CHEMICAL COMPOSITION AND ATMOSPHERE PARAMETERS OF THE DOUBLE-MODE CEPHEID U TRA

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ABSTRACT. Four high-resolution spectra of the doble-mode Cepheid U TrA have been obtained during its pulsational period. For the first time, we obtained accurate atmosphere parameters and the chemical abundance of a number of elements, in particular of sodium, magnesium, and aluminium. We estimated the mean $T_{\rm eff}$ = 6085±29 K, log g = 2.00±0.15, and $\rm V_t$ = 3.90±0.25 km s^{-1} . A deficit of carbon ([C/H] = –0.35±0.23 dex), overabundance of both sodium ([Na/H] = +0.15±0.25 dex) and aluminium ([Al/H] = +0.30±0.32 dex) are typical for Cepheids passing through the first dredge-up phase. The abundance of iron ([Fe/H] = +0.01±0.15 dex) is very close to the solar one. Moreover, we find that α-elements, those of Fe-group, as well as "light"- and "heavy"-, s- and r-process elements, all of them have abundances close to solar values, too, excepting maybe several elements with slight enhance or deficit.

1. Introduction

U TrA (*F8Ib/II*) is one of the doble-mode Cepheids variables. Being 2.57 days pulsational period's variable in the fundamental mode, it has a beat period of 6.304 days. According to Jansen (1962) the $P_1/P_0 = 0.7105$, therefore its first overtone period is equal to 1.825 day.

Spectroscopic investigations of U TrA were realized by Rodgers & Gingold (1973) and Barrell (1981, 1982). The first authors determined the mean $\rm T_{\it eff}$ = 6146 K; and $\log g$ = 2.1± 0.6, using the curve-of-growth method. Some years later Barell (1981), using 17 H_α line spectra determined the mean effective temperature as 5957 K, but using the curve-of-growth metod, she determined such mean atmosphere parameters: $\rm T_{\it eff}$ = 6215 K, $\log g$ = 2.35±0.5, $\rm V_{\it t}$ = 4.8±0.1 km s^{-1}, and [Fe/H] = –0.02 dex. After that any more detailed spectroscopic investigations of this double-mode Cepheid did not carried out.

Therefore, the main aim of this work was to determine the atmosphere parameters and chemical composition using four spectra of U TrA, obtained in different phases of its pulsational period.

2. Observations and primary reduction

The observations were performed in August 2011 with GIRAFFE (Grating Instrument for Radiation Analysis with a Fibre Fed Echelle) spectrograph mounted at the Coudé focus of the 1.9m telescope at the South African Astronomical Observatory (SAAO), South Africa. Four spectra of this Cepheid have been obtained during weekly observational set. Information about U TrA spectroscopic observations and heliocentric radial velocity measurements are given in Table 1. Phases were calculated according to Berdnikov (2013) ephemeris:

$$HJD_{max} = 2455122.8479 + 2.56844306E \qquad (1)$$

Since specrum 1080030 was obtained with low S/N ratio estimation we have leaved out it from further investigations.

GIRAFFE allows to obtain high-resolution CCD echelle spectra (R = 39 000) due to two dispersional prisms optimized for the blue (3770–5560Å) and red (5200–10400Å) spectral ranges. For our observations we used the red prism and a fiber with a projection diameter of 2". The detector was a 1024 × 1024 pixel TEK6 CCD camera. The total recorded spectral range (4300–6750 Å) contained 48 spectral orders.

Table 1: Observations log and radial velocity measurements.

Spectrum	HJD 2450000+	Phase	Exp. (min.)	RV ($\mathrm{km\,s^{-1}}$)
1080030	5784.3244	0.540	20	$+0.31 \pm 0.11$
1080101	5785.2752	0.910	20	-13.05 ± 0.10
1080155	5787.3440	0.716	20	$+3.80 \pm 0.09$
1080177	5788.2297	0.060	20	-37.42 ± 0.16

At the beginning of each night and before each exposure, we observed the spectra of a hollow-cathode (Th+Ar) lamp, which allowed us to take into account all temperature trends by cross-correlating the 2D images of comparison spectra during the reduction. On each night, we also observed CAMERA FLATS to correct the pixel sensitivity and FIBER FLATS to find the position of spectral orders and to apply a correction for the spectral sensitivity effect along each order (blaze correction).

We performed the primary reduction of CCD images using the standard XSPEC2 software (Balona 1999). It included: (1) background substraction; (2) search for and extraction of the 1D fragments corresponding to individual orders from the 2D images; (3) blaze correction; (4) construction of the dispersion curves from hollow-cathode lamp spectra; (5) conversion to the wavelength scale; (6) applying the heliocentric correction; (7) determining the radial velocity by cross-correlation.

The subsequent work with the spectra, including such procedures as the continuum placement, the wavelength calibration of lines, and the measurements of line equivalent widths was performed with the DECH20 software package (Galazutdinov 1992).

3. Atmosphere parameters and chemical composition

We have estimated the following atmosphere parameters.

1. Effective temperatures, $T_{\rm eff}$; they were determined using spectroscopic criteria based on the depth ratio of selected pairs of the spectral lines most sensitive to the temperature (Kovtyukh & Gorlova, 2000). This method provides an internal accuracy in determining $T_{\rm eff}$ of the order of $\sim$ 10–30 K.

2. Surface gravity, $\log g$; it was derived from the ionization equilibrium condition for Fe I and Fe II atoms with accuracy of $\sim$ 0.15 dex).

3. Microturbulent velocity, V_t , was deduced (with accuracy of 0.25 $\mathrm{km\,s^{-1}}$) from the condition that the abundance of ionized iron Fe II, determined from a set of lines, should be independent of their equivalent widths (Kovtyukh & Andrievsky 1999).

The mean atmosphere parameters are given in Table 2.

Table 2: Atmosphere parameters of U TrA

Spectrum	Phase	$T_{\rm eff}$ (K)	$\log g$	V_t ($\mathrm{km\,s^{-1}}$)
1080030	0.540	–	–	–
1080101	0.910	6101±24	2.0	3.8
1080155	0.716	5577±36	1.7	3.7
1080177	0.060	6576±27	2.3	4.1
Mean		6085±29	2.0	3.9

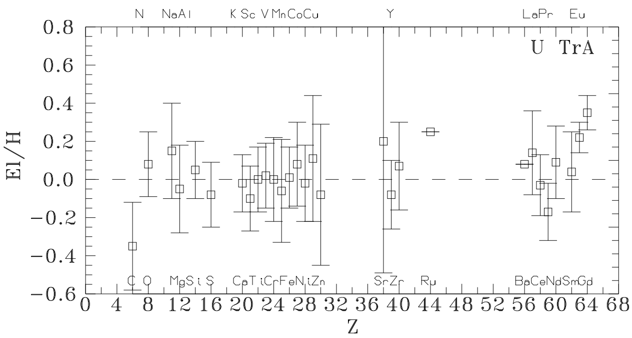

Figure 1: Averaged elemental abundances obtained for U TrA using our observations.

4. Chemical composition

All the atmosphere models and chemical abundances were calculated for each spectrum using our version of the WIDTH9 code on the basis of the Kurucz (1992) grid with the "solar" log gf values adopted from Kovtyukh & Andrievsky (1999). The data on the elemental abundances derived from each individual spectrum and averaged abundances of U TrA are given in Tables 3. Figure 1 shows the data of Table 3.

5. Conclusions

As seen from Table 2, the mean value of the effective temperature, 6085±29 K, is some smaller in comparison with 6146 K and 6215 K determinated by Rodgers & Gingold (1973) and Barrell (1982), respectively. Our surface gravity value of 2.00 formally coincides with Rodgers & Gingold (1973) estimate, but some smaller of Barrell's (1982) result. The same we can note about for the our estimate of microturbulent velocity.

Table 3: Elemental abundances in U TrA

Element	1080101			1080155			1080177			Mean		
	[El/H]	σ	NL	[El/H]	σ	NL	[El/H]	σ	NL	[El/H]	σ	NL
C I	–0.30	0.23	11	–0.36	0.23	12	–0.39	0.35	11	–0.35	0.23	34
O I	+0.00	0.05	2	–0.18	–	1	+0.21	0.06	3	+0.08	0.17	6
Na I	+0.29	0.28	6	+0.11	0.11	3	+0.02	0.21	6	+0.15	0.25	15
Mg I	+0.09	0.04	4	–0.04	0.33	5	–0.21	0.04	4	–0.05	0.23	13
Al I	–0.16	0.04	2	+0.23	0.02	2	+0.38	0.13	2	+0.30	0.32	6
Si I	+0.07	0.17	16	+0.07	0.22	16	–0.00	0.13	17	+0.05	0.16	49
Si II	–	–	–	–0.17	0.14	2	–	–	1	–0.17	0.14	2
S I	–0.04	0.29	4	–0.06	0.05	3	–0.04	0.24	5	–0.08	0.17	12
Ca I	+0.11	0.24	10	–0.00	0.15	10	–0.05	0.13	16	–0.02	0.15	36
Sc I	+0.19	0.02	2	–	0.07	3	+0.29	0.09	2	+0.24	0.08	4
Sc II	–0.06	0.19	6	–0.17	0.21	9	–0.14	0.16	8	–0.12	0.17	23
Ti I	+0.07	0.20	29	+0.02	0.16	34	+0.01	0.21	36	+0.04	0.18	99
Ti II	–0.08	0.25	9	–0.11	0.11	8	–0.11	0.16	16	–0.10	0.15	33
V I	+0.13	0.24	9	+0.08	0.22	13	+0.03	0.21	7	+0.07	0.20	29
V II	–0.09	0.16	4	–0.02	0.08	4	–0.13	0.11	5	–0.08	0.12	13
Cr I	+0.09	0.20	37	–0.03	0.26	16	–0.09	0.23	42	–0.00	0.23	95
Cr II	–0.05	0.20	16	+0.01	0.23	13	–0.00	0.22	17	–0.01	0.21	46
Mn I	–0.07	0.26	13	–0.10	0.32	13	+0.06	0.25	12	–0.06	0.27	38
Fe I	+0.02	0.15	139	+0.01	0.19	153	+0.00	0.16	162	+0.01	0.17	454
Fe II	+0.02	0.14	29	+0.01	0.16	33	–0.00	0.12	33	+0.01	0.14	95
Co I	+0.11	0.25	14	–0.01	0.27	12	+0.10	0.17	14	+0.08	0.22	40
Ni I	+0.06	0.19	71	–0.04	0.21	52	–0.05	0.20	75	–0.02	0.20	198
Cu I	+0.17	0.26	3	–0.31	0.12	2	+0.27	0.28	4	+0.11	0.33	9
Zn I	–0.08	0.35	3	–0.05	–	1	–0.08	0.66	2	–0.08	0.37	6
Sr I	–	–	1	+0.17	0.76	2	+0.23	0.93	2	+0.20	0.69	4
Y II	+0.07	0.18	7	–0.12	0.24	8	–0.13	0.08	8	–0.08	0.18	23
Zr II	+0.01	0.23	5	–0.01	0.08	3	+0.15	0.26	7	+0.07	0.23	15
Ru I	–	–	1	+0.25	–	1	–	–	–	+0.25	–	1
Ba II	–	–	–	–	–	–	+0.08	–	1	+0.08	–	1
La II	+0.23	0.20	6	+0.17	0.18	3	+0.05	0.25	7	+0.14	0.22	16
Ce II	+0.03	0.21	8	–0.07	0.15	8	+0.04	0.23	10	–0.03	0.16	26
Pr II	–0.26	0.19	2	+0.01	–	1	–0.17	0.08	2	–0.17	0.15	5
Nd II	+0.16	0.14	19	+0.01	0.20	16	+0.05	0.24	13	+0.09	0.19	48
Sm II	–0.06	0.06	4	+0.08	0.47	2	+0.15	0.11	3	+0.04	0.21	9
Eu II	+0.17	–	1	–	–	–	+0.24	0.10	2	+0.22	0.08	3
Gd II	+0.41	–	1	–	–	–	+0.28	–	1	+0.35	0.09	2

With respect to the elemental abundances obtained in the present study, we would like to summarize the following points.

1. The iron abundance is very close to solar one and is in good agreement with the results of Barrell (1982).

2. We estimated for the first time the abundances of the "key elements" of yellow supergiants evolution. Carbon is surely in deficit, and the abundance of oxygen is close to the solar one.

3. Sodium is obviously overabundant, thereas the abundances of magnesium and aluminium are close to solar ones.

4. α- element abundances are close to the solar ones.

5. The same can be noted for the element of Fe-group, as well as for "light"- and "heavy"-, s-process and r-process elements: their abundances demonstrate either slight enhance or slight deficit in comparison with the solar values. The abundances of these elements were obtained for the first time for U TrA, as well.

Taken at face value, these results suggest that U TrA is probably a Cepheid after first dredge-up phase.

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