Type II Cepheids in the Milky Way disc*

Chemical composition of two new W Vir stars: DD Vel and HQ Car

B. Lemasle¹, V. Kovtyukh², G. Bono³, P. François⁴, ⁵, I. Saviane⁶, I. Yegorova⁶, K. Genovali³, L. Inno³, ⁷, G. Galazutdinov⁸, ⁹, and R. da Silva¹

1 Anton Pannekoek Institute for Astronomy, University of Amsterdam, Science Park 904, PO Box 94249, 1090 GE, Amsterdam, The Netherlands, e-mail: B.J.P.Lemasle@uva.nl
2 Astronomical Observatory, Odessa National University, and Isaac Newton Institute of Chile, Odessa branch, Shevchenko Park, 65014, Odessa, Ukraine
3 Dipartimento di Fisica, Università di Roma Tor Vergata, via della Ricerca Scientifica 1, 00133 Rome, Italy
4 GEPI, Observatoire de Paris, CNRS, Université Paris Diderot, Place Jules Janssen, 92190 Meudon, France
5 UPJV-Université de Picardie Jules Verne, 80000 Amiens, France
6 European Southern Observatory, Alonso de Córdova 3107, Santiago, Chile
7 European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany
8 Instituto de Astronomía, Universidad Católica del Norte, av. Angamos 0610, Antofagasta, Chile
9 Pulkovo Observatory, Pulkovskoe Shosse 65, Saint-Petersburg 196140, Russia

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ABSTRACT

Context. A robust classification of Cepheids into their different sub-classes and, in particular, between classical and Type II Cepheids, is necessary to properly calibrate the period-luminosity relations and for populations studies in the Galactic disc. Type II Cepheids are, however, very diverse, and classifications based either on intrinsic (period, light curve) or external parameters (e.g., [Fe/H], [Z]) do not provide a unique classification.

Aims. We want to ascertain the classification of two Cepheids, HQ Car and DD Vel, that are sometimes classified as classical Cepheids and sometimes as Type II Cepheids.

Methods. To achieve this goal, we examine both their chemical composition and the presence of specific features in their spectra.

Results. We find emission features in the Hα and in the 5875.64 Å He I lines that are typical of W Vir stars. The [Na/Fe] (or [Na/Zn]) abundances are typical of thick-disc stars, while BL Her stars are Na-overabundant ([Na/Fe]>+0.5 dex). Finally, the two Cepheids show a possible (HQ Car) or probable (DD Vel) signature of mild dust-gas separation that is usually observed only in long-period Type II Cepheids and RV Tau stars.

Conclusions. These findings clearly indicate that HQ Car and DD Vel are both Type II Cepheids from the W Vir sub-class. Several studies have reported an increase in the Cepheids' abundance dispersion towards the outer (thin) disc. A detailed inspection of the Cepheid classification, in particular for those located in the outer disc, will indicate whether this feature is real or simply an artefact of the inclusion of type II Cepheids belonging to the thick disc in the current samples.

Key words. stars: abundances - stars: atmospheres - stars: variables: Cepheids

1. Introduction

Type II Cepheids are the older, fainter, low-mass counterpart to the classical Cepheids (e.g., Wallerstein 2003). As such, they fall into the instability strip between the RR Lyrae and the RV Tau stars, and their periods are bound to ≈ 1 day on the lower end and to ≈ 20 days on the upper end, following the classification of Soszyński et al. (2008b). However, the limit between RR Lyrae and Type II Cepheids, on the one hand, and between Type II Cepheids and RV Tau stars, on the other, are not clearly defined. Type II Cepheids are themselves divided in two sub-classes; the BL Her stars have periods ranging from ≈ 1 to ≈ 4 days while the W Vir stars have periods between ≈ 4 and ≈ 20 days, again according to Soszyński et al. (2008b). In our current understanding, the different classes correspond to stars in different evolutionary stages: BL Her stars are currently evolving from the horizontal branch (HB) to the asymptotic giant branch (AGB) and can be considered as post early-AGB stars (Castellani et al. 2007). W Vir stars cross the instability strip in their so-called “blue-nose” from the AGB while they are undergoing He-shell flashes. Finally, RV Tau stars are about to leave the AGB, so they are crossing the instability strip towards the white dwarf domain (Gingold et al. 1985; Bono et al. 1997 and references therein; see also Maas et al. 2007 for further considerations).

Various criteria have been tested to distinguish between classical and Type II Cepheids, and among the Type II Cepheids, to distinguish the BL Her and the W Vir stars. They are based on the shape of the light curve, on the stability of the period, or on the presence of distinctive features in the spectra. If these criteria have proved to be useful (see for instance Schmidt et al. 2004a), they are not sufficient to secure a robust classification.

* Based on observations collected at the European Organisation for Astronomical Research in the Southern Hemisphere, Chile (prog. ID: 060.A-9120 and 082.D-0901)
Indeed for various criteria, the properties of different types of variables overlap over various period ranges (e.g., Schmidt et al. 2005; Sozzi & Soszynski et al. 2008). Moreover, the use of external parameters (metallicity, proper motion, distance to the Galactic plane) is hampered by the fact that Type II Cepheids are very heterogeneous, because they span a wide metallicity range, and they can be found in the bulge, the thick disc, the halo, or in globular clusters.

The difficulty for properly classifying the Type II Cepheids can be illustrated by the two stars in our sample: DD Vel and HQ Car. DD Vel is classified as a classical Cepheid pulsating in the fundamental mode in the ASAS catalogue (Pojmanski 2000) before Maas et al. (2007) analysed 19 BL Her and W Vir stars with periods between 10 and 20 days. As BL Herculis stars, the HQ Car spectra have been obtained with different instruments: one spectrum was taken with the echelle spectrograph on the 4m Blanco telescope at Cerro Tololo Inter-American Observatory (CTIO). It has a resolution of 28 000 and covers the 5500–8000 Å wavelength range with a S/N (per pixel) of 57 in the order containing Hα. Another spectrum was obtained using the 2.2m ESO/MPG telescope and the FEROS echelle spectrograph at the ESO La Silla observatory (Kaufer et al. 1999). The spectrum covers the 3500–9200 Å wavelength range with a resolution of 48 000 and a S/N (per pixel) in excess of 150 over the largest part of the spectrum. Finally, two spectra were obtained with the HARPS (Mayor et al. 2003) echelle spectrograph mounted at the 3.6m telescope at the ESO La Silla observatory, which provides a resolution R=115 000 over a wide spectral range (3800–6900 Å). They both reach a S/N of 50 at 650 nm.

We analysed two spectra for DD Vel: the first one consists of four back-to-back FEROS spectra coadded in order to increase the S/N. The second was obtained with the UVES (Dekker et al. 2000) echelle spectrograph (R=40 000) using the DICZ (437+760) configuration. The blue and red arms cover the wavelength intervals [3750–5000] Å and [5650–7600/7660–9460] Å. Relevant information concerning the observations and pulsation parameters of the Cepheids are listed in Table II. As shown in the next sections, strong emission features become prominent at some phases, and the spectra are therefore not suitable for an accurate abundance determination. We used the CTIO spectrum (φ=0.361) for HQ Car and the FEROS spectrum (φ=0.292) in 1995 in the case of DD Vel.

3. Classification

3.1. Classification based on the location on a colour-magnitude diagram

Following the suggestion of an anonymous referee, we performed a detailed comparison in the K-J-K colour-magnitude diagram to constrain the nature of the candidate Type II Cepheids. Figure I shows evolutionary prescriptions for α-enhanced horizontal branch (HB) evolutionary models (Pietrinferni et al. 2004, 2006) at fixed chemical composition (see labelled values) and the two targets. It shows the Zero-Age-Horizontal-Branch (ZAHB) and HB evolutionary models for three different values of the stellar masses ranging from 0.49 to 0.58 M⊙. The apparent NIR magnitudes of the targets are based on 2MASS photometry (Skrutskie et al. 2006). They were unreddened using the empirical reddening law provided by Cardelli et al. (1989). The true distance modulus was estimated using the K-band period-luminosity relation for Type II Cepheids provided by Matsumaga et al. (2006). We found M⊙ = −3.81 mag for DD Vel and M⊙ = −3.87 mag for HQ Car. Data plotted in this figure show that the position of the targets agrees quite well, within the errors, with the current evolutionary prescriptions, thus further supporting the working hypothesis that they are Type II Cepheids. Although it also displays the instability strip for RR Lyrae and BL Herculis stars, the hottest edge shows the first overtone blue horizontal branch (HB) evolutionary models (Pietrinferni et al. 2004, 2006).

Since the Maas et al. (2007) paper, only two new Type II Cepheids have been studied in detail: QQ Per by Wallerstein et al. (2008) and W Vir by Kovtyukh et al. (2011).

After a brief description of the data in Sect. 2, we examine in Sect. 3 different classification criteria and discuss the chemical composition of HQ Car and DD Vel in Sect. 3.

2. Data

The HQ Car spectra have been obtained with different instruments: one spectrum was taken with the echelle spectrograph on the 4m Blanco telescope at Cerro Tololo Inter-American Observatory (CTIO). It has a resolution of 28 000 and covers the

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1. prog. ID: 060.A-9120
2. prog. ID: 082.D-0901
Table 1: Spectroscopic observations of HQ Car and DD Vel.

| Star   | RA (dms) | Dec (dms) | V (mag) | Epoch (d) | Period (d) | JD (d) | Phase  | Spectrograph |
|--------|----------|-----------|---------|-----------|------------|--------|--------|--------------|
| HQ Car | 10 20 32.00 | -61 14 57.4 | 11.84  | 2452784.603 | 14.06378 | 2450834.86370 | 0.361 | CTIO        |
|        |          |           |         |           |            | 2455284.51471 | 0.961 | HARPS       |
|        |          |           |         | 2456411.53798 | 0.891 | 2456412.51417 | 0.766 | FEROS       |
|        |          |           |         | 2456412.51417 | 0.891 | 2456412.51417 | 0.961 | FEROS       |
|        |          |           |         | 2454156.34518 | 0.798 | 2454156.34518 | 0.798 | UVES        |
| DD Vel | 09 12 09.63 | -50 22 33.6 | 12.18  | 2434746.312 | 13.19484 | 2454156.34518 | 0.291 | FEROS       |
|        |          |           |         | 2454156.34518 | 0.291 | 2454156.34518 | 0.291 | FEROS       |
|        |          |           |         | 2454773.35198 | 0.798 | 2454773.35198 | 0.798 | UVES        |

Notes.

(a) Computed from ASAS photometry
(b) GCVS values
(c) Spectrum used to derive the chemical composition of HQ Car
(d) Spectra coadded and used to derive the chemical composition of DD Vel.

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Fig. 1: Location of DD Vel and HQ Car in a K,J-K colour-magnitude diagram. The dashed line shows the zero-age-horizontal-branch (ZAHB), while the coloured lines display HB evolutionary models for stellar masses ranging from 0.49 to 0.58 M☉. The black lines display the instability strip for RR Lyrae and BL Herculis stars.

Fig. 2: Behaviour of the Hα line in HQ Car at different phases.

In Fig. 2 we present the variations in the Hα profile for HQ Car at four different phases. They are very similar to those presented for W Vir by Lèbre & Gillet (1992) (their Fig. 3) and by Kovtyukh et al. (2011) (their Fig. 12). The shock wave rising in the atmosphere of the star causes a broad emission feature comprising five components (3 in emission, 2 in absorption). The absorption features are associated to the presence of a circumstellar envelope for one and to the fall back of the upper atmosphere.
3.2.2. Emission in He I at 5875.64 Å

Emission lines of He I in the spectra of type II Cepheids were first mentioned by Wallerstein (1959). They enabled him to confirm the shock model. (The emission is caused by helium ionized by the shock wave that captures electrons.) More recent observations by Raga et al. (1989) were used to determine the H/He ratio in the atmosphere of W Vir. He I emission lines were extensively studied by both Lèbre & Gillet (1992) and Kovtyukh et al. (2011). The former reported the presence of emission in the He I 5875.64 Å line between phases $\phi=0.38$ and $\phi=0.44$, while the latter detected emission between $\phi=0.827$ and $\phi=0.961$, in good agreement with previous studies. In the same figure, we note the doubling of the Ba II line profile in the same phases. The mechanism responsible for the line doubling was first explained by Schwarzschild (1953): line doubling can be observed when the shock wave moves across the layer of formation of a given absorption line, provided that this layer is thick enough; the blueshifted line is produced by cooling gas moving upwards, while the redshifted line originates in gas already falling down. In the case of DD Vel, Fig. 5 shows no emission for the He I 5875.64 Å line, but the Ba II line is split into two components at $\phi=0.798$, indicating that the region where the Ba II line is formed is crossed by the shock wave.

3.3. Kinematics consistent with a thick disc membership

Kinematics alone is not sufficient to decide that a star belongs to the thin or the thick disc. It is, however, interesting to investigate the kinematic properties of DD Vel and HQ Car. Therefore we computed their space velocities $U_{LSR}$, $V_{LSR}$, $W_{LSR}$ in the local standard of rest using proper motions from the Naval Observatory Merged Astrometric Dataset (NOMAD, Zacharias et al. 2004) and the data shown in Table 2. Both stars have a total velocity $70 \leq V_{tot} \leq 180$ km/s, making them likely thick disc members (e.g., Nisshon 2004). Their velocity along the direction of Galactic rotation $V_{LSR}$ almost falls within $-100$ km/s and –40 km/s, the range quoted by Reddy et al. (2003) for a probable thick-disc membership. Finally, comparing the stars in our sample to the velocity–metallicity plots of Bensby et al. (2003) see their Fig. 1), we find that $U_{LSR}$ is not conclusive for HQ Car, while $V_{LSR}$ and $W_{LSR}$ both place this star in the thick disc. The situation is a bit less clear for DD Vel because its $U_{LSR}$ is still at the upper limit for a thin disc star, and its $V_{LSR}$ at the lower limit quoted by Reddy et al. (2003). $^1 [U_{LSR}, V_{LSR}, W_{LSR}] = [11.10, 12.24, 7.25]$ km/s (Schönrich et al. 2010).
limit, whereas its $W_{LSR}$ is typical of the thick disc. In conclusion, HQ Car seems to be a very likely thick-disc member, whereas it cannot be totally excluded that DD Vel is a thin-disc member. The above kinematical evidence therefore supports the hypothesis that both stars are Type II Cepheids in the thick disc rather than classical Cepheids located in the thin disc.

### 3.4. Classification based on the chemical composition

From their period (with respect to the classification of Soszyński et al. (2008b) for Type II Cepheids) and the emission features in Hα and He I at 5876 Å, it already appears to be clear that both HQ Car and DD Vel are W Vir stars. This will be reinforced in Sect. 4 where we examine their chemical composition.

### 4. Chemical composition

#### 4.1. Method

We used the DECH 30 software package to normalize the individual spectra to the local continuum, to identify the lines of different chemical elements, and to measure the equivalent widths (EW) of the absorption lines. The oscillator strengths have been taken from the Vienna Atomic Lines Database (VALD). The ratios of the central depths of carefully chosen pairs of lines that have a very different dependence on $T_{eff}$ are entered in previously calibrated relations. This technique allows determining $T_{eff}$ with great precision: the use of several tens (≥50) of ratios per spectrum leads to uncertainties of ±10-20 K when $S/N$>100 and of ±30-50 K when $S/N$<100. The method is independent of the interstellar reddening and only marginally dependent on the individual characteristics of stars, such as rotation, microturbulence, and metallicity.

To determine the surface gravity ($\log g$) and the microturbulent velocity $V_t$, we used a canonical analysis. We sought the surface gravity from the excitation equilibrium of Fe I and Fe II lines, and the microturbulent velocity is determined from the Fe I lines. We note that the excitation equilibrium is also satisfied by V I and V II and, to a slightly lesser extent, by Ti I and Ti II in HQ Car, while it is satisfied for the couples Si I / Si II, Ti I / Ti II (but not Cr I / Cr II) in the case of DD Vel. As far as the microturbulent velocity is concerned, an innovative approach using lines of several elements has been developed by Sahin et al. (2011) and is illustrated in Reddy et al. (2012). In this method, the standard errors are plotted as a function of the microturbulent velocity. We applied it to the stars in our sample, and the results are in good agreement with our values for $V_t$. They are described in Appendix A. The atmospheric parameters for DD Vel and HQ Car are listed in Table 3.

| Star     | $T_{eff}$ (K) | $\log g$ (dex) | $V_t$ (km/s) | $[Fe/H]$ (dex) |
|----------|---------------|----------------|--------------|----------------|
| HQ Car   | 5580          | 1.6            | 3.1          | -0.32          |
| DD Vel   | 5572          | 1.4            | 3.8          | -0.48          |

Table 3: Atmospheric parameters derived for HQ Car and DD Vel.

#### Notes

1/ Abundance determined by spectral synthesis

The lines of odd-Z elements can be broadened due to their hyperfine structure (hfs). However, the hfs corrections are negligible in the case of V or Co for the considered EW. This is not true in the case of Sc, Mn, or Cu (e.g., North et al. 2012; Reddy et al. 2012). We therefore computed the abundances of these elements via spectral synthesis using the 5526.79, 5657.90, 5667.15, 6245.62, 6604.60 lines for Sc II, 5420.35, 5432.56, 6013.48, 6021.79 for Mn I and 5105.55, 5218.21, 5782.14 for Cu I, and the STARSP code developed by Tsymbal (1996). We took the hyperfine structure of Sc II (Prochaska & McWilliam 2000). Mn I, and Cu I (Allen & Porto de Mello 2011) into account for the line profile calculations.

Atmospheric models are interpolated for each Type II Cepheid using the grid of 1D, LTE atmosphere models of Castelli & Kurucz (2004). Individual abundances are listed in Table 4 and abundance ratios (with respect to iron) in Table 5. We computed the solar reference abundances using lines in the Sun with EWs < 120mas and the same atmosphere models (Castelli & Kurucz 2004). They are listed in the Appendix B together with the prescriptions of Asplund et al. (2009) and the solar abundances of Reddy et al. (2003) that are used by Reddy et al. (2006) in their study of the thick disc.

We used 25 calibrations to determine the effective temperature of HQ Car and 26 calibrations for DD Vel, leading to standard deviations of 95 K and 109 K, respectively, and standard errors of 19 K and 22 K. We adopted 100 K as the uncertainty on $T_{eff}$. We estimated the uncertainty on $\log g$ as ±0.2 dex and the uncertainty on $V_t$ as ±0.5 km/s. Table 6 lists the variations.

| Ion     | [X/H] | $\sigma$ | N | [X/H] | $\sigma$ | N |
|---------|-------|---------|---|-------|---------|---|
| C I     | 6.00  | -0.14   | 0.19 | 7     | -0.48   | 0.15 | 2 |
| N I     | 7.00  | 0.20    | 0.21 | 2     | 0.23    | 0.11 | 2 |
| O I     | 8.00  | 0.23    | 0.01 | 2     | -0.22   | 0.22 | |
| Na I    | 11.00 | -0.25   | 0.09 | 3     | -0.33   | 0.12 | 4 |
| Mg I    | 12.00 | -0.17   | 1   | 1     | -0.41   | 1   | |
| Al I    | 13.00 | -0.43   | 0.18 | 4     | 0.16    | 0.16 | 7 |
| Si I    | 14.00 | -0.11   | 0.12 | 22    | -0.24   | 0.14 | 20 |
| Si II   | 14.01 |         |     |       | -0.28   | 0.15 | 2 |
| S I     | 16.00 | -0.05   | 0.12 | 5     | -0.39   | 0.00 | 2 |
| Ca I    | 20.00 | -0.47   | 0.18 | 9     | 0.73    | 0.06 | 14 |
| Sc II   | 21.01 | -0.55   | 1   |       | -1.12   | 1.12 | |
| Ti I    | 22.00 | -0.35   | 0.19 | 6     | 0.61    | 0.11 | 13 |
| Ti II   | 22.01 | -0.28   | 1   | 0.61  | 0.11    | 0.4 | |
| V I     | 23.00 | -0.39   | 0.13 | 9     | 0.48    | 0.10 | 4 |
| V II    | 23.01 | -0.43   | 0.13 | 2     | 0.15    | 0.15 | |
| Cr I    | 24.00 | -0.59   | 0.23 | 3     | -0.85   | 0.06 | 7 |
| Cr II   | 24.01 |         |     |       | -0.51   | 0.10 | 7 |
| Mn I    | 25.00 | -0.63   | 1   |       | -0.71   | 0.21 | |
| Fe I    | 26.00 | -0.32   | 0.10 | 133   | -0.45   | 0.11 | 162 |
| Fe II   | 26.01 | -0.32   | 0.07 | 8     | 0.51    | 0.09 | 19 |
| Co I    | 27.00 | -0.18   | 0.19 | 5     | -0.38   | 0.17 | 3 |
| Co II   | 27.00 | -0.18   | 0.19 | 5     | -0.38   | 0.17 | 3 |
| Ni I    | 28.00 | -0.34   | 0.13 | 38    | -0.52   | 0.06 | 44 |
| Cu I    | 29.00 | -0.48   | 1   |       | -0.43   | 0.43 | |
| Zn I    | 30.00 |         |     |       | -0.20   | 0.05 | 2 |
| Y II    | 39.01 | -0.82   | 0.10 | 2     | -1.41   | 0.13 | 3 |
| Zr II   | 40.01 | -1.16   | 1   |       | 1       |     | |
| La II   | 57.01 | -0.72   | 0.08 | 3     | 0.89    | 0.07 | 2 |
| Nd II   | 60.01 | -0.58   | 1   |       | 0.89    | 0.07 | 2 |
| Eu II   | 63.01 | -0.04   | 1   |       | 0.89    | 0.07 | 2 |

Table 4: Individual abundances [X/H] in HQ Car and DD Vel.
in the individual abundances [X/H] when changing the atmospheric parameters by \( \Delta T_{\text{eff}} = +100 \, \text{K} \), \( \Delta \log g = +0.2 \, \text{dex} \), and \( \Delta V_t = +0.2 \, \text{km/s} \) and their sum in quadrature, which we adopt as the uncertainty on the abundances due to the uncertainties on the atmospheric parameters. It is well documented (e.g., Johnson 2002) that such a method leads to overestimated values for the total error, because by construction it ignores covariances between the different atmospheric parameters. They nevertheless remain lower than 0.10 dex in most cases. The sum in quadrature of the errors associated with the uncertainties on the atmospheric parameters and of the standard deviation associated with the determination of the abundance of a given element gives the total error on the abundance for this element.

### 4.2. Chemical composition

The two stars in our sample have [Fe/H] in the −0.3 to −0.5 dex range, towards the lower end of the metallicity distribution for BL Her stars, but still in a domain where the metallicities of BL Her and W Vir stars overlap (see Maas et al. 2007). As shown just after this, they are probably affected by dust-gas separation. However, the [S/Fe] we measured for DD Vel (+0.09 dex) and HQ Car (+0.27 dex) are very similar to those already reported for [S/Fe] in different Galactic structures. Below [Fe/H] = −1.0 dex, [S/Fe], values are scattered around a plateau at \( \approx +0.25 \) dex and decrease at higher metallicities until reaching \([S/Fe] = 0.0 \) dex at [Fe/H] = −0.3 dex (e.g., Francois 1987, 1988; Chen et al. 2002, Nissen et al. 2007; Matrozos et al. 2013; Caffau et al. 2014, and references therein). Also our [Zn/Fe] measurement of +0.28±0.12 dex in DD Vel is very consistent with previous values ([Zn/Fe] = +0.1 to +0.2 dex) reported for the thick disc (e.g., Mischenina et al. 2002; Bensby et al. 2003).

### Table 2: Kinematics of HQ Car and DD Vel.

| Star | RA deg | Dec deg | PM (RA) mas/yr | PM (Dec) mas/yr | Vrad km/s | Distance pc | U_{LSR} km/s | V_{LSR} km/s | W_{LSR} km/s |
|------|--------|---------|----------------|----------------|-----------|-------------|--------------|--------------|--------------|
| HQ Car | 155.133 | −61.249 | 1.1±2.6a | 2.9±2.6a | 62.05b | 5725a | 10.13 | −57.07 | 85.55 | 103.34 |
| DD Vel | 138.040 | −50.376 | −5.7±4.7a | −1.3±4.7a | 26.02c | 2444a | 44.78 | −33.23 | −51.75 | 76.08 |

### Notes.

(1) NOMAD catalogue (Zacharias et al. 2004). (2) Radial velocity measured in our CTIO spectrum. The other spectra show line doubling with radial velocities of 85.26 & 108.7 km/s (FEROS), 79.78 & 113.8 km/s, 74.68 & 120.0 km/s (HARPS), respectively. (3) \( \gamma \)-velocity of DD Vel from Metzger et al. (1992). (4) Distance derived from the apparent magnitude in the J band (2MASS) and the period-luminosity relation of Matsumura et al. (2006). (5) \( V_{LSR} = (U_{LSR} + V_{LSR} + W_{LSR})/3 \) for individual species.

### Table 5: Abundance ratios [X/Fe] in HQ Car and DD Vel.

| Ion | [X/Fe] | \( \sigma \) | [X/Fe] | \( \sigma \) |
|-----|--------|-------------|--------|-------------|
| HQ Car | DD Vel | HQ Car | DD Vel | HQ Car | DD Vel | HQ Car | DD Vel |
| C i | 6.00 | +0.18 | 0.21 | +0.00 | +0.19 |
| N i | 7.00 | +0.52 | 0.23 | +0.17 | +0.16 |
| O i | 8.00 | +0.55 | 0.10 | +0.26 | +0.11 |
| Na i | 11.00 | +0.07 | 0.13 | +0.15 | +0.16 |
| Mg i | 12.00 | +0.15 | 0.10 | +0.07 | +0.11 |
| Al i | 13.00 | −0.11 | 0.21 | −0.02 | +0.19 |
| Si i | 14.00 | +0.21 | 0.16 | +0.44 | +0.18 |
| Si ii | 14.0 | +0.20 | 0.19 | +0.24 | +0.18 |
| S i | 16.00 | +0.27 | 0.16 | +0.09 | +0.11 |
| Ca i | 20.00 | −0.15 | 0.21 | −0.04 | +0.22 | +0.13 |
| Sc i | 21.01 | −0.23 | 0.10 | −0.64 | +0.11 |
| Ti i | 22.00 | −0.03 | 0.21 | −0.01 | −0.13 | +0.16 |
| Ti ii | 22.01 | +0.04 | 0.10 | −0.07 | −0.13 | +0.16 |
| V i | 23.00 | −0.07 | 0.16 | +0.00 | +0.15 |
| V ii | 23.01 | −0.11 | 0.16 | +0.19 | +0.13 |
| Cr i | 24.00 | −0.27 | 0.25 | −0.37 | −0.13 |
| Cr ii | 24.01 | −0.03 | 0.15 | +0.08 | +0.13 |
| Mn i | 25.00 | −0.31 | 0.10 | −0.23 | +0.11 |
| Co i | 27.00 | +0.14 | 0.21 | +0.10 | +0.20 |
| Ni i | 28.00 | −0.02 | 0.16 | −0.04 | +0.13 |
| Cu i | 29.00 | −0.16 | 0.10 | +0.05 | +0.11 |
| Zn i | 30.00 | +0.28 | 0.12 | +0.28 | +0.12 |
| Y ii | 39.01 | −0.50 | 0.14 | −0.93 | +0.17 |
| Zr ii | 40.01 | −0.84 | 0.10 | −0.23 | +0.11 |
| La ii | 57.01 | −0.40 | 0.13 | −0.64 | +0.11 |
| Nd ii | 60.01 | −0.26 | 0.10 | −0.41 | +0.13 |
| Eu ii | 63.01 | +0.28 | 0.10 | +0.06 | +0.06 |

### Notes.

(1) Yong et al. (2004)
Brewer & Carney 2006; Reddy et al. 2006. Since sulphur and zinc are only slightly depleted into dust (Savage & Sembach 1996), the typical thick-disc values for [S/Fe] and [Zn/Fe] in HQ Car and DD Vel indicate that their iron abundances are probably not very modified by the dust-gas separation. In particular, this allows us to use an average thick disc star for the −0.45 to −0.55 dex [Fe/H] bin for comparison purposes (Reddy et al. 2006, col. 4 in their Table 7).

Maas et al. (2007) have shown that W Vir stars have [Na/Fe] that is independent of [Fe/H] and consistent with thick disc stars where <[Na/Fe]>≈+0.12 dex (Reddy et al. 2006). This argument does not apply to the stars with a severe dust-gas separation. They find, in contrast, that BL Her stars are strongly overabundant in sodium with a mean [Na/Fe]=+0.73 dex. For the two Type II Cepheids in our sample, [Na/Fe] varies between +0.07 and +0.15 dex, similar to the representative thick disc value (see Fig. 6). Since iron could be affected by dust-gas separation, we also compare [Na/Zn] for the BL Her and W Vir stars, and again DD Vel has low [Na/Zn] similar to the other W Vir stars, while the BL Her stars show very high (>+0.5 dex) values of [Na/Zn]. The absence of Na overabundance in our sample confirms that they are W Vir stars and not BL Her stars, as could already be inferred from their period (P>4d).

When gas cools sufficiently, dust grains can form and the abundances of the elements in the gas phase decrease. Because this happens at different temperatures for different trace elements, the quantity “50% condensation temperature” (50% Tc) has been defined, at which 50% of the element is found in the gas phase and the other 50% is locked in dust grains. We adopted the 50% Tc determined by Lodders (2003). A correlation between the underabundance of a given element and its condensation temperature is then interpreted as a dust-gas separation.5

As can be seen in Fig. 7 the Type II Cepheids in our sample show hints of (mild) dust-gas separation: the more volatile elements have abundances similar to those of an average thick-disc star (Reddy et al. 2006), while the refractory elements are underabundant, because they are depleted into dust. For a better visibility, we focus in Fig. 8 on the elements with 50% Tc ≥1300 K.

As expected, the signature of dust-gas separation is especially marked for the elements with the highest 50% Tc. In HQ Car, Ca, Nd, Al, and Sc are mildly depleted by ≈−0.2 dex and Y by ≈−0.3 dex with respect to an average thick-disc star. Zr seems to be very depleted because [Zr/H] clearly falls below the abundances of the other neutron-capture elements, but we have no comparison with an average thick-disc star to draw a firm conclusion. The depletion is more severe for DD Vel as the underabundances with respect to an average thick disc star reach ≈−0.30 dex for Ti, ≈−0.45 dex for Nd and Ca, ≈−0.80 dex for Sc and ≈−0.90 dex for Y. To further support the dust-gas separation, we note that most of the individual abundances fall below those of the thick-disc reference star for the elements with 50% Tc ≥1400 K.

Hints or even clear evidence of dust-gas separation in Type II Cepheids have already been reported for ST Pup by Gonzalez & Wallerstein (1996) and for CO Pup, V1711 Sgr, MZ Cyg, and SZ Mon by Maas et al. (2007). On the other hand, these authors find the signature of dust-gas separation less convincing in RX Lib and W Vir because it relies mostly on the depletion in Sc. As we discuss in more detail in the next paragraph, severe dust-gas separation has also been reported in most of the RV Tau stars (see Giridhar et al. 2005 and references therein). Maas et al. (2007) found a Type II Cepheid (CC Lyr) with an extreme dust-gas separation, which is larger than in any RV Tau star. It is important to note that all the Type II Cepheids with a signature of dust-gas separation are W Vir stars and not BL Her stars. That the stars in our sample also show possible (HQ Car) or probable (DD Vel) signs of this phenomenon reinforces their classification as W Vir stars.

Fig. 6: Top: [Na/Fe] vs. [Fe/H] for BL Her stars (open circles) and W Vir stars (filled circles) from Maas et al. (2007). HQ Car and DD Vel are overplotted in red and blue, respectively. The ratio for a representative thick-disc star at [Fe/H]=−0.5 dex is shown as a dashed line. Bottom: same for [Na/Zn] vs. [Zn/H]. Abundances have been rescaled to the solar abundances of Reddy et al. (2003), used as a reference by Maas et al. (2007). Dust-gas separation is a common feature in RV Tau stars (see Giridhar et al. 2005, and references therein). In a qualitative scenario (Waters et al. 1992), binary RV Tau stars are surrounded by a dusty disc. The dust-gas separation occurs when radiation pressure traps the dust grains in the disc while some of the gas (deprived from dust) is re-accreted on the star via the viscous disc that allows for transfer of angular momentum. The origin of the circumbinary disc in RV Tau stars is not clear, but it is generally believed to be created during binary interaction when the primary was a giant.

This scenario excludes metal-poor systems ([Fe/H]<−1.0 dex) where dust cannot form in sufficient quantities, and indeed no sign of dust-gas separation has been found for metal-poor RV Tau variables in globular clusters (Gonzalez & Lambert 1996). Similarly, Maas et al. (2007) find no evidence of dust-gas separation for TW Cap, a W Vir star with [Fe/H]=−1.8 dex possibly associated to the halo of the Milky Way.

It is not clear that the dust-gas separation has the same origin in W Vir stars as in RV Tau stars. In particular, the observed depletion is generally much shallower in the W Vir stars. Only in the case of CC Lyr does it reach the extreme values more commonly seen in RV Tau stars (e.g., ≈−3.0 dex in HP Lyr and dynamic equilibrium) that may not be met in the surroundings of W Vir stars due to the presence of shocks in the atmosphere (Kovtyukh et al. 2011).
DY Ori, see Giridhar et al. (2005). The RV Tau stars depleted in their refractory elements are known binaries for a large number of them, supporting the hypothesis of a circumbinary dusty disc (Rao et al. 2012). Disentangling orbital velocities from pulsational velocities is very demanding in terms of observing time both in the case of RV Tau and W Vir stars, and indeed only four type II Cepheids are currently known as binaries: AU Peg, IX Cas, TX Del, and ST Pup. It is interesting to note that the only W Vir star in this group (ST Pup) shows obvious signs of dust-gas depletion, while the other shorter-period stars do not.

Recently reported observational (e.g., Marengo et al. 2010b) and theoretical (e.g., Neilson et al. 2012) lines of evidence support the existence of mass loss in classical Cepheids; however, these outflows seem to have a very low dust content (Marengo et al. 2013), possibly indicating that the wind is driven by pulsation and is not dust-driven as generally observed in evolved stars. On the other hand, extended dusty environments have been detected with high angular resolution techniques (e.g., Kervella et al. 2006; Gallenne et al. 2013 and references therein) and from extended emission in the mid- and far-infrared (Barmby et al. 2011). They have been attributed to the presence of a circumstellar envelope around the Cepheids.

As far as Type II Cepheids are concerned, Kovtyukh et al. (2011) analysed hydrogen, helium, and metallic lines in W Vir itself. They were able to reproduce the specifics of spectral line variability in W Vir with the help of a non-linear pulsation model. Results suggest that W Vir consists of two different layers, the inner part being the pulsating star itself and the outer part a very extended and dense atmosphere, and it might even include a circumstellar envelope with a very low expansion rate.

If the most desirable experiment in the near future were to systematically examine the binarity properties of W Vir stars, it would nevertheless be interesting to investigate whether dust-gas separation could also somehow take place in their circumstellar envelopes.

5. Summary and conclusion.

The status of the HQ Car and DD Vel Type II Cepheids has remained unclear. Depending on the catalogue (i.e., on the method and criteria used to perform the classification), they are sometimes listed as classical Cepheids and sometimes as Type II.
Because we observed emission features in the H$_\alpha$ gas, we conclude that HQ Car and DD Vel are Type II Cepheids from this sub-class. Their periods of 14.06 and 13.19 days, respectively, and the absence of Na overabundance further indicates that they are not BL Her stars. Moreover, they show a possible (H$\alpha$) or probable (DD Vel) signature of mild dust-gas separation. Such abundance patterns have currently been observed only in long-period Type II Cepheids and RV Tau stars, thus reinforcing our classification.

Several studies of the Galactic abundance gradients in the thin disc using classical Cepheids have reported increased dispersion in the outer disc (Yong et al. 2006; Lemasle et al. 2008; Bensby et al. 2007a,b) and increased[α/Fe] vs [Fe/H] plane (e.g., Recio-Blanco et al. 2014), and recent studies indicate that the thin disc contamination by thick-disc stars is not negligible (see, for instance, Mkolitsas et al. 2014; their Fig. 7).

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Reddy, B. E., Lambert, D. L., Allende Prieto, C., 2006, MNRAS 367, 1329
Reddy, A. B. S., Giridhar, S., Lambert, D. L., 2012, MNRAS 419, 1350
Richards, J. W., Starr, D. L., Miller, A. A., Bloom, J. S., Butler, N. R., Brink, H., Crellin-Quick, A., 2012, ApJS 203, 32
Rodgers, A. W., Bell, R. A., 1963, MNRAS 125, 487
Rodgers, A. W., Bell, R. A., 1968, MNRAS 1395, 75
Sahin, T., Lambert, D. L., Klochkova, V. G., Tavolganskaya, N. S., 2011, MNRAS 410, 612
Sanford, R. F., 1953, Trans. IAU, 8, 809
Savage, B. D., Sembach, K. R., 1996, ARA&A 34, 279
Schmidt, E. G., Johnston, D., Langan, S., Lee, K. M., 2004, AJ 128, 1748
Schmidt, E. G., Johnston, D., Langan, S., Lee, K. M., 2005, AJ 130, 832
Schönrich, R., Binney, J., Dehnen, W., 2010, MNRAS 403, 1829
Schwarzschild, M., 1953, Trans. IAU, 8, 811
Skrutskie, M. F., Cutri, R. M., Stiening, R., Weinberg, M. D., Schneider, S., Carpenter, J. M., Beichman, C., Capps, R., Chester, T., Elias, J., Huchra, J., Liebert, J., Lonsdale, C., Monet, D. G., Price, S., Seitzer, P., Jarrett, T., Kirkpatrick, J. D., Gizis, J. E., Howard, E., Evans, T., Fowler, J., Fullmer, L., Hurt, R., Light, R., Kopan, E. L., Marsh, K. A., McCallon, H. L., Tam, R., Van Dyk, S., Wheelock, S., 2006, AJ 131, 1163
Soszyński, I., Udalski, A., Szymański, M. K., Kubik, M., Pietrzyński, G., Wyrzykowski, L., Szewczyk, O., Ulaczyk, K., Poleski, R., 2008, A&A 58, 293
Tsynshyn, V. V., 1996, ASP Conf. Ser., 108, M.A.S.S.; Model Atmospheres and Spectrum Synthesis, ed. S. J. Adelman, F. Kupka & W. W. Weiss, 198.
Wallerstein, G., 1958, ApJ 127, 583
Wallerstein, G., 1959, ApJ 130, 560
Wallerstein, G., Gonzalez, G., 1996, MNRAS 282, 1236
Wallerstein, G., Matt, S., Gonzalez, G., 1996, MNRAS 311, 414
Wallerstein, G., 2002, PASP 114, 689
Wallerstein, G., Kovtyukh, V. V., Andrievsky, S. M., 2008, PASP 120, 361
Waters, L. B. F. M., Trams, N. R., Waelkens, C., 1992, A&A 262, 37
Winston, C. L., 2006, SASS 25, 47
Whitney, C. A., 1956a, AnAp 19, 34
Whitney, C. A., 1956b, AnAp 19, 142
Whitney, C. A., Scalafuris, A., 1963, ApJ 138, 200
Young, D., Carney, B. W., Teixera de Almeida, M. L., Pohl, B. L., 2006, AJ 131, 2256
Zacharias, N., Monet, D. G., Levine, S. E., Urban, S. E., Gaume, R., Wycoff, G. L., 2004, AAS 205, 48.15, 1418
Appendix A: An alternative approach to determining $V_t$

In this Appendix we show the standard deviation around the mean abundance plotted as a function of the microturbulent velocity, following the approach of Sahin et al. (2011). The dispersion of the abundances is computed for the Fe I, Fe II, Si I, and Ni I lines, while the microturbulent velocity $V_t$ is varied from 1 to 6 km/s. The minimum value of the dispersion is in good agreement within the different elements, confirming the values of the microturbulence (derived solely from Fe I) adopted in this study, namely 3.1 km/s for HQ Car and 3.8 km/s for DD Vel.

Fig. A.1: Standard deviation around the mean abundances as a function of microturbulence $V_t$ for HQ Car, shown for several elements.

Fig. A.2: Same as Fig. A.1, but for DD Vel.

Appendix B: Solar references

Table B.1: Solar abundance derived from the solar spectrum using the grid of models by Castelli & Kurucz (2004), compared to the solar photospheric abundance by Asplund et al. (2009) and by Reddy et al. (2003).

| Element | Log A (this work) dex | Lines used | Log A (Asplund et al. 2009) dex | Log A (Reddy et al. 2003) dex |
|---------|-----------------------|------------|---------------------------------|-------------------------------|
| C I     | 8.53±0.14             | 4          | 8.43±0.05                       | 8.51±0.06                     |
| N I     | 8.15                  | 2          | 7.83±0.05                       | 8.06                          |
| O I     | 8.98                  | 1          | 8.69±0.05                       | 8.86±0.05                     |
| Na I    | 6.32±0.04             | 10         | 6.24±0.04                       | 6.27                          |
| Mg I    | 7.68±0.02             | 9          | 7.60±0.04                       | 7.54±0.06                     |
| Al I    | 6.30±0.01             | 2          | 6.45±0.03                       | 6.28±0.05                     |
| Si I    | 7.55±0.08             | 23         | 7.51±0.03                       | 7.62±0.05                     |
| S I     | 7.20±0.10             | 6          | 7.12±0.03                       | 7.34±0.09                     |
| Ca I    | 6.32±0.07             | 16         | 6.34±0.04                       | 6.33±0.07                     |
| Sc I    |                        |            | 3.15±0.04                       |                               |
| Sc II   | 3.22±0.11             | 14         | 3.24±0.14                       |                               |
| Ti I    | 4.96±0.08             | 41         | 4.95±0.05                       | 4.90±0.06                     |
| Ti II   | 5.01±0.03             | 5          | 5.08±0.03                       |                               |
| V I     | 4.04±0.12             | 36         | 3.93±0.08                       | 3.93±0.03                     |
| Cr I    | 5.67±0.09             | 23         | 5.64±0.04                       | 5.68±0.07                     |
| Mn I    | 5.54±0.07             | 11         | 5.43±0.05                       | 5.37±0.05                     |
| Fe I    | 7.57±0.08             | 164        | 7.50±0.04                       | 7.45±0.04                     |
| Fe II   | 7.47±0.04             | 11         | 7.45±0.07                       |                               |
| Co I    | 5.00±0.10             | 28         | 4.99±0.07                       | 4.93±0.04                     |
| Ni I    | 6.29±0.06             | 56         | 6.22±0.04                       | 6.23±0.04                     |
| Cu I    | 4.29±0.20             | 3          | 4.19±0.04                       | 4.19±0.05                     |
| Zn I    | 4.45                  | 1          | 4.56±0.05                       | 4.47                          |
| Y II    | 2.15±0.17             | 7          | 2.21±0.05                       | 2.12±0.04                     |
| Zr I    |                        |            | 2.58±0.04                       |                               |
| Zr II   | 2.79±0.19             | 2          | 2.45                            |                               |
| La II   | 1.24±0.02             | 2          | 1.10±0.04                       |                               |
| Ce II   | 1.70±0.11             | 6          | 1.58±0.04                       | 1.58                          |
| Nd II   | 1.54±0.08             | 11         | 1.42±0.04                       | 1.50                          |
| Eu II   | 0.96                  | 1          | 0.52±0.04                       | 0.61                          |
## Appendix A: List of lines used

Table A.1: Atomic parameters and EWs of HQ Car and DD Vel

| Wavelength (Å) | Z    | Log gf | $\chi_{\text{ex}}$ (eV) | HQ Car EW (mÅ) | DD Vel EW (mÅ) |
|---------------|------|--------|------------------------|----------------|----------------|
| 6587.6100     | 6.00 | -1.002 | 8.537                  | 58.2           | 33.6           |
| 7087.8300     | 6.00 | -1.441 | 8.647                  | 27.8           | ...            |
| 7111.4700     | 6.00 | -1.084 | 8.640                  | 26.6           | 34.6           |
| 7113.1800     | 6.00 | -0.772 | 8.647                  | 51.6           | ...            |
| 7115.1700     | 6.00 | -0.933 | 8.643                  | 51.6           | ...            |
| 7116.9900     | 6.00 | -0.906 | 8.647                  | 71.4           | ...            |
| 7119.6600     | 6.00 | -1.147 | 8.643                  | 49.8           | ...            |
| 7442.2980     | 7.00 | -0.400 | 10.330                 | 13.8           | 24.8           |
| 7468.3120     | 7.00 | -0.182 | 10.336                 | 31.2           | 26.6           |
| 6300.3040     | 8.00 | -9.818 | 0.000                  | 107.9          | ...            |
| 5682.6330     | 11.00| -0.705 | 2.102                  | 105.8          | 97.6           |
| 5688.2050     | 11.00| -0.451 | 2.104                  | ...            | 141.9          |
| 6154.2260     | 11.00| -1.546 | 2.102                  | 32.6           | 29.0           |
| 6160.7470     | 11.00| -1.245 | 2.104                  | 45.6           | 38.1           |
| 7111.0880     | 12.00| -1.723 | 4.346                  | 132.2          | 123.4          |
| 6696.0230     | 13.00| -1.346 | 3.143                  | 27.4           | ...            |
| 6698.6730     | 13.00| -1.646 | 3.143                  | 8.4            | ...            |
| 7835.3090     | 13.00| -0.648 | 4.022                  | 26.0           | ...            |
| 7836.1340     | 13.00| -0.493 | 4.022                  | 18.5           | ...            |
| 5645.6130     | 14.00| -2.139 | 4.930                  | 52.7           | 38.9           |
| 5665.5540     | 14.00| -2.039 | 4.920                  | 53.4           | 37.7           |
| 5684.4840     | 14.00| -1.649 | 4.954                  | ...            | 102.8          |
| 5690.4250     | 14.00| -1.869 | 4.930                  | 81.8           | 51.5           |
| 5708.4000     | 14.00| -1.469 | 4.954                  | ...            | 110.1          |
| 5772.1460     | 14.00| -1.749 | 5.082                  | ...            | 60.8           |
| 5793.0730     | 14.00| -2.059 | 4.930                  | 63.4           | 64.5           |
| 5948.5410     | 14.00| -1.229 | 5.082                  | ...            | 114.2          |
| 6091.9190     | 14.00| -1.462 | 5.871                  | 25.4           | 30.6           |
| 6106.6080     | 14.00| -1.896 | 5.614                  | 21.2           | ...            |
| 6125.0210     | 14.00| -1.464 | 5.614                  | 44.3           | 31.2           |
| 6131.8520     | 14.00| -1.616 | 5.616                  | 41.6           | ...            |
| 6145.0160     | 14.00| -1.310 | 5.616                  | 46.6           | 37.6           |
| 6155.1340     | 14.00| -0.754 | 5.619                  | 117.4          | ...            |
| 6237.3190     | 14.00| -0.974 | 5.614                  | 87.2           | 62.4           |
| 6243.8150     | 14.00| -1.243 | 5.616                  | 71.9           | 44.6           |
| 6244.4650     | 14.00| -1.090 | 5.616                  | 56.8           | ...            |
| 6414.9800     | 14.00| -1.035 | 5.871                  | 66.5           | 45.9           |
| 6526.6300     | 14.00| -1.606 | 5.871                  | ...            | 22.3           |
| 6721.8480     | 14.00| -1.526 | 5.863                  | ...            | 37.4           |
| 6800.5960     | 14.00| -1.944 | 5.964                  | 14.3           | ...            |
| 6848.5800     | 14.00| -1.527 | 5.863                  | 21.5           | ...            |
| 7034.9010     | 14.00| -0.879 | 5.871                  | ...            | 68.5           |
| 7226.2080     | 14.00| -1.509 | 5.614                  | ...            | 31.3           |
| 7282.8160     | 14.00| -0.625 | 6.206                  | 69.9           | 78.6           |
| 7373.0040     | 14.00| -1.179 | 5.984                  | 34.0           | ...            |
| 7424.6100     | 14.00| -1.609 | 5.619                  | 24.0           | ...            |
| 7680.2660     | 14.00| -0.689 | 5.863                  | ...            | 95.5           |
| 7918.3830     | 14.00| -0.609 | 5.954                  | 100.9          | ...            |
| 7932.3480     | 14.00| -0.469 | 5.964                  | 107.0          | ...            |
| 7944.0010     | 14.00| -0.309 | 5.984                  | 128.8          | ...            |
| 6347.1090     | 14.01| 0.170  | 8.121                  | 166.4          | 132.4          |
| 6371.3710     | 14.01| -0.039 | 8.121                  | ...            | 93.5           |
| 6045.9720     | 16.00| -1.317 | 7.868                  | 44.8           | 29.0           |
| 6045.9920     | 16.00| -1.907 | 7.868                  | 44.8           | 29.0           |
| 6046.0380     | 16.00| -1.113 | 7.868                  | 44.8           | 29.0           |
| 6743.3800     | 16.00| -0.849 | 7.866                  | 52.5           | ...            |
| Wavelength (Å) | Z      | Log gf | $\chi_{ex}$ (eV) | HQ Car (EW(mÅ)) | DD Vel (EW(mÅ)) |
|----------------|--------|--------|----------------|----------------|-----------------|
| 6748.7900      | 16.00  | -0.529 | 7.868          | 68.8           | 33.9            |
| 6757.1500      | 16.00  | -0.239 | 7.870          | 83.6           | 41.4            |
| 6786.1010      | 16.00  | -0.987 | 7.868          | 26.8           | ...             |
| 5349.4650      | 20.00  | -0.309 | 2.709          | ...            | 106.3           |
| 5512.9800      | 20.00  | -0.463 | 2.933          | ...            | 60.7            |
| 5581.9650      | 20.00  | -0.554 | 2.523          | 104.4          | 91.8            |
| 5590.1140      | 20.00  | -0.570 | 2.521          | 97.3           | 88.4            |
| 5601.2770      | 20.00  | -0.522 | 2.526          | 133.2          | 104.2           |
| 5678.5620      | 20.00  | -1.569 | 2.933          | ...            | 41.4            |
| 5581.9650      | 20.00  | -0.554 | 2.523          | 104.4          | 91.8            |
| 5590.1140      | 20.00  | -0.570 | 2.521          | 97.3           | 88.4            |
| 5601.2770      | 20.00  | -0.522 | 2.526          | 133.2          | 104.2           |
| 5678.5620      | 20.00  | -1.569 | 2.933          | ...            | 41.4            |
| 5581.9650      | 20.00  | -0.554 | 2.523          | 104.4          | 91.8            |
| 5590.1140      | 20.00  | -0.570 | 2.521          | 97.3           | 88.4            |
| 5601.2770      | 20.00  | -0.522 | 2.526          | 133.2          | 104.2           |
| 5678.5620      | 20.00  | -1.569 | 2.933          | ...            | 41.4            |
| 5581.9650      | 20.00  | -0.554 | 2.523          | 104.4          | 91.8            |
| 5590.1140      | 20.00  | -0.570 | 2.521          | 97.3           | 88.4            |
| 5601.2770      | 20.00  | -0.522 | 2.526          | 133.2          | 104.2           |
| 5678.5620      | 20.00  | -1.569 | 2.933          | ...            | 41.4            |
| 5581.9650      | 20.00  | -0.554 | 2.523          | 104.4          | 91.8            |
| 5590.1140      | 20.00  | -0.570 | 2.521          | 97.3           | 88.4            |
| 5601.2770      | 20.00  | -0.522 | 2.526          | 133.2          | 104.2           |
Table A.1: continued.

| Wavelength (Å) | Z  | Log gf | $\chi_{ex}$ (eV) | HQ Car EW (mÅ) | DD Vel EW (mÅ) |
|----------------|----|--------|------------------|----------------|----------------|
| 7400.2490      | 24.00 | -0.049 | 2.900            |                | 64.2           |
| 5237.3280      | 24.01 | -1.349 | 4.073            |                | 160.9          |
| 5310.6860      | 24.01 | -2.407 | 4.072            |                | 46.2           |
| 5313.5630      | 24.01 | -1.778 | 4.074            |                | 115.3          |
| 5334.8690      | 24.01 | -1.825 | 4.072            |                | 107.4          |
| 5407.6040      | 24.01 | -2.150 | 3.827            |                | 82.5           |
| 5502.0670      | 24.01 | -2.116 | 4.168            |                | 53.3           |
| 5508.6060      | 24.01 | -2.251 | 4.156            |                | 56.1           |
| 5002.7930      | 26.00 | -1.579 | 3.397            |                | 107.3          |
| 5004.0440      | 26.00 | -1.399 | 4.209            |                | 50.3           |
| 5022.2360      | 26.00 | -0.529 | 3.984            |                | 142.9          |
| 5029.6180      | 26.00 | -2.049 | 3.415            |                | 53.9           |
| 5044.2110      | 26.00 | -2.037 | 2.851            |                | 91.5           |
| 5048.4360      | 26.00 | -1.029 | 3.960            |                | 83.1           |
| 5054.6430      | 26.00 | -1.920 | 3.640            |                | 48.8           |
| 5060.0360      | 26.00 | -1.147 | 4.301            |                | 74.6           |
| 5060.0790      | 26.00 | -5.459 | 0.000            |                | 74.6           |
| 5067.1500      | 26.00 | -0.969 | 4.220            |                | 84.8           |
| 5090.7740      | 26.00 | -0.399 | 4.256            |                | 128.9          |
| 5109.6520      | 26.00 | -0.979 | 4.301            |                | 94.6           |
| 5131.4690      | 26.00 | -2.514 | 2.223            |                | 141.0          |
| 5159.0580      | 26.00 | -0.819 | 4.283            |                | 89.6           |
| 5180.0700      | 26.00 | -1.259 | 4.473            |                | 40.1           |
| 5187.9140      | 26.00 | -1.370 | 4.143            |                | 49.3           |
| 5225.5260      | 26.00 | -4.788 | 0.110            |                | 132.8          |
| 5228.3770      | 26.00 | -1.289 | 4.220            |                | 58.7           |
| 5242.4910      | 26.00 | -0.966 | 3.634            |                | 120.9          |
| 5243.7770      | 26.00 | -1.149 | 4.256            |                | 65.9           |
| 5247.0500      | 26.00 | -4.945 | 0.087            |                | 130.4          |
| 5253.4620      | 26.00 | -1.572 | 3.283            |                | 99.4           |
| 5288.5250      | 26.00 | -1.507 | 3.695            |                | 56.8           |
| 5307.3610      | 26.00 | -2.986 | 1.608            |                | 151.2          |
| 5322.0410      | 26.00 | -2.802 | 2.279            |                | 78.3           |
| 5329.9890      | 26.00 | -1.188 | 4.076            |                | 58.6           |
| 5333.3740      | 26.00 | -0.839 | 4.103            |                | 121.8          |
| 5373.7090      | 26.00 | -0.859 | 4.473            |                | 66.3           |
| 5379.5740      | 26.00 | -1.513 | 3.695            |                | 59.2           |
| 5389.4790      | 26.00 | -0.409 | 4.415            |                | 110.1          |
| 5389.4790      | 26.00 | -0.669 | 4.446            |                | 82.3           |
| 5409.1340      | 26.00 | -1.299 | 4.371            |                | 52.4           |
| 5441.3390      | 26.00 | -1.729 | 4.313            |                | 20.7           |
| 5464.2800      | 26.00 | -1.401 | 4.143            |                | 34.2           |
| 5466.3960      | 26.00 | -0.629 | 4.371            |                | 95.5           |
| 5473.9010      | 26.00 | -0.759 | 4.154            |                | 100.1          |
| 5481.2430      | 26.00 | -1.242 | 4.103            |                | 77.5           |
| 5487.7450      | 26.00 | -0.316 | 4.320            |                | 129.9          |
| 5522.4470      | 26.00 | -1.549 | 4.209            |                | 35.4           |
| 5543.1500      | 26.00 | -1.569 | 3.695            |                | 66.6           |
| 5543.9360      | 26.00 | -1.139 | 4.218            | 67.6           | 69.9           |
| 5546.5060      | 26.00 | -1.309 | 4.371            | 56.7           | 51.1           |
| 5554.8950      | 26.00 | -0.439 | 4.549            | 104.4          | ...            |
| 5560.2120      | 26.00 | -1.189 | 4.435            | 54.4           | 50.7           |
| 5563.6000      | 26.00 | -0.989 | 4.191            |                | 99.9           |
| 5565.7040      | 26.00 | -0.212 | 4.608            | 118.1          | 105.0          |
| 5567.3910      | 26.00 | -2.563 | 2.609            | 83.1           | 67.9           |
| 5576.0890      | 26.00 | -0.999 | 3.430            | 147.5          | ...            |
| 5584.7650      | 26.00 | -2.319 | 3.573            | 26.1           | 29.3           |
| 5618.6330      | 26.00 | -1.275 | 4.209            | 51.9           | 42.7           |
| 5619.5950      | 26.00 | -1.699 | 4.387            | 32.7           | ...            |
| 5633.9470      | 26.00 | -0.269 | 4.991            | 86.7           | 72.6           |
| Wavelength (Å) | Z | Log gf | $\chi_{ex}$ | HQ Car EW(mÅ) | DD Vel EW(mÅ) |
|---------------|---|--------|-------------|---------------|----------------|
| 5638.2620     | 26.00 | -0.869 | 4.220       | 101.3         | ...            |
| 5650.7060     | 26.00 | -0.959 | 5.086       | 30.5          | ...            |
| 5651.4690     | 26.00 | -1.999 | 4.473       | 15.7          | ...            |
| 5652.3180     | 26.00 | -1.949 | 4.260       | 24.5          | ...            |
| 5653.8670     | 26.00 | -1.639 | 4.387       | 33.3          | 30.6           |
| 5661.3460     | 26.00 | -1.735 | 4.284       | 18.7          | ...            |
| 5662.5160     | 26.00 | -0.572 | 4.178       | ...           | 126.5          |
| 5679.0230     | 26.00 | -0.919 | 4.652       | 54.5          | 54.7           |
| 5686.5300     | 26.00 | -0.445 | 4.549       | 96.4          | 80.6           |
| 5691.4970     | 26.00 | -1.519 | 4.301       | 44.1          | 29.0           |
| 5701.5450     | 26.00 | -2.215 | 2.559       | 131.4         | 126.4          |
| 5705.9920     | 26.00 | -0.529 | 4.608       | ...           | 93.5           |
| 5717.8330     | 26.00 | -1.129 | 4.284       | 76.0          | 64.0           |
| 5731.7620     | 26.00 | -1.299 | 4.256       | 62.2          | 55.2           |
| 5741.8480     | 26.00 | -1.853 | 4.256       | 19.4          | 23.1           |
| 5752.0320     | 26.00 | -1.176 | 4.549       | 54.8          | 51.6           |
| 5753.1230     | 26.00 | -0.687 | 4.260       | 108.3         | 100.0          |
| 5762.9920     | 26.00 | -0.449 | 4.209       | ...           | 142.9          |
| 5775.0810     | 26.00 | -1.297 | 4.220       | 61.7          | 56.6           |
| 5784.6580     | 26.00 | -2.531 | 3.397       | ...           | 22.0           |
| 5793.9150     | 26.00 | -1.699 | 4.220       | 24.6          | 34.5           |
| 5806.7250     | 26.00 | -1.049 | 4.608       | 51.2          | 45.6           |
| 5809.2180     | 26.00 | -1.839 | 3.884       | 43.5          | 44.2           |
| 5814.8080     | 26.00 | -1.969 | 4.283       | 15.7          | ...            |
| 5816.3740     | 26.00 | -0.600 | 4.549       | 80.5          | ...            |
| 5852.2190     | 26.00 | -1.329 | 4.549       | 36.1          | 24.5           |
| 5859.5860     | 26.00 | -0.418 | 4.549       | 89.2          | ...            |
| 5862.3560     | 26.00 | -0.126 | 4.549       | 122.6         | 109.6          |
| 5883.8170     | 26.00 | -1.359 | 3.960       | 82.6          | 69.0           |
| 5905.6720     | 26.00 | -0.729 | 4.652       | 58.4          | 53.6           |
| 5909.9740     | 26.00 | -2.586 | 3.211       | ...           | 45.0           |
| 5916.2470     | 26.00 | -2.993 | 2.453       | ...           | 67.9           |
| 5927.7890     | 26.00 | -1.089 | 4.652       | 36.0          | ...            |
| 5930.1800     | 26.00 | -0.229 | 4.652       | 117.9         | 116.0          |
| 5934.6550     | 26.00 | -1.169 | 3.929       | 101.9         | 86.0           |
| 5952.7180     | 26.00 | -1.439 | 3.984       | 75.5          | 58.4           |
| 5956.6940     | 26.00 | -4.604 | 0.859       | ...           | 63.4           |
| 5976.7770     | 26.00 | -1.242 | 3.943       | 90.0          | 58.3           |
| 5984.8150     | 26.00 | -0.195 | 4.733       | 106.2         | 95.3           |
| 5987.0650     | 26.00 | -0.428 | 4.796       | 80.3          | ...            |
| 6003.0120     | 26.00 | -1.119 | 3.882       | 117.7         | 97.2           |
| 6007.9600     | 26.00 | -0.596 | 4.652       | 70.8          | 60.0           |
| 6011.5560     | 26.00 | -0.985 | 3.884       | 121.8         | 109.3          |
| 6020.1690     | 26.00 | -0.269 | 4.608       | ...           | 131.0          |
| 6024.0580     | 26.00 | -0.119 | 4.549       | 153.4         | ...            |
| 6027.0510     | 26.00 | -1.088 | 4.076       | 80.8          | 77.5           |
| 6056.0050     | 26.00 | -0.459 | 4.733       | 91.8          | 74.3           |
| 6062.8480     | 26.00 | -4.139 | 2.176       | 17.9          | ...            |
| 6078.4910     | 26.00 | -0.320 | 4.796       | 97.2          | 82.4           |
| 6082.7110     | 26.00 | -3.572 | 2.223       | 40.7          | 31.9           |
| 6085.2590     | 26.00 | -3.094 | 2.759       | 33.3          | ...            |
| 6093.6440     | 26.00 | -1.499 | 4.608       | 30.1          | ...            |
| 6096.6650     | 26.00 | -1.929 | 3.984       | 40.8          | 34.4           |
| 6098.2450     | 26.00 | -1.879 | 4.559       | 17.0          | ...            |
| 6127.9070     | 26.00 | -1.398 | 4.143       | ...           | 43.3           |
| 6151.6180     | 26.00 | -3.298 | 2.176       | 65.3          | 59.4           |
| 6157.7280     | 26.00 | -1.259 | 4.076       | 79.3          | 62.6           |
| 6165.3600     | 26.00 | -1.473 | 4.143       | ...           | 39.1           |
| 6170.5070     | 26.00 | -0.439 | 4.796       | 91.3          | 77.4           |
| 6173.3360     | 26.00 | -2.879 | 2.223       | 99.9          | 89.8           |
### Table A.1: continued.

| Wavelength (Å) | Z   | Log gf | $\chi_{ex}$ (eV) | HQ Car (EW(mÅ)) | DD Vel (EW(mÅ)) |
|----------------|-----|--------|------------------|-----------------|-----------------|
| 6180.2040      | 26.00 | -2.585 | 2.728            | 67.3            | 62.8            |
| 6187.9900      | 26.00 | -1.719 | 3.943            | 43.6            | 45.2            |
| 6200.3130      | 26.00 | -2.436 | 2.609            | 102.7           | 96.9            |
| 6213.4300      | 26.00 | -2.481 | 2.223            | 140.4           | 131.6           |
| 6215.1440      | 26.00 | -1.319 | 4.186            | 73.8            | ...             |
| 6219.2810      | 26.00 | -2.432 | 2.198            | ...             | 158.5           |
| 6220.7840      | 26.00 | -2.459 | 3.882            | 18.4            | ...             |
| 6226.7360      | 26.00 | -2.219 | 3.884            | 24.3            | ...             |
| 6229.2280      | 26.00 | -2.804 | 2.845            | 56.1            | 44.5            |
| 6232.6410      | 26.00 | -0.732 | 3.603            | 161.7           | 153.7           |
| 6236.3620      | 26.00 | -2.407 | 2.453            | ...             | 134.5           |
| 6265.1340      | 26.00 | -2.549 | 2.176            | ...             | 134.7           |
| 6271.2790      | 26.00 | -2.702 | 3.332            | 25.1            | ...             |
| 6290.9650      | 26.00 | -0.773 | 4.733            | ...             | 54.6            |
| 6297.7930      | 26.00 | -2.739 | 2.223            | ...             | 101.4           |
| 6301.5010      | 26.00 | -0.717 | 3.654            | ...             | 161.6           |
| 6311.5000      | 26.00 | -3.140 | 2.832            | 36.8            | 24.9            |
| 6322.6860      | 26.00 | -2.425 | 2.588            | 107.2           | 96.1            |
| 6336.8240      | 26.00 | -0.855 | 3.686            | 147.0           | 132.2           |
| 6344.1490      | 26.00 | -2.922 | 2.433            | 69.7            | 72.1            |
| 6355.0290      | 26.00 | -2.349 | 2.845            | 92.4            | 79.3            |
| 6358.6980      | 26.00 | -4.467 | 0.859            | 105.4           | 100.7           |
| 6364.3660      | 26.00 | -1.429 | 4.796            | 26.5            | ...             |
| 6380.7430      | 26.00 | -1.375 | 4.186            | 50.7            | 45.6            |
| 6392.5390      | 26.00 | -4.029 | 2.279            | 16.7            | ...             |
| 6408.0180      | 26.00 | -1.017 | 3.686            | 135.9           | ...             |
| 6419.9500      | 26.00 | -0.239 | 4.733            | 109.5           | 88.6            |
| 6475.6240      | 26.00 | -2.941 | 2.559            | 81.2            | 61.7            |
| 6481.8700      | 26.00 | -2.983 | 2.279            | ...             | 82.7            |
| 6498.9390      | 26.00 | -4.698 | 0.958            | 55.7            | 51.7            |
| 6518.3670      | 26.00 | -2.459 | 2.832            | 74.6            | 63.2            |
| 6533.9290      | 26.00 | -1.459 | 4.559            | 28.4            | 29.8            |
| 6593.8710      | 26.00 | -2.421 | 2.433            | 123.2           | 112.1           |
| 6597.5610      | 26.00 | -1.069 | 4.796            | 40.8            | 44.6            |
| 6609.1100      | 26.00 | -2.691 | 2.559            | 78.1            | 71.9            |
| 6625.0220      | 26.00 | -5.349 | 1.011            | 23.6            | ...             |
| 6627.5450      | 26.00 | -1.679 | 4.549            | 21.3            | ...             |
| 6663.4420      | 26.00 | -2.478 | 2.424            | ...             | 127.2           |
| 6703.5567      | 26.00 | -3.159 | 2.759            | 30.9            | 30.5            |
| 6710.3200      | 26.00 | -4.879 | 1.485            | 14.7            | ...             |
| 6715.3830      | 26.00 | -1.639 | 4.608            | 18.7            | ...             |
| 6725.3570      | 26.00 | -2.299 | 4.103            | 14.1            | ...             |
| 6726.6660      | 26.00 | -1.132 | 4.607            | 39.8            | 32.2            |
| 6733.1510      | 26.00 | -1.579 | 4.638            | 24.6            | 17.4            |
| 6739.5220      | 26.00 | -4.793 | 1.557            | 12.4            | ...             |
| 6750.1530      | 26.00 | -2.620 | 2.424            | 116.7           | 100.9           |
| 6752.7070      | 26.00 | -1.203 | 4.638            | 29.9            | ...             |
| 6783.7040      | 26.00 | -3.979 | 2.588            | 11.4            | ...             |
| 6786.8600      | 26.00 | -2.069 | 4.191            | 24.2            | ...             |
| 6804.0010      | 26.00 | -1.495 | 4.652            | 18.4            | ...             |
| 6806.8450      | 26.00 | -3.209 | 2.728            | 37.9            | 33.1            |
| 6810.2630      | 26.00 | -0.985 | 4.607            | 45.7            | 36.3            |
| 6820.3720      | 26.00 | -1.319 | 4.638            | 28.5            | 32.7            |
| 6828.5910      | 26.00 | -0.919 | 4.638            | 58.0            | 50.6            |
| 6837.0060      | 26.00 | -1.686 | 4.593            | 19.7            | ...             |
| 6839.8310      | 26.00 | -3.449 | 2.559            | 30.3            | 23.8            |
| 6841.3390      | 26.00 | -0.749 | 4.607            | 85.3            | 61.9            |
| 6842.6860      | 26.00 | -1.319 | 4.638            | 33.9            | 27.5            |
Table A.1: continued.

| Wavelength Å | Z   | Log gf | $\chi_{ex}$ eV | HQ Car EW(mÅ) | DD Vel EW(mÅ) |
|--------------|-----|--------|----------------|----------------|---------------|
| 6843.6560    | 26.00 | -0.929 | 4.549          | 70.4           | 58.0          |
| 6855.1620    | 26.00 | -0.741 | 4.559          | ...            | 75.4          |
| 6858.1500    | 26.00 | -0.929 | 4.608          | 58.3           | 36.1          |
| 7024.6430    | 26.00 | -1.079 | 4.559          | ...            | 38.0          |
| 7038.2230    | 26.00 | -1.299 | 4.218          | ...            | 57.4          |
| 7068.4100    | 26.00 | -1.379 | 4.076          | 71.6           | 54.8          |
| 7090.3840    | 26.00 | -1.209 | 4.231          | 69.2           | 62.0          |
| 7127.5680    | 26.00 | -1.045 | 4.988          | 24.8           | ...           |
| 7130.9220    | 26.00 | -0.789 | 4.218          | 112.3          | 98.8          |
| 7132.9860    | 26.00 | -1.627 | 4.076          | ...            | 32.5          |
| 7151.5000    | 26.00 | -3.729 | 2.484          | 28.0           | ...           |
| 7189.1450    | 26.00 | -2.770 | 3.071          | 49.0           | 31.1          |
| 7219.6850    | 26.00 | -1.689 | 4.076          | 34.0           | 33.5          |
| 7284.8530    | 26.00 | -1.749 | 4.143          | 29.8           | 32.6          |
| 7306.5620    | 26.00 | -1.739 | 4.178          | 40.1           | 36.2          |
| 7351.5120    | 26.00 | -0.636 | 4.956          | 52.7           | ...           |
| 7411.1530    | 26.00 | -0.298 | 4.283          | 138.7          | 135.0         |
| 7440.9120    | 26.00 | -0.572 | 4.913          | ...            | 44.5          |
| 7473.0220    | 26.00 | -1.819 | 4.186          | 29.2           | ...           |
| 7461.5210    | 26.00 | -3.579 | 2.559          | 22.8           | ...           |
| 7491.6470    | 26.00 | -0.898 | 4.301          | 75.3           | 73.3          |
| 7568.8990    | 26.00 | -0.772 | 4.283          | ...            | 76.7          |
| 7583.7880    | 26.00 | -1.884 | 3.018          | 107.0          | 102.4         |
| 7586.0180    | 26.00 | -0.457 | 4.313          | ...            | 151.2         |
| 7710.3650    | 26.00 | -1.112 | 4.220          | ...            | 67.7          |
| 7748.2690    | 26.00 | -1.750 | 2.949          | 150.6          | 141.3         |
| 7751.1090    | 26.00 | -0.752 | 4.991          | 45.4           | 33.5          |
| 7780.5570    | 26.00 | 0.029  | 4.473          | 149.8          | 164.3         |
| 7807.9090    | 26.00 | -0.540 | 4.991          | 52.6           | ...           |
| 7832.1950    | 26.00 | 0.111  | 4.435          | ...            | 171.1         |
| 7855.3990    | 26.00 | -1.019 | 5.064          | 26.1           | ...           |
| 5120.3520    | 26.01 | -4.255 | 2.828          | ...            | 90.7          |
| 5132.6690    | 26.01 | -3.979 | 2.807          | ...            | 98.3          |
| 5161.1840    | 26.01 | -4.572 | 2.856          | ...            | 49.0          |
| 5256.9370    | 26.01 | -4.181 | 2.891          | ...            | 94.3          |
| 5414.0730    | 26.01 | -3.539 | 3.221          | ...            | 128.4         |
| 5425.2570    | 26.01 | -3.159 | 3.199          | ...            | 156.7         |
| 5627.4970    | 26.01 | -4.129 | 3.387          | ...            | 57.4          |
| 5901.3760    | 26.01 | -3.539 | 3.153          | ...            | 132.0         |
| 6084.1110    | 26.01 | -3.779 | 3.199          | ...            | 96.5          |
| 6113.3220    | 26.01 | -4.109 | 3.221          | 80.9           | 73.5          |
| 6149.2580    | 26.01 | -2.719 | 3.889          | ...            | 143.1         |
| 6233.5340    | 26.01 | -2.831 | 5.484          | 11.5           | ...           |
| 6369.4620    | 26.01 | -4.159 | 2.891          | ...            | 100.9         |
| 6383.7220    | 26.01 | -2.069 | 5.553          | 47.3           | 31.6          |
| 6416.9190    | 26.01 | -2.649 | 3.892          | ...            | 145.9         |
| 6432.6800    | 26.01 | -3.519 | 2.891          | ...            | 155.8         |
| 6442.9550    | 26.01 | -2.670 | 5.549          | ...            | 17.7          |
| 6446.4100    | 26.01 | -1.959 | 6.223          | 23.0           | ...           |
| 7222.3940    | 26.01 | -3.359 | 3.889          | ...            | 84.8          |
| 7449.3350    | 26.01 | -3.089 | 3.889          | 102.2          | ...           |
| 7479.6930    | 26.01 | -3.679 | 3.892          | 55.7           | 44.7          |
| 7515.8310    | 26.01 | -3.459 | 3.903          | 76.9           | 71.6          |
| 7711.7230    | 26.01 | -2.499 | 3.903          | 161.8          | ...           |
| 5483.3530    | 27.00 | -1.489 | 1.710          | ...            | 59.4          |
| 5647.2340    | 27.00 | -1.559 | 2.280          | 23.0           | ...           |
| 6188.9960    | 27.00 | -2.449 | 1.710          | 19.4           | ...           |
| 6771.0340    | 27.00 | -1.969 | 1.883          | 15.4           | 16.5          |
| 6814.9440    | 27.00 | -1.899 | 1.956          | 22.5           | ...           |
| 7084.9830    | 27.00 | -1.114 | 1.883          | 70.4           | 54.9          |
Table A.1: continued.

| Wavelength (Å) | Z  | Log gf | $\chi_{ex}$ (eV) | HQ Car EW(mÅ) | DD Vel EW(mÅ) |
|----------------|----|--------|------------------|---------------|--------------|
| 5000.3430      | 28.00 | -0.429 | 3.635           | ...           | 102.7        |
| 5003.7410      | 28.00 | -2.799 | 1.676           | ...           | 50.3         |
| 5010.9380      | 28.00 | -0.869 | 3.635           | ...           | 51.6         |
| 5032.7270      | 28.00 | -1.269 | 3.898           | ...           | 15.5         |
| 5035.3570      | 28.00 | 0.290  | 3.635           | ...           | 162.8        |
| 5048.8470      | 28.00 | -0.379 | 3.847           | ...           | 77.4         |
| 5080.5280      | 28.00 | 0.330  | 3.655           | ...           | 171.7        |
| 5081.1100      | 28.00 | 0.300  | 3.847           | ...           | 142.3        |
| 5082.3440      | 28.00 | -0.539 | 3.658           | ...           | 77.1         |
| 5084.0960      | 28.00 | 0.030  | 3.679           | ...           | 133.1        |
| 5099.9300      | 28.00 | -0.099 | 3.679           | ...           | 121.5        |
| 5115.3920      | 28.00 | -0.109 | 3.834           | ...           | 108.1        |
| 5155.1260      | 28.00 | -0.649 | 3.898           | ...           | 46.5         |
| 5155.7640      | 28.00 | 0.074  | 3.898           | ...           | 91.4         |
| 5176.5600      | 28.00 | -0.439 | 3.898           | ...           | 57.7         |
| 5435.8580      | 28.00 | -0.589 | 1.986           | ...           | 53.5         |
| 5578.7180      | 28.00 | -2.639 | 1.676           | 69.6          | 63.3         |
| 5587.8580      | 28.00 | -2.139 | 1.935           | ...           | 70.0         |
| 5593.7350      | 28.00 | -0.839 | 3.898           | 49.7          | 35.5         |
| 5663.9850      | 28.00 | -0.429 | 4.538           | ...           | 25.0         |
| 5694.9830      | 28.00 | -0.609 | 4.089           | ...           | 37.4         |
| 5754.6560      | 28.00 | -2.329 | 1.935           | 106.2         | ...          |
| 5760.8300      | 28.00 | -0.799 | 4.105           | 34.0          | ...          |
| 5805.2170      | 28.00 | -0.639 | 4.167           | 44.5          | 31.4         |
| 5831.5950      | 28.00 | -0.944 | 4.167           | 25.3          | 21.3         |
| 5846.9930      | 28.00 | -3.209 | 1.676           | 26.4          | 21.3         |
| 5996.7300      | 28.00 | -1.059 | 4.236           | 16.2          | ...          |
| 6086.2810      | 28.00 | -0.529 | 4.266           | 28.0          | 29.1         |
| 6108.1160      | 28.00 | -2.449 | 1.676           | 88.7          | 90.4         |
| 6111.0700      | 28.00 | -0.869 | 4.088           | 35.6          | 22.3         |
| 6128.9730      | 28.00 | -3.329 | 1.676           | 28.2          | ...          |
| 6133.9630      | 28.00 | -1.829 | 4.088           | 7.1           | ...          |
| 6175.3660      | 28.00 | -0.529 | 4.088           | 67.2          | 48.6         |
| 6176.8070      | 28.00 | -0.259 | 4.088           | 78.4          | 64.3         |
| 6204.6000      | 28.00 | -1.099 | 4.088           | 21.6          | ...          |
| 6223.9810      | 28.00 | -0.909 | 4.105           | 25.4          | 21.7         |
| 6259.5950      | 28.00 | -1.236 | 4.089           | 17.4          | ...          |
| 6322.1660      | 28.00 | -1.169 | 4.154           | 25.8          | ...          |
| 6327.5980      | 28.00 | -3.149 | 1.676           | 42.4          | 37.7         |
| 6360.8110      | 28.00 | -1.026 | 4.167           | 15.5          | ...          |
| 6366.4800      | 28.00 | -0.873 | 4.167           | 17.7          | ...          |
| 6378.2470      | 28.00 | -0.829 | 4.154           | 33.3          | 28.1         |
| 6532.8730      | 28.00 | -3.389 | 1.935           | 23.9          | ...          |
| 6586.3100      | 28.00 | -2.809 | 1.951           | 53.0          | 37.7         |
| 6598.5980      | 28.00 | -0.979 | 4.236           | 30.4          | ...          |
| 6635.1220      | 28.00 | -0.819 | 4.419           | 16.8          | ...          |
| 6767.7720      | 28.00 | -2.169 | 1.826           | 137.5         | 120.5        |
| 6772.3150      | 28.00 | -0.979 | 3.658           | 58.7          | 46.3         |
| 6914.5590      | 28.00 | -2.269 | 1.951           | ...           | 86.3         |
| 7110.8960      | 28.00 | -2.979 | 1.935           | 35.9          | ...          |
| 7122.1970      | 28.00 | 0.040  | 3.542           | 159.0         | 153.9        |
| 7181.9690      | 28.00 | -0.739 | 3.743           | 79.3          | 74.4         |
| 7385.2370      | 28.00 | -1.969 | 2.740           | 38.6          | ...          |
| 7422.2750      | 28.00 | -0.139 | 3.635           | 134.7         | 139.5        |
| 7522.7590      | 28.00 | -0.464 | 3.658           | 95.6          | 90.7         |
| 7525.1110      | 28.00 | -0.432 | 3.635           | 99.8          | 82.1         |
| 7555.5970      | 28.00 | 0.054  | 3.847           | 129.3         | 120.0        |
| 7574.0420      | 28.00 | -0.448 | 3.833           | ...           | 74.8         |
| 7797.5800      | 28.00 | -0.184 | 3.898           | 102.9         | 97.1         |
| 4722.1530      | 30.00 | -0.337 | 4.030           | ...           | 143.8        |
Table A.1: continued.

| Wavelength  | Z  | Log gf | $\chi_{ex}$ | HQ Car EW(mÅ) | DD Vel EW(mÅ) |
|-------------|----|--------|-------------|---------------|---------------|
| Å           | eV |        |             |               |               |
| 4810.5280   | 30.00 | -0.136 | 4.078       | ...           | 163.0         |
| 5087.4160   | 39.01 | -0.169 | 1.084       | ...           | 75.9          |
| 5200.4060   | 39.01 | -0.569 | 0.992       | ...           | 54.1          |
| 5509.8950   | 39.01 | -0.947 | 0.992       | ...           | 39.7          |
| 6613.7320   | 39.01 | -0.847 | 1.748       | 27.6          | ...           |
| 6795.4140   | 39.01 | -1.029 | 1.738       | 14.9          | ...           |
| 6407.2160   | 40.01 | -2.699 | 0.154       | 55.7          | ...           |
| 6262.2900   | 57.01 | -1.219 | 0.403       | 19.6          | ...           |
| 6320.3760   | 57.01 | -1.609 | 0.173       | 19.8          | ...           |
| 6390.4800   | 57.01 | -1.409 | 0.321       | 17.8          | ...           |
| 5092.7900   | 60.01 | -0.609 | 0.380       | ...           | 32.3          |
| 5130.5900   | 60.01 | 0.450  | 1.304       | ...           | 32.5          |
| 5740.8600   | 60.01 | -0.529 | 1.160       | 11.5          | ...           |
| 6645.0940   | 63.01 | -0.161 | 1.380       | 66.5          | ...           |