 0.28 mÅ. The orange and green colored histograms show the error distributions of the lines falling at the central part of the CCD and the edges of the CCD with a mean of 0.27 and 0.31 mÅ, respectively.
the wavelength calibration of the spectra is done using the same methodology as described in Sec. 3. For an order, the new pixel position of each line belonging to that particular order is estimated and, then a third-order polynomial is fitted over these new positions and the central wavelength of the lines in the template. Then that polynomial solution is applied over the whole order. The same procedure has been iterated for all the 70 orders. In this way, the wavelength calibration of all the UAr–UAr spectra was done. The instrumental drift is calculated by cross-correlating each of these UAr spectra with a binary mask of U lines used in the wavelength calibration. The binary mask is defined as a template spectrum of U, which consists of several box-shaped or rectangular functions, each of them centered at U line position and has a constant value over the width associated with that line and is zero elsewhere. We have plotted the instrumental drift in Fig. 6. Figure 6(a) shows the absolute drift in both the fibers, while Fig. 6(b) depicts the relative drift between the two fibers with respect to time. Since both the fibers (fibers A and B) pass through the same opto-mechanical elements and see same minute changes in pressure and temperature, the drift in each fiber should be identical. We find that both the fibers drift identically [see Fig. 6(a)] and the 1σ scatter in the absolute drift is ∼75 m s\(^{-1}\) in both fibers. However, there is a better way to represent the achievable RV precision of the spectrograph using the differential drift (or inter-fiber drift) between both the fibers. In PARAS, we use the simultaneously acquired calibration lamp’s spectrum for the wavelength calibration of a stellar spectrum in order to correct the absolute instrumental drifts. Also, the inter-fiber drift is corrected using the UAr–UAr exposures acquired just before and after the stellar spectrum and that minimizes the wavelength calibration errors. Therefore, the 1σ scatter of this inter-fiber drift exhibits the RV precision due to the wavelength calibration errors. Here, the 1σ of the differential drift (\(\sigma_{\text{drift A−drift B}}\)) is found to be 0.88 m s\(^{-1}\). Earlier, with the ThAr HCL, this 1σ scatter was 0.92 m s\(^{-1}\). These results are comparable as the 1σ scatter of the differential drift from both the HCLs is in good agreement with each other. It is to note here that the typical dispersion in the differential drift with a UAr HCL on a night is ≤1 m s\(^{-1}\), and it also represents the wavelength calibration precision. This demonstrates that the UAr HCLs can replace the ThAr HCLs in PARAS-like spectrographs for achieving the wavelength calibration precision up to 1 m s\(^{-1}\). PARAS-like spectrographs here refer to the spectrographs with similar spectral resolution (\(R \leq 70,000\)), similar pressure and temperature stability as described in Ref. 12 and uses the similar calibration system (such as ThAr or UAr HCL) as PARAS.

Furthermore, we checked the residuals around the wavelength solution of a UAr spectrum from the line positions listed in the U lines template. The same has been done for the ThAr
spectra using the Th lines template. We have plotted the residuals in Fig. 7. The standard deviation of the residuals for ThAr and UAr spectrum is found to be 0.74 and 0.81 mÅ, respectively, and the difference between the two is within the photon noise error limit. The dispersion of the residuals from UAr spectrum is within the $3\sigma$ of the average measurement uncertainty asso-

6.2 RV Precision Achievable on HD55575 with UAr HCL

After successfully testing the HCL with the instrument and off-sky drift measurements, we did an on-sky test with a well-known RV standard star, HD55575, which has shown the RV dispersion of 3.4 m s$^{-1}$ over the span of 118 days with SOPHIE$^{10}$ and 3.1 m s$^{-1}$ with PARAS using Th lines, over the span of 420 days. We observed HD55575 for the span of $\sim$450 days, acquiring 27 spectra, simultaneously with the UAr HCL. The same U-lines template is used for the wavelength calibration of the extracted stellar spectra, which is used in Sec. 6.1. We imposed the wavelength solution of the simultaneously acquired UAr spectra over the stellar spectra. The instrumental drift in both the fibers is corrected using the UAr–UAr exposures taken just before and after the stellar spectra. We computed the RVs by cross-corelating the stellar spectra against the template stellar mask of a G2-type star. The mean absolute stellar RV using UAr HCL is found to be 85.7597 $\pm$ 0.001 km s$^{-1}$, while it was 85.7498 $\pm$ 0.001 km s$^{-1}$ for the stellar spectra acquired simultaneously with ThAr HCL. This corresponds to an absolute RV offset of $\sim$10 m s$^{-1}$ (0.18 mÅ at 5500 Å) between the two datasets, which can be treated as an instru-

Fig. 7 The plot shows the residuals between the observed central wavelength of a random UAr spectrum and the central wavelength from the line list for UAr in (a) and the same for ThAr in (b) using Th lines. The dispersion of the residuals to the wavelength solution is 0.81 mÅ for UAr and 0.74 mÅ for ThAr. The dispersion for UAr residuals is within the $3\sigma$ of the average measurement uncertainty (Fig. 5).

mental offset between the two HCLs. This offset is very close to the offset found between our final line list and the corresponding Ritz wavelengths for U lines (Sec. 4), and it is a supporting evidence of consistency between wavelength calibration systems using Th and U lines. The relative RVs for HD55575 are plotted in Fig. 8, and the RV dispersion for the star is found to be 3.2 m s$^{-1}$ by nightly binning the data for the whole span of 450 days. Previously, with the use of ThAr HCL, we have achieved an RV dispersion of 3.1 m s$^{-1}$ over 391 days.$^{13}$ It shows that the long-term RV dispersion measured here with UAr HCL is in good agreement with the previous measurements using ThAr HCL.

We have shown that the same level of RV precision on stars as well as the same level of wavelength calibration precision is achievable using the UAr HCLs compared to the ThAr HCLs in the PARAS spectrograph. Thus, ThAr HCLs can be replaced with the UAr HCLs for the precise wavelength calibration of a high-resolution spectrum in the visible region, in PARAS-like spectrographs for exoplanet detection work and to achieve the RV precision of 1 to 3 m s$^{-1}$.
7 Future Works

We are planning to use the UAr HCL in our upcoming high-resolution spectrograph, PARAS-231 ($R \sim 100,000$), for instrumental characterization and wavelength calibration. The spectrograph will be attached to the upcoming PRL 2.5-m telescope at Mt. Abu Observatory, India, for a goal of achieving sub-1 m s$^{-1}$ level of RV precision.

8 Summary

We have shown here the precise wavelength calibration of a high-resolution spectrum using U lines, acquired with the PARAS spectrograph, in the wavelength range of 3809 to 6833 Å. We initially identified a total of 4500 line features in the UAr HCL’s spectra and then filtered them through various selection steps to keep only well-resolved, well-separated, and unblended 1819 U lines. Then, we compared these lines with the closest Ritz wavelength and considered only 1540 lines for the final line list, discarding the lines with a significantly higher difference from Ritz wavelength. The comparison showed an offset of $-0.15$ mÅ, with a standard deviation of 2.1 mÅ and the average wavelength measurement uncertainty of our final line list is 0.28 mÅ. We identified 160 new U transitions in this work other than the previous work of P80, and the average uncertainty in estimating the line positions in our work was found much better than that of P80. Finally, the line list was included in the PARAS data analysis framework to check the instrumental stability and RV precision. The typical dispersion of residuals in wavelength solution of a U Ar spectrum is measured to be 0.8 mÅ, which is within 3$\sigma$ of mean errors in estimating the line positions. The 1$\sigma$ scatter of the inter-fiber drift is found to be 88 cm s$^{-1}$ over 6.5 h. The stellar spectra wavelength calibrated using U lines and Th lines shows an absolute RV offset of $\sim$10 m s$^{-1}$ (0.18 mÅ at 5500 Å). This offset is a supporting evidence of consistency between wavelength calibration systemics using Th and U lines, as it is in agreement with the offset our line list from absolute wavelength scale. We measured the RV dispersion ($\sigma_{RV}$) of 3.2 m s$^{-1}$ on an RV reference star HD55575 over the course of 450 days, using of U lines. These results are in good agreement with the previous results derived using wavelength calibration of ThAr HCL. Thus, we have demonstrated that the on-sky and off-sky acquired spectra, wavelength calibrated with the simultaneously acquired UAr HCL spectra, show good stability in the RV and, therefore, can be used as a replacement for the ThAr HCL in the high-resolution astronomical spectrographs for precision RV measurements at a level of 1 to 3 m s$^{-1}$.

Fig. 8 The plot showing relative RVs of standard star HD55575 for the span of 450 days. The blue colored data points are the RV from each observed spectra calibrated with the UAr spectra, while the red ones are the binned RV datapoints, average to each night. The dispersion of binned and unbinned RVs are 3.5 and 3.2 m s$^{-1}$, respectively.
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|---------------------|------------------|-------------------------------|---------|--------|
| 3809.4663              | 3809.4617          | 6153                | 0.2709           | 4.6000                        | UII     | RS21   |
| 3821.9472              | 3821.9467          | 2900                | 0.3183           | 0.5353                        | UI      | RS21   |
| 3824.5337              | 3824.5374          | 4240                | 0.2671           | −3.7387                       | UI      | RS21   |
| 3829.7954              | 3829.7935          | 2885                | 0.3030           | 1.9979                        | UI      | RS21   |
| 3831.8545              | 3831.8509          | 2295                | 0.3486           | 3.5569                        | UI      | RS21   |
| 3835.2266              | 3835.2240          | 4017                | 0.2662           | 2.6342                        | UI      | RS21   |
| 3839.6262              | 3839.6267          | 16468               | 0.1219           | −0.5369                       | UI      | RS21   |
| 3844.9362              | 3844.9361          | 4423                | 0.2621           | 0.0783                        | UI      | RS21   |
| 3846.2336              | 3846.2340          | 2320                | 0.3695           | −0.3674                       | UI      | RS21   |
| 3846.5552              | 3846.5531          | 6241                | 0.2008           | 2.1042                        | UI      | RS21   |
| 3847.8352              | 3847.8333          | 2744                | 0.3293           | 1.9423                        | UI      | RS21   |
| 3849.8459              | 3849.8464          | 2730                | 0.3671           | −0.4852                       | UII     | P80    |
| 3850.3220              | 3850.3234          | 2932                | 0.3877           | −1.3760                       | UI      | P80    |
| 3851.7208              | 3851.7266          | 3616                | 0.3706           | −5.8155                       | UI      | P80    |
| 3854.2204              | 3854.2198          | 55600               | 0.0623           | 0.5819                        | UI      | P80    |
| 3854.6435              | 3854.6442          | 9367                | 0.1687           | −0.6617                       | UII     | P80    |
| 3855.4299              | 3855.4278          | 5576                | 0.2356           | 2.1020                        | UI      | P80    |
| 3859.0029              | 3859.0075          | 3052                | 0.3462           | −4.5976                       | UII     | P80    |
| 3859.5742              | 3859.5714          | 33465               | 0.0830           | 2.7509                        | UII     | P80    |
| 3863.0985              | 3863.1017          | 4407                | 0.2660           | −3.1962                       | UII     | P80    |
| 3865.9207              | 3865.9168          | 10298               | 0.1585           | 3.9189                        | UII     | P80    |
| 3867.1734              | 3867.1719          | 4884                | 0.2469           | 1.5081                        | UI      | P80    |
| 3868.6937              | 3868.6968          | 4885                | 0.3230           | −3.0404                       | UI      | P80    |
| 3871.0370              | 3871.0348          | 96319               | 0.0474           | 2.2192                        | UI      | P80    |
| 3873.0805              | 3873.0791          | 6808                | 0.1901           | 1.3670                        | UI      | P80    |
| 3874.3545              | 3874.3515          | 5922                | 0.2339           | 3.0527                        | UI      | P80    |
| 3876.1317              | 3876.1327          | 26779               | 0.0902           | −1.0274                       | UI      | P80    |
| 3878.4534              | 3878.4536          | 3451                | 0.3964           | −0.2127                       | UI      | P80    |
| 3879.5363              | 3879.5345          | 3890                | 0.2863           | 1.8200                        | UI      | P80    |
| 3879.7099              | 3879.7107          | 3731                | 0.2939           | −0.7282                       | UI      | P80    |
| 3881.4516              | 3881.4539          | 3709                | 0.2861           | −2.2699                       | UII     | P80    |
| 3882.3555              | 3882.3556          | 3272                | 0.3372           | −0.0850                       | UII     | P80    |
| 3883.1103              | 3883.1114          | 2566                | 0.3941           | −1.1444                       | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|----------------------|---------------------|------------------|-------------------------------|---------|--------|
| 3883.6339              | 3883.6350            | 2528                | 0.4096           | −1.1069                       | UI      | P80    |
| 3887.4411              | 3887.4397            | 3127                | 0.3242           | 1.3727                        | UI      | P80    |
| 3889.2835              | 3889.2785            | 4661                | 0.2769           | 5.0163                        | UI      | P80    |
| 3890.3630              | 3890.3613            | 22125               | 0.1096           | 1.7274                        | UII     | P80    |
| 3891.8020              | 3891.8019            | 6755                | 0.2195           | 0.0778                        | UI      | P80    |
| 3892.6830              | 3892.6809            | 5293                | 0.2340           | 2.0157                        | UII     | P80    |
| 3892.8935              | 3892.8920            | 2896                | 0.3529           | 1.4235                        | UI      | P80    |
| 3893.7162              | 3893.7147            | 3146                | 0.3679           | 1.5331                        | UII     | P80    |
| 3894.1212              | 3894.1206            | 62820               | 0.0591           | 0.6696                        | UI      | P80    |
| 3894.9058              | 3894.9032            | 6980                | 0.1982           | 2.6250                        | UI      | P80    |
| 3895.2662              | 3895.2698            | 2939                | 0.3420           | −3.6473                       | UII     | P80    |
| 3895.7176              | 3895.7160            | 3066                | 0.3285           | 1.5505                        | UI      | P80    |
| 3896.7749              | 3896.7745            | 3859                | 0.3028           | 0.3755                        | UII     | P80    |
| 3897.2676              | 3897.2611            | 3842                | 0.3150           | 6.4362                        | UII     | P80    |
| 3899.2692              | 3899.2702            | 6389                | 0.1964           | −1.0529                       | UI      | P80    |
| 3899.4720              | 3899.4731            | 3350                | 0.3276           | −1.1083                       | UII     | P80    |
| 3899.7816              | 3899.7806            | 6000                | 0.2522           | 1.0188                        | UII     | P80    |
| 3915.2104              | 3915.2104            | 6471                | 0.2065           | 0.0176                        | UI      | P80    |
| 3916.3436              | 3916.3398            | 3114                | 0.3431           | 3.8548                        | UI      | P80    |
| 3916.5205              | 3916.5205            | 4298                | 0.2983           | 0.0137                        | UI      | P80    |
| 3921.5485              | 3921.5475            | 3733                | 0.2963           | 0.9701                        | UII     | P80    |
| 3923.0248              | 3923.0215            | 9463                | 0.1679           | 3.2665                        | UI      | P80    |
| 3924.2568              | 3924.2604            | 2407                | 0.3861           | −3.6242                       | UII     | P80    |
| 3926.2087              | 3926.2077            | 32720               | 0.0834           | 0.9985                        | UI      | P80    |
| 3928.8245              | 3928.8245            | 13038               | 0.1376           | 0.0104                        | UI      | P80    |
| 3931.5050              | 3931.5069            | 3273                | 0.3258           | −1.9663                       | UI      | P80    |
| 3932.0230              | 3932.0222            | 25576               | 0.0982           | 0.8433                        | UII     | P80    |
| 3935.3795              | 3935.3800            | 4920                | 0.2396           | −0.5082                       | UII     | P80    |
| 3938.3521              | 3938.3521            | 3383                | 0.3123           | 0.0233                        | UII     | RS21   |
| 3940.4848              | 3940.4839            | 3334                | 0.3372           | 0.9542                        | UI      | P80    |
| 3943.8175              | 3943.8161            | 92109               | 0.0476           | 1.4197                        | UI      | P80    |
| 3944.2723              | 3944.2719            | 10163               | 0.1682           | 0.3755                        | UI      | RS21   |
| 3948.4440              | 3948.4428            | 19971               | 0.1284           | 1.1676                        | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|----------------------------------|---------|--------|
| 3948.6595               | 3948.6555           | 2842                | 0.3618           | 4.0735                           | UI      | P80    |
| 3948.9821               | 3948.9863           | 26235               | 0.0969           | -4.2098                          | UI      | P80    |
| 3950.4764               | 3950.4731           | 5519                | 0.2354           | 3.3499                           | UI      | P80    |
| 3951.4756               | 3951.4734           | 4246                | 0.3075           | 2.2387                           | UI      | P80    |
| 3959.2074               | 3959.2058           | 2985                | 0.3467           | 1.5410                           | UI      | P80    |
| 3960.6566               | 3960.6565           | 2558                | 0.3776           | 0.1379                           | UI      | P80    |
| 3961.5097               | 3961.5123           | 14069               | 0.1518           | -2.6019                          | UI      | P80    |
| 3962.8003               | 3962.8054           | 4970                | 0.2612           | -5.1351                          | UI      | P80    |
| 3967.4634               | 3967.4624           | 16186               | 0.1192           | 0.9970                           | UI      | P80    |
| 3969.4134               | 3969.4119           | 12953               | 0.1288           | 1.5715                           | UI      | P80    |
| 3970.5871               | 3970.5869           | 7174                | 0.1945           | 0.1748                           | UI      | P80    |
| 3972.2125               | 3972.2124           | 9879                | 0.1634           | 0.1236                           | UI      | P80    |
| 3980.7976               | 3980.7955           | 3882                | 0.2887           | 2.1222                           | UI      | P80    |
| 3983.7723               | 3983.7686           | 3166                | 0.3387           | 3.7075                           | UI      | P80    |
| 3985.7944               | 3985.7919           | 6884                | 0.1976           | 2.5050                           | UI      | P80    |
| 3988.8866               | 3988.8838           | 3337                | 0.3115           | 3.0776                           | UI      | P80    |
| 3989.2897               | 3989.2885           | 2837                | 0.3519           | 1.1572                           | UI      | P80    |
| 3990.4222               | 3990.4203           | 9220                | 0.1643           | 1.8844                           | UI      | P80    |
| 3992.5322               | 3992.5344           | 3067                | 0.3515           | -2.2677                          | UI      | P80    |
| 3992.8416               | 3992.8384           | 2761                | 0.3967           | 3.2360                           | UI      | P80    |
| 3994.2909               | 3994.2907           | 2803                | 0.3450           | 0.1388                           | UI      | P80    |
| 3997.0841               | 3997.0812           | 4730                | 0.2314           | 2.9699                           | UI      | RS21   |
| 3999.1817               | 3999.1798           | 10199               | 0.1493           | 1.8472                           | UI      | P80    |
| 4001.2808               | 4001.2798           | 5307                | 0.2894           | 1.0262                           | UI      | P80    |
| 4002.5878               | 4002.5883           | 2859                | 0.3561           | -0.5652                          | UI      | P80    |
| 4002.9844               | 4002.9834           | 2819                | 0.3681           | 1.0715                           | UI      | P80    |
| 4005.2075               | 4005.2089           | 39252               | 0.0824           | -1.3937                          | UI      | P80    |
| 4005.6953               | 4005.6948           | 22761               | 0.1022           | 0.5395                           | UI      | P80    |
| 4010.8131               | 4010.8124           | 3119                | 0.3138           | 0.7723                           | UI      | P80    |
| 4014.8084               | 4014.8056           | 3898                | 0.2865           | 2.8439                           | UI      | P80    |
| 4015.2361               | 4015.2352           | 3641                | 0.2999           | 0.9831                           | UI      | P80    |
| 4017.7161               | 4017.7159           | 3885                | 0.2794           | 0.1697                           | UI      | P80    |
| 4018.2971               | 4018.2963           | 3334                | 0.3011           | 0.8709                           | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 4024.2476               | 4024.2487           | 2829                | 0.3474           | −1.0430                       | UI      | P80    |
| 4026.0228               | 4026.0225           | 9948                | 0.1579           | 0.2604                        | UII     | P80    |
| 4031.8056               | 4031.8054           | 3333                | 0.3073           | 0.2001                        | UI      | P80    |
| 4034.4956               | 4034.4965           | 7097                | 0.1958           | −0.8863                       | UI      | P80    |
| 4037.9678               | 4037.9680           | 3570                | 0.3004           | −0.2884                       | UI      | P80    |
| 4040.6955               | 4040.6923           | 9154                | 0.1814           | 3.2748                        | UI      | P80    |
| 4042.7511               | 4042.7495           | 8297                | 0.0626           | 1.5411                        | UI      | P80    |
| 4044.8963               | 4044.8942           | 2843                | 0.3804           | 2.0932                        | UI      | P80    |
| 4047.6127               | 4047.6114           | 76397               | 0.0539           | 1.2468                        | UI      | P80    |
| 4049.1890               | 4049.1878           | 6043                | 0.2075           | 1.1429                        | UI      | P80    |
| 4049.7746               | 4049.7744           | 4387                | 0.2710           | 0.1906                        | UI      | P80    |
| 4050.0451               | 4050.0414           | 30133               | 0.0944           | 3.7120                        | UI      | P80    |
| 4054.1912               | 4054.1911           | 7528                | 0.1895           | 2.3832                        | UII     | P80    |
| 4054.2302               | 4054.2303           | 6055                | 0.3549           | −1.3118                       | UI      | P80    |
| 4054.6751               | 4054.6732           | 12407               | 0.1459           | 1.8535                        | UI      | P80    |
| 4055.9449               | 4055.9401           | 3293                | 0.4095           | 4.8537                        | UI      | P80    |
| 4061.3483               | 4061.3494           | 21637               | 0.1025           | −1.1034                       | UII     | P80    |
| 4062.3212               | 4062.3186           | 13783               | 0.1342           | 2.5594                        | UI      | P80    |
| 4062.5432               | 4062.5443           | 21435               | 0.1092           | −1.0915                       | UI      | P80    |
| 4063.0904               | 4063.0896           | 5069                | 0.2373           | 0.7706                        | UI      | P80    |
| 4064.0236               | 4064.0213           | 2395                | 0.3931           | 2.2850                        | UI      | P80    |
| 4066.2889               | 4066.2872           | 8104                | 0.1943           | 1.6848                        | UI      | P80    |
| 4067.7473               | 4067.7475           | 5030                | 0.2390           | −0.1852                       | UII     | P80    |
| 4068.6997               | 4068.7004           | 3548                | 0.3374           | −0.7485                       | UI      | P80    |
| 4069.6472               | 4069.6454           | 5160                | 0.2314           | 1.7919                        | UI      | P80    |
| 4070.0075               | 4070.0065           | 8355                | 0.1675           | 0.9405                        | UI      | P80    |
| 4070.4439               | 4070.4438           | 5095                | 0.2555           | 0.0777                        | UI      | P80    |
| 4070.8834               | 4070.8850           | 12858               | 0.1489           | −1.6052                       | UI      | P80    |
| 4072.8304               | 4072.8322           | 3083                | 0.3682           | −1.8050                       | UI      | P80    |
| 4073.5409               | 4073.5401           | 8841                | 0.1740           | 0.8417                        | UI      | P80    |
| 4074.6142               | 4074.6131           | 12131               | 0.1557           | 1.0792                        | UI      | P80    |
| 4075.8961               | 4075.8938           | 4589                | 0.2713           | 2.2834                        | UI      | P80    |
| 4077.7852               | 4077.7850           | 15579               | 0.1241           | 0.2077                        | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 4081.2134               | 4081.2172           | 4625                | 0.3023           | −3.7802                       | UI      | P80    |
| 4082.8220               | 4082.8202           | 7129                | 0.2056           | 1.8444                        | UI      | P80    |
| 4083.0315               | 4083.0374           | 13227               | 0.1463           | −5.9123                       | UI      | P80    |
| 4084.0974               | 4084.0962           | 13344               | 0.1374           | 1.1852                        | UI      | P80    |
| 4088.2553               | 4088.2521           | 4453                | 0.2639           | 3.1249                        | UI      | P80    |
| 4089.1549               | 4089.1542           | 5711                | 0.2175           | 0.6903                        | UI      | P80    |
| 4090.1324               | 4090.1326           | 25864               | 0.0930           | −0.1872                       | UIi     | P80    |
| 4091.6275               | 4091.6268           | 35994               | 0.0780           | 0.7417                        | UI      | P80    |
| 4094.8856               | 4094.8900           | 2316                | 0.4248           | −4.4720                       | UIi     | P80    |
| 4096.3519               | 4096.3500           | 10411               | 0.1572           | 1.8430                        | UI      | P80    |
| 4097.7450               | 4097.7438           | 17256               | 0.1164           | 1.2025                        | UI      | P80    |
| 4098.0258               | 4098.0243           | 9654                | 0.2045           | 1.4743                        | UI      | P80    |
| 4098.9868               | 4098.9842           | 2643                | 0.3917           | 2.5279                        | UI      | P80    |
| 4101.9061               | 4101.9045           | 15451               | 0.1257           | 1.5856                        | UI      | P80    |
| 4103.1126               | 4103.1123           | 16104               | 0.1251           | 0.3761                        | UI      | P80    |
| 4104.9452               | 4104.9458           | 8399                | 0.1873           | −0.5851                       | UI      | P80    |
| 4105.3163               | 4105.3100           | 5871                | 0.2267           | 6.2962                        | UI      | P80    |
| 4106.9277               | 4106.9230           | 7161                | 0.2132           | 4.6213                        | UIi     | P80    |
| 4107.5221               | 4107.5235           | 4915                | 0.2994           | −1.4795                       | UI      | P80    |
| 4108.3527               | 4108.3524           | 29849               | 0.0889           | 0.3424                        | UI      | P80    |
| 4109.5343               | 4109.5342           | 2694                | 0.3879           | 0.0590                        | UI      | P80    |
| 4109.6987               | 4109.6982           | 2493                | 0.3965           | 0.4722                        | UI      | P80    |
| 4110.6416               | 4110.6458           | 3824                | 0.3299           | −4.2309                       | UI      | P80    |
| 4110.8323               | 4110.8300           | 2550                | 0.4180           | 2.3011                        | UIi     | P80    |
| 4111.0173               | 4111.0182           | 8588                | 0.1729           | −0.9373                       | UI      | P80    |
| 4115.6440               | 4115.6444           | 4731                | 0.2431           | −0.3674                       | UI      | P80    |
| 4116.0963               | 4116.0975           | 23429               | 0.0995           | −1.1642                       | UIi     | P80    |
| 4116.3471               | 4116.3428           | 10004               | 0.1905           | 4.2799                        | UI      | P80    |
| 4116.8839               | 4116.8818           | 5371                | 0.2529           | 2.1227                        | UIi     | P80    |
| 4122.1675               | 4122.1698           | 3118                | 0.3430           | −2.3005                       | UI      | P80    |
| 4122.3563               | 4122.3567           | 6219                | 0.2197           | −0.4021                       | UI      | P80    |
| 4122.9987               | 4122.9962           | 3478                | 0.3182           | 2.5027                        | UI      | P80    |
| 4124.7272               | 4124.7273           | 11683               | 0.1525           | −0.0623                       | UIi     | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|--------------------|------------------|-------------------------------|---------|-------|
| 4125.1305              | 4125.1298          | 7785               | 0.1848           | 0.6802                        | UI      | P80   |
| 4127.3339              | 4127.3359          | 5378               | 0.2469           | −2.0101                       | UII     | P80   |
| 4127.5530              | 4127.5502          | 3036               | 0.6602           | 2.8107                        | UII     | P80   |
| 4128.3350              | 4128.3345          | 12773              | 0.1352           | 0.4481                        | UII     | P80   |
| 4130.6617              | 4130.6587          | 6083               | 0.2294           | 3.0296                        | UI      | P80   |
| 4131.7247              | 4131.7253          | 420538             | 0.0229           | −0.6646                       | UI      | RS21  |
| 4132.0111              | 4132.0102          | 7096               | 0.2701           | 0.8932                        | UI      | P80   |
| 4133.2037              | 4133.2007          | 4216               | 0.3026           | 3.0322                        | UII     | P80   |
| 4133.4924              | 4133.4911          | 79374              | 0.0548           | 1.3487                        | UI      | P80   |
| 4135.7563              | 4135.7552          | 3423               | 0.4522           | 1.1108                        | UII     | P80   |
| 4137.0387              | 4137.0335          | 3715               | 0.3941           | 5.2087                        | UI      | P80   |
| 4137.7157              | 4137.7134          | 3233               | 0.3763           | 2.3561                        | UI      | P80   |
| 4138.6591              | 4138.6585          | 3530               | 0.3427           | 0.5651                        | UII     | P80   |
| 4138.9611              | 4138.9621          | 4959               | 0.2665           | −0.9847                       | UI      | P80   |
| 4139.1405              | 4139.1388          | 10870              | 0.1694           | 1.7334                        | UII     | P80   |
| 4141.8590              | 4141.8579          | 40662              | 0.0724           | 1.1952                        | UI      | P80   |
| 4146.6154              | 4146.6149          | 5307               | 0.2278           | 0.5730                        | UI      | RS21  |
| 4148.0346              | 4148.0293          | 3129               | 0.2989           | 5.2972                        | UI      | P80   |
| 4166.6391              | 4166.6449          | 2481               | 0.3845           | −5.7460                       | UI      | P80   |
| 4169.0473              | 4169.0473          | 2878               | 0.3527           | −0.0133                       | UI      | P80   |
| 4171.5913              | 4171.5889          | 11288              | 0.1478           | 2.4195                        | UII     | P80   |
| 4176.4568              | 4176.4561          | 3613               | 0.2950           | 0.7478                        | UI      | P80   |
| 4179.0044              | 4179.0029          | 2962               | 0.4095           | 1.4407                        | UI      | P80   |
| 4179.2991              | 4179.3025          | 21653              | 0.1199           | −3.4035                       | UII     | RS21  |
| 4180.3063              | 4180.3053          | 24353              | 0.0938           | 1.0006                        | UI      | P80   |
| 4182.9634              | 4182.9663          | 5357               | 0.2698           | −2.9225                       | UI      | RS21  |
| 4183.2598              | 4183.2572          | 5870               | 0.2252           | 2.5900                        | UI      | P80   |
| 4184.7716              | 4184.7727          | 2922               | 0.6583           | −1.1195                       | UI      | P80   |
| 4186.9601              | 4186.9604          | 33207              | 0.0845           | −0.3249                       | UI      | P80   |
| 4188.0645              | 4188.0639          | 9100               | 0.1741           | 0.6035                        | UII     | P80   |
| 4188.8884              | 4188.8910          | 3858               | 0.3203           | −2.6071                       | UII     | P80   |
| 4189.6511              | 4189.6566          | 5571               | 0.2596           | −5.5697                       | UI      | RS21  |
| 4191.9334              | 4191.9326          | 36889              | 0.0785           | 0.7760                        | UI      | P80   |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|---------------------|------------------|-------------------------------|---------|--------|
| 4192.9063              | 4192.9099          | 5137                | 0.2602           | −3.5429                       | UI      | P80    |
| 4195.6134              | 4195.6120          | 3076                | 0.3844           | 1.4125                        | UI      | P80    |
| 4196.3983              | 4196.3997          | 4388                | 0.3086           | −1.4129                       | UI      | P80    |
| 4198.3130              | 4198.3131          | 143729              | 0.0521           | −0.1487                       | Uii RS21|        |
| 4199.6274              | 4199.6252          | 3634                | 0.3089           | 2.1707                        | UI      | P80    |
| 4201.1266              | 4201.1260          | 7929                | 0.1895           | 0.5670                        | UI      | P80    |
| 4203.4112              | 4203.4127          | 2345                | 0.4245           | −1.4916                       | Uii RS21|        |
| 4204.1628              | 4204.1616          | 4472                | 0.2455           | 1.1876                        | UI      | P80    |
| 4204.3480              | 4204.3529          | 2742                | 0.3667           | −4.8808                       | Uii P80 |        |
| 4222.3630              | 4222.3675          | 5414                | 0.2252           | −4.5775                       | UI      | P80    |
| 4228.4238              | 4228.4237          | 6067                | 0.2268           | 0.1198                        | Uii P80 |        |
| 4229.8687              | 4229.8651          | 3545                | 0.3616           | 3.6115                        | Uii RS21|        |
| 4231.6689              | 4231.6682          | 10726               | 0.1682           | 0.7750                        | UI      | P80    |
| 4232.0338              | 4232.0373          | 3598                | 0.3294           | −3.4934                       | UI      | P80    |
| 4233.1318              | 4233.1321          | 8606                | 0.1705           | −0.3057                       | UI      | P80    |
| 4233.5471              | 4233.5431          | 3744                | 0.3185           | 4.0053                        | UI      | P80    |
| 4236.0261              | 4236.0301          | 7775                | 0.2172           | −3.9653                       | Uii P80 |        |
| 4241.1089              | 4241.1117          | 15609               | 0.1259           | −2.8093                       | UI      | P80    |
| 4241.6651              | 4241.6642          | 22140               | 0.1011           | 0.8365                        | UI      | P80    |
| 4244.3731              | 4244.3726          | 34111               | 0.0841           | 0.5880                        | Uii P80 |        |
| 4246.2601              | 4246.2599          | 142241              | 0.0399           | 0.2158                        | UI      | P80    |
| 4247.9011              | 4247.9003          | 5131                | 0.2563           | 0.8143                        | UI      | P80    |
| 4252.4263              | 4252.4265          | 4662                | 0.2650           | −0.1880                       | Uii P80 |        |
| 4253.7059              | 4253.7054          | 2672                | 0.4015           | 0.4809                        | UI      | P80    |
| 4266.3051              | 4266.3016          | 53946               | 0.0778           | 3.4819                        | UI      | P80    |
| 4267.2994              | 4267.2989          | 4163                | 0.2812           | 0.4981                        | Uii P80 |        |
| 4268.8487              | 4268.8471          | 4153                | 0.2604           | 1.6623                        | Uii P80 |        |
| 4269.6077              | 4269.6094          | 9727                | 0.1615           | −1.7265                       | Uii P80 |        |
| 4271.2289              | 4271.2281          | 13114               | 0.1461           | 0.8517                        | UI      | P80    |
| 4272.1702              | 4272.1735          | 72105               | 0.0575           | −3.3154                       | UI      | RS21   |
| 4273.9709              | 4273.9711          | 5083                | 0.2238           | −0.1614                       | Uii P80 |        |
| 4277.5283              | 4277.5311          | 478484              | 0.0212           | −2.8064                       | Uii RS21|        |
| 4279.3244              | 4279.3235          | 3350                | 0.3257           | 0.8632                        | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mA) | Offset from Ritz wavelength (mA) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 4280.0346               | 4280.0338           | 2794                | 0.4037           | 0.8481                        | UI      | P80    |
| 4281.2206               | 4281.2234           | 2706                | 0.4989           | −2.8111                       | UI      | P80    |
| 4282.0238               | 4282.0232           | 13404               | 0.1398           | 0.5774                        | UII     | P80    |
| 4283.9049               | 4283.8997           | 3284                | 0.3303           | 5.2514                        | UI      | P80    |
| 4285.2279               | 4285.2285           | 2875                | 0.3403           | −0.5553                       | UI      | P80    |
| 4287.8647               | 4287.8613           | 6983                | 0.2317           | 3.3968                        | UII     | P80    |
| 4288.8378               | 4288.8349           | 17388               | 0.1193           | 2.9096                        | UII     | P80    |
| 4297.1083               | 4297.1098           | 6575                | 0.2133           | −1.5281                       | UI      | P80    |
| 4301.4647               | 4301.4635           | 9400                | 0.1721           | 1.1284                        | UII     | P80    |
| 4307.1721               | 4307.1722           | 3216                | 0.3177           | −0.1042                       | UI      | P80    |
| 4308.8115               | 4308.8133           | 21289               | 0.1148           | −1.7741                       | UII     | P80    |
| 4309.1977               | 4309.1970           | 3281                | 0.2919           | 0.6629                        | UI      | P80    |
| 4310.6900               | 4310.6882           | 23461               | 0.1024           | 1.7770                        | UII     | P80    |
| 4313.1379               | 4313.1386           | 34650               | 0.0864           | −0.7197                       | UI      | P80    |
| 4313.8722               | 4313.8737           | 7091                | 0.2141           | −1.4825                       | UII     | P80    |
| 4316.4836               | 4316.4828           | 4509                | 0.2609           | 0.8415                        | UI      | P80    |
| 4317.0693               | 4317.0697           | 3626                | 0.2966           | −0.3296                       | UII     | P80    |
| 4318.0881               | 4318.0905           | 3314                | 0.3312           | −2.3920                       | UI      | P80    |
| 4322.3807               | 4322.3821           | 5974                | 0.2201           | −1.3734                       | UII     | P80    |
| 4325.0889               | 4325.0892           | 3316                | 0.3163           | −0.3122                       | UI      | P80    |
| 4325.8862               | 4325.8839           | 2953                | 0.3471           | 2.2576                        | UII     | P80    |
| 4328.7304               | 4328.7298           | 24371               | 0.0992           | 0.5752                        | UI      | P80    |
| 4331.4390               | 4331.4438           | 5961                | 0.2635           | −4.7961                       | UII     | P80    |
| 4335.7330               | 4335.7315           | 61394               | 0.0613           | 1.4952                        | UII     | P80    |
| 4337.3983               | 4337.3981           | 11081               | 0.1491           | 0.2326                        | UI      | P80    |
| 4337.6266               | 4337.6267           | 2706                | 0.3661           | −0.0866                       | UII     | P80    |
| 4341.6865               | 4341.6869           | 38605               | 0.0792           | −0.3227                       | UII     | P80    |
| 4345.1682               | 4345.1725           | 15160               | 0.1327           | −4.2407                       | UII     | RS21   |
| 4347.1939               | 4347.1956           | 5680                | 0.2384           | −1.6234                       | UII     | P80    |
| 4354.5474               | 4354.5487           | 8623                | 0.1852           | −1.3217                       | UII     | P80    |
| 4355.7401               | 4355.7393           | 102224              | 0.0499           | 0.7956                        | UI      | P80    |
| 4357.9149               | 4357.9136           | 10413               | 0.1558           | 1.2501                        | UI      | P80    |
| 4362.0529               | 4362.0513           | 271630              | 0.0286           | 1.6487                        | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 4362.2577              | 4362.2602           | 23774               | 0.1179           | −2.4479                       | UII     | P80    |
| 4363.1819              | 4363.1816           | 3908                | 0.3350           | 0.2450                        | UI      | P80    |
| 4364.4128              | 4364.4105           | 2863                | 0.3234           | 2.2664                        | UI      | P80    |
| 4367.8323              | 4367.8332           | 32311               | 0.0946           | −0.9096                       | UI      | RS21   |
| 4369.9542              | 4369.9528           | 6263                | 0.2278           | 1.3762                        | UI      | P80    |
| 4370.7539              | 4370.7592           | 183551              | 0.0386           | −5.2305                       | UII     | RS21   |
| 4371.7586              | 4371.7585           | 17779               | 0.1231           | 0.0495                        | UI      | P80    |
| 4372.0077              | 4372.0054           | 9519                | 0.1918           | 2.3719                        | UI      | P80    |
| 4372.5663              | 4372.5656           | 14656               | 0.1823           | 0.6700                        | UI      | P80    |
| 4372.7559              | 4372.7554           | 88012               | 0.0524           | 0.5269                        | UI      | P80    |
| 4373.4046              | 4373.4029           | 8412                | 0.2032           | 1.7413                        | UI      | P80    |
| 4382.0700              | 4382.0692           | 4129                | 0.2842           | 0.8735                        | UI      | P80    |
| 4382.3363              | 4382.3359           | 18955               | 0.1126           | 0.3512                        | UII     | RS21   |
| 4382.8425              | 4382.8388           | 2546                | 0.4586           | 3.7200                        | UI      | P80    |
| 4383.2617              | 4383.2617           | 17549               | 0.1201           | −0.0792                       | UI      | P80    |
| 4387.3113              | 4387.3104           | 8639                | 0.1785           | 0.8882                        | UI      | P80    |
| 4392.4979              | 4392.5024           | 4166                | 0.2999           | −4.5509                       | UI      | P80    |
| 4393.5860              | 4393.5857           | 252206              | 0.0293           | 0.3146                        | UI      | P80    |
| 4400.9864              | 4400.9809           | 130467              | 0.0452           | 5.4851                        | UII     | RS21   |
| 4413.1334              | 4413.1336           | 6656                | 0.2045           | −0.1968                       | UI      | P80    |
| 4415.2366              | 4415.2376           | 5508                | 0.2458           | −1.0681                       | UII     | P80    |
| 4418.4723              | 4418.4727           | 4281                | 0.2653           | −0.4116                       | UI      | P80    |
| 4422.9889              | 4422.9853           | 2795                | 0.3717           | 3.5666                        | UII     | P80    |
| 4425.4093              | 4425.4091           | 7700                | 0.2043           | 0.2784                        | UI      | P80    |
| 4426.0014              | 4425.9984           | 335096              | 0.0275           | 3.0387                        | UII     | RS21   |
| 4426.9350              | 4426.9343           | 80768               | 0.0519           | 0.6345                        | UII     | P80    |
| 4427.6517              | 4427.6523           | 6844                | 0.2062           | −0.6427                       | UII     | P80    |
| 4429.6144              | 4429.6142           | 2794                | 0.4287           | 0.2195                        | UII     | P80    |
| 4431.8688              | 4431.8668           | 3895                | 0.2746           | 2.0791                        | UI      | P80    |
| 4434.5321              | 4434.5315           | 13991               | 0.1392           | 0.6489                        | UII     | P80    |
| 4434.9038              | 4434.8980           | 2839                | 0.4332           | 5.7817                        | UII     | P80    |
| 4440.7377              | 4440.7369           | 21065               | 0.1111           | 0.8130                        | UII     | P80    |
| 4441.0815              | 4441.0782           | 3892                | 0.3832           | 3.2060                        | UII     | P80    |
### Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|-------------------|-------------------------------|---------|--------|
| 4444.6839              | 4444.6840           | 4259                | 0.2715            | −0.1162                       | UI      | P80    |
| 4446.5173              | 4446.5216           | 3155                | 0.4331            | −4.3102                       | UI      | P80    |
| 4447.0430              | 4447.0408           | 3468                | 0.3260            | 2.2299                        | UI      | P80    |
| 4448.3327              | 4448.3305           | 8949                | 0.1885            | 2.2649                        | UI      | P80    |
| 4452.9306              | 4452.9303           | 2553                | 0.4140            | 0.2819                        | UI      | P80    |
| 4453.2128              | 4453.2119           | 8478                | 0.1755            | 0.9098                        | UI      | P80    |
| 4457.4526              | 4457.4526           | 6591                | 0.2072            | −0.0301                       | UI      | P80    |
| 4458.7016              | 4458.7014           | 31712               | 0.0882            | 0.1967                        | UI      | P80    |
| 4461.4434              | 4461.4451           | 7309                | 0.2010            | −1.7806                       | UI      | P80    |
| 4462.9681              | 4462.9685           | 8477                | 0.1756            | −0.3423                       | UII     | P80    |
| 4469.3247              | 4469.3248           | 58129               | 0.0653            | −0.0812                       | UI      | P80    |
| 4472.3309              | 4472.3298           | 35913               | 0.0828            | 1.1140                        | UII     | P80    |
| 4476.4715              | 4476.4676           | 6281                | 0.2249            | 3.8925                        | UI      | P80    |
| 4490.8336              | 4490.8318           | 7738                | 0.2428            | 1.7488                        | UII     | P80    |
| 4492.6400              | 4492.6395           | 4446                | 0.2638            | 0.5060                        | UI      | P80    |
| 4493.0423              | 4493.0410           | 2834                | 0.4082            | 1.2758                        | UI      | P80    |
| 4494.7124              | 4494.7115           | 33187               | 0.0818            | 0.8755                        | UI      | P80    |
| 4510.0915              | 4510.0912           | 6098                | 0.2252            | 0.3444                        | UI      | RS21   |
| 4510.7329              | 4510.7299           | 38078               | 0.0843            | 2.9858                        | UI      | RS21   |
| 4515.2752              | 4515.2773           | 13710               | 0.1445            | −2.0497                       | UII     | P80    |
| 4515.9803              | 4515.9764           | 2544                | 0.4225            | 3.9183                        | UI      | P80    |
| 4516.7242              | 4516.7228           | 44413               | 0.0752            | 1.3735                        | UI      | P80    |
| 4520.0783              | 4520.0781           | 6829                | 0.1964            | 0.2244                        | UI      | RS21   |
| 4522.3234              | 4522.3273           | 9060                | 0.1828            | −3.9414                       | UI      | RS21   |
| 4523.3393              | 4523.3444           | 2640                | 0.3988            | −5.0741                       | UII     | P80    |
| 4526.2454              | 4526.2464           | 2397                | 0.3989            | −1.0407                       | UI      | P80    |
| 4527.6918              | 4527.6926           | 2728                | 0.3563            | −0.8066                       | UI      | P80    |
| 4529.7057              | 4529.7032           | 2615                | 0.3756            | 2.4629                        | UI      | P80    |
| 4531.1373              | 4531.1368           | 4795                | 0.2793            | 0.5283                        | UI      | P80    |
| 4532.5809              | 4532.5805           | 12716               | 0.1506            | 0.4460                        | UI      | P80    |
| 4536.6007              | 4536.6014           | 6316                | 0.2243            | −0.6558                       | UII     | P80    |
| 4538.1799              | 4538.1854           | 9554                | 0.1973            | −5.4317                       | UI      | P80    |
| 4539.0771              | 4539.0772           | 3342                | 0.3333            | −0.1093                       | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 4541.3277              | 4541.3276           | 6311                | 0.2270           | 0.0464                          | UI      | P80    |
| 4541.7076              | 4541.7112           | 2309                | 0.4641           | -3.6653                         | UI      | P80    |
| 4543.6248              | 4543.6259           | 29563               | 0.0958           | -1.0688                         | UII     | P80    |
| 4544.3529              | 4544.3548           | 7208                | 0.2146           | -1.8403                         | UI      | P80    |
| 4545.5921              | 4545.5962           | 50833               | 0.0740           | -4.1235                         | UI      | P80    |
| 4546.0862              | 4546.0875           | 2522                | 0.4555           | -1.3532                         | UII     | P80    |
| 4550.9772              | 4550.9764           | 3231                | 0.3628           | 0.8073                          | UI      | P80    |
| 4551.5725              | 4551.5725           | 12962               | 0.1454           | -0.0069                         | UI      | P80    |
| 4551.9739              | 4551.9744           | 50892               | 0.0698           | -0.4842                         | UI      | P80    |
| 4553.8525              | 4553.8540           | 6397                | 0.2257           | -1.4475                         | UII     | P80    |
| 4555.0887              | 4555.0896           | 3212                | 0.3608           | -0.8766                         | UII     | P80    |
| 4558.0425              | 4558.0422           | 13677               | 0.1380           | 0.2820                          | UI      | P80    |
| 4559.6429              | 4559.6428           | 16654               | 0.1253           | 0.1297                          | UI      | P80    |
| 4566.5082              | 4566.5042           | 2864                | 0.5103           | 4.0395                          | UI      | P80    |
| 4567.6844              | 4567.6848           | 15658               | 0.1341           | -0.3471                         | UII     | P80    |
| 4569.9092              | 4569.9090           | 18341               | 0.1232           | 0.2135                          | UI      | P80    |
| 4571.6821              | 4571.6767           | 2632                | 0.4662           | 5.3041                          | UI      | P80    |
| 4573.2731              | 4573.2731           | 2534                | 0.4529           | 0.0080                          | UII     | P80    |
| 4573.5193              | 4573.5195           | 3214                | 0.4136           | -0.1249                         | UII     | P80    |
| 4573.6778              | 4573.6797           | 11833               | 0.1582           | -1.8701                         | UII     | P80    |
| 4575.0210              | 4575.0218           | 3729                | 0.3355           | -0.7447                         | UI      | P80    |
| 4576.6387              | 4576.6397           | 57549               | 0.0674           | -0.9102                         | UI      | P80    |
| 4578.0035              | 4578.0048           | 3352                | 0.3310           | -1.3374                         | UI      | P80    |
| 4579.3479              | 4579.3498           | 150888              | 0.0446           | -1.9620                         | UII     | RS21   |
| 4583.2880              | 4583.2855           | 2388                | 0.4466           | 2.4623                          | UII     | P80    |
| 4584.8480              | 4584.8481           | 3917                | 0.3182           | -0.0660                         | UI      | P80    |
| 4585.5695              | 4585.5681           | 3841                | 0.3226           | 1.3689                          | UI      | P80    |
| 4587.2387              | 4587.2391           | 3029                | 0.4909           | -0.3979                         | UII     | P80    |
| 4588.6436              | 4588.6431           | 6750                | 0.2115           | 0.5651                          | UI      | P80    |
| 4592.6210              | 4592.6191           | 6388                | 0.2421           | 1.9134                          | UI      | P80    |
| 4593.6388              | 4593.6379           | 4616                | 0.2939           | 0.9113                          | UI      | P80    |
| 4594.8430              | 4594.8412           | 9073                | 0.1801           | 1.7417                          | UI      | P80    |
| 4595.4492              | 4595.4468           | 7567                | 0.2241           | 2.3667                          | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 4601.1252               | 4601.1281           | 10091               | 0.1871           | −2.9055                         | UII     | P80    |
| 4603.4203               | 4603.4202           | 4253                | 0.3183           | 0.0618                          | UI      | P80    |
| 4603.6590               | 4603.6583           | 16736               | 0.1321           | 0.6504                          | UII     | P80    |
| 4608.3455               | 4608.3490           | 2676                | 0.4450           | −3.4818                         | UI      | P80    |
| 4618.7377               | 4618.7384           | 4138                | 0.2989           | −0.6441                         | UI      | P80    |
| 4620.2149               | 4620.2126           | 41990               | 0.0888           | 2.3138                          | UI      | P80    |
| 4620.4274               | 4620.4278           | 51049               | 0.0738           | −0.3470                         | UI      | P80    |
| 4622.4229               | 4622.4219           | 5108                | 0.2768           | 0.9944                          | UII     | P80    |
| 4625.4873               | 4625.4892           | 9265                | 0.1966           | −1.9007                         | UI      | P80    |
| 4630.8973               | 4630.8977           | 4152                | 0.3392           | −0.4100                         | UI      | P80    |
| 4631.6154               | 4631.6151           | 319240              | 0.0278           | 0.3288                          | UI      | P80    |
| 4637.9368               | 4637.9376           | 5298                | 0.2690           | −0.7166                         | UII     | P80    |
| 4641.6551               | 4641.6501           | 2508                | 0.4497           | 5.0314                          | UII     | P80    |
| 4643.6032               | 4643.6023           | 10032               | 0.1780           | 0.8401                          | UI      | P80    |
| 4646.5982               | 4646.5974           | 17843               | 0.1281           | 0.8253                          | UII     | P80    |
| 4654.8362               | 4654.8333           | 3670                | 0.3422           | 2.8894                          | UI      | P80    |
| 4657.9019               | 4657.9039           | 479801              | 0.0237           | −2.0492                         | UI      | RS21   |
| 4660.1097               | 4660.1066           | 3103                | 0.4339           | 3.0840                          | UI      | P80    |
| 4661.6482               | 4661.6464           | 6599                | 0.2401           | 1.7815                          | UI      | P80    |
| 4663.7492               | 4663.7489           | 122024              | 0.0438           | 0.2982                          | UI      | P80    |
| 4665.8161               | 4665.8150           | 18533               | 0.1201           | 1.1014                          | UI      | P80    |
| 4666.8515               | 4666.8513           | 20562               | 0.1130           | 0.1432                          | UII     | P80    |
| 4667.7202               | 4667.7195           | 3863                | 0.3732           | 0.6974                          | UI      | P80    |
| 4671.3966               | 4671.3976           | 9423                | 0.1918           | −0.9807                         | UII     | P80    |
| 4677.5288               | 4677.5291           | 2832                | 0.4102           | −0.3250                         | UI      | P80    |
| 4677.7385               | 4677.7381           | 3546                | 0.3595           | 0.3915                          | UI      | P80    |
| 4678.6681               | 4678.6681           | 2902                | 0.4036           | −0.0262                         | UI      | P80    |
| 4682.0065               | 4682.0084           | 12999               | 0.1989           | −1.8978                         | UI      | P80    |
| 4685.1912               | 4685.1922           | 4654                | 0.2915           | −1.0520                         | UI      | P80    |
| 4686.9218               | 4686.9225           | 22532               | 0.1134           | −0.6524                         | UI      | P80    |
| 4689.0739               | 4689.0740           | 25585               | 0.1064           | −0.0914                         | UII     | P80    |
| 4691.2519               | 4691.2517           | 4172                | 0.3669           | 0.2568                          | UI      | P80    |
| 4693.7008               | 4693.6995           | 4447                | 0.3673           | 1.2986                          | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|--------------------|-----------------|---------------------------------|---------|--------|
| 4694.7014              | 4694.7008           | 7606               | 0.2111          | 0.5931                          | UI      | P80    |
| 4695.2232              | 4695.2223           | 26708              | 0.1139          | 0.8276                          | UI      | P80    |
| 4695.6382              | 4695.6350           | 5061               | 0.3372          | 3.2252                          | UI      | P80    |
| 4696.0480              | 4696.0434           | 3167               | 0.4269          | 4.6125                          | UI      | P80    |
| 4700.7050              | 4700.7050           | 5262               | 0.2869          | −0.0567                         | UI      | P80    |
| 4700.9754              | 4700.9753           | 9394               | 0.2242          | 0.1591                          | UI      | P80    |
| 4701.2271              | 4701.2266           | 120903             | 0.0450          | 0.4738                          | UI      | P80    |
| 4702.0395              | 4702.0376           | 6960               | 0.2481          | 1.8606                          | UI      | P80    |
| 4702.3168              | 4702.3227           | 24057              | 0.1165          | −5.8983                         | UI      | RS21   |
| 4702.5114              | 4702.5120           | 12350              | 0.1678          | −0.5244                         | UI      | P80    |
| 4705.1363              | 4705.1419           | 3288               | 0.4532          | −5.6276                         | UI      | P80    |
| 4708.1588              | 4708.1550           | 6017               | 0.2980          | 3.8071                          | UI      | P80    |
| 4709.3509              | 4709.3567           | 4045               | 0.3855          | −5.7865                         | UI      | P80    |
| 4710.8143              | 4710.8156           | 4050               | 0.3694          | −1.2932                         | UI      | P80    |
| 4712.1366              | 4712.1323           | 2633               | 0.8236          | 4.3051                          | UI      | P80    |
| 4713.9352              | 4713.9328           | 3472               | 0.4134          | 2.4271                          | UI      | P80    |
| 4715.6677              | 4715.6695           | 11543              | 0.1837          | −1.8198                         | UI      | P80    |
| 4717.8302              | 4717.8306           | 6762               | 0.2560          | −0.4436                         | UI      | P80    |
| 4722.7178              | 4722.7174           | 20983              | 0.1270          | 0.4715                          | UI      | P80    |
| 4727.1091              | 4727.1078           | 12296              | 0.2531          | 1.3088                          | UI      | P80    |
| 4727.3361              | 4727.3370           | 11271              | 0.1860          | −0.8590                         | UI      | P80    |
| 4727.6580              | 4727.6579           | 22208              | 0.1283          | 0.1176                          | UI      | P80    |
| 4730.6760              | 4730.6746           | 57449              | 0.0714          | 1.4264                          | UI      | P80    |
| 4730.9971              | 4730.9986           | 7207               | 0.2416          | −1.4421                         | UI      | P80    |
| 4731.5918              | 4731.5942           | 17437              | 0.1437          | −2.3713                         | UI      | P80    |
| 4732.5665              | 4732.5659           | 4412               | 0.3764          | 0.6569                          | UI      | P80    |
| 4735.9068              | 4735.9008           | 415796             | 0.0274          | 6.0489                          | UI      | RS21   |
| 4736.7728              | 4736.7725           | 17614              | 0.1362          | 0.2907                          | UI      | P80    |
| 4737.6195              | 4737.6187           | 9658               | 0.1957          | 0.8417                          | UI      | P80    |
| 4738.4391              | 4738.4384           | 34856              | 0.0930          | 0.6824                          | UI      | P80    |
| 4739.1946              | 4739.1930           | 14935              | 0.1591          | 1.6088                          | UI      | P80    |
| 4739.4993              | 4739.4993           | 3049               | 0.5341          | 0.0078                          | UI      | P80    |
| 4741.7545              | 4741.7535           | 12482              | 0.1717          | 1.0582                          | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 4742.3307               | 4742.3307           | 31772               | 0.0998           | −0.0811                       | UI      | P80    |
| 4742.7943               | 4742.7921           | 3107                | 0.4675           | 2.2092                        | UI      | P80    |
| 4743.5200               | 4743.5204           | 44938               | 0.0815           | −0.4032                       | UI      | P80    |
| 4744.0310               | 4744.0260           | 4746                | 0.3758           | 4.9194                        | UI      | P80    |
| 4744.2966               | 4744.2965           | 12466               | 0.1657           | 0.1227                        | UII     | P80    |
| 4748.3922               | 4748.3914           | 5875                | 0.2897           | 0.8046                        | UI      | P80    |
| 4750.7130               | 4750.7175           | 4344                | 0.3817           | −4.4830                       | UI      | P80    |
| 4751.6583               | 4751.6618           | 7113                | 0.2370           | −3.4020                       | UI      | P80    |
| 4755.7356               | 4755.7363           | 17317               | 0.1384           | −0.7126                       | UII     | P80    |
| 4756.8053               | 4756.8054           | 219033              | 0.0370           | −0.1351                       | UI      | P80    |
| 4760.3392               | 4760.3446           | 2779                | 0.4884           | −5.3193                       | UII     | P80    |
| 4761.3300               | 4761.3298           | 8862                | 0.2079           | 0.2190                        | UI      | P80    |
| 4762.8913               | 4762.8889           | 7290                | 0.2367           | 2.3204                        | UI      | P80    |
| 4764.1500               | 4764.1484           | 4349                | 0.4180           | 1.5946                        | UII     | P80    |
| 4768.6641               | 4768.6637           | 113925              | 0.0476           | 0.3623                        | UI      | P80    |
| 4769.2665               | 4769.2662           | 23404               | 0.1211           | 0.2912                        | UII     | P80    |
| 4771.7149               | 4771.7147           | 10379               | 0.1957           | 0.2248                        | UI      | P80    |
| 4772.6956               | 4772.6945           | 31168               | 0.1073           | 1.0917                        | UII     | P80    |
| 4773.4315               | 4773.4329           | 104394              | 0.0500           | −1.3613                       | UI      | P80    |
| 4774.3848               | 4774.3817           | 4005                | 0.4512           | 3.0762                        | UI      | P80    |
| 4775.9223               | 4775.9213           | 5657                | 0.4185           | 1.0244                        | UI      | P80    |
| 4777.6745               | 4777.6733           | 119239              | 0.0501           | 1.2509                        | UI      | P80    |
| 4778.0949               | 4778.0961           | 22408               | 0.1347           | −1.1658                       | UI      | P80    |
| 4779.0913               | 4779.0927           | 5129                | 0.3465           | −1.3959                       | UI      | P80    |
| 4779.6317               | 4779.6291           | 17099               | 0.2051           | 2.5470                        | UII     | P80    |
| 4780.1872               | 4780.1862           | 21764               | 0.1295           | 0.9705                        | UI      | P80    |
| 4782.8051               | 4782.8108           | 12522               | 0.1935           | −5.7330                       | UI      | P80    |
| 4783.5015               | 4783.5072           | 3994                | 0.4228           | −5.6984                       | UI      | P80    |
| 4785.9177               | 4785.9194           | 31201               | 0.1115           | −1.6376                       | UI      | P80    |
| 4786.7260               | 4786.7294           | 4089                | 0.3843           | −3.4876                       | UI      | P80    |
| 4787.6089               | 4787.6030           | 3134                | 0.6331           | 5.9654                        | UI      | P80    |
| 4790.3763               | 4790.3716           | 3452                | 0.4381           | 4.7015                        | UI      | P80    |
| 4791.5687               | 4791.5739           | 3478                | 0.4229           | −5.1459                       | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|--------------------|-----------------|------------------------|--------|--------|
| 4791.8286              | 4791.8349          | 4142               | 0.4089          | −6.2967                | UII    | P80    |
| 4794.4869              | 4794.4805          | 3538               | 0.5030          | 6.4760                 | UI     | P80    |
| 4799.7413              | 4799.7398          | 8699               | 0.2352          | 1.5290                 | UI     | RS21   |
| 4800.2266              | 4800.2250          | 4824               | 0.3209          | 1.5695                 | UI     | P80    |
| 4801.0522              | 4801.0571          | 5715               | 0.4715          | −4.8595                | UI     | P80    |
| 4804.2333              | 4804.2290          | 4834               | 0.4550          | 4.3069                 | UI     | P80    |
| 4807.6112              | 4807.6084          | 12321              | 0.1781          | 2.8065                 | UI     | P80    |
| 4808.6012              | 4808.6007          | 3318               | 0.5473          | 0.5023                 | UI     | P80    |
| 4808.8448              | 4808.8460          | 8837               | 0.2551          | −1.2197                | UI     | P80    |
| 4809.9911              | 4809.9920          | 4124               | 0.4926          | −0.3494                | UI     | P80    |
| 4810.8893              | 4810.8890          | 120712             | 0.0472          | 0.3542                 | UI     | P80    |
| 4811.6877              | 4811.6890          | 15715              | 0.1651          | −1.2715                | UII    | P80    |
| 4813.7838              | 4813.7819          | 3482               | 0.6101          | 1.9242                 | UI     | P80    |
| 4814.0990              | 4814.1011          | 32126              | 0.1050          | −2.1490                | UI     | P80    |
| 4815.7071              | 4815.7068          | 67231              | 0.0668          | 0.3002                 | UI     | RS21   |
| 4818.6095              | 4818.6119          | 16843              | 0.1538          | −2.3256                | UI     | P80    |
| 4819.2452              | 4819.2452          | 5825               | 0.3283          | 0.0366                 | UII    | P80    |
| 4819.5438              | 4819.5492          | 14721              | 0.1670          | −5.4271                | UII    | P80    |
| 4824.2771              | 4824.2816          | 11910              | 0.2225          | −4.5213                | UI     | P80    |
| 4824.5019              | 4824.5031          | 5999               | 0.2968          | −1.1386                | UI     | P80    |
| 4827.8425              | 4827.8432          | 2989               | 0.6156          | −0.6981                | UII    | P80    |
| 4834.1768              | 4834.1798          | 5000               | 0.3169          | −2.9531                | UI     | P80    |
| 4838.1805              | 4838.1794          | 3704               | 0.4297          | 1.1159                 | UI     | P80    |
| 4841.0440              | 4841.0435          | 12916              | 0.1851          | 0.5421                 | UI     | P80    |
| 4842.4838              | 4842.4884          | 170862             | 0.0490          | −4.6124                | UI     | P80    |
| 4843.4944              | 4843.4892          | 10410              | 0.2012          | 5.2198                 | UII    | P80    |
| 4844.7166              | 4844.7178          | 7816               | 0.2529          | −1.2640                | UII    | P80    |
| 4845.6809              | 4845.6805          | 11721              | 0.1796          | 0.3814                 | UI     | P80    |
| 4847.9991              | 4848.0006          | 43820              | 0.1164          | −1.4772                | UI     | P80    |
| 4849.4004              | 4849.4001          | 3989               | 0.4170          | 0.3165                 | UII    | RS21   |
| 4850.5979              | 4850.5968          | 4138               | 0.4426          | 1.0623                 | UI     | RS21   |
| 4851.4593              | 4851.4565          | 6781               | 0.3130          | 2.7778                 | UI     | P80    |
| 4852.1071              | 4852.1078          | 7690               | 0.2769          | −0.6631                | UII    | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 4852.9550               | 4852.9570           | 13745               | 0.1695           | −1.9303                         | UI      | P80    |
| 4854.8615               | 4854.8631           | 5751                | 0.3625           | −1.5564                         | UI      | P80    |
| 4856.0919               | 4856.0869           | 3017                | 0.6909           | 5.0034                          | UI      | P80    |
| 4856.6559               | 4856.6564           | 15929               | 0.1541           | −0.5167                         | UI      | P80    |
| 4857.5041               | 4857.5017           | 4145                | 0.5324           | 2.4161                          | UII     | P80    |
| 4858.0840               | 4858.0831           | 17122               | 0.1508           | 0.9350                          | UI      | P80    |
| 4859.6933               | 4859.6919           | 18371               | 0.1442           | 1.4171                          | UII     | P80    |
| 4860.9941               | 4860.9906           | 13506               | 0.1801           | 3.4586                          | UII     | P80    |
| 4861.8263               | 4861.8240           | 10182               | 0.1999           | 2.3098                          | UI      | P80    |
| 4863.4922               | 4863.4871           | 7166                | 0.2933           | 5.1486                          | UI      | P80    |
| 4868.8633               | 4868.8582           | 34022               | 0.1021           | 5.1010                          | UI      | P80    |
| 4869.0444               | 4869.0444           | 5326                | 0.3570           | 0.0065                          | UI      | P80    |
| 4870.6423               | 4870.6447           | 6060                | 0.3011           | −2.4100                         | UI      | P80    |
| 4871.8002               | 4871.7944           | 8602                | 0.2190           | 5.7509                          | UI      | P80    |
| 4874.0816               | 4874.0815           | 4514                | 0.3663           | 0.1196                          | UII     | RS21   |
| 4874.3486               | 4874.3433           | 15053               | 0.1559           | 5.5596                          | UI      | P80    |
| 4877.9915               | 4877.9866           | 4584                | 0.3864           | 4.9189                          | UII     | P80    |
| 4878.5049               | 4878.5013           | 24168               | 0.1232           | 3.5856                          | UI      | P80    |
| 4880.2544               | 4880.2549           | 12850               | 0.2640           | −0.4221                         | UI      | P80    |
| 4884.3477               | 4884.3460           | 5195                | 0.3558           | 1.6503                          | UI      | P80    |
| 4885.1409               | 4885.1408           | 415284              | 0.0258           | 0.0324                          | UI      | P80    |
| 4886.3307               | 4886.3249           | 9056                | 0.2885           | 5.7464                          | UII     | P80    |
| 4886.6015               | 4886.6011           | 9494                | 0.2117           | 0.4140                          | UI      | P80    |
| 4887.7332               | 4887.7308           | 6697                | 0.3347           | 2.3637                          | UI      | P80    |
| 4891.1747               | 4891.1777           | 26232               | 0.1310           | −3.0683                         | UI      | P80    |
| 4892.6129               | 4892.6140           | 4727                | 0.4199           | −1.1281                         | UII     | P80    |
| 4894.7047               | 4894.7012           | 5006                | 0.4577           | 3.5187                          | UI      | RS21   |
| 4895.6650               | 4895.6684           | 36415               | 0.1034           | −3.3534                         | UI      | P80    |
| 4896.0023               | 4896.0023           | 3448                | 0.5152           | −0.0114                         | UI      | P80    |
| 4898.6072               | 4898.6108           | 6888                | 0.3166           | −3.6332                         | UII     | P80    |
| 4899.2883               | 4899.2878           | 39554               | 0.1029           | 0.4726                          | UII     | P80    |
| 4900.4353               | 4900.4338           | 3223                | 0.5324           | 1.5512                          | UII     | RS21   |
| 4904.2057               | 4904.2050           | 5502                | 0.3099           | 0.7085                          | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 4906.2632               | 4906.2696           | 3100                | 0.4880           | −6.4430                         | UI      | P80    |
| 4909.3641               | 4909.3660           | 8114                | 0.2180           | −1.9531                         | UI      | P80    |
| 4910.3503               | 4910.3522           | 69760               | 0.0645           | −1.9347                         | UI      | P80    |
| 4911.6669               | 4911.6688           | 8951                | 0.2073           | −1.8186                         | UII     | P80    |
| 4913.1688               | 4913.1685           | 14620               | 0.1742           | 0.3291                          | UII     | P80    |
| 4916.6356               | 4916.6358           | 18678               | 0.1563           | −0.2001                         | UI      | P80    |
| 4916.8718               | 4916.8739           | 17939               | 0.1540           | −2.1011                         | UI      | P80    |
| 4918.9042               | 4918.9019           | 6369                | 0.2917           | 2.2625                          | UI      | P80    |
| 4919.1342               | 4919.1345           | 32311               | 0.1031           | −0.2662                         | UI      | P80    |
| 4920.1301               | 4920.1303           | 4665                | 0.3928           | −0.1808                         | UI      | P80    |
| 4921.3846               | 4921.3877           | 18004               | 0.1510           | −3.1044                         | UI      | P80    |
| 4923.6140               | 4923.6127           | 3430                | 0.5869           | 1.3311                          | UI      | P80    |
| 4924.6423               | 4924.6444           | 11276               | 0.2102           | −2.1895                         | UII     | P80    |
| 4925.6604               | 4925.6614           | 3853                | 0.5335           | −1.0338                         | UI      | P80    |
| 4926.4405               | 4926.4389           | 6003                | 0.2852           | 1.5618                          | UII     | P80    |
| 4927.6889               | 4927.6892           | 20660               | 0.1359           | −0.2681                         | UI      | P80    |
| 4928.4191               | 4928.1617           | 7520                | 0.2753           | 0.1622                          | UII     | P80    |
| 4928.4490               | 4928.4474           | 223081              | 0.0370           | 1.5971                          | UI      | P80    |
| 4933.6629               | 4933.6624           | 13641               | 0.1713           | 0.4416                          | UII     | P80    |
| 4934.0274               | 4934.0315           | 4933                | 0.3975           | −4.1010                         | UI      | P80    |
| 4934.5624               | 4934.5609           | 4443                | 0.3700           | 1.5081                          | UI      | P80    |
| 4936.9519               | 4936.9559           | 26522               | 0.1303           | −3.9957                         | UII     | P80    |
| 4937.9187               | 4937.9185           | 3438                | 0.7133           | 0.2508                          | UI      | RS21   |
| 4938.9643               | 4938.9629           | 4169                | 0.4057           | 1.4280                          | UII     | P80    |
| 4941.4692               | 4941.4676           | 8204                | 0.2491           | 1.6113                          | UI      | P80    |
| 4942.6377               | 4942.6376           | 9699                | 0.2125           | 0.0503                          | UII     | P80    |
| 4943.6909               | 4943.6921           | 5273                | 0.3146           | −1.2189                         | UI      | P80    |
| 4944.5022               | 4944.5045           | 89578               | 0.0592           | −2.3173                         | UI      | P80    |
| 4945.7639               | 4945.7639           | 4999                | 0.3282           | −0.0145                         | UII     | P80    |
| 4950.1702               | 4950.1715           | 5319                | 0.2959           | −1.3441                         | UII     | P80    |
| 4951.8427               | 4951.8467           | 4488                | 0.3655           | −4.0437                         | UI      | P80    |
| 4952.5223               | 4952.2199           | 2997                | 0.5480           | 0.3948                          | UI      | P80    |
| 4954.9558               | 4954.9539           | 12668               | 0.1937           | 1.8475                          | UII     | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 4955.7741               | 4955.7752           | 43241               | 0.0972           | −1.1779                       | UI      | P80    |
| 4958.0666               | 4958.0689           | 9380                | 0.2120           | −2.3251                       | UI      | P80    |
| 4959.5334               | 4959.5356           | 14204               | 0.1764           | −2.1723                       | UI      | P80    |
| 4961.0966               | 4961.0959           | 3685                | 0.5884           | 0.6242                        | Ull     | P80    |
| 4961.5420               | 4961.5427           | 7182                | 0.2552           | −0.7057                       | UI      | P80    |
| 4963.3043               | 4963.3064           | 8827                | 0.2306           | −2.1639                       | UI      | P80    |
| 4967.3238               | 4967.3226           | 162544              | 0.0407           | 1.2319                        | UI      | P80    |
| 4968.4444               | 4968.4408           | 4574                | 0.5249           | 3.5956                        | UI      | P80    |
| 4969.0122               | 4969.0090           | 5032                | 0.4188           | 3.2406                        | UI      | RS21   |
| 4970.2012               | 4970.2002           | 42467               | 0.0916           | 0.9832                        | UI      | P80    |
| 4972.7239               | 4972.7237           | 9625                | 0.2230           | 0.2114                        | UI      | P80    |
| 4981.9516               | 4981.9518           | 7747                | 0.2402           | −0.1767                       | UI      | P80    |
| 4984.6164               | 4984.6134           | 3092                | 0.4961           | 3.0411                        | UI      | P80    |
| 4986.8923               | 4986.8974           | 9981                | 0.2367           | −5.0700                       | Ull     | P80    |
| 4988.3311               | 4988.3320           | 5215                | 0.3054           | −0.9092                       | UI      | P80    |
| 4990.1145               | 4990.1173           | 11201               | 0.1841           | −2.8547                       | UI      | P80    |
| 4991.5951               | 4991.5977           | 3863                | 0.4237           | −2.5509                       | Ull     | P80    |
| 4992.9279               | 4992.9304           | 4991                | 0.3239           | −2.4674                       | Ull     | P80    |
| 4996.6205               | 4996.6215           | 3338                | 0.4613           | −0.9354                       | UI      | P80    |
| 4997.4107               | 4997.4128           | 7658                | 0.2444           | −2.0758                       | UI      | P80    |
| 4999.6072               | 4999.6123           | 4357                | 0.4591           | −5.0482                       | UI      | P80    |
| 4999.9463               | 4999.9429           | 5305                | 0.3449           | 3.3784                        | Ull     | P80    |
| 5001.5475               | 5001.5479           | 2996                | 0.5162           | −0.3753                       | UI      | P80    |
| 5004.0075               | 5004.0064           | 51668               | 0.0805           | 1.0744                        | UI      | P80    |
| 5006.0135               | 5006.0105           | 6579                | 0.3159           | 3.0013                        | UI      | P80    |
| 5008.2105               | 5008.2103           | 54933               | 0.0775           | 0.2571                        | Ull     | P80    |
| 5008.6844               | 5008.6798           | 37954               | 0.0974           | 4.6860                        | UI      | P80    |
| 5011.4099               | 5011.4088           | 184751              | 0.0408           | 1.1143                        | UI      | P80    |
| 5011.8287               | 5011.8263           | 7736                | 0.2996           | 2.3835                        | UI      | P80    |
| 5012.4097               | 5012.4040           | 11135               | 0.2424           | 5.6640                        | UI      | P80    |
| 5012.9231               | 5012.9268           | 5952                | 0.4155           | −3.6798                       | Ull     | P80    |
| 5017.6373               | 5017.6400           | 4569                | 0.4682           | −2.6552                       | UI      | RS21   |
| 5021.1773               | 5021.1771           | 7474                | 0.2483           | 0.1858                        | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 5024.5669              | 5024.5673           | 12726               | 0.1824           | −0.3536                         | UI      | P80    |
| 5027.3835              | 5027.3837           | 741287              | 0.0202           | −0.2543                         | UI      | P80    |
| 5032.0403              | 5032.0435           | 3257                | 0.4129           | −3.1843                         | UII     | P80    |
| 5036.5227              | 5036.5255           | 8157                | 0.2433           | −2.8623                         | UI      | P80    |
| 5047.4038              | 5047.4038           | 9763                | 0.1992           | 0.0095                          | UII     | P80    |
| 5048.8231              | 5048.8247           | 4707                | 0.4617           | −1.6401                         | UII     | RS21   |
| 5049.0484              | 5049.0473           | 35511               | 0.0924           | 1.0425                          | UI      | P80    |
| 5051.4290              | 5051.4292           | 17403               | 0.1560           | −0.1150                         | UI      | P80    |
| 5052.6359              | 5052.6379           | 4387                | 0.4885           | −1.9355                         | UI      | P80    |
| 5053.3500              | 5053.3502           | 135836              | 0.0481           | −0.1959                         | UI      | P80    |
| 5054.1856              | 5054.1870           | 4091                | 0.5916           | −1.3901                         | UI      | RS21   |
| 5054.8039              | 5054.8074           | 3392                | 0.5362           | −3.4804                         | UI      | RS21   |
| 5055.4129              | 5055.4065           | 3321                | 0.5532           | 6.4248                          | UI      | P80    |
| 5056.2144              | 5056.2165           | 5737                | 0.3092           | −2.0922                         | UI      | P80    |
| 5057.1762              | 5057.1777           | 6150                | 0.2983           | −1.4680                         | UI      | P80    |
| 5059.2402              | 5059.2401           | 2636                | 0.5549           | 0.1294                          | UI      | P80    |
| 5059.5556              | 5059.5522           | 3329                | 0.5119           | 3.4019                          | UI      | P80    |
| 5061.4891              | 5061.4874           | 5684                | 0.3300           | 1.7233                          | UI      | P80    |
| 5062.0371              | 5062.0390           | 140353              | 0.0494           | −1.9228                         | UI      | RS21   |
| 5063.7575              | 5063.7582           | 60081               | 0.0760           | −0.7348                         | UII     | P80    |
| 5067.2110              | 5067.2122           | 3152                | 0.4742           | −1.2463                         | UII     | P80    |
| 5074.7636              | 5074.7636           | 11995               | 0.1819           | −0.0012                         | UI      | P80    |
| 5076.7502              | 5076.7508           | 28298               | 0.1060           | −0.6011                         | UI      | P80    |
| 5076.9867              | 5076.9870           | 5458                | 0.2968           | −0.2872                         | UI      | P80    |
| 5077.8059              | 5077.8054           | 7354                | 0.2376           | 0.4715                          | UII     | P80    |
| 5078.1978              | 5078.1979           | 4140                | 0.3650           | −0.1034                         | UI      | P80    |
| 5080.4818              | 5080.4802           | 9721                | 0.2239           | 1.6068                          | UI      | P80    |
| 5081.4042              | 5081.3976           | 6657                | 0.2893           | 6.5324                          | UI      | P80    |
| 5086.8147              | 5086.8142           | 3481                | 0.4875           | 0.5209                          | UII     | P80    |
| 5088.2859              | 5088.2857           | 142938              | 0.0471           | 0.1395                          | UI      | P80    |
| 5090.1543              | 5090.1549           | 3497                | 0.5078           | −0.6212                         | UII     | P80    |
| 5090.4964              | 5090.4961           | 46358               | 0.0939           | 0.3236                          | UII     | RS21   |
| 5091.2878              | 5091.2865           | 3575                | 0.5564           | 1.2642                          | UII     | RS21   |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mA) | Offset from Ritz wavelength (mA) | Species | Source |
|-------------------------|---------------------|---------------------|-----------------|---------------------------------|---------|--------|
| 5093.0986               | 5093.0956           | 39521               | 0.1008          | 3.0077                          | UI      | P80    |
| 5093.8939               | 5093.8934           | 8550                | 0.2665          | 0.4979                          | UI      | P80    |
| 5101.0074               | 5101.0076           | 42458               | 0.0886          | -0.1498                         | UI      | P80    |
| 5101.7427               | 5101.7428           | 5999                | 0.3071          | -0.0397                         | UI      | P80    |
| 5106.7384               | 5106.7330           | 10204               | 0.2157          | 5.4510                          | UI      | P80    |
| 5107.3229               | 5107.3261           | 5610                | 0.3500          | -3.2210                         | UI      | P80    |
| 5107.6756               | 5107.6768           | 27706               | 0.1141          | -1.1812                         | UI      | P80    |
| 5109.3855               | 5109.3832           | 3785                | 0.4383          | 2.2577                          | UI      | P80    |
| 5110.6864               | 5110.6857           | 10815               | 0.1986          | 0.6939                          | UII     | P80    |
| 5115.8251               | 5115.8274           | 4114                | 0.3933          | -2.3081                         | UI      | P80    |
| 5116.9251               | 5116.9270           | 3696                | 0.4464          | -1.8851                         | UI      | P80    |
| 5117.2393               | 5117.2380           | 17791               | 0.1497          | 1.2739                          | UII     | P80    |
| 5119.5017               | 5119.5018           | 23281               | 0.1244          | -0.0568                         | UI      | P80    |
| 5120.4184               | 5120.4211           | 4376                | 0.3749          | -2.6555                         | UI      | P80    |
| 5123.3301               | 5123.3327           | 2901                | 0.5948          | -2.6519                         | UII     | P80    |
| 5124.0816               | 5124.0821           | 16928               | 0.1475          | -0.4612                         | UI      | P80    |
| 5124.9427               | 5124.9430           | 7897                | 0.2531          | -0.2506                         | UI      | P80    |
| 5125.4846               | 5125.4911           | 16191               | 0.1703          | -6.4349                         | UI      | P80    |
| 5126.1468               | 5126.1481           | 5702                | 0.4352          | -1.3276                         | UII     | P80    |
| 5128.3598               | 5128.3602           | 15725               | 0.1644          | -0.3560                         | UI      | P80    |
| 5130.1546               | 5130.1597           | 5219                | 0.3958          | -5.0816                         | UI      | P80    |
| 5132.1908               | 5132.1905           | 32363               | 0.1041          | 0.3270                          | UI      | P80    |
| 5132.6183               | 5132.6146           | 5609                | 0.3775          | 3.7370                          | UI      | P80    |
| 5134.1866               | 5134.1858           | 16095               | 0.1805          | 0.7730                          | UI      | P80    |
| 5136.5188               | 5136.5224           | 3979                | 0.7911          | -3.5516                         | UI      | RS21   |
| 5137.0460               | 5137.0462           | 11284               | 0.2561          | -0.1230                         | UII     | P80    |
| 5139.3401               | 5139.3404           | 10841               | 0.2774          | -0.2600                         | UI      | P80    |
| 5139.9772               | 5139.9788           | 19641               | 0.1936          | -1.5795                         | UII     | P80    |
| 5140.5089               | 5140.5083           | 6054                | 0.4297          | 0.6401                          | UII     | RS21   |
| 5141.7827               | 5141.7819           | 193113              | 0.0437          | 0.8210                          | UII     | RS21   |
| 5142.3946               | 5142.3945           | 44154               | 0.0912          | 0.0809                          | UI      | P80    |
| 5142.7167               | 5142.7164           | 11417               | 0.2327          | 0.3452                          | UI      | P80    |
| 5144.5141               | 5144.5146           | 42692               | 0.0946          | -0.5644                         | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|---------------------|------------------|-----------------------------|---------|--------|
| 5146.9849              | 5146.9858          | 25294               | 0.1231           | −0.9331                    | UI      | P80    |
| 5147.9432              | 5147.9388          | 3213                | 0.6538           | 4.3544                     | UI      | P80    |
| 5148.9574              | 5148.9590          | 6567                | 0.3050           | −1.6019                    | UI      | P80    |
| 5149.2433              | 5149.2434          | 8261                | 0.2533           | −0.0968                    | UI      | P80    |
| 5151.3903              | 5151.3935          | 12346               | 0.2043           | −3.2236                    | UI      | RS21   |
| 5152.1313              | 5152.1309          | 3442                | 0.5719           | 0.3722                     | UI      | P80    |
| 5152.3868              | 5152.3871          | 6759                | 0.3973           | −0.3113                    | UI      | P80    |
| 5152.7733              | 5152.7709          | 4576                | 0.5028           | 2.3861                     | UI      | P80    |
| 5153.3901              | 5153.3914          | 3096                | 0.6225           | −1.2950                    | UI      | P80    |
| 5154.2147              | 5154.2186          | 12571               | 0.2069           | −3.8807                    | UI      | P80    |
| 5156.0262              | 5156.0327          | 10281               | 0.2565           | −6.4586                    | UI      | P80    |
| 5156.5591              | 5156.5599          | 3428                | 0.4976           | −0.7452                    | UI      | P80    |
| 5160.3178              | 5160.3159          | 22493               | 0.1322           | 1.8417                     | UI      | P80    |
| 5160.6675              | 5160.6676          | 11026               | 0.2014           | −0.1101                    | UI      | P80    |
| 5164.1378              | 5164.1384          | 58676               | 0.0743           | −0.5563                    | UI      | P80    |
| 5166.7362              | 5166.7422          | 3840                | 0.5646           | −5.9842                    | UI      | P80    |
| 5168.4074              | 5168.4023          | 4827                | 0.3852           | 5.1234                     | UI      | P80    |
| 5170.8925              | 5170.8918          | 4729                | 0.3712           | 0.6970                     | UI      | P80    |
| 5171.6401              | 5171.6452          | 4150                | 0.5988           | −5.1121                    | UI      | P80    |
| 5172.6563              | 5172.6549          | 4798                | 0.4076           | 1.3604                     | UI      | P80    |
| 5174.3188              | 5174.3188          | 14021               | 0.1767           | 0.0163                     | UI      | P80    |
| 5174.9826              | 5174.9837          | 3407                | 0.6151           | −1.1465                    | UI      | RS21   |
| 5175.6828              | 5175.6776          | 4230                | 0.4840           | 5.2509                     | UI      | P80    |
| 5177.2103              | 5177.2146          | 5567                | 0.4176           | −4.2612                    | UI      | P80    |
| 5178.1126              | 5178.1154          | 4290                | 0.6034           | −2.8481                    | UI      | RS21   |
| 5180.0136              | 5180.0124          | 7452                | 0.3288           | 1.2133                     | UI      | P80    |
| 5180.6677              | 5180.6662          | 64645               | 0.0773           | 1.4746                     | UI      | P80    |
| 5180.8776              | 5180.8786          | 96991               | 0.0618           | −0.9994                    | UI      | P80    |
| 5183.0274              | 5183.0253          | 9083                | 0.2839           | 2.1249                     | UI      | P80    |
| 5184.2180              | 5184.2233          | 4681                | 0.5912           | −5.2535                    | UI      | RS21   |
| 5184.5751              | 5184.5719          | 31851               | 0.1291           | 3.1926                     | UI      | P80    |
| 5188.5589              | 5188.5609          | 13622               | 0.2018           | −2.0175                    | UI      | P80    |
| 5189.2000              | 5189.2026          | 9197                | 0.2522           | −2.6137                    | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|--------------------|-----------------|-------------------------------|---------|--------|
| 5189.8668              | 5189.8709          | 3378               | 0.6385          | −4.0841                       | UII     | RS21   |
| 5191.5098              | 5191.5121          | 55844              | 0.0906          | −2.3187                       | UI      | P80    |
| 5192.0003              | 5192.0019          | 16324              | 0.1707          | 1.1256                        | UI      | P80    |
| 5193.8911              | 5193.8954          | 4989               | 0.3994          | −4.2291                       | UI      | P80    |
| 5196.4590              | 5196.4570          | 3796               | 0.5208          | 2.0545                        | UI      | P80    |
| 5197.9876              | 5197.9863          | 3156               | 0.6191          | 1.2783                        | UII     | P80    |
| 5201.4644              | 5201.4641          | 4968               | 0.3790          | 0.2515                        | UI      | P80    |
| 5202.4539              | 5202.4533          | 4002               | 0.4530          | 0.6015                        | UII     | P80    |
| 5205.1595              | 5205.1620          | 111618             | 0.0571          | −2.5651                       | UI      | P80    |
| 5206.0028              | 5206.0059          | 7051               | 0.2830          | −3.1172                       | UI      | P80    |
| 5207.7850              | 5207.7862          | 19293              | 0.1445          | −1.1927                       | UI      | P80    |
| 5212.4848              | 5212.4882          | 3245               | 0.5487          | −3.3841                       | UI      | P80    |
| 5212.7334              | 5212.7323          | 4898               | 0.3691          | 1.0915                        | UI      | P80    |
| 5215.1782              | 5215.1792          | 25604              | 0.1263          | −0.9908                       | UI      | P80    |
| 5216.1638              | 5216.1651          | 3330               | 0.7314          | −1.2999                       | UI      | P80    |
| 5216.9317              | 5216.9333          | 130834             | 0.0536          | −1.5644                       | UI      | P80    |
| 5218.5501              | 5218.5476          | 9908               | 0.2351          | 2.5532                        | UI      | P80    |
| 5221.8929              | 5221.8963          | 106018             | 0.0602          | −3.4228                       | UI      | P80    |
| 5223.7827              | 5223.7845          | 4728               | 0.6170          | −1.7867                       | UI      | P80    |
| 5224.2804              | 5224.2825          | 8475               | 0.2916          | −2.1212                       | UII     | P80    |
| 5225.1195              | 5225.1209          | 17538              | 0.1744          | −1.4194                       | UII     | P80    |
| 5226.4857              | 5226.4873          | 13142              | 0.2044          | −1.5726                       | UI      | P80    |
| 5228.7342              | 5228.7328          | 5820               | 0.5060          | 1.3424                        | UI      | P80    |
| 5228.9971              | 5228.9967          | 8676               | 0.3424          | 0.4153                        | UI      | P80    |
| 5229.2913              | 5229.2927          | 26224              | 0.1232          | −1.3998                       | UI      | P80    |
| 5230.2933              | 5230.2951          | 7698               | 0.3126          | −1.7669                       | UI      | P80    |
| 5230.9964              | 5230.9991          | 8359               | 0.2770          | −0.6561                       | UI      | P80    |
| 5232.1654              | 5232.1685          | 17149              | 0.1820          | −3.0790                       | UI      | P80    |
| 5232.8012              | 5232.8029          | 32601              | 0.1164          | −1.6436                       | UI      | P80    |
| 5233.2089              | 5233.2084          | 7100               | 0.3120          | 0.4633                        | UI      | P80    |
| 5234.1586              | 5234.1594          | 36685              | 0.1025          | −0.8172                       | UI      | P80    |
| 5238.6174              | 5238.6159          | 5479               | 0.3498          | 1.5511                        | UII     | P80    |
| 5239.3574              | 5239.3580          | 25056              | 0.1251          | −0.6145                       | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|------------------|----------------------------------|---------|--------|
| 5240.0093              | 5240.0113           | 5715                | 0.3283           | −1.9850                          | UI      | P80    |
| 5241.7828              | 5241.7837           | 37305               | 0.0971           | −0.9522                          | UI      | P80    |
| 5242.3049              | 5242.3007           | 5587                | 0.3757           | 4.1549                           | UI      | P80    |
| 5243.4963              | 5243.4951           | 3211                | 0.5438           | 1.2482                           | UI      | P80    |
| 5244.6840              | 5244.6835           | 10223               | 0.2299           | 0.4275                           | UI      | P80    |
| 5247.3525              | 5247.3525           | 7462                | 0.2624           | −0.0360                          | UII     | P80    |
| 5247.7407              | 5247.7410           | 18696               | 0.1959           | −0.3054                          | UI      | P80    |
| 5248.0212              | 5248.0256           | 8562                | 0.2573           | −4.3629                          | UI      | P80    |
| 5250.7412              | 5250.7416           | 4587                | 0.3914           | −0.4117                          | UI      | P80    |
| 5251.2098              | 5251.2081           | 7232                | 0.2995           | 1.7072                           | UI      | P80    |
| 5253.5597              | 5253.5580           | 3122                | 0.5438           | 1.6365                           | UI      | P80    |
| 5253.8656              | 5253.8687           | 7470                | 0.2800           | −3.0712                          | UI      | P80    |
| 5255.2754              | 5255.2706           | 8806                | 0.2631           | 4.7322                           | UI      | P80    |
| 5255.6920              | 5255.6910           | 6110                | 0.3279           | 1.0269                           | UI      | P80    |
| 5257.0477              | 5257.0448           | 15288               | 0.2005           | 2.9279                           | UII     | P80    |
| 5258.7188              | 5258.7180           | 5869                | 0.3404           | 0.7581                           | UI      | P80    |
| 5259.9040              | 5259.9031           | 22366               | 0.1319           | 0.8862                           | UI      | P80    |
| 5263.4238              | 5263.4232           | 5298                | 0.4211           | 0.5865                           | UII     | RS21   |
| 5263.8651              | 5263.8665           | 7561                | 0.2876           | −1.3827                          | UI      | P80    |
| 5265.9885              | 5265.9915           | 4818                | 0.5218           | −3.0075                          | UI      | P80    |
| 5268.5516              | 5268.5510           | 20971               | 0.1543           | 0.5882                           | UI      | P80    |
| 5270.1818              | 5270.1860           | 4936                | 0.5146           | −4.2466                          | UII     | P80    |
| 5270.4318              | 5270.4291           | 8502                | 0.3756           | 2.6412                           | UII     | P80    |
| 5270.6281              | 5270.6289           | 56643               | 0.0833           | −0.7135                          | UI      | P80    |
| 5272.0058              | 5272.0050           | 51709               | 0.0949           | 0.8151                           | UI      | P80    |
| 5273.2402              | 5273.2418           | 7601                | 0.3131           | −1.5573                          | UI      | P80    |
| 5275.1975              | 5275.1928           | 6233                | 0.3401           | 4.6702                           | UI      | P80    |
| 5275.9246              | 5275.9258           | 45571               | 0.0936           | −1.2047                          | UI      | P80    |
| 5278.1699              | 5278.1683           | 10023               | 0.2548           | 1.5700                           | UII     | P80    |
| 5280.3798              | 5280.3790           | 495695              | 0.0269           | 0.7330                           | UI      | P80    |
| 5283.3812              | 5283.3757           | 6134                | 0.4682           | 5.5051                           | UI      | P80    |
| 5283.5768              | 5283.5780           | 32953               | 0.1121           | −1.2444                          | UI      | P80    |
| 5286.0838              | 5286.0875           | 3968                | 0.4570           | −3.6860                          | UII     | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 5288.3786               | 5288.3797           | 4950                | 0.3629           | -1.1233                         | UII     | P80    |
| 5294.0306               | 5294.0310           | 7093                | 0.2863           | -0.3549                         | UI      | P80    |
| 5297.4452               | 5297.4461           | 36797               | 0.1009           | -0.9267                         | UI      | P80    |
| 5299.4415               | 5299.4404           | 5421                | 0.3748           | 1.1214                          | UI      | P80    |
| 5300.5706               | 5300.5687           | 23733               | 0.1274           | 1.8935                          | UI      | P80    |
| 5303.0979               | 5303.0927           | 12242               | 0.2035           | 5.2849                          | UI      | P80    |
| 5304.5676               | 5304.5700           | 4789                | 0.4444           | -2.3196                         | UI      | P80    |
| 5306.5896               | 5306.5872           | 12491               | 0.1885           | 2.4619                          | UI      | P80    |
| 5308.5420               | 5308.5409           | 253604              | 0.0363           | 1.0784                          | UI      | P80    |
| 5310.0426               | 5310.0438           | 15808               | 0.1623           | -1.2496                         | UI      | P80    |
| 5310.4779               | 5310.4752           | 4555                | 0.3951           | 2.6745                          | UII     | P80    |
| 5310.6818               | 5310.6780           | 5649                | 0.3543           | 3.7814                          | UI      | P80    |
| 5313.2559               | 5313.2546           | 5583                | 0.4170           | 1.2409                          | UII     | RS21   |
| 5315.2759               | 5315.2779           | 49517               | 0.0936           | -1.9884                         | UI      | P80    |
| 5319.0104               | 5319.0079           | 5321                | 0.4157           | 2.5267                          | UI      | P80    |
| 5319.3901               | 5319.3959           | 11292               | 0.2375           | -5.8164                         | UI      | P80    |
| 5320.4431               | 5320.4432           | 10732               | 0.2322           | -0.0974                         | UI      | P80    |
| 5321.6066               | 5321.6048           | 6784                | 0.3183           | 1.7777                          | UII     | P80    |
| 5322.7867               | 5322.7830           | 33173               | 0.1146           | 3.6621                          | UII     | P80    |
| 5325.4991               | 5325.5027           | 4821                | 0.4173           | -3.5862                         | UI      | P80    |
| 5327.3261               | 5327.3246           | 6649                | 0.3822           | 1.4330                          | UII     | P80    |
| 5327.7543               | 5327.7555           | 7330                | 0.2871           | -1.1480                         | UII     | P80    |
| 5329.2620               | 5329.2648           | 66773               | 0.0779           | -2.8696                         | UII     | P80    |
| 5331.5731               | 5331.5774           | 3347                | 0.5376           | -4.3604                         | UI      | P80    |
| 5336.5423               | 5336.5436           | 19552               | 0.1438           | -1.2244                         | UI      | P80    |
| 5341.5078               | 5341.5056           | 28416               | 0.1117           | 2.2144                          | UII     | P80    |
| 5344.2761               | 5344.2735           | 2800                | 0.6729           | 2.6315                          | UII     | P80    |
| 5345.3359               | 5345.3372           | 4480                | 0.3900           | -1.3089                         | UI      | P80    |
| 5346.6421               | 5346.6404           | 5952                | 0.3216           | 1.6968                          | UI      | P80    |
| 5348.9878               | 5348.9922           | 4419                | 0.4025           | -4.3258                         | UI      | P80    |
| 5354.3596               | 5354.3588           | 6371                | 0.3043           | 0.8249                          | UI      | P80    |
| 5355.3694               | 5355.3716           | 6263                | 0.3310           | -2.2649                         | UI      | P80    |
| 5355.5783               | 5355.5767           | 10725               | 0.2088           | 1.5550                          | UI      | RS21   |

Sharma and Chakraborty: Precision wavelength calibration for radial velocity measurements...
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 5356.5736               | 5356.5749           | 11254               | 0.2114           | −1.3310                         | UII     | P80    |
| 5357.1871               | 5357.1854           | 3833                | 0.5531           | 1.7009                          | UI      | RS21   |
| 5359.0469               | 5359.0526           | 4057                | 0.9030           | −5.7327                         | UII     | RS21   |
| 5359.4233               | 5359.4264           | 8050                | 0.3056           | −3.0304                         | UI      | P80    |
| 5363.8033               | 5363.8054           | 10024               | 0.2534           | −2.0909                         | UI      | P80    |
| 5364.0616               | 5364.0622           | 5620                | 0.5112           | −0.6519                         | UII     | P80    |
| 5364.7135               | 5364.7122           | 16075               | 0.1838           | 1.3876                          | UI      | P80    |
| 5368.3860               | 5368.3835           | 12973               | 0.2401           | 2.4710                          | UI      | P80    |
| 5370.9126               | 5370.9162           | 4818                | 0.4547           | −3.5637                         | UI      | P80    |
| 5371.3491               | 5371.3513           | 4583                | 0.4103           | −2.1899                         | UI      | P80    |
| 5373.9965               | 5373.9933           | 4178                | 0.5364           | 3.1218                          | UII     | RS21   |
| 5374.2129               | 5374.2134           | 3534                | 0.6321           | −0.5190                         | UI      | P80    |
| 5375.5009               | 5375.5008           | 14406               | 0.1759           | 0.1026                          | UI      | P80    |
| 5375.7595               | 5375.7616           | 13423               | 0.1824           | −2.1186                         | UI      | P80    |
| 5378.1085               | 5378.1125           | 6759                | 0.3261           | −4.0331                         | UI      | P80    |
| 5378.6836               | 5378.6827           | 2850                | 0.5902           | 0.8372                          | UI      | P80    |
| 5382.0047               | 5382.0020           | 6514                | 0.5688           | 2.7435                          | UI      | P80    |
| 5382.9289               | 5382.9302           | 45027               | 0.0940           | −1.3296                         | UI      | P80    |
| 5386.1982               | 5386.1924           | 5040                | 0.4121           | 5.8655                          | UII     | P80    |
| 5390.2789               | 5390.2780           | 4543                | 0.4592           | 0.8385                          | UI      | P80    |
| 5391.0932               | 5391.0910           | 3874                | 0.4619           | 2.1341                          | UI      | P80    |
| 5392.8303               | 5392.8348           | 4275                | 0.4485           | −4.5073                         | UII     | RS21   |
| 5394.4708               | 5394.4745           | 2975                | 0.5898           | −3.6532                         | UI      | P80    |
| 5395.5421               | 5395.5418           | 7448                | 0.2788           | 0.2191                          | UI      | P80    |
| 5398.8372               | 5398.8392           | 4252                | 0.4779           | −2.0465                         | UI      | RS21   |
| 5399.5302               | 5399.5289           | 9291                | 0.2711           | 1.3243                          | UII     | P80    |
| 5400.9161               | 5400.9100           | 21086               | 0.1666           | 6.0956                          | UI      | P80    |
| 5401.4229               | 5401.4223           | 3097                | 0.6266           | 0.5008                          | UI      | P80    |
| 5401.8918               | 5401.8915           | 13729               | 0.1781           | 0.3218                          | UI      | P80    |
| 5403.1834               | 5403.1876           | 9523                | 0.2342           | −4.1815                         | UII     | P80    |
| 5404.6629               | 5404.6573           | 5946                | 0.4886           | 5.5972                          | UI      | RS21   |
| 5405.9760               | 5405.9736           | 11086               | 0.2370           | 2.4018                          | UII     | P80    |
| 5406.3760               | 5406.3802           | 13942               | 0.2518           | −4.1619                         | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|-----------------|---------------------------------|---------|--------|
| 5406.6318              | 5406.6326           | 7004                | 0.4066          | −0.8053                         | UI      | RS21   |
| 5406.8689              | 5406.8690           | 33959               | 0.1176          | −0.1576                         | UI      | P80    |
| 5407.8207              | 5407.8230           | 5733                | 0.4691          | −2.2742                         | UI      | P80    |
| 5408.1336              | 5408.1338           | 4407                | 0.6040          | −0.2426                         | Uii     | RS21   |
| 5408.3290              | 5408.3224           | 4441                | 0.5766          | 6.5461                          | UI      | RS21   |
| 5409.0787              | 5409.0757           | 6034                | 0.4003          | 3.0448                          | Uii     | P80    |
| 5410.2337              | 5410.2334           | 42285               | 0.0994          | 0.2281                          | UI      | P80    |
| 5414.7546              | 5414.7578           | 12045               | 0.2231          | −3.2072                         | UI      | P80    |
| 5416.5641              | 5416.5616           | 3239                | 0.7865          | 2.4898                          | UI      | RS21   |
| 5419.3699              | 5419.3717           | 4510                | 0.4244          | −1.7559                         | UI      | P80    |
| 5423.3519              | 5423.3567           | 15547               | 0.1727          | −4.8080                         | UI      | P80    |
| 5424.7042              | 5424.7023           | 3101                | 0.5690          | 1.8820                          | Uii     | P80    |
| 5426.6751              | 5426.6779           | 5421                | 0.3359          | −2.7803                         | UI      | P80    |
| 5429.0462              | 5429.0458           | 4593                | 0.4009          | 0.3338                          | UI      | P80    |
| 5430.2346              | 5430.2358           | 10791               | 0.2103          | −1.1626                         | UI      | P80    |
| 5431.3469              | 5431.3473           | 22550               | 0.1352          | −0.3971                         | UI      | P80    |
| 5438.6276              | 5438.6292           | 3352                | 0.5489          | −1.5227                         | UI      | P80    |
| 5439.0831              | 5439.0863           | 3132                | 0.5034          | −3.2317                         | UI      | P80    |
| 5441.0803              | 5441.0839           | 3540                | 0.5894          | −3.6148                         | UI      | P80    |
| 5441.9921              | 5441.9910           | 3393                | 0.6400          | 1.0631                          | UI      | P80    |
| 5443.9400              | 5443.9404           | 4546                | 0.4524          | −0.3841                         | UI      | P80    |
| 5444.4685              | 5444.4685           | 6666                | 0.3158          | 0.0243                          | UI      | P80    |
| 5445.8674              | 5445.8657           | 6554                | 0.2945          | 1.7554                          | UI      | P80    |
| 5447.0558              | 5447.0508           | 4403                | 0.5080          | 4.9027                          | UI      | P80    |
| 5451.6585              | 5451.6561           | 33215               | 0.1159          | 2.3742                          | Uii     | RS21   |
| 5452.3952              | 5452.3937           | 17897               | 0.1763          | 1.5691                          | UI      | P80    |
| 5453.4219              | 5453.4213           | 5343                | 0.4938          | 0.6585                          | Uii     | RS21   |
| 5455.2466              | 5455.2481           | 4175                | 0.6547          | −1.4308                         | UI      | P80    |
| 5455.5884              | 5455.5888           | 8743                | 0.2897          | −0.3505                         | Uii     | P80    |
| 5456.1289              | 5456.1285           | 6579                | 0.4226          | 0.4130                          | UI      | P80    |
| 5456.7770              | 5456.7729           | 8038                | 0.3278          | 4.0557                          | UI      | P80    |
| 5459.2512              | 5459.2505           | 59872               | 0.0939          | 0.6318                          | UI      | P80    |
| 5459.5678              | 5459.5673           | 9623                | 0.3171          | 0.4560                          | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|---------------------|-----------------|-------------------------------|---------|--------|
| 5461.2912              | 5461.2875          | 3577                | 0.6977          | 3.7082                        | UI      | P80    |
| 5464.2235              | 5464.2235          | 50277               | 0.0924          | −0.0127                       | UI      | P80    |
| 5475.7091              | 5475.7059          | 11153               | 0.2442          | 3.1836                        | UII     | P80    |
| 5476.2905              | 5476.2877          | 2750                | 0.5973          | 2.7920                        | UI      | P80    |
| 5476.7637              | 5476.7687          | 5957                | 0.3297          | −4.9937                       | UI      | P80    |
| 5477.4996              | 5477.5019          | 3231                | 0.5604          | −2.3056                       | UII     | P80    |
| 5477.8460              | 5477.8478          | 12792               | 0.1883          | −1.7562                       | UI      | P80    |
| 5480.2628              | 5480.2618          | 6901                | 0.3308          | 0.9445                        | UII     | P80    |
| 5487.0020              | 5487.0019          | 7522                | 0.2804          | 0.0420                        | UII     | RS21   |
| 5487.2396              | 5487.2390          | 3290                | 0.6197          | 0.5814                        | UI      | P80    |
| 5488.8837              | 5488.8831          | 8970                | 0.2370          | 0.6517                        | UI      | P80    |
| 5491.2211              | 5491.2197          | 5551                | 0.4012          | 1.4420                        | UII     | P80    |
| 5492.9504              | 5492.9510          | 126206              | 0.0530          | −0.5884                       | UII     | P80    |
| 5494.6042              | 5494.6103          | 13587               | 0.2542          | −6.0482                       | UI      | P80    |
| 5495.2984              | 5495.2981          | 19984               | 0.1479          | 0.2694                        | UI      | P80    |
| 5496.4267              | 5496.4264          | 107653              | 0.0571          | 0.3598                        | UI      | P80    |
| 5497.7437              | 5497.7429          | 12744               | 0.1936          | 0.8380                        | UI      | P80    |
| 5498.1776              | 5498.1764          | 9692                | 0.2478          | 1.2035                        | UI      | RS21   |
| 5498.9745              | 5498.9726          | 3833                | 0.5104          | 1.9110                        | UI      | P80    |
| 5500.1015              | 5500.1000          | 3285                | 0.5898          | 1.4793                        | UI      | P80    |
| 5500.6838              | 5500.6840          | 178079              | 0.0459          | −0.1772                       | UI      | P80    |
| 5501.4927              | 5501.4928          | 8892                | 0.3446          | −0.1465                       | UII     | P80    |
| 5501.8137              | 5501.8157          | 28807               | 0.1292          | −1.9245                       | UI      | P80    |
| 5502.1844              | 5502.1853          | 49082               | 0.0954          | −0.9329                       | UI      | P80    |
| 5503.6479              | 5503.6513          | 3687                | 0.6815          | −3.3961                       | UI      | RS21   |
| 5504.1254              | 5504.1218          | 18440               | 0.1734          | 3.5104                        | UI      | P80    |
| 5505.4724              | 5505.4705          | 6736                | 0.3782          | 1.9583                        | UI      | P80    |
| 5507.0590              | 5507.0567          | 4114                | 0.7125          | 2.2226                        | UI      | P80    |
| 5509.3066              | 5509.3092          | 3818                | 0.6381          | −2.6390                       | UI      | RS21   |
| 5510.1175              | 5510.1193          | 6124                | 0.4441          | −1.8921                       | UI      | P80    |
| 5510.4146              | 5510.4159          | 29400               | 0.1273          | −1.3607                       | UI      | P80    |
| 5511.0858              | 5511.0799          | 6226                | 0.4880          | 5.9899                        | UII     | RS21   |
| 5511.4948              | 5511.4958          | 677221              | 0.0225          | −1.0340                       | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|---------------------|-----------------|----------------------------------|---------|--------|
| 5513.8311              | 5513.8303          | 4520                | 0.5338          | 0.7812                           | UI      | RS21   |
| 5515.1160              | 5515.1160          | 5971                | 0.3663          | 0.2807                           | UI      | P80    |
| 5518.1395              | 5518.1417          | 3052                | 0.5763          | −2.2066                          | UI      | P80    |
| 5519.3330              | 5519.3330          | 3061                | 0.6931          | 0.0277                           | UI      | RS21   |
| 5519.8072              | 5519.8085          | 3670                | 0.5426          | −1.3760                          | UI      | P80    |
| 5521.0242              | 5521.0267          | 26719               | 0.1259          | −2.4835                          | UI      | P80    |
| 5522.9248              | 5522.9247          | 3025                | 0.5639          | 0.1642                           | UI      | P80    |
| 5524.9611              | 5524.9599          | 5793                | 0.3537          | 1.1334                           | UI      | RS21   |
| 5526.3317              | 5526.3343          | 8755                | 0.2486          | −2.6300                          | UI      | P80    |
| 5527.9759              | 5527.9810          | 34784               | 0.1236          | −5.0314                          | UI      | P80    |
| 5530.6983              | 5530.6976          | 4969                | 0.3794          | 0.7346                           | UI      | P80    |
| 5531.2693              | 5531.2719          | 19686               | 0.1732          | −2.6361                          | UI      | P80    |
| 5533.0862              | 5533.0896          | 3208                | 0.4971          | −3.4284                          | UI      | P80    |
| 5534.7137              | 5534.7182          | 14014               | 0.1994          | −4.4409                          | UI      | P80    |
| 5535.7755              | 5535.7765          | 4641                | 0.3915          | −1.0298                          | UII     | P80    |
| 5536.5289              | 5536.5262          | 3113                | 0.5677          | 2.6879                           | UI      | P80    |
| 5538.1910              | 5538.1867          | 3002                | 0.6555          | 4.2582                           | UI      | P80    |
| 5542.8936              | 5542.8958          | 2788                | 0.6199          | −2.2918                          | UI      | RS21   |
| 5545.0521              | 5545.0504          | 4743                | 0.4769          | 1.7297                           | UI      | RS21   |
| 5545.7478              | 5545.7497          | 5063                | 0.4441          | −1.8808                          | UI      | P80    |
| 5546.0958              | 5546.0934          | 3011                | 0.6772          | 2.3524                           | UII     | RS21   |
| 5548.0388              | 5548.0399          | 4198                | 0.4772          | −1.0815                          | UII     | P80    |
| 5551.4200              | 5551.4240          | 11811               | 0.2539          | −4.0203                          | UI      | P80    |
| 5553.6859              | 5553.6864          | 9097                | 0.2992          | −0.5305                          | UI      | P80    |
| 5557.8806              | 5557.8806          | 165726              | 0.0479          | 0.0001                           | UI      | P80    |
| 5558.7048              | 5558.7020          | 149089              | 0.0541          | 2.7652                           | UI      | RS21   |
| 5559.8818              | 5559.8837          | 20981               | 0.2148          | −1.9089                          | UI      | P80    |
| 5562.4633              | 5562.4643          | 5445                | 0.4651          | −0.9141                          | UI      | P80    |
| 5563.7963              | 5563.7981          | 60387               | 0.0928          | −1.7912                          | UI      | P80    |
| 5564.1708              | 5564.1707          | 696105              | 0.0229          | 0.1085                           | UI      | P80    |
| 5564.6219              | 5564.6171          | 7917                | 0.4107          | 4.8110                           | UI      | P80    |
| 5568.4876              | 5568.4867          | 16871               | 0.1674          | 0.9774                           | UI      | P80    |
| 5570.6622              | 5570.6636          | 10042               | 0.2422          | −1.3493                          | UII     | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 5573.0719               | 5573.0739           | 10728               | 0.2282           | −2.0126                       | UI      | P80    |
| 5573.5904               | 5573.5910           | 24687               | 0.1334           | −0.6050                       | UI      | P80    |
| 5574.6538               | 5574.6533           | 16352               | 0.1697           | 0.5084                        | UI      | P80    |
| 5577.0366               | 5577.0379           | 5108                | 0.4173           | −1.3480                       | UI      | P80    |
| 5577.6823               | 5577.6791           | 10808               | 0.2792           | 3.1995                        | UII     | RS21   |
| 5578.5169               | 5578.5222           | 4778                | 0.5242           | −5.3268                       | UI      | RS21   |
| 5580.8031               | 5580.8055           | 5139                | 0.3638           | −2.3901                       | UII     | P80    |
| 5581.2222               | 5581.2236           | 11485               | 0.2050           | −1.4498                       | UII     | P80    |
| 5581.6013               | 5581.6034           | 25330               | 0.1395           | −2.0692                       | UII     | P80    |
| 5584.6218               | 5584.6209           | 12948               | 0.1860           | 0.8789                        | UI      | P80    |
| 5589.3714               | 5589.3727           | 2770                | 0.5926           | −1.3269                       | UI      | P80    |
| 5591.1024               | 5591.1018           | 7119                | 0.2885           | 0.5849                        | UI      | P80    |
| 5591.7083               | 5591.7126           | 3909                | 0.5714           | −4.2488                       | UI      | P80    |
| 5595.1411               | 5595.1429           | 3787                | 0.4774           | −1.7908                       | UI      | P80    |
| 5596.2816               | 5596.2856           | 5523                | 0.4163           | −3.9788                       | UI      | P80    |
| 5603.0550               | 5603.0555           | 13252               | 0.2674           | −0.4724                       | UI      | P80    |
| 5603.9685               | 5603.9732           | 10454               | 0.2721           | −4.7288                       | UII     | P80    |
| 5608.8446               | 5608.8484           | 14181               | 0.2677           | −3.7276                       | UI      | P80    |
| 5609.2941               | 5609.2965           | 11335               | 0.2633           | −2.3102                       | UI      | P80    |
| 5610.2450               | 5610.2402           | 4529                | 0.6141           | 4.8120                        | UI      | RS21   |
| 5610.8900               | 5610.8903           | 266537              | 0.0376           | −0.2907                       | UI      | P80    |
| 5612.3158               | 5612.3120           | 9612                | 0.3355           | 3.8265                        | UII     | P80    |
| 5613.2602               | 5613.2623           | 24238               | 0.1500           | −2.1195                       | UI      | P80    |
| 5614.7450               | 5614.7438           | 16600               | 0.2042           | 1.1659                        | UI      | P80    |
| 5616.5747               | 5616.5736           | 45517               | 0.0998           | 1.0803                        | UI      | P80    |
| 5616.8800               | 5616.8775           | 14058               | 0.2349           | 2.5516                        | UI      | P80    |
| 5618.5058               | 5618.5046           | 6324                | 0.3325           | 1.1989                        | UI      | P80    |
| 5620.7795               | 5620.7763           | 608192              | 0.0241           | 3.1995                        | UI      | P80    |
| 5621.5177               | 5621.5134           | 129132              | 0.0549           | 4.3428                        | UI      | P80    |
| 5622.5512               | 5622.5477           | 19058               | 0.1662           | 3.4662                        | UI      | P80    |
| 5622.9783               | 5622.9844           | 5010                | 0.4038           | −6.0424                       | UI      | P80    |
| 5624.6118               | 5624.6082           | 3873                | 0.6276           | 3.5898                        | UI      | P80    |
| 5625.0088               | 5625.0038           | 11857               | 0.2374           | 4.9774                        | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 5628.1508               | 5628.1557           | 29614               | 0.1331           | -4.9345                       | UI      | P80    |
| 5628.9857               | 5628.9876           | 5589                | 0.3796           | -1.8730                       | UI      | P80    |
| 5641.6665               | 5641.6605           | 3852                | 0.6114           | 6.0070                        | UI      | P80    |
| 5642.5914               | 5642.5896           | 4192                | 0.5664           | 1.7556                        | UI      | P80    |
| 5645.9397               | 5645.9381           | 12208               | 0.2134           | 1.5889                        | UI      | P80    |
| 5646.7460               | 5646.7447           | 5495                | 0.4247           | 1.2581                        | UI      | P80    |
| 5653.3290               | 5653.3276           | 9473                | 0.3249           | 1.4004                        | UI      | P80    |
| 5653.7703               | 5653.7703           | 14460               | 0.2302           | 0.0080                        | UII     | P80    |
| 5654.8022               | 5654.8022           | 93105               | 0.0681           | -0.0123                       | UI      | P80    |
| 5655.4022               | 5655.4007           | 10919               | 0.3186           | 1.4214                        | UI      | P80    |
| 5655.6046               | 5655.6076           | 22474               | 0.1670           | -3.0286                       | UI      | P80    |
| 5656.7919               | 5656.7889           | 5251                | 0.5676           | 2.9542                        | UI      | P80    |
| 5657.5113               | 5657.5104           | 16467               | 0.2203           | 0.8701                        | UI      | P80    |
| 5657.7365               | 5657.7406           | 9139                | 0.3481           | -4.1102                       | UI      | P80    |
| 5658.2680               | 5658.2634           | 110159              | 0.0672           | 4.6127                        | UI      | P80    |
| 5658.8226               | 5658.8239           | 4928                | 0.6396           | -1.3430                       | UII     | RS21   |
| 5659.7085               | 5659.7099           | 10742               | 0.2901           | -1.4730                       | UI      | P80    |
| 5662.0505               | 5662.0483           | 6525                | 0.4706           | 2.1610                        | UI      | P80    |
| 5663.0780               | 5663.0763           | 12984               | 0.2343           | 1.6974                        | UI      | P80    |
| 5664.2295               | 5664.2288           | 11383               | 0.3265           | 0.7534                        | UII     | P80    |
| 5665.7949               | 5665.7918           | 15260               | 0.2138           | 3.0951                        | UI      | P80    |
| 5668.7308               | 5668.7347           | 5200                | 0.5131           | -3.9373                       | UI      | P80    |
| 5671.2478               | 5671.2496           | 3240                | 0.6541           | -1.7787                       | UI      | P80    |
| 5674.2533               | 5674.2541           | 9330                | 0.2558           | -0.8798                       | UII     | P80    |
| 5676.1255               | 5676.1249           | 6405                | 0.3454           | 0.6691                        | UI      | P80    |
| 5680.3703               | 5680.3724           | 14482               | 0.2061           | -2.1359                       | UI      | P80    |
| 5682.4445               | 5682.4465           | 5374                | 0.3957           | -2.0215                       | UI      | P80    |
| 5685.2097               | 5685.2110           | 40070               | 0.1047           | -1.3137                       | UI      | P80    |
| 5686.4546               | 5686.4540           | 3853                | 0.5228           | 0.6656                        | UI      | P80    |
| 5688.3405               | 5688.3448           | 2853                | 0.6314           | -4.3074                       | UI      | P80    |
| 5691.3440               | 5691.3415           | 75663               | 0.0801           | 2.5137                        | UI      | P80    |
| 5692.1695               | 5692.1732           | 4115                | 0.4662           | -3.6204                       | UI      | P80    |
| 5694.8454               | 5694.8419           | 9171                | 0.2892           | 3.4813                        | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mA) | Offset from Ritz wavelength (mA) | Species | Source |
|------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 5695.1802              | 5695.1816           | 18523               | 0.1615           | −1.3369                       | UI      | P80    |
| 5696.0820              | 5696.0841           | 3320                | 0.6400           | −2.1060                       | UI      | P80    |
| 5697.5225              | 5697.5233           | 3969                | 0.4947           | −0.8659                       | UI      | P80    |
| 5698.3264              | 5698.3320           | 4831                | 0.4675           | −5.6284                       | UII     | RS21   |
| 5699.2573              | 5699.2540           | 7149                | 0.3552           | 3.3760                        | UI      | P80    |
| 5699.8742              | 5699.8749           | 57429               | 0.0832           | −0.4481                       | UI      | P80    |
| 5702.2546              | 5702.2571           | 4617                | 0.6129           | −2.5136                       | UI      | P80    |
| 5702.8506              | 5702.8505           | 32181               | 0.1136           | 0.1277                        | UI      | P80    |
| 5704.6312              | 5704.6353           | 5869                | 0.5355           | −4.0017                       | UI      | P80    |
| 5705.3309              | 5705.3296           | 10312               | 0.3054           | 1.3288                        | UI      | P80    |
| 5706.6846              | 5706.6851           | 41477               | 0.1113           | −0.5366                       | UI      | P80    |
| 5706.9964              | 5706.9924           | 9415                | 0.3141           | 3.9400                        | UII     | P80    |
| 5707.2978              | 5707.2979           | 14231               | 0.2240           | −0.0929                       | UI      | P80    |
| 5708.2186              | 5708.2233           | 4295                | 0.8278           | −4.7090                       | UI      | RS21   |
| 5709.4936              | 5709.4930           | 47747               | 0.1010           | 0.6786                        | UI      | P80    |
| 5714.2083              | 5714.2091           | 37273               | 0.1166           | −0.7544                       | UI      | P80    |
| 5715.6977              | 5715.6983           | 77775               | 0.0739           | −0.6899                       | UI      | P80    |
| 5716.8745              | 5716.8749           | 133189              | 0.0546           | −0.4332                       | UI      | P80    |
| 5717.2767              | 5717.2804           | 7408                | 0.3617           | −3.6372                       | UI      | P80    |
| 5719.5001              | 5719.4978           | 6243                | 0.4460           | 2.2293                        | UI      | P80    |
| 5721.5800              | 5721.5757           | 25183               | 0.1598           | 4.3412                        | UI      | P80    |
| 5722.2367              | 5722.2371           | 21122               | 0.1811           | −0.3836                       | UI      | P80    |
| 5726.3134              | 5726.3111           | 6117                | 0.3513           | 2.2735                        | UI      | P80    |
| 5728.9321              | 5728.9338           | 9437                | 0.2506           | −1.6366                       | UI      | P80    |
| 5730.0174              | 5730.0163           | 3273                | 0.5890           | 1.1052                        | UII     | P80    |
| 5730.8932              | 5730.8978           | 3488                | 0.5592           | −4.6644                       | UI      | P80    |
| 5731.4838              | 5731.4824           | 7178                | 0.3387           | 1.3254                        | UI      | P80    |
| 5731.8675              | 5731.8688           | 20775               | 0.1479           | −1.3235                       | UI      | P80    |
| 5732.7283              | 5732.7290           | 9062                | 0.2704           | −0.7070                       | UI      | P80    |
| 5734.3522              | 5734.3558           | 3615                | 0.5184           | −3.6108                       | UI      | P80    |
| 5736.3903              | 5736.3918           | 32809               | 0.1193           | −1.4681                       | UI      | P80    |
| 5737.2767              | 5737.2727           | 25614               | 0.1466           | 4.0772                        | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|----------------------------------|--------|--------|
| 5741.3205               | 5741.3211           | 22396               | 0.1394           | -0.06241                         | UI     | P80    |
| 5742.7723               | 5742.7673           | 6102                | 0.3407           | 5.0350                           | UI     | RS21   |
| 5748.1032               | 5748.1033           | 7406                | 0.3009           | -0.00885                         | UII    | P80    |
| 5748.4463               | 5748.4493           | 4561                | 0.4725           | -2.9566                          | UII    | P80    |
| 5748.7829               | 5748.7850           | 3556                | 0.5397           | -2.1032                          | UII    | RS21   |
| 5750.5500               | 5750.5547           | 15578               | 0.1856           | -4.7107                          | UI     | P80    |
| 5751.7374               | 5751.7366           | 37556               | 0.1075           | 0.8026                           | UI     | P80    |
| 5755.1570               | 5755.1590           | 9598                | 0.2409           | -1.9398                          | UI     | P80    |
| 5755.6042               | 5755.6055           | 10528               | 0.2215           | -1.3304                          | UI     | P80    |
| 5756.8714               | 5756.8736           | 3063                | 0.6512           | -2.2582                          | UI     | P80    |
| 5757.3128               | 5757.3140           | 34633               | 0.1125           | -1.1609                          | UI     | P80    |
| 5758.1426               | 5758.1430           | 302605              | 0.0382           | -0.3953                          | UI     | P80    |
| 5758.3548               | 5758.3568           | 120921              | 0.0678           | -1.9979                          | UI     | P80    |
| 5761.2679               | 5761.2650           | 3620                | 0.9269           | 2.8855                           | UII    | RS21   |
| 5762.8526               | 5762.8496           | 4062                | 0.7816           | 2.9448                           | UI     | RS21   |
| 5765.3829               | 5765.3799           | 19008               | 0.1855           | 3.0445                           | UI     | P80    |
| 5767.4466               | 5767.4437           | 34882               | 0.1244           | 2.8334                           | UII    | P80    |
| 5767.6965               | 5767.6959           | 6070                | 0.4526           | 0.6177                           | UII    | RS21   |
| 5771.0526               | 5771.0527           | 50218               | 0.0953           | -0.1366                          | UI     | P80    |
| 5776.8774               | 5776.8789           | 4127                | 0.5454           | -1.5266                          | UII    | RS21   |
| 5777.2916               | 5777.2897           | 3962                | 0.5718           | 1.9059                           | UI     | P80    |
| 5780.5898               | 5780.5892           | 157036              | 0.0516           | 0.6699                           | UI     | P80    |
| 5781.9452               | 5781.9447           | 27112               | 0.1344           | 0.4991                           | UI     | P80    |
| 5782.8041               | 5782.8057           | 34268               | 0.1234           | -1.5823                          | UI     | P80    |
| 5783.6309               | 5783.6297           | 3337                | 0.9065           | 1.2246                           | UI     | RS21   |
| 5787.2514               | 5787.2472           | 3667                | 0.5114           | 4.2396                           | UI     | P80    |
| 5787.5930               | 5787.5914           | 16116               | 0.1722           | 1.5871                           | UI     | P80    |
| 5791.7473               | 5791.7466           | 3912                | 0.6344           | 0.7027                           | UII    | P80    |
| 5792.0107               | 5792.0114           | 7280                | 0.3106           | -0.6481                          | UI     | P80    |
| 5793.7868               | 5793.7874           | 3188                | 0.5448           | -0.5985                          | UI     | P80    |
| 5796.5187               | 5796.5195           | 20026               | 0.1550           | -0.7614                          | UI     | P80    |
| 5798.5287               | 5798.5282           | 15939               | 0.1725           | 0.4879                           | UII    | P80    |
| 5799.3525               | 5799.3501           | 3073                | 0.5513           | 2.3471                           | UI     | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 5800.7761               | 5800.7763           | 11395               | 0.2185           | −0.1928                       | UI      | RS21   |
| 5802.1005               | 5802.1059           | 39096               | 0.1096           | −5.3974                       | UI      | P80    |
| 5803.6022               | 5803.6078           | 3440                | 0.5950           | −5.5612                       | U1I     | RS21   |
| 5805.1945               | 5805.1934           | 29666               | 0.1229           | 1.0504                        | UI      | P80    |
| 5808.6482               | 5808.6468           | 3342                | 0.6075           | 1.4449                        | UI      | P80    |
| 5809.3043               | 5809.3087           | 9769                | 0.2493           | −4.3919                       | UI      | P80    |
| 5809.5643               | 5809.5658           | 3799                | 0.5181           | −1.5865                       | UI      | P80    |
| 5811.2640               | 5811.2662           | 4463                | 0.3933           | −2.2208                       | U1I     | RS21   |
| 5811.7037               | 5811.7050           | 3201                | 0.5865           | −1.2895                       | UI      | P80    |
| 5812.0992               | 5812.1043           | 3901                | 0.6872           | −5.0723                       | U1I     | RS21   |
| 5813.8190               | 5813.8214           | 44048               | 0.1052           | −2.3257                       | UI      | P80    |
| 5814.4155               | 5814.4171           | 51429               | 0.0969           | −1.5349                       | UI      | P80    |
| 5816.7636               | 5816.7621           | 15031               | 0.2172           | 1.5090                        | U1I     | P80    |
| 5817.9092               | 5817.9099           | 21280               | 0.1744           | −0.6523                       | UI      | P80    |
| 5819.0081               | 5819.0038           | 17944               | 0.2002           | 4.2732                        | U1I     | P80    |
| 5820.6119               | 5820.6131           | 11275               | 0.2487           | −1.2213                       | UI      | P80    |
| 5821.0285               | 5821.0282           | 4792                | 0.5294           | 0.3774                        | UI      | P80    |
| 5821.8728               | 5821.8730           | 10585               | 0.3073           | −0.1377                       | UI      | P80    |
| 5823.8835               | 5823.8841           | 3526                | 0.7400           | −0.5647                       | UI      | P80    |
| 5825.3544               | 5825.3555           | 5465                | 0.4612           | −1.1284                       | UI      | P80    |
| 5826.1605               | 5826.1638           | 15782               | 0.2090           | −3.2764                       | UI      | P80    |
| 5829.0214               | 5829.0208           | 12564               | 0.2291           | 0.6402                        | UI      | P80    |
| 5831.8119               | 5831.8154           | 27186               | 0.1428           | −3.5252                       | UI      | P80    |
| 5833.3180               | 5833.3161           | 2969                | 0.6857           | 1.8217                        | UI      | P80    |
| 5833.6194               | 5833.6200           | 10495               | 0.2631           | −0.6208                       | UI      | P80    |
| 5835.1628               | 5835.1689           | 4531                | 0.5262           | −6.0727                       | U1I     | P80    |
| 5835.4880               | 5835.4915           | 3180                | 0.6710           | −3.5177                       | UI      | P80    |
| 5836.0226               | 5836.0218           | 34057               | 0.1153           | 0.8037                        | UI      | P80    |
| 5837.6830               | 5837.6838           | 15944               | 0.1912           | −0.8225                       | U1I     | P80    |
| 5840.4866               | 5840.4874           | 6890                | 0.3147           | −0.7722                       | UI      | P80    |
| 5841.8174               | 5841.8159           | 3273                | 0.5474           | 1.4484                        | UI      | RS21   |
| 5843.2838               | 5843.2891           | 5400                | 0.4180           | −5.3120                       | U1I     | P80    |
| 5845.2484               | 5845.2489           | 12695               | 0.1991           | −0.5092                       | U1I     | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 5846.2074               | 5846.2063           | 8967                | 0.2754           | 1.1296                          | UII     | P80    |
| 5849.1603               | 5849.1625           | 9621                | 0.2507           | −2.1793                         | UI      | P80    |
| 5852.0028               | 5852.0033           | 45098               | 0.0993           | −0.4591                         | UI      | P80    |
| 5853.9031               | 5853.9027           | 9700                | 0.2316           | 0.4340                          | UII     | P80    |
| 5856.4462               | 5856.4465           | 27372               | 0.1304           | −0.3567                         | UI      | P80    |
| 5857.5717               | 5857.5698           | 2842                | 0.7562           | 1.9409                          | UI      | P80    |
| 5859.6789               | 5859.6848           | 6254                | 0.3650           | −5.8280                         | UI      | P80    |
| 5862.0050               | 5862.0040           | 20232               | 0.1599           | 0.9273                          | UI      | P80    |
| 5863.7177               | 5863.7138           | 3576                | 0.5626           | 3.9252                          | UI      | P80    |
| 5866.2578               | 5866.2594           | 4704                | 0.4278           | −1.6000                         | UI      | P80    |
| 5868.0409               | 5868.0396           | 5961                | 0.4144           | 1.3106                          | UI      | P80    |
| 5869.7361               | 5869.7367           | 7668                | 0.3551           | −0.6347                         | UI      | P80    |
| 5870.9271               | 5870.9284           | 18951               | 0.1809           | −1.2749                         | UII     | P80    |
| 5875.4107               | 5875.4099           | 7284                | 0.3734           | 0.8393                          | UI      | P80    |
| 5877.7841               | 5877.7902           | 4603                | 0.6140           | −6.0395                         | UI      | RS21   |
| 5884.3967               | 5884.3967           | 8732                | 0.3241           | 0.0048                          | UI      | P80    |
| 5886.9372               | 5886.9387           | 6136                | 0.4376           | −1.5053                         | UII     | RS21   |
| 5887.6243               | 5887.6254           | 4479                | 0.6184           | −1.0053                         | UI      | P80    |
| 5888.1133               | 5888.1143           | 4091                | 0.6660           | −1.0251                         | UI      | RS21   |
| 5888.5897               | 5888.5939           | 85851               | 0.0768           | −4.2644                         | UII     | RS21   |
| 5889.1539               | 5889.1509           | 5168                | 0.5863           | 3.0092                          | UI      | RS21   |
| 5891.3573               | 5891.3592           | 6256                | 0.3329           | −1.9196                         | UI      | P80    |
| 5892.6224               | 5892.6208           | 51021               | 0.0938           | 1.6062                          | UI      | P80    |
| 5893.6563               | 5893.6568           | 6605                | 0.3946           | −0.4818                         | UII     | P80    |
| 5898.7727               | 5898.7733           | 34665               | 0.1134           | −0.5381                         | UI      | P80    |
| 5900.2226               | 5900.2243           | 2738                | 0.6175           | −1.6677                         | UI      | P80    |
| 5901.8978               | 5901.9013           | 6955                | 0.3148           | −3.4684                         | UI      | P80    |
| 5902.4894               | 5902.4893           | 49455               | 0.1040           | 0.0950                          | UI      | P80    |
| 5905.1230               | 5905.1219           | 6514                | 0.3213           | 1.1416                          | UI      | P80    |
| 5907.7502               | 5907.7534           | 3039                | 0.5709           | −3.2329                         | UI      | P80    |
| 5910.3519               | 5910.3566           | 6022                | 0.4043           | −4.6413                         | UI      | P80    |
| 5911.5480               | 5911.5498           | 18423               | 0.1666           | −1.7920                         | UI      | P80    |
| 5914.6062               | 5914.6087           | 8127                | 0.3311           | −2.4783                         | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|------------------|----------------------------------|---------|--------|
| 5919.6674              | 5919.6664           | 9931                | 0.2453           | 1.0273                           | UI      | P80    |
| 5926.5028              | 5926.5027           | 4757                | 0.6942           | 0.1605                           | UII     | RS21   |
| 5927.8714              | 5927.8713           | 4646                | 0.7146           | 0.1613                           | UI      | P80    |
| 5928.8179              | 5928.8168           | 68573               | 0.0951           | 1.1620                           | UI      | RS21   |
| 5929.3169              | 5929.3174           | 51155               | 0.0997           | -0.5227                          | UI      | P80    |
| 5932.4273              | 5932.4271           | 6810                | 0.4534           | 0.2202                           | UII     | RS21   |
| 5933.8169              | 5933.8170           | 228015              | 0.0432           | -0.1142                          | UI      | P80    |
| 5934.4494              | 5934.4478           | 6412                | 0.4478           | 1.5091                           | UI      | P80    |
| 5935.2455              | 5935.2454           | 7703                | 0.9389           | 0.1333                           | UII     | RS21   |
| 5935.5026              | 5935.5069           | 13533               | 0.4711           | -4.3370                          | UI      | P80    |
| 5937.3718              | 5937.3735           | 7164                | 0.3652           | -1.6936                          | UI      | P80    |
| 5939.9920              | 5939.9897           | 18245               | 0.1838           | 2.2782                           | UI      | P80    |
| 5940.6634              | 5940.6639           | 5443                | 0.5078           | -0.5484                          | UI      | P80    |
| 5942.0172              | 5942.0211           | 6083                | 0.4815           | -3.9708                          | UII     | RS21   |
| 5942.7513              | 5942.7490           | 50168               | 0.1260           | 2.3214                           | UI      | RS21   |
| 5943.4080              | 5943.4114           | 14110               | 0.2282           | -3.3762                          | UI      | P80    |
| 5947.6699              | 5947.6712           | 15255               | 0.1841           | -1.2855                          | UI      | P80    |
| 5948.1764              | 5948.1709           | 4635                | 0.4451           | 5.5455                           | UI      | P80    |
| 5948.5640              | 5948.5663           | 29583               | 0.1273           | -2.2423                          | UI      | P80    |
| 5949.6582              | 5949.6615           | 20767               | 0.1586           | -3.2701                          | UI      | P80    |
| 5952.0303              | 5952.0332           | 5272                | 0.5584           | -2.8355                          | UII     | P80    |
| 5954.3680              | 5954.3673           | 3015                | 0.6091           | 0.7915                           | UII     | P80    |
| 5954.8986              | 5954.8986           | 7428                | 0.3018           | -0.0090                          | UI      | P80    |
| 5956.8566              | 5956.8591           | 45176               | 0.1028           | -2.5060                          | UI      | P80    |
| 5967.1510              | 5967.1501           | 3024                | 0.6334           | 0.8504                           | UI      | P80    |
| 5968.7696              | 5968.7714           | 15718               | 0.1922           | -1.8502                          | UI      | P80    |
| 5971.4993              | 5971.5004           | 443365              | 0.0319           | -1.0851                          | UI      | P80    |
| 5972.7596              | 5972.7630           | 5958                | 0.4775           | -3.3874                          | UII     | P80    |
| 5974.7625              | 5974.7618           | 19973               | 0.1801           | 0.6154                           | UI      | P80    |
| 5978.6891              | 5978.6895           | 10756               | 0.2293           | -0.3936                          | UI      | P80    |
| 5982.8695              | 5982.8685           | 21907               | 0.2051           | 1.0377                           | UI      | P80    |
| 5983.7607              | 5983.7603           | 5895                | 0.5942           | 0.4874                           | UII     | P80    |
| 5985.5684              | 5985.5719           | 14354               | 0.2427           | -3.5009                          | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|--------------------|-----------------|---------------------------------|---------|--------|
| 5986.0988               | 5986.1004           | 349061             | 0.0361          | −1.5922                         | UI      | P80    |
| 5993.7472               | 5993.7479           | 4848               | 0.5988          | −0.6739                         | UI      | P80    |
| 5996.7514               | 5996.7527           | 21725              | 0.1806          | −1.3184                         | UI      | P80    |
| 5997.3093               | 5997.3106           | 225763             | 0.0429          | −1.2986                         | UI      | P80    |
| 5997.9576               | 5997.9592           | 94543              | 0.0697          | −1.6411                         | UI      | P80    |
| 5999.4066               | 5999.4082           | 106400             | 0.0653          | −1.5636                         | UI      | P80    |
| 6000.1759               | 6000.1775           | 20162              | 0.1748          | −1.6835                         | UI      | P80    |
| 6001.0768               | 6001.0759           | 6180               | 0.4917          | 0.9724                          | UII     | P80    |
| 6003.7322               | 6003.7387           | 21005              | 0.1863          | −6.4587                         | UI      | P80    |
| 6004.8147               | 6004.8135           | 5593               | 0.5279          | 1.2443                          | UII     | P80    |
| 6008.8358               | 6008.8358           | 8940               | 0.3473          | −0.0555                         | UI      | P80    |
| 6010.8602               | 6010.8603           | 13459              | 0.2076          | −0.0705                         | UII     | P80    |
| 6013.2614               | 6013.2605           | 10761              | 0.2432          | 0.8759                          | UI      | P80    |
| 6014.0526               | 6014.0532           | 6399               | 0.3572          | −0.5941                         | UI      | P80    |
| 6016.7402               | 6016.7438           | 25621              | 0.1456          | −3.6051                         | UI      | P80    |
| 6017.5639               | 6017.5630           | 27905              | 0.1461          | 0.9798                          | UI      | P80    |
| 6019.1905               | 6019.1905           | 32267              | 0.1215          | −0.0205                         | UI      | P80    |
| 6024.7235               | 6024.7224           | 3647               | 0.5383          | 1.0995                          | UI      | P80    |
| 6028.1215               | 6028.1232           | 57612              | 0.0900          | −1.6264                         | UI      | P80    |
| 6028.6213               | 6028.6266           | 7876               | 0.3012          | −5.3000                         | UI      | P80    |
| 6031.1932               | 6031.1952           | 7769               | 0.3168          | −1.9922                         | UI      | P80    |
| 6034.5872               | 6034.5869           | 7294               | 0.3165          | 0.2108                          | UI      | P80    |
| 6035.5471               | 6035.5483           | 19733              | 0.1610          | −1.1842                         | UI      | P80    |
| 6036.3118               | 6036.3120           | 3458               | 0.5697          | −0.1708                         | UI      | P80    |
| 6039.6169               | 6039.6169           | 36922              | 0.1065          | 0.0262                          | UI      | P80    |
| 6039.9381               | 6039.9376           | 4612               | 0.6361          | 0.5070                          | UI      | P80    |
| 6040.1222               | 6040.1236           | 5317               | 0.5876          | −1.4271                         | UI      | P80    |
| 6042.6600               | 6042.6600           | 6252               | 0.4792          | 0.0041                          | UI      | P80    |
| 6045.0182               | 6045.0150           | 13851              | 0.2479          | 3.1816                          | UI      | P80    |
| 6045.8484               | 6045.8547           | 5156               | 0.5687          | −6.3178                         | UI      | RS21   |
| 6046.4527               | 6046.4582           | 4982               | 0.7211          | −5.4438                         | UI      | P80    |
| 6048.3434               | 6048.3408           | 4295               | 0.6718          | 2.5779                          | UI      | P80    |
| 6050.4870               | 6050.4850           | 84164              | 0.0864          | 1.9724                          | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mA) | Offset from Ritz wavelength (mA) | Species | Source |
|------------------------|--------------------|---------------------|------------------|-------------------------------|---------|--------|
| 6050.6704              | 6050.6745          | 53517               | 0.1119           | -4.0783                       | UI      | P80    |
| 6051.7404              | 6051.7404          | 44505               | 0.1085           | -0.0870                       | UI      | P80    |
| 6056.8099              | 6056.8098          | 224446              | 0.0443           | 0.1203                        | UI      | P80    |
| 6057.0799              | 6057.0814          | 67647               | 0.0892           | -1.5144                       | UI      | P80    |
| 6057.5329              | 6057.5359          | 4961                | 0.5894           | -2.9368                       | UI      | P80    |
| 6059.3728              | 6059.3724          | 78223               | 0.0801           | 0.4219                        | UI      | RS21   |
| 6059.7412              | 6059.7454          | 11273               | 0.2834           | -4.1617                       | UI      | P80    |
| 6060.1790              | 6060.1809          | 3849                | 0.6537           | -1.9153                       | UI      | P80    |
| 6060.4883              | 6060.4901          | 12962               | 0.2313           | -1.8621                       | UI      | P80    |
| 6062.3054              | 6062.3090          | 127372              | 0.0604           | -3.6388                       | UI      | P80    |
| 6067.2205              | 6067.2220          | 15939               | 0.1840           | -1.5332                       | UI      | P80    |
| 6070.1806              | 6070.1865          | 3096                | 0.6627           | -5.8682                       | UI      | P80    |
| 6072.7034              | 6072.7057          | 8247                | 0.2808           | -2.2812                       | UI      | P80    |
| 6074.8637              | 6074.8642          | 13464               | 0.2131           | -0.5715                       | UI      | P80    |
| 6076.1886              | 6076.1890          | 6310                | 0.3440           | -0.3743                       | UI      | P80    |
| 6077.2898              | 6077.2906          | 296110              | 0.0381           | -0.8308                       | UI      | P80    |
| 6078.1132              | 6078.1133          | 3731                | 0.4709           | -0.0996                       | UI      | P80    |
| 6080.3799              | 6080.3783          | 13022               | 0.2067           | 1.5763                        | UI      | P80    |
| 6085.7598              | 6085.7569          | 5170                | 0.4746           | 2.9035                        | UI      | P80    |
| 6087.3390              | 6087.3369          | 6457                | 0.3224           | 2.1130                        | UI      | P80    |
| 6087.5412              | 6087.5432          | 4423                | 0.4928           | -2.0004                       | UI      | P80    |
| 6088.1066              | 6088.1066          | 3196                | 0.5268           | -0.0052                       | UI      | P80    |
| 6089.1864              | 6089.1901          | 24048               | 0.6340           | -3.7133                       | UI      | P80    |
| 6091.2799              | 6091.2828          | 7780                | 0.2878           | -2.9106                       | UI      | P80    |
| 6101.4789              | 6101.4817          | 8971                | 0.3361           | -2.8047                       | UI      | P80    |
| 6101.7785              | 6101.7784          | 78820               | 0.0808           | 0.0408                        | UI      | P80    |
| 6107.7391              | 6107.7427          | 14584               | 0.2222           | -3.5524                       | UI      | P80    |
| 6110.3093              | 6110.3081          | 3798                | 0.8163           | 1.2069                        | UI      | P80    |
| 6110.6846              | 6110.6848          | 10789               | 0.3122           | -0.2224                       | UI      | P80    |
| 6114.2765              | 6114.2743          | 8029                | 0.3471           | 2.1268                        | UI      | P80    |
| 6114.9230              | 6114.9200          | 581711              | 0.0283           | 2.9539                        | UI      | RS21   |
| 6116.1587              | 6116.1644          | 6784                | 0.3962           | -5.6836                       | UI      | P80    |
| 6116.6672              | 6116.6639          | 4444                | 0.5663           | 3.2117                        | UI      | P80    |

Sharma and Chakraborty: Precision wavelength calibration for radial velocity measurements...
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|--------------------|---------------------|-----------------|-------------------------------|---------|--------|
| 6118.2036               | 6118.1975          | 3566                | 0.7179          | 6.1209                        | UI      | RS21   |
| 6120.6434               | 6120.6454          | 25175               | 0.1488          | -2.0357                       | UI      | P80    |
| 6121.4357               | 6121.4363          | 15531               | 0.2016          | -0.6439                       | UI      | P80    |
| 6125.0186               | 6125.0216          | 4780                | 0.4830          | -3.0305                       | Uii     | P80    |
| 6127.2260               | 6127.2198          | 4701                | 0.5881          | 6.1945                        | UI      | P80    |
| 6129.7209               | 6129.7230          | 139350              | 0.0552          | -2.1228                       | UI      | P80    |
| 6130.2007               | 6130.2009          | 7495                | 0.3076          | -0.1749                       | UI      | P80    |
| 6132.6172               | 6132.6188          | 35745               | 0.1210          | -1.6340                       | UI      | P80    |
| 6135.7222               | 6135.7199          | 5032                | 0.4007          | 2.2062                        | UI      | P80    |
| 6140.3746               | 6140.3778          | 8444                | 0.2761          | -3.1714                       | UI      | P80    |
| 6142.3291               | 6142.3323          | 12100               | 0.2191          | -3.1291                       | UI      | P80    |
| 6143.6432               | 6143.6438          | 2715                | 0.6478          | -0.6423                       | Uii     | P80    |
| 6147.9274               | 6147.9297          | 8327                | 0.2712          | -2.2159                       | UI      | P80    |
| 6150.0800               | 6150.0811          | 3123                | 0.5694          | -1.1470                       | Uii     | P80    |
| 6152.2598               | 6152.2599          | 37008               | 0.1173          | -0.1635                       | UI      | P80    |
| 6153.6708               | 6153.6704          | 23518               | 0.1494          | 0.3808                        | UI      | RS21   |
| 6154.3683               | 6154.3719          | 3701                | 0.5970          | -3.5889                       | UI      | P80    |
| 6159.3921               | 6159.3923          | 3794                | 0.5040          | -0.1440                       | UI      | P80    |
| 6161.9687               | 6161.9705          | 7403                | 0.3651          | -1.7996                       | UI      | P80    |
| 6164.2423               | 6164.2450          | 9954                | 0.3533          | -2.6410                       | Uii     | RS21   |
| 6164.5121               | 6164.5145          | 60976               | 0.0958          | -2.4160                       | UI      | P80    |
| 6165.8196               | 6165.8221          | 35751               | 0.1299          | -2.5900                       | UI      | P80    |
| 6167.6019               | 6167.6023          | 12279               | 0.2667          | -0.3399                       | UI      | P80    |
| 6169.4925               | 6169.4920          | 22532               | 0.1700          | 0.5654                        | UI      | P80    |
| 6171.8612               | 6171.8587          | 261266              | 0.0439          | 2.4453                        | UI      | P80    |
| 6172.6080               | 6172.6052          | 11674               | 0.3533          | 2.7111                        | UI      | P80    |
| 6173.8982               | 6173.8948          | 4058                | 0.7166          | 3.4566                        | Uii     | RS21   |
| 6174.3775               | 6174.3800          | 73983               | 0.0856          | -2.4364                       | UI      | P80    |
| 6174.8883               | 6174.8876          | 22641               | 0.1725          | 0.7373                        | UI      | P80    |
| 6175.3927               | 6175.3949          | 332121              | 0.0367          | -2.1794                       | UI      | P80    |
| 6176.4702               | 6176.4709          | 23572               | 0.1599          | -0.7576                       | UI      | P80    |
| 6181.3836               | 6181.3805          | 8235                | 0.3505          | 3.1882                        | UI      | P80    |
| 6181.6949               | 6181.6936          | 5274                | 0.5551          | 1.2866                        | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|--------------------------|---------------------|---------------------|-------------------|-------------------------------|---------|--------|
| 6182.8068                | 6182.8099           | 6589                | 0.4261            | −3.1611                       | UI      | P80    |
| 6183.1118                | 6183.1147           | 11619               | 0.2804            | −2.8487                       | UI      | P80    |
| 6184.2822                | 6184.2864           | 5252                | 0.5117            | −4.2294                       | UI      | P80    |
| 6184.9808                | 6184.9862           | 3334                | 0.7967            | −5.4875                       | Uii     | RS21   |
| 6188.0791                | 6188.0789           | 4319                | 0.6827            | 0.1927                        | UI      | P80    |
| 6194.6245                | 6194.6247           | 5695                | 0.3740            | −0.1576                       | UI      | P80    |
| 6196.5236                | 6196.5257           | 13580               | 0.2136            | −2.0759                       | UI      | P80    |
| 6197.9821                | 6197.9798           | 3045                | 0.6117            | 2.2137                        | UI      | P80    |
| 6198.3995                | 6198.3994           | 13132               | 0.2175            | 0.1014                        | UI      | P80    |
| 6201.9736                | 6201.9744           | 16414               | 0.1850            | −0.8101                       | UI      | P80    |
| 6203.3690                | 6203.3713           | 18628               | 0.1786            | −2.2797                       | UI      | P80    |
| 6205.7610                | 6205.7649           | 4692                | 0.4238            | −3.8359                       | UI      | P80    |
| 6206.8537                | 6206.8564           | 3593                | 0.5484            | −2.6680                       | UI      | P80    |
| 6211.2026                | 6211.2000           | 2969                | 0.7661            | 2.6202                        | UI      | P80    |
| 6214.3386                | 6214.3412           | 4212                | 0.4779            | −2.6181                       | UI      | P80    |
| 6215.3728                | 6215.3738           | 101867              | 0.0680            | −1.0188                       | UI      | P80    |
| 6216.8601                | 6216.8591           | 14988               | 0.1835            | 0.9800                        | UI      | P80    |
| 6220.2886                | 6220.2895           | 8945                | 0.2817            | −0.9236                       | UI      | P80    |
| 6221.5766                | 6221.5767           | 3907                | 0.5243            | −0.1254                       | Uii     | P80    |
| 6222.1489                | 6222.1496           | 28745               | 0.1334            | −0.6669                       | UI      | P80    |
| 6223.9932                | 6223.9870           | 10696               | 0.3455            | 6.2145                        | UI      | P80    |
| 6226.8680                | 6226.8707           | 3810                | 0.6477            | −2.6267                       | Uii     | RS21   |
| 6227.3453                | 6227.3392           | 7231                | 0.4191            | 6.0999                        | UI      | P80    |
| 6227.9734                | 6227.9746           | 16925               | 0.2040            | −1.1901                       | UI      | P80    |
| 6229.6381                | 6229.6361           | 14465               | 0.2322            | 2.0175                        | UI      | P80    |
| 6230.0709                | 6230.0740           | 5224                | 0.5318            | −3.0158                       | UI      | P80    |
| 6231.2188                | 6231.2196           | 10421               | 0.2889            | −0.7915                       | UI      | P80    |
| 6231.6393                | 6231.6402           | 9875                | 0.3074            | −0.9855                       | UI      | P80    |
| 6232.2847                | 6232.2867           | 7812                | 0.3876            | −1.9959                       | UI      | P80    |
| 6232.5336                | 6232.5333           | 6739                | 0.4330            | 0.2987                        | Uii     | RS21   |
| 6234.3022                | 6234.3036           | 147809              | 0.0599            | −1.3567                       | UI      | P80    |
| 6238.1940                | 6238.1957           | 26224               | 0.1486            | −1.6389                       | UI      | P80    |
| 6239.4420                | 6239.4458           | 5940                | 0.4924            | −3.8248                       | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|------------------|-------------------------------|---------|--------|
| 6239.9894              | 6239.9893           | 4084                | 0.7352           | 0.1460                        | UI      | P80    |
| 6244.0431              | 6244.0469           | 3917                | 0.6205           | −3.8699                       | UI      | P80    |
| 6246.5327              | 6246.5341           | 90942               | 0.0734           | −1.4382                       | UI      | P80    |
| 6251.7984              | 6251.8015           | 55049               | 0.0973           | −3.1382                       | UI      | P80    |
| 6252.6448              | 6252.6443           | 4897                | 0.5006           | 0.5275                        | UI      | P80    |
| 6253.6461              | 6253.6473           | 6498                | 0.3719           | −1.2059                       | UI      | P80    |
| 6253.8731              | 6253.8723           | 4427                | 0.5920           | 0.7932                        | UI      | P80    |
| 6255.1093              | 6255.1104           | 3086                | 0.5771           | −1.0974                       | UI      | P80    |
| 6256.7146              | 6256.7138           | 4066                | 0.4956           | 0.8087                        | UI      | P80    |
| 6258.9970              | 6259.0018           | 2751                | 0.8907           | −4.7864                       | UI      | RS21   |
| 6263.9302              | 6263.9315           | 9672                | 0.2700           | −1.2574                       | UI      | P80    |
| 6266.6715              | 6268.6705           | 23780               | 0.1448           | 1.0050                        | UI      | P80    |
| 6270.5624              | 6270.5624           | 28768               | 0.1369           | 0.0753                        | UI      | P80    |
| 6272.5470              | 6272.5414           | 2915                | 0.5805           | 5.5867                        | UI      | P80    |
| 6274.1071              | 6274.1130           | 2613                | 0.7037           | −5.9142                       | UI      | P80    |
| 6280.1814              | 6280.1825           | 11223               | 0.2391           | −1.1258                       | UII     | P80    |
| 6282.2117              | 6282.2120           | 4311                | 0.5201           | −0.2856                       | UI      | RS21   |
| 6282.5662              | 6282.5640           | 6008                | 0.4048           | 2.1893                        | UI      | P80    |
| 6283.8796              | 6283.8814           | 3031                | 0.6730           | −1.7503                       | UI      | P80    |
| 6284.5766              | 6284.5757           | 17065               | 0.1838           | 0.8489                        | UI      | P80    |
| 6285.4336              | 6285.4355           | 3474                | 0.6547           | −1.8919                       | UII     | RS21   |
| 6288.4116              | 6288.4142           | 5847                | 0.4824           | −2.5914                       | UI      | P80    |
| 6289.0756              | 6289.0787           | 4374                | 0.7429           | −3.0535                       | UI      | P80    |
| 6291.4510              | 6291.4480           | 9762                | 0.3664           | 2.9715                        | UII     | P80    |
| 6292.0224              | 6292.0211           | 121912              | 0.0679           | 1.3658                        | UII     | P80    |
| 6293.3267              | 6293.3277           | 479352              | 0.0321           | −1.0288                       | UII     | P80    |
| 6293.9743              | 6293.9716           | 28191               | 0.1650           | 2.7154                        | UI      | P80    |
| 6295.8754              | 6295.8737           | 5566                | 0.5290           | 1.7434                        | UI      | P80    |
| 6298.5314              | 6298.5326           | 224500              | 0.0456           | −1.1779                       | UI      | P80    |
| 6299.2435              | 6299.2453           | 6700                | 0.4619           | −1.7511                       | UI      | P80    |
| 6302.8396              | 6302.8433           | 5198                | 0.6792           | −3.6123                       | UII     | RS21   |
| 6303.5685              | 6303.5725           | 4244                | 0.7598           | −4.0101                       | UI      | P80    |
| 6306.9641              | 6306.9582           | 28722               | 0.1500           | 5.9422                        | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|----------------------------------|---------|--------|
| 6308.7240               | 6308.7259           | 4840                | 0.6075           | −1.8540                          | UI      | RS21   |
| 6311.6768               | 6311.6824           | 4641                | 0.7152           | −5.6253                          | UI      | P80    |
| 6312.6856               | 6312.6885           | 3486                | 0.7990           | −2.8661                          | UI      | RS21   |
| 6318.3293               | 6318.3267           | 11785               | 0.2599           | 2.5856                           | UII     | P80    |
| 6318.6149               | 6318.6168           | 4795                | 0.5835           | −1.9796                          | UI      | P80    |
| 6319.4750               | 6319.4796           | 3296                | 0.6594           | −4.6858                          | UI      | P80    |
| 6321.2579               | 6321.2579           | 8173                | 0.3041           | −0.0039                          | UI      | P80    |
| 6322.3625               | 6322.3627           | 6390                | 0.3558           | −0.1426                          | UII     | P80    |
| 6323.3776               | 6323.3757           | 4737                | 0.5082           | 1.8939                           | UI      | P80    |
| 6324.1113               | 6324.1078           | 3980                | 0.5850           | 3.5020                           | UI      | P80    |
| 6324.4399               | 6324.4363           | 22838               | 0.1807           | 3.5141                           | UI      | P80    |
| 6327.3890               | 6327.3892           | 10339               | 0.2888           | −0.2789                          | UI      | P80    |
| 6327.9713               | 6327.9720           | 4416                | 0.4793           | −0.7462                          | UI      | P80    |
| 6330.7542               | 6330.7548           | 4754                | 0.4460           | −0.5774                          | UII     | P80    |
| 6331.6519               | 6331.6526           | 3869                | 0.5105           | −0.6867                          | UI      | P80    |
| 6332.2578               | 6332.2593           | 6206                | 0.3657           | −1.5123                          | UI      | P80    |
| 6338.7349               | 6338.7338           | 18584               | 0.2006           | 1.0797                           | UI      | P80    |
| 6343.7078               | 6343.7114           | 2689                | 0.6382           | −3.5845                          | UI      | P80    |
| 6348.2315               | 6348.2259           | 6019                | 0.4662           | 5.6086                           | UI      | RS21   |
| 6350.0280               | 6350.0298           | 6609                | 0.3352           | −1.7505                          | UI      | P80    |
| 6351.0370               | 6351.0383           | 3559                | 0.5076           | −1.3376                          | UI      | P80    |
| 6353.4159               | 6353.4135           | 18692               | 0.1971           | 2.4258                           | UI      | P80    |
| 6354.8926               | 6354.8925           | 12662               | 0.2429           | 0.0533                           | UI      | P80    |
| 6355.5299               | 6355.5246           | 8206                | 0.3547           | 5.3042                           | UI      | P80    |
| 6358.5820               | 6358.5848           | 4100                | 0.6953           | −2.7520                          | UI      | P80    |
| 6359.2889               | 6359.2898           | 559569              | 0.0291           | −0.9349                          | UI      | P80    |
| 6359.6176               | 6359.6237           | 14134               | 0.2721           | −6.0801                          | UI      | P80    |
| 6360.7272               | 6360.7281           | 21953               | 0.1826           | −0.9048                          | UI      | P80    |
| 6362.3814               | 6362.3837           | 3623                | 0.9236           | −2.3015                          | UII     | RS21   |
| 6364.1500               | 6364.1446           | 1306                | 0.2469           | 5.3735                           | UI      | P80    |
| 6364.4736               | 6364.4711           | 9024                | 0.3336           | 2.5727                           | UI      | P80    |
| 6367.6576               | 6367.6559           | 18995               | 0.1884           | 1.6657                           | UI      | P80    |
| 6369.1077               | 6369.1142           | 7960                | 0.4281           | −6.5595                          | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|--------------------|---------------------|------------------|-------------------------------|---------|--------|
| 6369.8527              | 6369.8521          | 78448               | 0.0825           | 0.5639                        | UI      | P80    |
| 6371.7005              | 6371.7017          | 5079                | 0.6136           | −1.1532                       | UI      | P80    |
| 6372.4506              | 6372.4509          | 71717               | 0.0247           | −0.2921                       | UI      | P80    |
| 6372.9910              | 6372.9904          | 76452               | 0.0841           | 0.5949                        | UI      | P80    |
| 6374.1472              | 6374.1495          | 29125               | 0.1424           | −2.2866                       | UI      | P80    |
| 6374.4754              | 6374.4738          | 11327               | 0.2889           | 1.6479                        | UI      | P80    |
| 6374.7222              | 6374.7211          | 6637                | 0.4752           | 1.1403                        | UII     | RS21   |
| 6375.9668              | 6375.9694          | 10115               | 0.2923           | −2.5893                       | UII     | RS21   |
| 6376.7205              | 6376.7176          | 4234                | 0.6454           | 2.9187                        | UI      | P80    |
| 6379.6207              | 6379.6178          | 12904               | 0.2763           | 2.9705                        | UI      | P80    |
| 6380.4470              | 6380.4508          | 6498                | 0.4552           | −3.8348                       | UI      | P80    |
| 6383.5702              | 6383.5717          | 99901               | 0.0713           | −1.4661                       | UI      | P80    |
| 6384.7185              | 6384.7195          | 100177              | 0.0776           | −1.0143                       | UI      | RS21   |
| 6386.8374              | 6386.8374          | 3519                | 0.5950           | −0.0537                       | UII     | RS21   |
| 6388.6061              | 6388.6035          | 6417                | 0.4254           | 2.5618                        | UI      | P80    |
| 6389.7871              | 6389.7895          | 120467              | 0.0630           | −2.3670                       | UI      | P80    |
| 6392.7603              | 6392.7622          | 294055              | 0.0411           | −1.8765                       | UI      | P80    |
| 6397.1615              | 6397.1561          | 67227               | 0.0931           | 5.3585                        | UI      | P80    |
| 6404.4588              | 6404.4580          | 17827               | 0.1798           | 0.7425                        | UI      | P80    |
| 6407.1390              | 6407.1344          | 2564                | 0.7399           | 4.5640                        | UI      | P80    |
| 6409.8572              | 6409.8568          | 12428               | 0.2251           | 0.3583                        | UI      | P80    |
| 6411.5928              | 6411.5943          | 33654               | 0.1290           | −1.5516                       | UI      | P80    |
| 6416.3065              | 6416.3093          | 294281              | 0.0420           | −2.8436                       | UI      | RS21   |
| 6416.8723              | 6416.8756          | 2966                | 0.7317           | −3.3624                       | UI      | P80    |
| 6417.6627              | 6417.6681          | 4994                | 0.5413           | −5.3909                       | UI      | P80    |
| 6418.3721              | 6418.3706          | 12287               | 0.3067           | 1.4759                        | UII     | RS21   |
| 6420.5004              | 6420.5054          | 3271                | 0.8024           | −4.9182                       | UI      | P80    |
| 6421.4163              | 6421.4168          | 3594                | 0.7125           | −0.4763                       | UI      | P80    |
| 6422.2233              | 6422.2273          | 3953                | 0.7216           | −4.0390                       | UI      | P80    |
| 6424.8725              | 6424.8698          | 9485                | 0.3319           | 2.7240                        | UII     | P80    |
| 6425.4492              | 6425.4480          | 3446                | 0.8497           | 1.1488                        | UII     | P80    |
| 6427.5008              | 6427.4979          | 29740               | 0.1522           | 2.8859                        | UII     | P80    |
| 6428.6893              | 6428.6922          | 48860               | 0.1168           | −2.8996                       | UI      | P80    |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mA) | Offset from Ritz wavelength (mA) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|----------------------------------|---------|--------|
| 6430.9366               | 6430.9376           | 81939               | 0.0818           | -1.0322                          | UI      | P80    |
| 6434.6306               | 6434.6290           | 8711                | 0.4527           | 1.5608                           | UI      | P80    |
| 6435.1209               | 6435.1273           | 5946                | 0.4933           | -6.4524                          | UI      | RS21   |
| 6441.3419               | 6441.3455           | 8168                | 0.3393           | -3.6088                          | UI      | P80    |
| 6442.5559               | 6442.5564           | 23576               | 0.1613           | -0.4449                          | UI      | P80    |
| 6443.8631               | 6443.8655           | 15712               | 0.2506           | -2.3573                          | UI      | RS21   |
| 6445.8085               | 6445.8114           | 5584                | 0.4377           | -2.8455                          | UI      | P80    |
| 6448.0200               | 6448.0253           | 4951                | 0.5319           | -5.3272                          | UII     | P80    |
| 6446.5784               | 6448.5797           | 18180               | 0.2061           | -1.2901                          | UI      | P80    |
| 6449.9106               | 6449.9067           | 6263                | 0.5217           | 3.8793                           | UI      | P80    |
| 6451.2022               | 6451.1988           | 5774                | 0.4735           | 3.3759                           | UI      | P80    |
| 6458.9581               | 6458.9637           | 2841                | 0.6753           | -5.6236                          | UI      | P80    |
| 6460.3497               | 6460.3439           | 4394                | 0.4485           | 5.8128                           | UI      | P80    |
| 6461.9327               | 6461.9327           | 14022               | 0.2143           | 0.0738                           | UI      | P80    |
| 6464.9888               | 6464.9847           | 171623              | 0.0551           | 4.0524                           | UI      | P80    |
| 6466.5786               | 6466.5803           | 13633               | 0.2737           | -1.6563                          | UI      | RS21   |
| 6467.0407               | 6467.0378           | 3240                | 0.5626           | 2.8485                           | UI      | P80    |
| 6479.9576               | 6479.9563           | 13271               | 0.2490           | 1.3269                           | UII     | P80    |
| 6481.7281               | 6481.7283           | 34225               | 0.1315           | -0.1653                          | UI      | P80    |
| 6486.6423               | 6486.6449           | 15182               | 0.2306           | -2.5727                          | UI      | P80    |
| 6487.0329               | 6487.0366           | 30346               | 0.1465           | -3.7078                          | UI      | P80    |
| 6491.3287               | 6491.3306           | 5840                | 0.5177           | -1.9563                          | UI      | P80    |
| 6496.8011               | 6496.8056           | 14617               | 0.2444           | -4.4778                          | UI      | P80    |
| 6498.8003               | 6498.7944           | 6699                | 0.4811           | 5.9701                           | UI      | P80    |
| 6499.7340               | 6499.7310           | 4415                | 0.5914           | 2.9588                           | UI      | P80    |
| 6503.6188               | 6503.6216           | 260248              | 0.0473           | -2.7668                          | UI      | P80    |
| 6506.2813               | 6506.2827           | 7835                | 0.4070           | -1.4783                          | UI      | P80    |
| 6506.7969               | 6506.7935           | 4199                | 0.5808           | 3.4259                           | UI      | RS21   |
| 6507.3756               | 6507.3750           | 6132                | 0.4148           | 0.5595                           | UI      | P80    |
| 6507.6712               | 6507.6666           | 3918                | 0.7413           | 4.6124                           | UII     | P80    |
| 6508.1738               | 6508.1780           | 7091                | 0.5443           | -4.1759                          | UII     | RS21   |
| 6510.7810               | 6510.7857           | 4115                | 0.6198           | -4.6851                          | UI      | RS21   |
| 6511.1516               | 6511.1497           | 3657                | 0.7300           | 1.8754                           | UII     | RS21   |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|-----------------|---------------------------------|---------|--------|
| 6515.4171               | 6515.4160           | 5635                | 0.4442          | 1.0900                          | UI      | P80    |
| 6515.9600               | 6515.9601           | 3190                | 0.6620          | −0.0779                         | UI      | P80    |
| 6517.6663               | 6517.6659           | 8725                | 0.3506          | 0.3912                          | UI      | P80    |
| 6518.9468               | 6518.9472           | 134077              | 0.0618          | −0.3495                         | UI      | P80    |
| 6519.4927               | 6519.4939           | 3384                | 0.7398          | −1.2717                         | UI      | P80    |
| 6520.9829               | 6520.9815           | 25076               | 0.1522          | 1.4261                          | UI      | P80    |
| 6521.9917               | 6521.9902           | 8007                | 0.3080          | 1.4391                          | UI      | P80    |
| 6523.1618               | 6523.1626           | 4252                | 0.4337          | −0.7895                         | UI      | P80    |
| 6524.4536               | 6524.4543           | 2688                | 0.6377          | −0.6759                         | UI      | P80    |
| 6526.0793               | 6526.0773           | 19238               | 0.1788          | 2.0356                          | UI      | P80    |
| 6527.0475               | 6527.0459           | 24270               | 0.1639          | 1.5858                          | UII     | P80    |
| 6531.7047               | 6531.7085           | 3496                | 0.5650          | −3.8810                         | UI      | P80    |
| 6534.3583               | 6534.3552           | 7335                | 0.3319          | 3.1248                          | UI      | P80    |
| 6542.9892               | 6542.9848           | 35589               | 0.1245          | 4.4088                          | UI      | P80    |
| 6544.4919               | 6544.4911           | 5828                | 0.3614          | 0.7727                          | UII     | P80    |
| 6545.7387               | 6545.7331           | 10624               | 0.2712          | 5.5923                          | UI      | P80    |
| 6549.8867               | 6549.8843           | 3577                | 0.5567          | 2.3499                          | UI      | RS21   |
| 6550.7639               | 6550.7620           | 2719                | 0.6536          | 1.9470                          | UI      | P80    |
| 6551.8178               | 6551.8177           | 7784                | 0.3071          | 0.1888                          | UI      | P80    |
| 6552.7585               | 6552.7575           | 18167               | 0.1847          | 1.0214                          | UI      | P80    |
| 6555.0099               | 6555.0103           | 243733              | 0.0477          | −0.3973                         | UI      | P80    |
| 6555.8970               | 6555.8968           | 9622                | 0.3151          | 0.1331                          | UI      | P80    |
| 6556.8620               | 6556.8630           | 14061               | 0.2326          | −1.0852                         | UI      | P80    |
| 6558.9375               | 6558.9329           | 4748                | 0.5321          | 4.6235                          | UI      | P80    |
| 6564.1615               | 6564.1660           | 4177                | 0.7076          | −4.4981                         | UI      | P80    |
| 6566.2147               | 6566.2139           | 3584                | 0.6609          | 0.7721                          | UI      | RS21   |
| 6566.8103               | 6566.8116           | 11211               | 0.2683          | −1.2546                         | UI      | P80    |
| 6573.0228               | 6573.0236           | 2991                | 0.7910          | −0.8588                         | UI      | RS21   |
| 6573.8191               | 6573.8172           | 4042                | 0.6029          | 1.9386                          | UI      | P80    |
| 6574.7400               | 6574.7435           | 7511                | 0.3479          | −3.4367                         | UI      | P80    |
| 6578.7955               | 6578.7959           | 19781               | 0.1767          | −0.3460                         | UI      | P80    |
| 6579.5200               | 6579.5172           | 6779                | 0.4436          | 2.7720                          | UI      | P80    |
| 6580.6379               | 6580.6380           | 3162                | 0.6953          | −0.1483                         | UI      | P80    |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|------------------------|---------------------|---------------------|------------------|---------------------------------|---------|--------|
| 6582.2301              | 6582.2340           | 3880                | 0.5413           | −3.9354                         | UI      | P80    |
| 6582.7759              | 6582.7779           | 30785               | 0.1419           | −1.9969                         | UI      | P80    |
| 6585.2093              | 6585.2090           | 33863               | 0.1294           | 0.3748                          | UI      | P80    |
| 6586.8973              | 6586.9004           | 4017                | 0.5560           | −3.1398                         | UI      | P80    |
| 6587.8410              | 6587.8406           | 5254                | 0.4338           | 0.4169                          | UI      | P80    |
| 6588.9039              | 6588.8998           | 4652                | 0.5529           | 4.1417                          | UI      | P80    |
| 6590.0542              | 6590.0569           | 7469                | 0.3466           | −2.6559                         | UI      | P80    |
| 6601.3905              | 6601.3906           | 13644               | 0.2326           | −0.1087                         | UI      | P80    |
| 6603.3393              | 6603.3412           | 4051                | 0.5037           | −1.9020                         | UI      | P80    |
| 6603.9902              | 6603.9921           | 35120               | 0.1258           | −1.9062                         | UI      | P80    |
| 6607.3289              | 6607.3292           | 4578                | 0.5009           | −0.3002                         | UI      | P80    |
| 6609.2372              | 6609.2351           | 2392                | 0.6668           | 2.0497                          | UI      | P80    |
| 6616.7507              | 6616.7511           | 3284                | 0.5318           | −0.3807                         | UI      | P80    |
| 6619.2681              | 6619.2659           | 3137                | 0.6028           | 2.2287                          | UI      | P80    |
| 6620.5285              | 6620.5317           | 219184              | 0.0473           | −3.2012                         | UI      | P80    |
| 6621.7741              | 6621.7779           | 10616               | 0.2491           | −3.8511                         | UI      | P80    |
| 6622.8407              | 6622.8348           | 3303                | 0.5814           | 5.9609                          | UI      | P80    |
| 6625.2933              | 6625.2955           | 58187               | 0.1013           | −2.1512                         | UI      | P80    |
| 6629.0456              | 6629.0455           | 24081               | 0.1753           | 0.0733                          | UI      | P80    |
| 6629.8532              | 6629.8583           | 3396                | 0.6806           | −5.0223                         | UI      | P80    |
| 6630.1790              | 6630.1820           | 13808               | 0.2366           | −3.0599                         | UI      | P80    |
| 6633.4150              | 6633.4132           | 9579                | 0.3150           | 1.7963                          | UI      | P80    |
| 6641.0745              | 6641.0747           | 10053               | 0.3180           | −0.2483                         | UI      | P80    |
| 6642.3445              | 6642.3438           | 6028                | 0.4221           | 0.7665                          | UI      | P80    |
| 6647.7928              | 6647.7933           | 51451               | 0.1057           | −0.5203                         | UI      | P80    |
| 6649.5419              | 6649.5404           | 2998                | 0.7752           | 1.4352                          | UI      | P80    |
| 6650.4798              | 6650.4800           | 3079                | 0.7747           | −0.1509                         | UI      | P80    |
| 6653.3571              | 6653.3578           | 2970                | 0.7975           | −0.6973                         | UI      | P80    |
| 6656.8169              | 6656.8185           | 113542              | 0.0843           | −1.6453                         | UI      | P80    |
| 6657.6921              | 6657.6961           | 26428               | 0.1614           | −3.9982                         | UI      | P80    |
| 6662.5413              | 6662.5434           | 5486                | 0.4615           | −2.1125                         | UI      | P80    |
| 6672.6652              | 6672.6667           | 12275               | 0.2240           | −1.4771                         | UI      | P80    |
| 6677.2799              | 6677.2845           | 329990              | 0.0421           | −4.5839                         | UI      | RS21   |
| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mA) | Offset from Ritz wavelength (mA) | Species | Source |
|------------------------|--------------------|--------------------|------------------|-------------------------------|---------|--------|
| 6683.3839              | 6683.3845          | 80180              | 0.0815           | −0.6336                       | UI      | P80    |
| 6685.9266              | 6685.9276          | 3773               | 0.5098           | −0.9784                       | UI      | P80    |
| 6688.3971              | 6688.4022          | 4247               | 0.5125           | −5.0543                       | UI      | P80    |
| 6691.2028              | 6691.1983          | 13521              | 0.2303           | 4.4788                        | UI      | P80    |
| 6692.0249              | 6692.0224          | 10198              | 0.2649           | 2.5040                        | UI      | P80    |
| 6694.2363              | 6694.2406          | 5975               | 0.3911           | −4.2869                       | UI      | P80    |
| 6697.7129              | 6697.7151          | 5242               | 0.4637           | −2.1636                       | UI      | P80    |
| 6701.5227              | 6701.5182          | 12673              | 0.2800           | 4.4563                        | UI      | P80    |
| 6707.5980              | 6707.5949          | 4195               | 0.6056           | 3.1449                        | UI      | RS21   |
| 6711.1240              | 6711.1255          | 4843               | 0.5200           | −1.4787                       | UI      | P80    |
| 6716.6466              | 6716.6476          | 14167              | 0.2332           | −1.0145                       | UI      | P80    |
| 6717.4493              | 6717.4502          | 9012               | 0.3190           | −0.8316                       | UI      | P80    |
| 6717.9622              | 6717.9633          | 26904              | 0.1530           | −1.0930                       | UI      | P80    |
| 6719.2188              | 6719.2147          | 25269              | 0.1640           | 4.1895                        | UI      | RS21   |
| 6719.9031              | 6719.9071          | 4967               | 0.6223           | −4.0750                       | UI      | P80    |
| 6721.5615              | 6721.5617          | 4297               | 0.5466           | −0.2204                       | UI      | P80    |
| 6730.4759              | 6730.4752          | 7428               | 0.3828           | 0.7993                        | UI      | RS21   |
| 6732.1507              | 6732.1566          | 3698               | 0.5775           | −5.8848                       | UI      | P80    |
| 6733.1424              | 6733.1440          | 5639               | 0.4202           | −1.6558                       | UI      | P80    |
| 6735.0330              | 6735.0355          | 5052               | 0.6092           | −2.5233                       | UI      | P80    |
| 6736.8020              | 6736.8044          | 116343             | 0.0681           | −2.4285                       | UI      | P80    |
| 6738.1702              | 6738.1742          | 18882              | 0.1905           | −3.9569                       | UI      | RS21   |
| 6739.6160              | 6739.6137          | 7687               | 0.3399           | 2.2958                        | UI      | P80    |
| 6741.3605              | 6741.3632          | 84705              | 0.0794           | −2.6631                       | UI      | P80    |
| 6743.1138              | 6743.1150          | 4256               | 0.4548           | −1.1878                       | UI      | P80    |
| 6748.2869              | 6748.2886          | 16577              | 0.1926           | −1.7194                       | UI      | P80    |
| 6751.6314              | 6751.6315          | 16534              | 0.2313           | −0.0750                       | UI      | P80    |
| 6752.8321              | 6752.8260          | 531180             | 0.0345           | 6.1674                        | UI      | RS21   |
| 6754.9266              | 6754.9282          | 12828              | 0.2248           | −1.6034                       | UI      | P80    |
| 6767.2607              | 6767.2598          | 4918               | 0.4204           | 0.9081                        | UI      | P80    |
| 6768.6436              | 6768.6406          | 23142              | 0.1646           | 3.0336                        | UI      | P80    |
| 6770.6670              | 6770.6681          | 6569               | 0.4761           | −1.1021                       | UI      | P80    |
| 6771.0009              | 6771.0008          | 6595               | 0.4137           | 0.1352                        | UI      | RS21   |
Table 1 (Continued).

| Observed wavelength (Å) | Ritz wavelength (Å) | Relative flux (ADU) | Uncertainty (mÅ) | Offset from Ritz wavelength (mÅ) | Species | Source |
|-------------------------|---------------------|---------------------|------------------|---------------------------------|--------|--------|
| 6772.0872               | 6772.0861           | 3876                | 0.7670           | 1.0868                          | UI     | P80    |
| 6773.2371               | 6773.2376           | 9987                | 0.3006           | −0.5062                         | UI     | P80    |
| 6776.8860               | 6776.8861           | 4709                | 0.5089           | −0.1368                         | UII    | P80    |
| 6780.6325               | 6780.6315           | 32895               | 0.1424           | 0.9890                          | UI     | P80    |
| 6788.7595               | 6788.7627           | 8623                | 0.3333           | −3.1809                         | UI     | P80    |
| 6790.3018               | 6790.3018           | 158174              | 0.0590           | 0.0177                          | UI     | P80    |
| 6791.4273               | 6791.4240           | 3496                | 0.6701           | 3.3324                          | UI     | P80    |
| 6792.3135               | 6792.3130           | 4239                | 0.5744           | 0.4438                          | UI     | P80    |
| 6793.7618               | 6793.7609           | 4709                | 0.5035           | 0.8704                          | UI     | P80    |
| 6796.4403               | 6796.4419           | 4499                | 0.5271           | −1.5135                         | UII    | RS21   |
| 6804.9422               | 6804.9453           | 4862                | 0.4926           | −3.0683                         | UI     | P80    |
| 6805.2115               | 6805.2109           | 3785                | 0.6519           | 0.6822                          | UI     | P80    |
| 6812.9872               | 6812.9908           | 26566               | 0.1589           | −3.5835                         | UI     | P80    |
| 6816.1293               | 6816.1317           | 3997                | 0.5355           | −2.3375                         | UI     | P80    |
| 6818.2982               | 6818.3013           | 121562              | 0.0684           | −3.0402                         | UI     | P80    |
| 6819.2910               | 6819.2850           | 3121                | 0.5883           | 5.9408                          | UI     | P80    |
| 6820.1265               | 6820.1269           | 3596                | 0.5332           | −0.3679                         | UI     | P80    |
| 6820.7653               | 6820.7653           | 161104              | 0.0578           | −0.0040                         | UI     | P80    |
| 6823.9371               | 6823.9398           | 10622               | 0.2626           | −2.6351                         | UI     | P80    |
| 6824.4556               | 6824.4575           | 26737               | 0.1662           | −1.8994                         | UI     | P80    |
| 6829.3295               | 6829.3307           | 9556                | 0.2744           | −1.1632                         | UI     | P80    |
| 6830.8513               | 6830.8495           | 5793                | 0.3844           | 1.7800                          | UI     | P80    |
| 6832.7223               | 6832.7188           | 16291               | 0.2019           | 3.5403                          | UI     | P80    |

Acknowledgments

The PARAS spectrograph is fully funded and being supported by Physical Research Laboratory (PRL), which is part of the Department of Space, Government of India. R.S. and A.C. would like to thank the director of PRL for his support and encouragement. R.S. is thankful to Priyanka Chaturvedi from TLS, Tautenburg, Germany, for her valuable suggestions in improving the script and efforts in developing the various codes for analysis of the PARAS spectra. R.S. also acknowledges the help from Vishal Shah, Kapil Kumar, Neelam J.S.S.V. Prasad, Kevi Kumar, Ashirbad Nayak, Dishendra, Akanksha Khandelwal, and Mount Abu Observatory staff at the time of observations. A.C. is grateful to Suvrath Mahadevan and Arpita Roy from Pennsylvania University, USA, for their tremendous efforts in developing the PARAS data pipeline during the period of 2010-2014.
References

1. D. Rouan et al., “The exosolar planets program of the COROT satellite,” *Earth Moon Planets* **81**, 79–82 (1998).
2. W. J. Borucki et al., “Kepler planet-detection mission: introduction and first results,” *Science* **327**, 977 (2010).
3. G. R. Ricker et al., “Transiting exoplanet survey satellite (TESS),” *J. Astron. Telesc. Instrum. Syst.* **1**, 014003 (2015).
4. D. L. Pollacco et al., “The WASP project and the SuperWASP cameras,” *Publ. Astron. Soc. Pac.* **118**, 1407–1418 (2006).
5. J. Pepper et al., “The kilodegree extremely little telescope (KELT): a small robotic telescope for large-area synoptic surveys,” *Publ. Astron. Soc. Pac.* **119**, 923–935 (2007).
6. C. Jurgenson et al., “EXPRES: a next generation RV spectrograph in the search for earth-like worlds,” *Proc. SPIE* **9908**, 99086T (2016).
7. F. Pepe et al., “ESPRESSO: the next European exoplanet hunter,” *Astron. Nachr.* **355**(1), 8–20 (2014).
8. T. Wilken et al., “A spectrograph for exoplanet observations calibrated at the centimetre-per-second level,” *Nature* **485**, 611–614 (2012).
9. A. J. Metcalf et al., “Stellar spectroscopy in the near-infrared with a laser frequency comb,” *Optica* **6**, 233 (2019).
10. G. Lo Curto et al., “Astronomical spectrograph calibration at the exo-earth detection limit,” *Messenger* **149**, 2–6 (2012).
11. F. Kerber et al., “The spectrum of Th-Ar hollow cathode lamps in the 900–4500 nm region: establishing wavelength standards for the calibration of VLT spectrographs,” in *The Future of Photometric, Spectrophotometric and Polarimetric Standardization*, C. Sterken, Ed., Astronomical Society of the Pacific Conference Series, Vol. **364**, p. 461 (2007).
12. A. Chakraborty et al., “The PRL stabilized high-resolution Echelle fiber-fed spectrograph: instrument description and first radial velocity results,” *Publ. Astron. Soc. Pac.* **126**, 133 (2014).
13. A. Chakraborty et al., “Evidence of a sub-Saturn around EPIC 211945201,” *Astron. J.* **156**, 3 (2018).
14. X. Dumusque et al., “An Earth-mass planet orbiting α Centauri B,” *Nature* **491**, 207–211 (2012).
15. “S & J Juniper & Co,” [http://www.sjjuniper.com](http://www.sjjuniper.com).
16. G. Nave et al., “The dirt in astronomy’s genie lamp: ThO contamination of Th-Ar calibration lamps,” *Proc. SPIE* **10704**, 1070407 (2018).
17. S. L. Redman et al., “A high-resolution Atlas of uranium-neon in the H band,” *Astrophys. J. Suppl. Ser.* **199**, 2 (2012).
18. L. F. Sarmiento et al., “Comparing the emission spectra of U and Th hollow cathode lamps and a new U line list,” *Astron. Astrophys.* **618**, A118 (2018).
19. B. A. Palmer, R. A. Keller, and R. Engelman, “Atlas of uranium emission intensities in a hollow cathode discharge,” Los Alamos Scientific Laboratory, 12, Report number LA–8251–MS (1980).
20. “Hollow cathode lamp power supply from Cathodeon,” [https://www.msscientific.de/hollow_cathode_lamp_power_supply.htm](https://www.msscientific.de/hollow_cathode_lamp_power_supply.htm).
21. “Neutral density filter from Newport,” [https://www.newport.com/p/FSQ-OD50##mz-expanded-view-462354496971](https://www.newport.com/p/FSQ-OD50##mz-expanded-view-462354496971).
22. N. E. Piskunov and J. A. Valenti, “New algorithms for reducing cross-dispersed echelle spectra,” *Astron. Astrophys.* **385**, 1095–1106 (2002).
23. C. B. Markwardt, *Non-Linear Least-Squares Fitting in IDL with MPFIT*, Astronomical Society of the Pacific Conference Series, Vol. **411**, p. 251 (2009).
24. C. Lovis and F. Pepe, “A new list of thorium and argon spectral lines in the visible,” *Astron. Astrophys.* **468**, 1115–1121 (2007).
25. “Actinides energy database,” [http://www.lac.u-psud.fr/old-lac/lac/Database/Tab-energy/Uranium/](http://www.lac.u-psud.fr/old-lac/lac/Database/Tab-energy/Uranium/).
26. S. L. Redman, G. Nave, and C. J. Sansonetti, “The spectrum of thorium from 250 nm to 5500 nm: Ritz wavelengths and optimized energy levels,” Astrophys. J. Suppl. Ser. 211, 4 (2014).
27. “References for energy levels of neutral Uranium - 238U I,” http://www.lac.u-psud.fr/old-lac/lac/Database/Tab-energy/Uranium/U1-ref.html.
28. “References for energy levels of singly-ionized Uranium - 238U II,” http://www.lac.u-psud.fr/old-lac/lac/Database/Tab-energy/Uranium/U2-ref.html.
29. F. Bouchy, F. Pepe, and D. Queloz, “Fundamental photon noise limit to radial velocity measurements,” Astron. Astrophys. 374, 733–739 (2001).
30. F. Bouchy et al., “SOPHIE+: first results of an octagonal-section fiber for high-precision radial velocity measurements,” Astron. Astrophys. 549, A49 (2013).
31. A. Chakraborty et al., “PARAS-2 precision radial velocimeter: optical and mechanical design of a fiber-fed high resolution spectrograph under vacuum and temperature control,” Proc. SPIE 10702, 107026G (2018).

Rishikesh Sharma is a senior scientific assistant in the Astronomy and Astrophysics Division, Physical Research Laboratory, India. He completed his MSc degree in physics recently. His current research interests include data analysis of high-resolution spectroscopy and photometry data for characterization of exoplanetary candidates.

Abhijit Chakraborty is a professor at the Astronomy and Astrophysics Division, Physical Research Laboratory, India. He received his PhD in astrophysics from Gujarat University/Physical Research Laboratory, Ahmedabad, India. His current research interests include optical instrumentation and characterization of exoplanets.