First discovery of trans-iron elements in a DAO-type white dwarf (BD−22°3467)

L. Löbling1*, M. A. Maney1,2, T. Rauch1, P. Quinet3,4, S. Gamrath3, J. W. Kruk5, and K. Werner1

1 Institute for Astronomy and Astrophysics, Kepler Center for Astro and Particle Physics, Eberhard Karls University, Sand 1, 72076 Tübingen, Germany
2 Department of Astronomy & Astrophysics, Eberly College of Science, The Pennsylvania State University, 525 Davey Lab, University Park, PA 16802, USA
3 Physique Atomique et Astrophysique, Université de Mons – UMONS, 7000 Mons, Belgium
4 IPNAS, Université de Liège, Sart Tilman, 4000 Liège, Belgium
5 NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

Accepted 2019 November 18. Received 2019 November 11; in original form 2019 September 16

ABSTRACT

We have identified 484 lines of the trans-iron elements (TIEs) Zn, Ga, Ge, Se, Br, Kr, Sr, Zr, Mo, In, Te, I, Xe, and Ba, for the first time in the ultraviolet spectrum of a DAO-type WD, namely BD−22°3467, surrounded by the ionized nebula Abell 35. Our TIE abundance determination shows extremely high overabundances of up to five dex – a similar effect is already known from hot, H-deficient (DO-type) white dwarfs. In contrast to these where a pulse-driven convection zone has enriched the photosphere with TIEs during a final thermal pulse and radiative levitation has established the extreme TIE overabundances, here the extreme TIE overabundances are exclusively driven by radiative levitation on the initial stellar metallicity. The very low mass (0.533±0.029 M⊙) of BD−22°3467 implies that a third dredge-up with enrichment of s-process elements in the photosphere did not occur in the AGB precursor.

Key words: line: identification – planetary nebulae: individual: A66 35 – stars: abundances – stars: AGB and post-AGB – stars: atmospheres – stars: individual: BD−22°3467

1 INTRODUCTION

Trans-iron elements (TIEs) are synthesized during the asymptotic giant branch (AGB) phase of a star by the slow neutron-capture (s)-process. Depending on the initial stellar mass, its yields vary strongly (Karakas & Lugaro 2010). To become detectable, TIEs have to be transported from the helium-rich intershell region to the stellar surface. This happens, if the star experiences a third dredge-up (TDU, c.f., Herwig 2000). A scenario in which the envelope becomes mixed with the intershell region is known as the late helium-shell flash. Such a late thermal pulse (LTP) was predicted, e.g., by Iben et al. (1983). When it occurs after the star’s descent from the AGB at already declining luminosity, i.e., close to the end of nuclear burning, the H-burning shell is “off” and a pulse-driven convection zone (PDCZ) establishes between the He-burning shell and the photosphere. The remaining H is mixed into the stellar interior, becomes diluted or even burned, making the star H-deficient (c.f., Fujimoto 1977; Schönberner 1979; Iben et al. 1983; Blöcker 1995). Thus, it was – although surprising – well understandable, that lines of ten TIEs were identified (Werner et al. 2012) in the ultraviolet (UV) spectrum of the DO-type white dwarf (WD) RE 0503−289 (effective temperature Teff = 70 000 ± 2000 K, surface gravity log(g / cm s−2) = 7.5±0.1, Rauch et al. 2016b), which became an archetype for TIE search in WDs. Presently, 18 of these species are identified in RE 0503−289 (Rauch et al. submitted). Chayer et al. (2005) first succeeded in the detection of TIEs in DO WDs, namely six species in two other objects (HD 149499 B, HZ 21).

In a subsequent investigation, TIE line identification was successfully performed in three related H-deficient objects (two DO-type WDs and one PG 1159-type WD, namely WD 0111+002, PG 0109+111, and PG 1707+427, Hoyer et al. 2018). The commonality of these stars is that they are located close to the so-called PG 1159 wind limit (Unglaub & Bues 2000) that approximately separates the regions of PG 1159-type stars and DO-type WDs in the Hertzsprung-Russell diagram (HRD). Here, the stellar wind

* E-mail: loebling@astro.uni-tuebingen.de

© 2019 The Authors
is already weak enough and diffusion can establish strong TIE overabundances of up to five dex in the photosphere (Rauch et al. 2016a).

The search for TIE lines has not been restricted to He-rich WDs. Vennes et al. (2005) discovered the first TIE in WDs at all, namely Ge in three DA WDs. One of them is G191−B2B, an object that is employed as spectrophotometric flux standard for the Hubble Space Telescope (e.g., Bohlin 2007; Rauch et al. 2013). Recently, the TIEs Cu, Zn, Ga, Ge, As, Sn, and Ba were identified (Rauch et al. submitted, Rauch et al. 2014a, 2015, 2012, 2016a, 2013, 2014b). The TIE abundance pattern is similar to RE 0503−289, but at a lower absolute level probably because of the lower $T_{\text{eff}}$ of G191−B2B ($T_{\text{eff}}=60 000$ K, Rauch et al. 2013). TIE line search and abundance analyses are also successfully performed in the field of He-rich, hot subdwarf stars. The first one was LS IV−14′116, for which extreme overabundances of Fe, Sr, Y, and Zr were detected (Naslim et al. 2011). The most recent members of the group of “heavy metal” subdwarfs are HD 127493, and Feige 46 (e.g., Dorsch et al. 2019; Latour et al. 2019), with TIE enrichment patterns similar to those in Fig. 1.

Abell 35 was discovered by Abell (1955) and characterized as homogeneous disk planetary nebula (PN, Abell 1966). Jacoby (1981) classified the visible nucleus as G8 III−IV. Later, Grewing & Bianchi (1988) classified the hot, ionizing central star as DAO-type white dwarf (WD). Shortwards of 2800 Å, the WD dominates the flux, whereas the cool companion outshines it in the optical. Herald & Bianchi (2002) analyzed the binary and found $T_{\text{eff}}=80 000$ K and $\log (g / \text{cm}^2 / \text{s}^2) = 7.7$ for the hot and $T_{\text{eff}}=50 000$ K and $\log g = 3.5$ for the cool star. Ziegler et al. (2012) corrected the surface gravity of the WD to $g = 7.2$ and Frew & Parker (2010) classified the nebula as “bow shock nebula in a photo-ionized Strömgren sphere”. Recently, a close re-inspection of the UV spectrum of the exciting star of the ionized nebula Abell 35, BD−22′3467 (WD1250−226, McCook & Sion 1999), led us to the identification of TIE absorption lines. In this work, a systematic TIE line search was performed in order to constrain abundances analogously to Hoyler et al. (2017, for RE 0503−289). It is based on the BD−22′3467 model of Ziegler et al. (2012, atmospheric parameters given in Table A1) that was calculated using the non-local thermodynamic equilibrium (NLTE) model-atmosphere code of the Tübingen NLTE Model Atmosphere Package (TMAD1, Werner et al. 2003, 2012). In Sects. 2 and 3, we briefly describe the available observations and the model atmospheres used for the spectral analysis, respectively. In Sect. 4, the process of line identification and subsequent abundance measurement is explained. Lastly, we summarize our results and conclude in Sect. 5.

2 OBSERVATIONS

Our analysis is based on high-resolution Far Ultraviolet Spectroscopic Explorer (FUSE) and Space Telescope Imaging Spectrograph (HST/STIS) observations. These were obtained from the MAST2 archive. The FUSE spectrum taken

with the LWRS aperture has a resolving power of $R = \lambda / \Delta \lambda = 20 000$. Four STIS observations with grating E140M and $R = 45 800$ are available. The observation log is shown in Table B1. We convolved the synthetic spectra with Gaussians to model the respective instrument’s resolution. The signal-to-noise ratio of the STIS observations was improved by co-adding the observations. The combined spectra are the same as used by Ziegler et al. (2012). No optical observation of the DAO WD are available, since the G-star companion dominates this spectral range.

3 MODEL ATMOSPHERES AND ATOMIC DATA

The analysis was carried out using TMAD. This code assumes plane-parallel geometry and calculates chemically homogeneous NLTE atmospheres in radiative and hydrostatic equilibrium.

For the TIEs Cu, Zn, Ga, Ge, Sr, Br, Kr, Sr, Zr, Mo, In, Te, I, Xe, and Ba, we used the recently calculated data that is available via the Tübingen Oscillator Strengths Service (TOSS). For the elements with $Z \geq 20$, it is necessary to create model atoms using a statistical approach that calculates super levels and super lines (Rauch & Deetjen 2003) to take their complex atomic structure into account for the calculation. The statistics of all elements considered in our model-atmosphere calculations are summarized in Table B2.

We constructed a new classical model ion for BaVIII from the level and line data of Churilov et al. (2001) available via the National Standards and Technology Institute (NIST) Atomic Spectra Database (ASD3, Kramida et al. 2018), which was incorporated into TMAD.

For all considered elements with an atomic number $Z \leq 28$, we used the same model atoms like Ziegler et al. (2012). For $Z < 20$ these were obtained from the Tübingen Model Atom Database (TMAD, Rauch & Deetjen 2003) that was constructed as part of the German Astrophysical Virtual Observatory (GAVO). For the iron-group elements (IGEs, atomic number $20 \leq Z \leq 28$), Kurucz’s line lists4 (Kurucz 2009, 2011, 2017) were utilized.

For this analysis, we adopted the photospheric parameters of Ziegler et al. (2012) and used their final model ($T_{\text{eff}}=80 000$ K, $\log g = 7.2$, see Table A1 for the element abundances) to start our TIE analysis. To identify lines and determine abundances of the 15 TIEs (Cu, Zn, Ga, Ge, Se, Br, Kr, Sr, Zr, Mo, In, Te, I, Xe, and Ba), we performed line-formation calculations by adding each of them individually to the start model from Ziegler et al. (2012), while temperature and density structure of the atmosphere were kept fixed. To verify our method, a final model including all TIEs with their previously determined abundances was then calculated with temperature and density corrections. The deviations in the abundances were marginal.

The observed spectra are affected by reddening due to interstellar material within the line of sight. By comparing the slope of the flux calibrated observations as well as GALEX, HIPPARCOS, and 2MASS magnitudes

---

1 http://astro.uni-tuebingen.de/TMAP
2 http://archive.stsci.edu
3 https://physics.nist.gov/PhysRefData/ASD
4 http://kurucz.harvard.edu/atoms.html
(Bianchi et al. 2011; Perryman et al. 1997; Cutri et al. 2003) with the synthetic spectra of the central star, Ziegler et al. (2012) found a color excess $E_{B-V} = 0.02 \pm 0.02$. This value was used to apply interstellar reddening following the law of Fitzpatrick (1999, with the standard $R_V = 3.1$) to the model spectra to reproduce the observation. Absorption due to neutral interstellar hydrogen, assuming a column density of $N_{H} = 5.0 \times 10^{20}$ cm$^{-2}$ (Ziegler et al. 2012), was applied to the synthetic spectra. Furthermore, we applied the interstellar line-absorption model of Ziegler et al. (2012) that was calculated using the program OWENS (Hébrard et al. 2002; Hébrard & Moos 2003) to unambiguously identify lines of stellar and interstellar origin.

### 4 LINE IDENTIFICATION AND ABundance DETERMINATION

We calculated synthetic spectra from our line-formation models with each of the 15 elements added individually to the best model of Ziegler et al. (2012). The spectrum is crowded with a multitude of blended metal lines which hampers their unambiguous identification. To clearly see the contribution of the individual TIE elements, we divided the synthetic spectrum including this species by another model spectrum without it. The individual abundances were varied by small steps of 0.2 dex or smaller to derive the final values from evaluation of line-profile fits by eye. To estimate the influence of the uncertainty in $T_{\text{eff}}$ of ±10000 K and in log g of ±0.3 for the error propagation, we redid the abundance determination for models with $T_{\text{eff}} = 90000$ K and log g = 6.9 as well as for $T_{\text{eff}} = 70000$ K and log g = 7.5. The abundances are affected by typical errors below 0.3 dex.

For Cu, a line identification was not possible with appreciable certainty. Instead, upper limits were determined by reducing the abundance until the strongest computed lines become undetectable. An equivalent width of $W_{\lambda} = 5$ mÅ was set as a detection limit. Table B3 – Table B17 list all lines of TIEs, that appear with an equivalent width above the threshold in the model spectrum. These tables include also those lines that could not be identified in the spectrum of BD−22°3467 due to, e.g., blending with other photospheric or interstellar lines to make them a useful tool for the identification of TIE lines in the spectra of other DAO-type WDs. The abundances are given in Table A1 and are illustrated in Fig. 1. The complete FUSE and STIS observations compared to our best model are shown online\(^5\) within the Tubingen VISualization tool (TVIS). The ionization fractions as well as the temperature structure and electron density in the final atmosphere model are shown in Fig. B1.

The number of identified lines per TIE ion is shown in Table 1. The observation is well reproduced by our final model with the abundances shown in Table A1 as it is illustrated in Fig. B2 to B16 for prominent lines of each of the TIEs.

\(^5\) http://astro.uni-tuebingen.de/~TVIS/objects/Abell35

### 5 RESULTS AND CONCLUSIONS

To identify TIE lines, the UV spectrum of BD−22°3467 was closely inspected which led to the discovery of Zn, Ga, Ge, Se, Br, Kr, Sr, Zr, Mo, In, Te, I, Xe, and Ba (Table 1). In total, 484 TIE lines were discovered.

Our spectral analysis has shown that the enrichment of TIEs in BD−22°3467 ($T_{\text{eff}} = 80000 \pm 10000$ K, log g = 7.2 ± 0.3) and RE 0503−289 ($T_{\text{eff}} = 70000 \pm 2000$ K, log g = 7.5 ± 0.1) is considerably high ($\approx 1.5 − 5$ dex, Fig. 1). The origin of the high enrichment of TIEs is diffusion, i.e., efficient radiative levitation. This was shown already for RE 0503−289 by detailed diffusion calculations (Rauch et al. 2016a). While it was possible to determine abundances for several TIEs with consecutive atomic number in RE 0503−289 and find that the odd-even shape of the solar abundance pattern seems to be reflected also by the enriched TIEs (Fig. 2, cf., Rauch et al. 2019, submitted), there is not enough information to confirm this finding based on the results for BD−22°3467.

The evolutionary difference between BD−22°3467 and RE 0503−289 is that the latter most likely experienced an LTP in which it became hydrogen-deficient. As a result, a pulse-driven convection zone, established during the flash, enriched the TIEs in the atmosphere. Their abundances were later on amplified to the observed values by radiative levitation. In contrast, the high abundances of TIEs in BD−22°3467 are possibly the result of radiative levitation on the initial stellar metallicity without previous enrichment by s-processed matter. This is because of the very low mass of BD−22°3467, (Fig. 1) which corresponds to an initial mass of below 1.0$M_\odot$ (Cummings et al. 2018), implying that no TDU occurred on the AGB (Karaka & Lugaresi 2016). From the position in the $T_{\text{eff}}$−log g diagram (Fig. 3) only, a possible evolution without an AGB phase, directly from the extended horizontal branch (EHB) to the WD cooling sequence, cannot be excluded. Conversely, it is then possible that the high amount of TIEs in RE 0503−289 is solely due to diffusion, independent of the occurrence of a previous LTP. This is an interesting conclusion, because a large fraction of DOs is not initiated by an LTP but by a merger event with the so-called O(He) stars as merger products and DO precursors (Reindl et al. 2014). DOs from this evolutionary chan-

---

**Table 1.** Numbers of identified lines in the ionization stages IV-VIII of TIEs in the UV spectrum of BD−22°3467.

| Element | Z | IV | V | VI | VII | VIII |
|---------|---|----|---|----|-----|------|
| Zn      | 30| 2  |   | 141|     |      |
| Ga      | 31| 2  | 71| 52 |     |      |
| Ge      | 32| 2  | 32| 57 |     |      |
| Se      | 34| 14 |   |    |     |      |
| Br      | 35| 1  | 7 |    |     |      |
| Kr      | 36| 4  |   |    |     |      |
| Sr      | 38| 17 |   |    |     |      |
| Zr      | 40| 1  | 28| 3  |     |      |
| Mo      | 42| 2  |   |    |     |      |
| In      | 49| 28 |   |    |     |      |
| Te      | 52| 3  |   |    |     |      |
| I       | 53| 4  |   |    |     |      |
| Xe      | 54| 4  |   |    |     |      |
| Ba      | 56| 3  | 3 |    |     |      |
The evolution of stellar winds decreases but is still high enough to maintain the convective envelope.

Figure 1. Photospheric abundance ratios \([X] = \log(\text{mass fraction}/\text{solar mass fraction})\) of BD−22°3467 determined from detailed line profile fits. Solar values are taken from Asplund et al. (2009); Scott et al. (2015b,a); Grevesse et al. (2015). Upper limits are indicated with arrows. The black, solid line indicates solar abundances. Blue triangles represent the abundances determined by Ziegler et al. (2012), red triangles show the TIE abundances (Table A1). For comparison, the abundances determined for G191−B2B (Rauch et al. 2013, green circles) and RE 0503−289 are shown (Hoyer et al. 2017, black squares).

Figure 2. Photospheric TIE abundances in BD−22°3467 (red triangles) compared to RE 0503−289 (black squares) (Hoyer et al. 2017, Rauch et al. 2019 submitted). Solar values are shown for comparison.

nel should therefore also go through a phase with an extreme TIE enrichment by diffusion.

We have to keep in mind that diffusion-established abundance patterns do not contain anymore information about the previous stellar evolution, i.e., wherever the TIEs (or other elements) stem from, the exhibited surface abundance may be the same. Investigations on yields of the AGB s-process nucleosynthesis elements have to be performed before diffusion dominates the stellar evolution. This is the phase of just declining luminosity when the strength of the stellar wind decreases but is still high enough to maintain the original abundance ratios produced by the s-process. Spectral analyses of stars in that evolutionary phase might help to directly constrain AGB nucleosynthesis.

The formation of Abell 35-like central stars of planetary nebulae (CSPNe), i.e., binary CSPNe with a rapidly rotating late-type (sub)giant and an extremely hot companion (Bond et al. 1993), is discussed controversially in the literature. Thevenin & Jasniwicz (1997) found the companion of BD−22°3467 to be enriched in Ba indicating that this still unevolved star experienced mass transfer from a (post-) AGB star. However, this formation channel is debated since Abell 35 was found to only mimic a PN (Frew & Parker 2010) and the mass of the ionizing star was considered to be too low for a post-AGB star (Ziegler et al. 2012). As explained above, an evolution directly from the EHB to the WD cooling track is possible (Fig. 3). The peculiar ionized nebula around BD−22°3467 is not a real PN but, nevertheless, it also cannot be excluded, that the nebula material is in some way connected to the evolution of the central star. Assuming that it ejected a PN as an AGB star, the original PN might have already dispersed. The star has a high proper motion (\(\mu_\alpha = -54.566 \pm 0.226\) mas/yr and \(\mu_\delta = -10.097\pm0.187\) mas/yr, Gaia Collaboration et al. 2018) and, thus, might now be passing through the edges of the ejected former nebula material or another dense ISM region while ionizing the surrounding material. The classification of Abell 35 as a bow shock nebula in a photoionized Strömgren sphere in the ambient ISM (Frew & Parker 2010) does not necessarily include a PN but also, does not rule out the post-AGB nature of BD−22°3467. Further detailed abundance analyses of a sample of Abell 35-like CSPNe as well as their ambient nebulae and companion stars should give us a better handle on their evolution. The nebulae, if ejected from an AGB star, contain signatures of s-process elements (Madonna et al. 2017) as well as the unevolved companions, if they accreted a fraction of the ejected material. Therefore, a precise knowledge of the companion is mandatory because any accreted material would become diluted in this star’s convective envelope.

To better understand the late evolutionary phases of low-mass stars, it is highly desirable to improve the determination of \(T_{\text{eff}}\) and log g with much narrower error ranges. For
this purpose, the analysis of high-resolution optical spectra, may be helpful. Although the cool companion dominates this wavelength regime, broad lines of H and He of BD−22°3467 should be detectable like demonstrated by Aller et al. (2015) for the binary CS of NGC 1514. These lines may reduce the error and, thus, allow to better constrain the stellar mass (Fig. 3).

As a remark, we would like to mention that the discrepancy found by Ziegler et al. (2012) between the spectroscopic distance of 361±137 pc and the distance based on the HIPPARCOS parallax is still present in the era of Gaia with a distance of 124.84±2.21 pc (Bailer-Jones et al. 2018). Ziegler et al. (2012) demonstrated, that the H i lines in the FUSE range are poorly reproduced with models with log g > 7.7. This phenomenon of too large spectroscopic distances has already been reported in the literature for CSPNe (Schönberner et al. 2018; Schönberner & Steffen 2019). The argument that missing metal-line blanketing and back warming may result in too-high temperatures does not hold in our analysis, because all elements in the model calculation were considered in full NLTE computations. The objects of the mentioned studies are all located before the knee at highest temperatures in the Hertzsprung-Russell diagram. Thus, the spectroscopic mass derived from fitting of the spectral energy distribution using the parallax distance is systematically too high. In our case, the spectroscopic mass derived from the dereddened GALEX FUV flux (Bianchi et al. 2011) using the Gaia distance is unreasonably low. With the given T eff, at least a log g > 8.0 would be required to reach masses above 0.4 M⊙. In conclusion, the discrepancy remains unexplained and needs further investigation.

Following the discovery of TIE lines in BD−22°3467, we have initiated an analogous search in other DAO-type WDs. Since the FUSE and HST archives provide quite a number of high-quality UV spectra of such stars, that have not been inspected in focus of TIEs, we expect to identify TIE enrichment as a common phenomenon in many hot WDs.

ACKNOWLEDGMENTS

We thank the referee for the very useful comments that improved this paper. LL has been supported by the German Research Foundation (DFG) under grant WE1312/49−1. MAM had been supported by the DAAD RISE Germany program. The GAVO project at Tübingen had been supported by the Federal Ministry of Education and Research (BMBF) at Tübingen (05 AC 6 VTB, 05 AC 11 VTB). Financial support from the Belgian FRS-FNRS is also acknowledged. PQ is research director of this organization. Some of the data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. Support for MAST for non-HST data is provided by the NASA Office of Space Science via grant NNX09AF08G and by other grants and contracts. The TIRO (http://astro-uni-tuebingen.de/”TIR0), TMAD (http://astro-uni-tuebingen.de/”TMAD), TOSS (http://astro-uni-tuebingen.de/”TOSS), and TVIS (http://astro-uni-tuebingen.de/”TVIS) tools and services used for this paper were constructed as part of the Tübingen project (https://uni-tuebingen.de/de/122430) of the German Astrophysical Virtual Observatory (GAVO, http://www.g-vo.org). This research has made use of NASA’s Astrophysics Data System and of the SIMBAD database, operated at CDS, Strasbourg, France. This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

References

Abell G. O., 1955, PASP, 67, 258
Abell G. O., 1966, ApJ, 144, 259
Aller A., Miranda L. F., Olguín L., Vázquez R., Guillén P. F., Oreiro R., Ulla A., Solano E., 2015, MNRAS, 446, 317
Asplund M., Grevesse N., Sauval A. J., Scott P., 2009, ARA&A, 47, 481
Bailer-Jones C. A. L., Rybizki J., Fouesneau M., Mantelet G., Andrae R., 2018, AJ, 156, 58
Bianchi L., Herald J., Efremova B., Girardi L., Zabot A., Marigo P., Conti A., Shiao B., 2011, Ap&SS, 335, 161
Blöcker T., 1995, A&A, 299, 755
Bohlin R. C., 2007, in Astronomical Society of the Pacific Conference Series, Vol. 364, Sterken C., ed, The Future of Photometric, Spectrophotometric and Polarimetric Standardization, p. 315
Bond H. E., Ciardullo R., Meakes M. G., 1993, in IAU Symposium, Vol. 155, Weinberger R., Acker A., ed, Planetary Nebulae, p. 397

MN000 000, 1−34 (2019)
APPENDIX A: PHOTOSPHERIC PARAMETERS OF BD–22°3467
Table A1. Parameters of BD–22° 3467.

| Element | [X] | Mass fraction | Number fraction | ε(Fe) | [X/Fe] |
|---------|-----|---------------|----------------|-------|--------|
| H      | (a) | 0.07          | 8.67 × 10^{-1} | 9.67 × 10^{-1} | 12.09 | -0.00 |
| He     | (a) | -0.33         | 1.17 × 10^{-1} | 3.29 × 10^{-2} | 10.62 | -0.40 |
| C      | (a) | -2.93         | 2.77 × 10^{-6} | 2.59 × 10^{-7} | 5.51  | -3.00 |
| N      | (a) | -1.75         | 1.24 × 10^{-3} | 9.99 × 10^{-7} | 6.10  | -1.82 |
| O      | (a) | -2.61         | 1.42 × 10^{-3} | 9.99 × 10^{-7} | 6.10  | -2.68 |
| F      | (a) | ≤ -0.16       | ≤ 5.04 × 10^{-7} | ≤ 2.98 × 10^{-8} | ≤ 4.57 | ≤ -0.07 |
| Ne     | (a) | ≤ -0.00       | ≤ 1.26 × 10^{-3} | ≤ 6.99 × 10^{-5} | ≤ 7.94 | ≤ -0.07 |
| Na     | (a) | ≤ 0.03        | ≤ 2.92 × 10^{-4} | ≤ 1.43 × 10^{-6} | ≤ 6.25 | ≤ -0.07 |
| Mg     | (a) | ≤ 1.08        | ≤ 8.31 × 10^{-4} | ≤ 3.84 × 10^{-4} | ≤ 8.68 | ≤ 1.00 |
| Al     | (a) | ≤ 0.02        | ≤ 5.65 × 10^{-5} | ≤ 2.31 × 10^{-6} | ≤ 6.46 | ≤ -0.07 |
| Si     | (a) | -2.12         | 5.00 × 10^{-6} | 2.00 × 10^{-7} | 5.40  | -2.19 |
| P      | (a) | ≤ -2.85       | ≤ 8.26 × 10^{-9} | ≤ 3.00 × 10^{-10} | ≤ 2.58 | ≤ -2.92 |
| S      | (a) | ≤ -2.93       | ≤ 3.64 × 10^{-7} | ≤ 1.27 × 10^{-8} | ≤ 4.21 | ≤ -3.00 |
| Ar     | (a) | 1.07          | 8.65 × 10^{-4} | 2.43 × 10^{-5} | 7.49  | 1.00  |
| Cu     | (a) | ≤ 0.02        | ≤ 6.41 × 10^{-3} | ≤ 1.80 × 10^{-6} | ≤ 6.35 | ≤ -0.07 |
| Sc     | (a) | ≤ -0.01       | ≤ 4.64 × 10^{-3} | ≤ 1.16 × 10^{-9} | ≤ 3.16 | ≤ -0.07 |
| Ti     | (a) | ≤ 0.02        | ≤ 3.12 × 10^{-6} | ≤ 7.31 × 10^{-8} | ≤ 4.96 | ≤ -0.07 |
| V      | (a) | ≤ 0.04        | ≤ 3.17 × 10^{-7} | ≤ 6.99 × 10^{-9} | ≤ 3.94 | ≤ -0.07 |
| Cr     | (a) | 1.86          | 1.16 × 10^{-3} | 2.50 × 10^{-5} | 7.50  | 1.77  |
| Mn     | (a) | 1.56          | 3.81 × 10^{-4} | 7.80 × 10^{-6} | 6.99  | 1.48  |
| Fe     | (a) | 0.10          | 1.52 × 10^{-3} | 3.06 × 10^{-5} | 7.58  | 0.00  |
| Co     | (a) | 2.18          | 1.57 × 10^{-4} | 3.00 × 10^{-6} | 6.58  | 1.50  |
| Ni     | (a) | 0.70          | 3.39 × 10^{-4} | 6.49 × 10^{-6} | 6.91  | 0.61  |
| Cu     | ≤ 1.38 | ≤ 1.70 × 10^{-5} | ≤ 3.00 × 10^{-7} | ≤ 5.85 | ≤ 1.30 |
| Zn     | 1.37   | 4.08 × 10^{-5} | 7.00 × 10^{-7} | 5.95  | 1.30  |
| Ga     | 3.77   | 3.11 × 10^{-4} | 5.00 × 10^{-6} | 6.80  | 3.67  |
| Ge     | 3.76   | 1.29 × 10^{-3} | 2.00 × 10^{-5} | 7.40  | 3.67  |
| Sn     | 4.52   | 4.21 × 10^{-3} | 6.00 × 10^{-5} | 7.88  | 4.45  |
| Br     | 3.19   | 3.13 × 10^{-3} | 4.40 × 10^{-7} | 5.74  | 3.12  |
| Kr     | 2.68   | 5.23 × 10^{-5} | 7.00 × 10^{-7} | 5.95  | 2.61  |
| Sr     | 5.21   | 6.98 × 10^{-3} | 9.00 × 10^{-5} | 8.05  | 5.10  |
| Zr     | 3.97   | 2.44 × 10^{-4} | 3.00 × 10^{-6} | 6.58  | 3.91  |
| Mo     | 3.68   | 2.57 × 10^{-5} | 3.00 × 10^{-7} | 5.58  | 3.61  |
| In     | 5.83   | 3.58 × 10^{-4} | 3.50 × 10^{-6} | 6.64  | 5.76  |
| Te     | 4.51   | 4.55 × 10^{-4} | 4.00 × 10^{-6} | 6.70  | 4.44  |
| I      | 4.24   | 5.66 × 10^{-3} | 5.00 × 10^{-7} | 5.80  | 4.16  |
| Xe     | 3.85   | 1.17 × 10^{-3} | 1.00 × 10^{-6} | 6.10  | 3.77  |
| Ba     | 3.54   | 6.12 × 10^{-5} | 5.00 × 10^{-7} | 5.80  | 3.53  |

Notes. (a) From Ziegler et al. (2012). (b) Interpolated from post-AGB evolutionary tracks, cf., Fig. 3. (c) Interpolated from post-EHB evolutionary tracks, cf., Fig. 3. (d) Abundances ε_i = log n_i + c with ∑_i a_i n_i = 12.15 and the atomic weights a_i.
APPENDIX B: ADDITIONAL FIGURES AND TABLES.
Table B1. Observation log for BD−22°3467.

| Instrument | Dataset Id   | Start Time (UT) | Wavelength range (Å) | Aperture/Grating | Exposure time (s) | Resolving power $R = \lambda / \Delta \lambda$ |
|------------|--------------|-----------------|----------------------|------------------|-------------------|-----------------------------------------------|
| FUSE       | P1330101000  | 2000-05-20 20:27:37 | 910 – 1180          | LWRS             | 4416              | 20 000                                        |
| STIS       | O4GT02010    | 1999-04-17 21:14:49 | 1150 – 1730          | E140M            | 2050              | 45 800                                        |
| STIS       | O4GT02020    | 1999-04-17 22:37:03 | 1150 – 1730          | E140M            | 2800              | 45 800                                        |
| STIS       | O4GT02030    | 1999-04-18 00:16:10 | 1150 – 1730          | E140M            | 2740              | 45 800                                        |
| STIS       | O4GT02040    | 1999-04-18 01:52:54 | 1150 – 1730          | E140M            | 2740              | 45 800                                        |

Notes. a: Far Ultraviolet Spectroscopic Explorer, b: Space Telescope Imaging Spectrograph.

Figure B1. Temperature and electron density structure and ionization fractions of all TIE ions which are considered in our final model for BD−22°3467.
Table B2. Statistics of the H – Ar$^a$ and Ca – Ba$^b$ model atoms used in our model-atmosphere calculations.

| Ion | Levels | Lines | Ion | Super levels$^c$ | Lines | Ion | Super levels$^c$ | Lines |
|-----|--------|-------|-----|------------------|-------|-----|------------------|-------|
|     | NLTE   | LTE   |     |                  |       |     |                  |       |
| H i | 12     | 4     | 66  | Ca iv            | 6     | 16  | 20291            | Cu iv |
| He i| 5      | 9     | 83  | vi               | 6     | 19  | 114545           | v     |
| N ii| 16     | 16    | 120 | vii              | 6     | 21  | 71608            | vii   |
| C iii| 6      | 61    | 12  | ix               | 1     | 0   | 9124             | Zn iv |
|     |        |       |     |                  |       |     |                  |       |
| iv  | 54     | 4     | 295 | Sc iv            | 6     | 20  | 15024            | vii   |
|     |        |       |     |                  |       |     |                  |       |
| N iii| 1      | 65    | 0   | vi               | 6     | 19  | 237271           | v      |
| iv  | 16     | 78    | 30  | vii              | 6     | 20  | 176143           | vi     |
|     |        |       |     |                  |       |     |                  |       |
| v   | 54     | 8     | 297 | viii              | 6     | 21  | 91935            | vi     |
|     |        |       |     |                  |       |     |                  |       |
| O iii| 3      | 69    | 0   | Ti iv            | 6     | 19  | 1000             | v      |
| iv  | 18     | 76    | 39  | vi                | 6     | 20  | 26654            | vi     |
| v   | 90     | 36    | 610 | vii               | 6     | 19  | 95448            | vii    |
|     |        |       |     |                  |       |     |                  |       |
| Ne ii| 1      | 33    | 0   | ix                | 1     | 0   | 0               | Ge iv$^d$ |
| iv  | 18     | 125   | 16  | vii               | 6     | 19  | 35251            | iv     |
| v   | 12     | 80    | 0   | viii              | 6     | 19  | 112883           | v      |
|     |        |       |     |                  |       |     |                  |       |
| Ca ii| 1      | 10    | 0   | iv                | 6     | 19  | 37130            | vi     |
| ii  | 15     | 91    | 31  | v                  | 6     | 20  | 2123             | Br iii |
| i   | 12     | 115   | 16  | vii               | 6     | 19  | 35251            | iv     |
|      |        |       |     |                  |       |     |                  |       |
| Ne iii| 1      | 34    | 0   | ix                | 1     | 0   | 0               | vii    |
| iv  | 27     | 37    | 35  | Cr iv             | 6     | 20  | 234170           | Kr iv  |
| i   | 1      | 0     | 0   | vi                 | 6     | 20  | 4406             | vi     |
| v   | 8      | 42    | 9   | ix                | 1     | 0   | 0               | Sr iv  |
| vi  | 43     | 10    | 130 | Mn iv             | 6     | 20  | 719387           | v      |
|    |        |       |     |                  |       |     |                  |       |
| Mg i| 1      | 187   | 0   | vii               | 6     | 19  | 37070            | vii    |
| ii  | 1      | 237   | 0   | viii              | 6     | 20  | 132221           | vii    |
| i   | 8      | 42    | 9   | ix                | 1     | 0   | 0               | Sr iv  |
|      |        |       |     |                  |       |     |                  |       |
| Si iii| 3      | 31    | 1   | ix                | 1     | 0   | 0               | Ge iv$^d$ |
|      |        |       |     |                  |       |     |                  |       |
| Al ii| 1      | 1     | 0   | Fe iv             | 6     | 20  | 310237           | vi     |
| iii | 3      | 44    | 0   | Cr iv             | 6     | 20  | 438600           | v      |
| iv  | 2      | 22    | 9   | Fe iv             | 6     | 20  | 3266247          | vii    |
|      |        |       |     |                  |       |     |                  |       |
| Ar ii| 1      | 340   | 0   | Cr iv             | 6     | 20  | 552916           | vii    |
| iii | 3      | 44    | 0   | Co iv             | 6     | 20  | 469717           | vii    |
| iv  | 25     | 59    | 0   | Cr iv             | 6     | 20  | 898484           | In iii |
|      |        |       |     |                  |       |     |                  |       |
| P ii| 1      | 9     | 0   | vii               | 6     | 19  | 492913           | iv     |
| iv  | 15     | 36    | 9   | viii              | 6     | 20  | 88548            | v      |
| v   | 18     | 7     | 12  | vii               | 6     | 19  | 19587            | Fe iv  |
| vi  | 1      | 0     | 0   | viii              | 6     | 20  | 2512561          | vi     |
|     |        |       |     |                  |       |     |                  |       |
| S ii| 6      | 94    | 4   | Ni iv             | 6     | 20  | 2766664          | Te iv  |
| iv  | 21     | 89    | 37  | v                  | 6     | 18  | 7408657          | v      |
| i   | 18     | 19    | 48  | vi                 | 6     | 18  | 4195381          | vi     |
|      |        |       |     |                  |       |     |                  |       |
| Ar iv| 1      | 340   | 0   | Cr iv             | 6     | 20  | 1473122          | vi     |
| v   | 32     | 329   | 38  | vii               | 6     | 19  | 19587            | Fe iv  |
| vi  | 16     | 168   | 21  | vii               | 6     | 18  | 19587            | Fe iv  |
| v   | 40     | 112   | 130 | viii              | 6     | 20  | 14731223         | vi     |
|      |        |       |     |                  |       |     |                  |       |
| Xe iv| 1      | 340   | 0   | Cr iv             | 6     | 20  | 14731223         | vi     |
| v   | 32     | 329   | 38  | vii               | 6     | 19  | 19587            | Fe iv  |
| vi  | 16     | 168   | 21  | vii               | 6     | 18  | 19587            | Fe iv  |
| v   | 40     | 112   | 130 | viii              | 6     | 20  | 14731223         | vi     |
|      |        |       |     |                  |       |     |                  |       |
| Ba v| 1      | 340   | 0   | Cr iv             | 6     | 20  | 14731223         | vi     |
| v   | 32     | 329   | 38  | vii               | 6     | 19  | 19587            | Fe iv  |
| vi  | 16     | 168   | 21  | vii               | 6     | 18  | 19587            | Fe iv  |
| v   | 40     | 112   | 130 | viii              | 6     | 20  | 14731223         | vi     |
|      |        |       |     |                  |       |     |                  |       |
| Notes. | (a) classical model atoms, (b) model atoms constructed using a statistical approach (Rauch & Deetjen 2003), (c) levels treated as NLTE levels, (d) Ge iv classical model atom with 8 NLTE levels, 1 LTE level, and 8 transitions, (e) Ba viii classical model atom with 34 NLTE levels, 0 LTE level, and 44 transitions.

MRNAS 000, 1–34 (2019)
Figure B2. Prominent computed and identified lines of Zn\textsubscript{V} (blue wavelength labels) in the FUSE (\(\lambda < 1180\) Å) and STIS observations of BD\textdegree\textcircled{69}22\textdegree\textcircled{3467}. The model was calculated with the abundances given in Table A1 (red). In addition, a model without Zn (green dashed) is shown.
Figure B3. Like Fig. B2, for Ga V (blue) and Ga VI (green).

Relative flux

\[ \Delta \lambda \]

Discovery of transition elements in BD-22°3467
Figure B4. Like Fig. B2, for Ge IV (dark cyan), Ge V (blue), and Ge VI (green).

Figure B5. Like Fig. B2, for Sr V (blue).

Figure B6. Like Fig. B2, for Zr VI (blue) and Zr VII (green).
Discovery of trans-iron elements in BD−22°3467

Figure B7. Like Fig. B2, for In V (blue).

Figure B8. Like Fig. B2, for I VI (blue).

Relative flux

MNRAS 000, 1–34 (2019)
Figure B9. Like Fig. B2, for Cu VI (blue).

Figure B10. Like Fig. B2, for Se V (blue).

Figure B11. Like Fig. B2, for Br VI (blue).

Figure B12. Like Fig. B2, for Kr VI (blue).

Figure B13. Like Fig. B2, for Mo VI (blue).

Figure B14. Like Fig. B2, for Te VI (blue).

Figure B15. Like Fig. B2, for Xe VII (blue).

Figure B16. Like Fig. B2, for Ba VII (blue) and Ba VIII (green).
Discovery of trans-iron elements in BD\textsuperscript{−}22\textdegree\textsuperscript{3467}

Table B3: Cu lines with $\mathcal{W}_A \geq 5 \mathrm{m \AA}$ in the model spectrum of BD\textsuperscript{−}22\textdegree\textsuperscript{3467}.

| Ion | Stage | Wavelength / \text{\AA} | Comment |
|-----|-------|--------------------------|---------|
| Cu  | vi    | 1060.890                 | too strong in the model |
|     |       | 1082.265                 | too weak in model |
|     |       | 1094.708                 | uncertain |
|     |       | 1098.480                 | uncertain |
|     |       | 1104.996                 | blend Ga v |
|     |       | 1115.821                 | uncertain |
|     |       | 1157.930                 | uncertain |

Table B4: Identified Zn lines with $\mathcal{W}_A \geq 5 \mathrm{m \AA}$ in model spectrum of BD\textsuperscript{−}22\textdegree\textsuperscript{3467}.

| Ion | Wavelength / \text{\AA} | Comment |
|-----|--------------------------|---------|
| Zn  | iv                       | 1239.119 |
|     |                          | 1261.296 |
| Zn  | v                        | 1017.935 blend ISM |
|     |                          | 1023.521 blend ISM |
|     |                          | 1043.353 |
|     |                          | 1052.441 blend ISM |
|     |                          | 1053.278 blend ISM |
|     |                          | 1055.878 blend ISM |
|     |                          | 1056.330 uncertain |
|     |                          | 1058.185 blend Ga v |
|     |                          | 1061.472 uncertain |
|     |                          | 1061.656 blend ISM |
|     |                          | 1063.299 blend ISM |
|     |                          | 1063.979 |
|     |                          | 1066.547 uncertain |
|     |                          | 1068.284 |
|     |                          | 1069.674 uncertain |
|     |                          | 1069.764 uncertain |
|     |                          | 1071.501 blend ISM |
|     |                          | 1072.992 blend ISM |
|     |                          | 1074.241 uncertain |
|     |                          | 1075.171 too strong in model |
|     |                          | 1076.878 |
|     |                          | 1085.290 uncertain |
|     |                          | 1086.033 blend Ge v |
|     |                          | 1086.739 blend ISM |
|     |                          | 1088.709 |
|     |                          | 1090.831 |
|     |                          | 1094.088 blend ISM |
|     |                          | 1095.797 uncertain |
|     |                          | 1095.961 uncertain |
|     |                          | 1098.108 blend ISM |
|     |                          | 1102.490 uncertain |
|     |                          | 1103.598 too weak in model |
|     |                          | 1104.199 blend ISM |
|     |                          | 1106.788 |
|     |                          | 1107.318 |
|     |                          | 1109.078 |
|     |                          | 1109.166 |
|     |                          | 1111.530 |
|     |                          | 1111.603 |
|     |                          | 1112.829 |
| Ion     | Wavelength / Å | Comment                  |
|---------|----------------|--------------------------|
| 1114.482 |                |                          |
| 1115.266 |                |                          |
| 1115.680 |                |                          |
| 1116.630 |                | too strong in model      |
| 1116.842 |                |                          |
| 1117.466 |                | too weak in the model    |
| 1118.778 |                |                          |
| 1119.950 |                |                          |
| 1120.101 |                | uncertain                |
| 1120.325 |                |                          |
| 1121.109 |                | blend Cr v, Fe v1        |
| 1121.524 |                | uncertain                |
| 1122.502 |                | blend ISM                |
| 1123.127 |                | blend Ga v               |
| 1124.718 |                |                          |
| 1125.019 | 1125.048       |                          |
| 1126.660 |                |                          |
| 1127.242 |                |                          |
| 1128.098 |                | blend Ga v               |
| 1128.244 |                | uncertain                |
| 1128.813 |                |                          |
| 1129.898 |                |                          |
| 1130.051 |                |                          |
| 1130.242 |                |                          |
| 1131.242 |                |                          |
| 1131.788 |                |                          |
| 1132.271 |                |                          |
| 1132.659 |                | blend Co vi              |
| 1133.031 |                |                          |
| 1133.128 |                |                          |
| 1133.278 |                |                          |
| 1133.498 |                |                          |
| 1135.324 |                |                          |
| 1135.588 |                |                          |
| 1136.311 |                |                          |
| 1136.603 |                |                          |
| 1136.986 |                |                          |
| 1137.625 |                |                          |
| 1138.248 |                | blend Co vi              |
| 1138.497 |                |                          |
| 1138.586 |                |                          |
| 1139.278 |                | uncertain                |
| 1139.997 |                | uncertain                |
| 1140.703 |                |                          |
| 1141.003 |                |                          |
| 1141.095 |                |                          |
| 1141.344 |                | uncertain                |
| 1142.792 |                |                          |
| 1142.925 |                |                          |
| 1143.196 |                |                          |
| 1143.403 |                | blend Ga v               |
| 1144.136 |                |                          |
| 1145.151 |                |                          |
| 1146.057 |                |                          |
| 1146.149 |                |                          |
| 1147.020 |                |                          |
| 1147.371 |                |                          |
| 1147.648 |                |                          |
Table B4: continued.

| Ion   | Wavelength / Å | Comment          |
|-------|----------------|------------------|
|       | 1148.922       |                  |
|       | 1149.398       |                  |
|       | 1149.486       |                  |
|       | 1149.608       |                  |
|       | 1149.873       | blend Ni VI      |
|       | 1150.743       |                  |
|       | 1151.368       |                  |
|       | 1151.787       | uncertain        |
|       | 1152.985       |                  |
|       | 1153.160       |                  |
|       | 1155.027       | blend Fe VII     |
|       | 1155.725       |                  |
|       | 1156.394       |                  |
|       | 1157.725       | uncertain        |
|       | 1158.475       | blend Ga V       |
|       | 1158.759       |                  |
|       | 1160.221       |                  |
|       | 1160.827       | uncertain        |
|       | 1161.971       |                  |
|       | 1162.281       |                  |
|       | 1162.401       | uncertain        |
|       | 1163.779       | uncertain        |
|       | 1164.090       |                  |
|       | 1164.632       |                  |
|       | 1165.189       | blend Ge V       |
|       | 1165.706       |                  |
|       | 1165.880       | too strong in model |
|       | 1168.302       | uncertain        |
|       | 1169.290       | uncertain        |
|       | 1169.301       | uncertain        |
|       | 1170.105       | uncertain        |
|       | 1170.885       | uncertain        |
|       | 1171.106       | uncertain        |
|       | 1171.422       |                  |
|       | 1171.801       |                  |
|       | 1171.951       |                  |
|       | 1172.038       |                  |
|       | 1173.366       |                  |
|       | 1173.823       | uncertain        |
|       | 1173.892       | too strong in model |
|       | 1174.346       |                  |
|       | 1174.945       | uncertain        |
|       | 1176.122       |                  |
|       | 1176.527       | too weak in model |
|       | 1176.868 1176.911 |                  |
|       | 1176.980 1177.016 1177.036 1177.087 |                  |
|       | 1178.639       |                  |
|       | 1178.759       |                  |
|       | 1179.145       |                  |
|       | 1179.969 1180.018 |                  |
|       | 1182.019       | uncertain        |
|       | 1182.567       |                  |
|       | 1183.041 1183.158 |                  |
|       | 1183.314       | uncertain        |
|       | 1185.619 1185.645 1185.676 |                  |
|       | 1185.898 1185.948 1185.961 |                  |
|       | 1186.057       |                  |
|       | 1186.447       |                  |
Table B4: continued.

| Ion    | Wavelength / Å | Comment             |
|--------|----------------|---------------------|
|        | 1187.706       |                     |
|        | 1189.072       |                     |
|        | 1189.331       |                     |
|        | 1190.003       |                     |
|        | 1190.376       |                     |
|        | 1192.014       |                     |
|        | 1192.703       | 1192.755            |
|        | 1193.846       |                     |
|        | 1195.745       |                     |
|        | 1198.795       |                     |
|        | 1200.639       |                     |
|        | 1201.961       |                     |
|        | 1202.128       | too strong in model |
|        | 1202.906       |                     |
|        | 1204.391       |                     |
|        | 1204.722       |                     |
|        | 1205.380       | too strong in the model |
|        | 1224.788       |                     |
|        | 1230.267       |                     |
|        | 1238.430       |                     |
|        | 1239.108       |                     |
|        | 1247.065       |                     |
|        | 1262.252       |                     |
|        | 1268.158       |                     |
|        | 1274.197       |                     |
|        | 1281.310       |                     |
|        | 1295.850       | too strong in model |
|        | 1302.786       |                     |
|        | 1318.204       |                     |
|        | 1344.241       | too strong in model |

Table B5: Like Table B4, for Ga.

| Ion | Wavelength / Å | Comment          |
|-----|----------------|------------------|
| Ga iv | 965.237 965.272 | blend ISM        |
|      | 981.831       | blend ISM        |
|      | 1003.780      | blend ISM        |
|      | 1004.367      | blend ISM        |
|      | 1005.270      | blend ISM        |
|      | 1009.849      | blend ISM        |
|      | 1010.080      | blend ISM        |
|      | 1014.822      | uncertain         |
|      | 1074.966      | uncertain         |
| Ga v  | 943.583       | uncertain         |
|      | 962.084       | blend ISM        |
|      | 967.324 967.404 | blend Ge v1    |
|      | 979.614       | determinant      |
|      | 980.988       | determinant      |
|      | 982.395       | blend ISM        |
|      | 984.078       | determinant      |
|      | 990.138       | uncertain         |
|      | 997.855       | blend ISM        |
|      | 1002.617      | blend ISM        |
|      | 1009.928      | blend ISM        |
|      | 1014.456      | blend ISM        |
|      | 1014.868      | uncertain         |
Table B5: continued.

| Ion    | Wavelength / Å | Comment                  |
|--------|----------------|--------------------------|
| 1015.610 |                | too strong in model      |
| 1019.711 |                | uncertain                |
| 1032.775 |                | blend ISM                |
| 1033.353 1033.549 1033.580 | |                            |
| 1034.822 |                | blend ISM                |
| 1037.334 |                | blend ISM                |
| 1038.778 |                | blend ISM                |
| 1040.204 |                | blend ISM                |
| 1045.850 |                | blend ISM                |
| 1047.504 |                | blend ISM                |
| 1050.453 |                | blend ISM                |
| 1053.600 |                | blend ISM                |
| 1054.430 |                | blend Ge v                |
| 1058.123 |                | blend ISM                |
| 1062.677 |                | blend ISM                |
| 1063.807 |                | blend ISM                |
| 1065.371 |                | blend ISM                |
| 1068.593 1068.616 | | too strong in model        |
| 1069.484 1069.530 | | too strong in model        |
| 1069.587 |                | too strong in model        |
| 1071.123 1071.168 | | blend ISM                |
| 1073.791 |                | blend ISM                |
| 1074.911 |                | uncertain                |
| 1078.225 |                | blend ISM                |
| 1078.795 |                | blend ISM                |
| 1079.587 1079.599 | | blend ISM                |
| 1079.879 1079.925 | | blend ISM                |
| 1080.474 |                | blend ISM                |
| 1080.988 |                | blend ISM                |
| 1087.358 |                | uncertain                |
| 1088.068 |                | blend ISM                |
| 1091.703 |                | blend ISM                |
| 1094.355 |                | blend ISM                |
| 1094.739 |                | blend ISM                |
| 1095.110 |                | blend ISM                |
| 1100.401 |                | uncertain                |
| 1101.613 |                | uncertain                |
| 1102.767 1102.803 | | too strong in model        |
| 1103.047 |                | too strong in model        |
| 1104.936 |                | blend ISM                |
| 1105.253 |                | blend ISM                |
| 1105.620 |                | blend ISM                |
| 1107.763 |                | blend ISM                |
| 1109.829 |                | blend ISM                |
| 1115.561 |                | blend ISM                |
| 1118.018 |                | blend ISM                |
| 1118.318 |                | blend ISM                |
| 1120.260 |                | blend ISM                |
| 1123.154 |                | blend ISM                |
| 1123.646 |                | blend ISM                |
| 1126.393 |                | blend ISM                |
| 1127.332 |                | blend ISM                |
| 1127.726 |                | blend ISM                |
| 1127.752 |                | blend ISM                |
| 1128.082 |                | blend Zn v                |
| 1128.554 |                | blend Zn v                |
| 1129.152 |                | blend Zn v                |
### Table B5: continued.

| Ion     | Wavelength / Å | Comment                  |
|---------|----------------|--------------------------|
| 1129.956 |                |                          |
| 1131.452 |                |                          |
| 1132.054 |                |                          |
| 1132.157 |                |                          |
| 1133.247 | blend Zn v     |                          |
| 1133.903 |                |                          |
| 1136.067 |                |                          |
| 1138.187 |                |                          |
| 1143.367 |                |                          |
| 1145.974 |                |                          |
| 1148.409 | too strong in model |                          |
| 1150.113 |                |                          |
| 1150.219 |                |                          |
| 1154.708 | uncertain      |                          |
| 1155.976 |                |                          |
| 1156.511 |                |                          |
| 1157.729 | uncertain      |                          |
| 1158.534 |                |                          |
| 1160.847 | uncertain      |                          |
| 1161.994 | uncertain      |                          |
| 1162.048 | uncertain      |                          |
| 1178.967 | blend Ni v     |                          |
| 1180.958 | uncertain      |                          |
| 1183.110 |                |                          |
| 1183.656 |                |                          |
| 1189.329 | blend Zn v     |                          |
| 1190.179 | uncertain      |                          |
| 1191.029 |                |                          |
| 1193.061 |                |                          |
| 1197.633 |                |                          |
| 1265.454 |                |                          |
| 1276.911 | blend Fe vi    |                          |
| 1283.615 |                |                          |
| 1311.389 |                |                          |
| Ga vi   | 915.720        | no observation           |
| 919.117 | blend ISM      |                          |
| 929.964 | blend ISM      |                          |
| 935.522 | blend ISM      |                          |
| 945.329 | blend ISM      |                          |
| 948.171 | blend ISM      |                          |
| 953.738 | blend ISM      |                          |
| 955.510 | blend ISM      |                          |
| 955.616 | blend ISM      |                          |
| 956.648 | blend ISM      |                          |
| 957.642 | blend ISM      |                          |
| 960.172 | blend ISM      |                          |
| 961.262 | blend ISM      |                          |
| 964.264 | blend ISM      |                          |
| 964.311 | blend ISM      |                          |
| 964.363 | blend ISM      |                          |
| 964.569 | blend ISM      |                          |
| 964.647 | blend ISM      |                          |
| 964.831 | blend ISM      |                          |
| 964.925 | blend ISM      |                          |
| 966.130 | blend ISM      |                          |
| 966.255 | blend ISM      |                          |
| 966.990 | blend ISM      |                          |
| 967.825 | blend ISM      |                          |
| 968.107 |                |                          |
| 970.064 |                |                          |
| 974.853 |                |                          |
| 975.165 |                |                          |
Table B5: continued.

| Ion       | Wavelength / Å     | Comment         |
|-----------|--------------------|-----------------|
| 975.342   | 975.396            | blend ISM       |
| 976.133   |                    | blend ISM       |
| 977.848   |                    | blend ISM       |
| 978.897   |                    | uncertain       |
| 979.298   | 979.383            |                 |
| 979.689   |                    |                 |
| 980.240   |                    | too strong in model |
| 980.489   |                    | uncertain       |
| 980.580   |                    | blend ISM       |
| 982.066   |                    | blend ISM       |
| 983.110   | 983.160            | uncertain       |
| 983.430   | 983.485            | blend ISM       |
| 983.630   |                    |                 |
| 984.009   |                    | blend ISM       |
| 985.273   |                    |                 |
| 985.596   |                    | blend ISM       |
| 985.812   |                    | blend ISM       |
| 986.662   |                    | blend ISM       |
| 987.862   |                    | blend ISM       |
| 988.063   |                    | blend ISM       |
| 989.169   |                    | blend ISM       |
| 989.374   |                    |                 |
| 990.416   |                    | blend ISM       |
| 990.639   |                    | blend ISM       |
| 992.053   |                    | blend ISM       |
| 992.709   |                    | blend ISM       |
| 993.094   |                    |                 |
| 993.640   | 993.654            | blend ISM       |
| 994.051   |                    | blend ISM       |
| 995.305   |                    |                 |
| 996.027   |                    | blend ISM       |
| 996.309   | 996.391            | uncertain       |
| 996.556   |                    |                 |
| 997.065   |                    | blend ISM       |
| 999.083   |                    | blend ISM       |
| 999.673   |                    |                 |
| 999.945   |                    |                 |
| 1000.117  |                    | blend ISM       |
| 1000.531  |                    | too strong in model |
| 1001.483  |                    | blend ISM       |
| 1001.821  |                    | blend ISM       |
| 1002.376  |                    | blend ISM       |
| 1002.985  |                    | uncertain       |
| 1003.127  | 1003.147           | uncertain       |
| 1003.390  | 1003.427           | uncertain       |
| 1003.691  |                    | uncertain       |
| 1004.170  |                    | blend ISM       |
| 1004.355  |                    |                 |
| 1005.228  |                    | uncertain       |
| 1006.156  |                    | uncertain       |
| 1006.396  |                    | blend ISM       |
| 1006.894  | 1006.951           | too strong in model |
| 1007.264  |                    | blend Fe v       |
| 1007.511  |                    | blend Fe v       |
| 1008.086  |                    | blend ISM       |
| 1008.757  |                    | blend ISM       |
| 1008.924  | 1009.049           | blend ISM       |
| 1009.262  |                    |                 |
| Ion Wavelength / Å | Comment               |
|--------------------|-----------------------|
| 1009.512           | blend ISM             |
| 1009.743 1009.796 1009.806 | blend ISM             |
| 1010.102           | blend ISM             |
| 1011.047           | blend ISM             |
| 1011.696 1011.698  | blend ISM             |
| 1012.260           | blend ISM             |
| 1013.620           | blend ISM             |
| 1014.434           | blend ISM             |
| 1015.598           | too strong in model   |
| 1015.782           | uncertain              |
| 1016.307           | uncertain              |
| 1017.003           | uncertain              |
| 1017.074           | uncertain              |
| 1018.785           | blend ISM             |
| 1019.083           | blend ISM             |
| 1019.206           | blend ISM             |
| 1020.741           | blend ISM             |
| 1022.008 1022.098  | uncertain              |
| 1027.809           | uncertain              |
| 1029.168           | uncertain              |
| 1030.457 1030.469  | uncertain              |
| 1037.061           | blend ISM             |
| 1037.419           | blend ISM             |
| 1038.800           | blend ISM             |
| 1042.324           | blend Fe v             |
| 1047.696           | blend ISM             |
| 1051.311           | blend ISM             |
| 1051.589           | blend ISM             |
| 1058.653           | blend ISM             |
| 1058.931           | blend ISM             |
| 1059.854 1058.931  | blend ISM             |
| 1060.387           | uncertain              |
| 1061.790           | blend ISM             |
| 1063.972           | uncertain              |
| 1066.724           | blend ISM             |
| 1071.544           | blend ISM             |
| 1073.814           | blend ISM             |
| 1076.760           | blend ISM             |
| 1077.944           | blend ISM             |
| 1078.331           | blend ISM             |
| 1089.450           | blend ISM             |
| 1099.109           | blend ISM             |
| 1101.237           | blend ISM             |
| 1105.669           | blend ISM             |
| 1106.251           | blend ISM             |
| 1121.262           | uncertain              |
| 1129.110           | blend ISM             |
| 1138.016           | blend ISM             |
| 1149.078           | blend ISM             |
| 1237.472           | blend ISM             |
| 1259.673           | blend Co vi            |
| 1288.359           | blend ISM             |
Table B6: Like Table B4, for Ge.

| Ion | Wavelength / Å | Comment          |
|-----|----------------|-----------------|
| Ge  IV | 936.765 | blend ISM       |
|      | 1189.028 |                 |
|      | 1229.839 |                 |
|      | 1494.889 | uncertain       |
| Ge  V  | 942.717  | blend ISM       |
|      | 958.508  |                 |
|      | 965.501  |                 |
|      | 971.357  | blend ISM       |
|      | 977.455  |                 |
|      | 984.923  | blend ISM       |
|      | 986.767  | blend ISM       |
|      | 988.132  | blend ISM       |
|      | 990.668  |                 |
|      | 992.307  | blend ISM       |
|      | 1004.380 |                 |
|      | 1004.938 | too strong in model |
|      | 1008.122 | blend ISM       |
|      | 1016.667 |                 |
|      | 1033.107 | too strong in model |
|      | 1035.504 | uncertain       |
|      | 1038.430 |                 |
|      | 1042.127 | too strong in model |
|      | 1045.713 |                 |
|      | 1048.318 | 1048.371 1048.411  uncertain |
|      | 1050.057 | blend ISM       |
|      | 1054.590 |                 |
|      | 1058.932 |                 |
|      | 1068.430 |                 |
|      | 1069.132 | too strong in model |
|      | 1069.703 |                 |
|      | 1069.857 | uncertain       |
|      | 1072.495 |                 |
|      | 1072.659 |                 |
|      | 1080.427 | 1080.484 1080.586  blend ISM |
|      | 1086.653 |                 |
|      | 1087.855 |                 |
|      | 1089.491 | 1089.526       |
|      | 1092.089 |                 |
|      | 1103.185 | uncertain       |
|      | 1116.947 |                 |
|      | 1123.746 | too strong in model |
|      | 1125.424 |                 |
|      | 1139.187 |                 |
|      | 1163.400 |                 |
|      | 1165.259 |                 |
|      | 1176.690 | uncertain       |
|      | 1222.300 |                 |
| Ge  VI | 911.098  | no observation  |
|      | 911.114  | no observation  |
|      | 914.143  | no observation  |
|      | 915.041  | no observation  |
|      | 917.352  | blend ISM       |
|      | 918.280  | blend ISM       |
|      | 919.278  | blend ISM       |
|      | 919.731  | 919.760 blend ISM |
|      | 920.510  |                 |
| Ion | Wavelength / Å | Comment            |
|-----|----------------|--------------------|
| 921.084 | blend ISM     |
| 921.780 | blend ISM     |
| 923.486 | uncertain     |
| 925.476 |              |
| 926.822 | too strong in model |
| 928.136 |              |
| 928.907 |              |
| 929.428 | blend ISM     |
| 930.081 | blend ISM     |
| 933.766 | blend ISM     |
| 935.016 |              |
| 936.912 | blend ISM     |
| 940.427 |              |
| 942.474 | blend ISM     |
| 942.567 | blend ISM     |
| 944.851 | blend ISM     |
| 946.589 | blend ISM     |
| 947.937 |              |
| 951.739 |              |
| 952.415 | blend ISM     |
| 953.132 |              |
| 954.504 | blend ISM     |
| 955.708 | blend ISM     |
| 957.548 | blend ISM     |
| 957.886 |              |
| 958.100 |              |
| 958.310 | uncertain     |
| 960.102 | too strong in model |
| 964.813 | blend ISM     |
| 965.203 | blend ISM     |
| 965.914 | blend ISM     |
| 967.300 |              |
| 968.723 |              |
| 969.010 | blend ISM     |
| 969.171 | blend ISM     |
| 969.568 |              |
| 970.977 | blend ISM     |
| 971.392 | blend ISM     |
| 973.353 | blend ISM     |
| 975.996 |              |
| 979.258 |              |
| 979.905 | blend ISM     |
| 980.431 | blend ISM     |
| 980.697 | too strong in model |
| 981.946 | blend ISM     |
| 983.648 |              |
| 988.180 | too strong in model |
| 990.049 | blend ISM     |
| 990.848 | blend Fe v    |
| 991.519 | blend ISM     |
| 991.888 | blend ISM     |
| 992.377 | blend He ii   |
| 993.015 | blend ISM     |
| 995.489 |              |
| 996.771 | too strong in model |
| 1002.276 | blend ISM     |
Table B6: continued.

| Ion    | Wavelength / Å | Comment           |
|--------|----------------|-------------------|
|       1004.661 | blend ISM      |
| 1008.410 | blend ISM      |
| 1011.518 | too strong in model |
| 1013.528 | blend ISM      |
| 1014.766 | too strong in model |
| 1015.582 | blend ISM      |
| 1016.817 | blend ISM      |
| 1023.527 | blend ISM      |
| 1031.263 | blend ISM      |
| 1031.324 | blend ISM      |
| 1033.152 | too strong in model |
| 1034.251 | uncertain      |
| 1039.483 | too strong in model |
| 1039.890 | too strong in model |
| 1047.139 | too strong in model |
| 1047.207 | too strong in model |
| 1051.515 | blend ISM      |
| 1053.196 | too strong in model |
| 1061.890 | too strong in model |
| 1062.394 | too strong in model |
| 1064.323 | too strong in model |
| 1080.148 | too strong in model |
| 1080.510 | too strong in model |
| 1088.522 | too strong in model |
| 1102.998 | too strong in model |
| 1103.103 | too strong in model |
| 1106.146 | too strong in model |
| 1113.177 | uncertain      |
| 1114.431 | too strong in model |
| 1127.159 | too strong in model |
| 1148.327 | too strong in model |
| 1227.850 | too strong in model |
| 1228.870 | too strong in model |
| 1237.128 | too strong in model |
| 1237.892 | too strong in model |
| 1251.447 | too strong in model |
| 1255.318 | blend Mo v     |
| 1257.218 | too strong in model |
| 1292.751 | too strong in model |
| 1300.093 | too strong in model |
| 1305.406 | too strong in model |
| 1391.639 | too strong in model |
| 1500.600 | blend ISM      |

Table B7: Like Table B4, for Se.

| Ion  | Wavelength / Å | Comment         |
|------|----------------|-----------------|
| Se v | 943.957        | blend ISM       |
|      | 964.515        | blend ISM       |
|      | 1030.609       | blend ISM       |
|      | 1047.219       | too strong in model |
|      | 1059.951       | uncertain       |
|      | 1094.691       | blend ISM       |
|      | 1151.016       | blend ISM       |
|      | 1184.343       | blend ISM       |
|      | 1227.540       | blend ISM       |
|      | 1249.048       | uncertain       |
Table B7: continued.

| Ion      | Wavelength / Å | Comment          |
|----------|----------------|------------------|
|          | 1264.063       | blend Mn vi      |
|          | 1426.676       |                  |
|          | 1433.568       |                  |
|          | 1445.567       |                  |
|          | 1447.283       |                  |
|          | 1447.408       |                  |
|          | 1451.653       |                  |
|          | 1454.292       |                  |
|          | 1473.253       |                  |
| 1730.014 | no observation |                  |
| 1736.835 | no observation |                  |
| 1740.038 | no observation |                  |

Table B8: Like Table B4, for Br.

| Ion   | Wavelength / Å | Comment |
|-------|----------------|---------|
| Br v  | 945.815        | blend ISM |
|       | 1069.410       |          |
| Br vi | 955.883        | blend ISM |
|       | 966.753        | blend ISM |
|       | 969.735        | blend ISM |
|       | 981.423        | blend ISM |
|       | 1050.548       |          |
|       | 1069.382 1069.432 |      |
|       | 1073.708       |          |
|       | 1074.992       |          |
|       | 1230.318       |          |
|       | 1399.153       | uncertain |

Table B9: Like Table B4, for Kr.

| Ion  | Wavelength / Å | Comment |
|------|----------------|---------|
| Kr vi| 927.334        | blend ISM |
|      | 944.046        | uncertain |
|      | 965.093        | blend ISM |
|      | 980.411        |          |
|      | 1002.748       |          |
|      | 1045.238       |          |
|      | 1061.064       |          |
| Kr vii| 918.444     | blend ISM |
|       | 960.645        | blend ISM |
|       | 1197.166       | uncertain |

Table B10: Like Table B4, for Sr.

| Ion   | Wavelength / Å | Comment |
|-------|----------------|---------|
| Sr v  | 917.802        | blend ISM |
|       | 927.356        | blend ISM |
|       | 928.353        | blend ISM |
|       | 935.509        | blend ISM |
Table B10: continued.

| Ion  | Wavelength / Å | Comment       |
|------|----------------|---------------|
|      |                | blend ISM     |
| 936.808 |              |               |
| 942.943 |              | blend ISM     |
| 946.530 |              | blend ISM     |
| 951.044 |              | blend ISM     |
| 951.159 |              | blend ISM     |
| 955.369 |              | blend Nv      |
| 957.714 |              | blend ISM     |
| 962.378 |              | blend ISM     |
| 969.103 |              | blend ISM     |
| 979.150 |              | blend ISM     |
| 985.408 |              | blend ISM     |
| 1007.201 |             | uncertain     |
| 1011.422 |             | blend ISM     |
| 1013.714 |             | blend ISM     |
| 1020.002 |             | uncertain     |
| 1020.439 |             | blend ISM     |
| 1030.445 |             | too strong in model |
| 1031.343 |             | blend ISM     |
| 1038.990 |             | uncertain     |
| 1041.940 |             | blend ISM     |
| 1056.104 |             | uncertain     |
| 1065.215 |             | uncertain     |
| 1070.578 |             | uncertain     |
| 1114.594 |             | blend ISM     |
| 1114.876 |             | uncertain     |
| 1132.353 |             | uncertain     |
| 1141.221 |             | uncertain     |
| 1152.104 |             | uncertain     |
| 1154.871 |             | blend ISM     |
| 1163.040 |             | blend Zn v  |
| 1164.173 |             | blend ISM     |
| 1175.115 |             | uncertain     |
| 1200.728 |             | blend ISM     |
| 1238.652 |             | blend Ni v    |
| 1280.995 |             | blend ISM     |
| 1281.911 |             | blend ISM     |
| 1311.334 |             | blend Fe v    |
| 1311.781 |             | blend Fe v    |
| 1332.065 |             | blend ISM     |
| 1387.288 |             | blend ISM     |
| 1415.404 |             | blend ISM     |
| 1447.665 |             | blend ISM     |
| 1459.369 |             | blend ISM     |
| 1472.784 |             | blend ISM     |
| Sr vi | 912.3760      | no observation |

Table B11: Like Table B4, for Zr.

| Ion | Wavelength / Å | Comment       |
|-----|----------------|---------------|
| Zr v | 1200.802      | blend ISM     |
| Zr vi | 955.500   | blend ISM     |
|      | 1040.904     | blend ISM     |
|      | 1040.995     | blend ISM     |
|      | 1044.483     | uncertain     |
|      | 1050.580     | blend Br vi   |
|      | 1053.548     | blend ISM     |
Table B11: continued.

| Ion   | Wavelength / Å | Comment          |
|-------|----------------|------------------|
|       |                | blend ISM        |
| 1064.818 |               | blend ISM        |
| 1068.836 |               | uncertain        |
| 1072.877 |               | uncertain        |
| 1073.197 |               | blend ISM        |
| 1074.554 |               | uncertain        |
| 1081.130 |               | uncertain        |
| 1083.484 |               | blend ISM        |
| 1084.439 |               | uncertain        |
| 1095.491 |               | uncertain        |
| 1099.591 |               |                  |
| 1101.742 |               | blend ISM        |
| 1113.736 |               | uncertain        |
| 1114.481 |               | uncertain        |
| 1118.689 |               | too strong in model |
| 1129.371 |               | uncertain        |
| 1134.606 |               | uncertain        |
| 1142.550 |               |                  |
| 1143.393 |               |                  |
| 1150.774 |               |                  |
| 1151.571 |               | uncertain        |
| 1158.582 |               | uncertain        |
| 1161.639 |               |                  |
| 1314.034 |               |                  |
| 1417.865 |               |                  |
| 1514.568 |               |                  |
| 1521.699 |               |                  |
| 1529.396 |               | uncertain        |
| 1536.035 |               | uncertain        |
| 1538.423 |               | uncertain        |
| 1541.255 |               | uncertain        |
| 1591.799 |               | uncertain        |
| 1604.549 |               | uncertain        |
| 1645.326 |               |                  |
| 1663.952 |               |                  |
| 1679.018 |               | uncertain        |
| 1682.241 |               | uncertain        |
| 1683.302 |               | uncertain        |
| 1733.091 |               | no observation   |
| 1733.937 |               | no observation   |
| 1741.948 |               | no observation   |
| 1749.350 |               | no observation   |
| Zr vii | 1233.578       | uncertain        |
|        | 1234.964       |                  |
|        | 1376.633       |                  |
|        | 1469.098       | uncertain        |

Table B12: Like Table B4, for Mo.

| Ion | Wavelength / Å | Comment          |
|-----|----------------|------------------|
| Mo vi | 995.806        | uncertain        |
|      | 1038.640       | blend ISM        |
|      | 1047.182       | uncertain        |
|      | 1479.168       |                  |
|      | 1595.435       |                  |
Table B13: Like Table B4, for In.

| Ion | Wavelength / Å | Comment     |
|-----|----------------|-------------|
| In  | 933.577        | blend ISM   |
|     | 940.079        | uncertain   |
|     | 942.218        | uncertain   |
|     | 1101.860       | uncertain   |
|     | 1122.517       | blend ISM   |
|     | 1135.588       | uncertain   |
|     | 1136.347       |             |
|     | 1137.787       |             |
|     | 1148.852       |             |
|     | 1151.723       |             |
|     | 1153.836       |             |
|     | 1156.652       |             |
|     | 1160.561       |             |
|     | 1168.056       |             |
|     | 1177.447       |             |
|     | 1181.329       |             |
|     | 1183.049       |             |
|     | 1190.489       | blend ISM   |
|     | 1191.583       |             |
|     | 1192.278       |             |
|     | 1192.541       |             |
|     | 1196.281       |             |
|     | 1199.170       |             |
|     | 1200.843       | blend ISM   |
|     | 1210.126       | uncertain   |
|     | 1228.000       | uncertain   |
|     | 1228.483       | uncertain   |
|     | 1238.448       |             |
|     | 1241.025       |             |
|     | 1241.299       |             |
|     | 1242.210       |             |
|     | 1243.632       | blend Ni v  |
|     | 1252.836       | blend Fe v1 |
|     | 1256.570       | uncertain   |
|     | 1276.318       | uncertain   |
|     | 1278.758       |             |
|     | 1285.468       | uncertain   |
|     | 1289.800       |             |
|     | 1290.449       |             |
|     | 1292.930       |             |
|     | 1295.035       | uncertain   |
|     | 1296.427       |             |
|     | 1315.139       |             |
|     | 1317.671       | uncertain   |
|     | 1320.468       | uncertain   |
|     | 1334.123       |             |
|     | 1339.599       |             |
|     | 1355.458       | uncertain   |

Table B14: Like Table B4, for Te.

| Ion | Wavelength / Å | Comment     |
|-----|----------------|-------------|
| Te  | 951.021        | blend ISM   |
|     | 1071.414       |             |
|     | 1242.023       | uncertain   |
Table B14: continued.

| Ion | Wavelength / Å | Comment          |
|-----|----------------|------------------|
|     | 1267.986       |                  |
|     | 1313.874       |                  |

Table B15: Like Table B4, for I.

| Ion  | Wavelength / Å | Comment          |
|------|----------------|------------------|
| I vi | 911.192        | no observation   |
|      | 919.210        | blend ISM        |
|      | 970.448        | uncertain         |
|      | 987.381        | blend ISM        |
|      | 989.005        | blend ISM        |
|      | 1000.999       | uncertain         |
|      | 1045.423       | blend ISM        |
|      | 1053.389       | blend ISM        |
|      | 1057.530       |                  |
|      | 1120.301       | blend ISM        |
|      | 1121.218       | uncertain         |
|      | 1137.370       | uncertain         |
|      | 1153.262       | too strong in model |
|      | 1185.111       | uncertain         |
|      | 1191.601       |                  |
|      | 1195.359       | uncertain         |
|      | 1395.979       |                  |

Table B16: Like Table B4, for Xe.

| Ion  | Wavelength / Å | Comment          |
|------|----------------|------------------|
| Xe vi| 1080.080       | blend Ge vi      |
|      | 1091.630       | uncertain         |
|      | 1136.410       | uncertain         |
| Xe vii| 912.875       | no observation   |
|      | 920.861        | blend ISM        |
|      | 942.152        |                  |
|      | 943.218        |                  |
|      | 970.177        | uncertain         |
|      | 995.510        |                  |
|      | 997.407        | blend Fe v        |
|      | 1071.226       | uncertain         |
|      | 1077.110       | blend ISM        |
|      | 1093.781       | blend ISM        |
|      | 1243.565       |                  |
|      | 1460.856       | uncertain         |

Table B17: Like Table B4, for Ba.

| Ion  | Wavelength / Å | Comment          |
|------|----------------|------------------|
| Ba vi| 937.595        | blend ISM        |
| Ba vii| 924.898       | blend ISM        |
|      | 943.102        | blend ISM        |
|      | 993.411        |                  |
Table B17: continued.

| Ion | Wavelength / Å | Comment |
|-----|----------------|---------|
|     | 1074.937       |         |
|     | 1255.520       | uncertain |
|     | 1465.045       |         |
| Ba VIII | 921.761       | uncertain |
|     | 941.168        | uncertain |
|     | 952.762        | blend ISM |
|     | 961.679        | blend ISM |
|     | 1013.130       | blend ISM |
|     | 1039.555       |         |
|     | 1048.339       | blend ISM |
|     | 1074.911       |         |
|     | 1083.072       |         |
|     | 1113.140       | uncertain |
