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Spectrophotometry of Wolf-Rayet Binary CQ Cephei

by

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ABSTRACT

Spectrophotometric observations of CQ Cep – the shortest period binary with WN component – are presented. Basing on the low dispersion spectra we obtain continous energy distribution and a consistent set of emission line fluxes in blue optical region. The Balmer-Pickering decrement method was applied for the H/He=0.60 abundance determination in the optically thin case

1. Introduction

CQ Cephei (HD 214419 = WR 155; V_{max}=8.63 mag, V_{min}=9.12 mag) is an eclipsing binary with a period of 1.64 d. One component is a WN7 star and a companion is probably a massive early type star (van der Hucht *et al.* 1981). The distance between the stars is probably the smallest known for such a massive system.

The binary nature of CQ Cep was discovered by Mc Laughlin and Hiltner (1941) using prismatic plates with dispersion of 150 Å/mm. A more extensive study of CQ Cep was made by Hiltner (1944) based on a series of 50 plates with dispersion of 40 Å/mm. He found no evidence for the secondary spectrum and derived the first spectroscopic orbit. He determined circular elements from the NIV λ4058 emission line which he found to vary little in intensity, while the HeII λ4686 emission showed a single radial velocity curve with high eccentricity and reduced velocity amplitude together with appreciable variations in structure and intensity.

Hiltner (1950) attempted to explain the behaviour of the HeII λ4686 emission line by assuming that although the nitrogen lines are produced more or less symmetrically, the HeII lines are produced throughout a common envelope surrounding both stars. An interesting finding by Hiltner (1950) was that the behaviour of HeII λ4686: its minima occured at phases 0.25 and 0.75 and the intensity increased at phases 0.0 and 0.5. This behaviour was further investigated by Bappu (1951, 1952) and Bappu and Sinvhal (1955, 1959) who pointed out that not only other HeII lines but also NIII λ4528, NIV λ4058 and NV λ4604 lines followed the same pattern as λ4686.

Gaposhkin (1944) discovered that CQ Cep is an eclipsing binary. Many light curves of the star have been obtained by Soviet observers (see references in Leung *et al.* 1983). These curves resemble light curves of the contact W UMa systems. Variability of orbital period and of the shape of the light curve was also discovered (see *e.g.* Stickland *et al.* 1988, Antokhina and Cherepashchuk 1988).

The extensive studies of CQ Cep were done by Stickland *et al.* (1984), who analyzed the IUE data, $UBVJKL$ photometry and the radial velocities in the optical region obtained from Hiltner's (1950) plates. Stickland *et al.* (1984) obtained a total of 18 continuum light curves covering the wavelength range 0.13–0.3 μm. Kartasheva and Snezhko (1985) claim to have detected the spectrum of the companion star, but Shylaja (1986) finds no spectroscopic signature for it.

The most recent study of CQ Cep is by Underhill *et al.* (1990), who report the radial velocities and line profiles shown by 22 spectra in the spectral range 5200 – 6000 Å. The spectral lines of the companion are not detected. The evolved massive model stars which show anomalous abundances on their surfaces (Maeder and Meynet 1987, Langer 1989) have surface brightnesses which do not agree with values deduced from the light curves of CQ Cep. The properties of the system are compatible with the suggestion by Bhatia and Underhill that Wolf-Rayet stars are young stars of solar composition still surrounded by a remnants of the primordial disk. Thus CQ Cep has become an important case in a discussion about the nature of W-R stars.

In former investigations energy distributions were obtained mostly from photometric measurements and there are significant differences among the authors. The measured line fluxes (Shylaja 1986) were based on the early 1950 observations by Bappu; moreover, the line fluxes published by Shylaja give line intensity ratios different from what could be expected for a WN7 star (see Section 5).

The aim of this paper is to present the results of a spectrophotometric study of CQ Cep based on the low dispersion spectra in the blue part of the optical region.

2. Observations and reduction

17 spectra were obtained on Kodak IIa-O plates with a slit spectrograph (Richardson and Brealey 1973) attached to the 0.9-m Cassegrain telescope at Toruń Observatory. The dispersion in the region from 3400 to 5000 Åwas about 160 Å/mm. The spectra of comparison star – a spectrophotometric standard α Lac (V=3.77 mag, MKSp=A2V) – were obtained before and after each observation; most exposures were about 2 hours. Averaged standard star spectrum was adopted in reduction procedure to remove atmospheric extinction (see below). The spectra are listed in the first two columns of Table 2, with the Julian Day of mid exposure and the

orbital phase derived from the ephemeris:

$$\text{JD Min. I} = 2432456.668 + 1.641246\,E$$

taken from Semeniuk (1968).

The spectra were scanned on Zeiss microphotometer with the automatic reduction system SOWA, using a calibration obtained with a spot sensitometer. The spectra were then analyzed using ReWiA – Astronomical Spectra Reducing Program (Borkowski, unpublished) working on an IBM PC computer. Wavelengths in CQ Cep spectra were estimated by comparison with the line positions in the spectra of α Lac and assuming the circular elements for the NIV λ4058 in CQ Cep spectra: $\gamma = (-53.4 \pm 2.3)$ km/s and $K = (297.4 \pm 2.7)$ km/s (Stickland *et al.* 1984).

All spectra were then calibrated to the absolute energy scale. Since the difference in zenital distance between studied and standard star is insignificant, the difference in the air mass between them may be neglected; thus comparing published (Voloshina *et al.* 1982) and observed energy distribution in α Lac spectra it was possible to derive the correction coefficients curve and apply them to CQ Cep spectra. In this way we removed the influence of the emulsion and spectrograph spectral sensitivity and atmospheric extinction, obtaining the spectral energy distribution $f_{CQ}(\lambda)$. To obtain the spectra in ergs cm^{-2}s^{-1}Å^{-1}, we still have to multiply this distribution by the α coefficient resulting from photometric relations. The expression for B-magnitude of CQ Cephei is the following:

$$m_{CQ} = -2.5\log \int_0^{+\infty} \Phi_B(\lambda)\alpha f_{CQ}(\lambda)\,\mathrm{d}\lambda + const \tag{1}$$

where $\Phi_B(\lambda)$ is the table value of B filter profile from Straižys (1977). For A0 spectral type star with $m_B = 0.0$ mag and spectral energy distribution $F_{A0}(\lambda)$ we have

$$m_{A0} = -2.5\log \int_0^{+\infty} \Phi_B(\lambda)F_{A0}(\lambda)\,\mathrm{d}\lambda + const = 0 \tag{2}$$

We determine

$$const = 2.5\log \int_0^{+\infty} \Phi_B(\lambda)F_{A0}(\lambda)\,\mathrm{d}\lambda \tag{3}$$

We also know (Straižys 1977) that

$$\int_0^{+\infty} \Phi_B(\lambda)F_{A0}(\lambda)\,\mathrm{d}\lambda \Big/ \int_0^{+\infty} \Phi_B(\lambda)\,\mathrm{d}\lambda = 6.4 \times 10^{-9}\ \text{ergs s}^{-1}\text{cm}^{-2} \tag{4}$$

thus

$$const = 2.5\log\int_0^{+\infty}\Phi_B(\lambda)\,\mathrm{d}\lambda + 2.5\log(6.4\times10^{-9}) \tag{5}$$

Going back to Eq. (2), we have

$$m_{A0} = -2.5\log(\int_0^{+\infty}\Phi_B(\lambda)F_{A0}(\lambda)\,\mathrm{d}\lambda/\int_0^{+\infty}\Phi_B(\lambda)\,\mathrm{d}\lambda) + 2.5\log(6.4\times10^{-9}) = 0 \tag{6}$$

Let

$$m_{cal} = -2.5\log(6.4\times10^{-9}) = 20.48 \tag{7}$$

For a star to be calibrated we have

$$m_{CQ} = -2.5\log(\alpha\int_0^{+\infty}\Phi_B(\lambda)f_{CQ}(\lambda)\,\mathrm{d}\lambda/\int_0^{+\infty}\Phi_B(\lambda)\,\mathrm{d}\lambda) - m_{cal} \tag{8}$$

From our spectra and the table of Straižys (1977) we can easily measure the quantity:

$$M_{CQ} = -2.5\log(\int_0^{+\infty}\Phi_B(\lambda)f_{CQ}(\lambda)\,\mathrm{d}\lambda/\int_0^{+\infty}\Phi_B(\lambda)\,\mathrm{d}\lambda) \tag{9}$$

We will have

$$m_{CQ} = -2.5\log\alpha + M_{CQ} - m_{cal} \tag{10}$$

and adopting the mean B-filter light curve m_{CQ} of Tchugainov (1960), which does not introduce the significant error in our result, we obtain the coefficient α for a spectrum in the given orbital phase. Finally we have

$$F_{CQ}(\lambda) = \alpha f_{CQ}(\lambda) \tag{11}$$

what gives the absolute energy scale (ergs $\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{\AA}^{-1}$) for our spectra. See Fig. 1 for an example.

This form of spectra can be used for deriving observed (reddened) spectral characteristics, which have the advantage of being independent of assumed reddening. Fortunately, in the optical region there are not significant differences in the value of $E(B-V)$ or mean extinction law adopted by different authors. Thus, for comparison purposes (dereddened spectra were mainly used for measurements published so far), we have adopted the mean extinction law for Cepheus region (Sudzius 1974) and $E(B-V) = 0.66$ (Hua *et al.* 1983). All spectral characteristics discussed below were determined from observed and dereddened spectra independently.

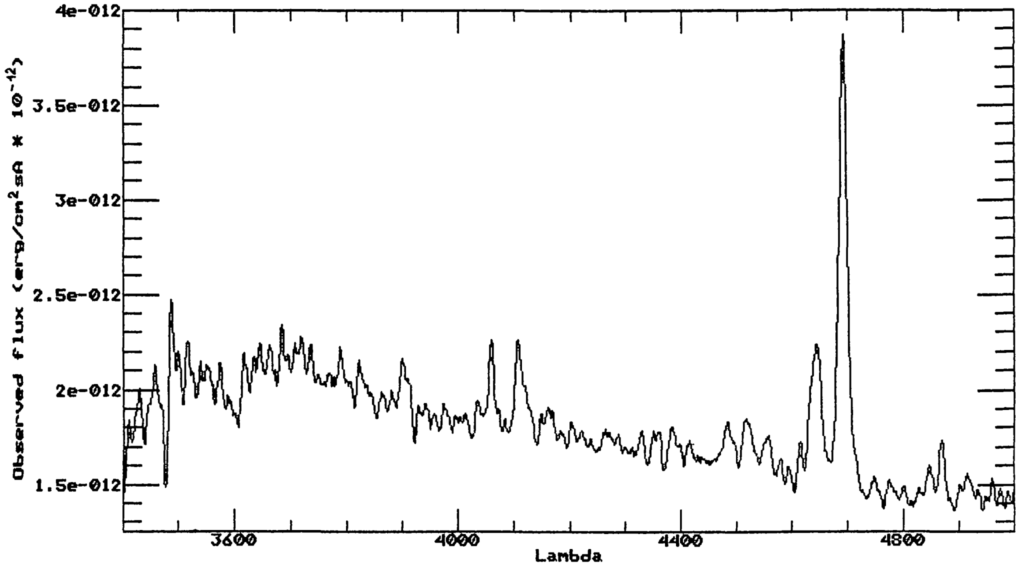

Fig. 1. The observed spectrum of CQ Cep in absolute energy scale. The strongest features are HeII, NIII and NIV lines. See Table 2 for an identification.

3. Continuous energy distribution

The spectra were normalized to the level of flux at λ5000 and converted to magnitude scale (see Fig. 2). Following earlier investigation of Shylaja (1986), the continuum was measured at eight selected wavelengths. Dereddened energy distributions are compared in Table 1. The observed deviations from mean distributions were used to determine the mean standard error (Table 1, column 7). The error in definition of the flux level at λ5000 is typically around 10%. Dereddened energy distributions are also compared in Fig. 3. A good agreement with the estimates of Cohen *et al.* (1975) and Stickland *et al.* (1984) is seen.

4. Monochromatic light curves

Following the paper by Shylaja (1986) three monochromatic light curves were constructed – for continuum at λλ 4260, 4780 and 5000 Å. They are shown in Fig. 4. Our data fit nicely with previous investigation. As it was expected, no significant dependence on wavelength is present. All curves are similar to the λ5300 light curve of Hiltner (1950).

5. Emission line fluxes

The only available measurements of emission line fluxes in optical region are those by Shylaja (1986). However, one can be aware of some inexactitudes of her study. First of all there is a difference between the values of fluxes listed in her

Table 1

Dereddened energy distribution, -2.5log (F_λ / F_{5000}) for CQ Cep.

Wavelength	Cohen *et al.* (1975)	Hua *et al.* (1982)	Stickland *et al.* (1984)	Shylaja (1986)	This study	Mean standard error
4037	-	-0.727	-	-0.682	-0.77	0.06
4150	-0.63	-	-0.65	-0.680	-0.66	0.07
4168	-	-0.688	-	-0.604	-0.64	0.07
4255	-0.57	-0.523	-0.61	-0.604	-0.55	0.08
4420	-0.40	-	-0.42	-0.572	-0.43	0.06
4460	-	-0.523	-	-0.525	-0.40	0.06
4560	-	-0.437	-	-	-0.32	0.04
4786	-0.13	-0.165	-0.13	-0.150	-0.15	0.02
5000	0.00	0.000	0.00	0.000	0.00	-

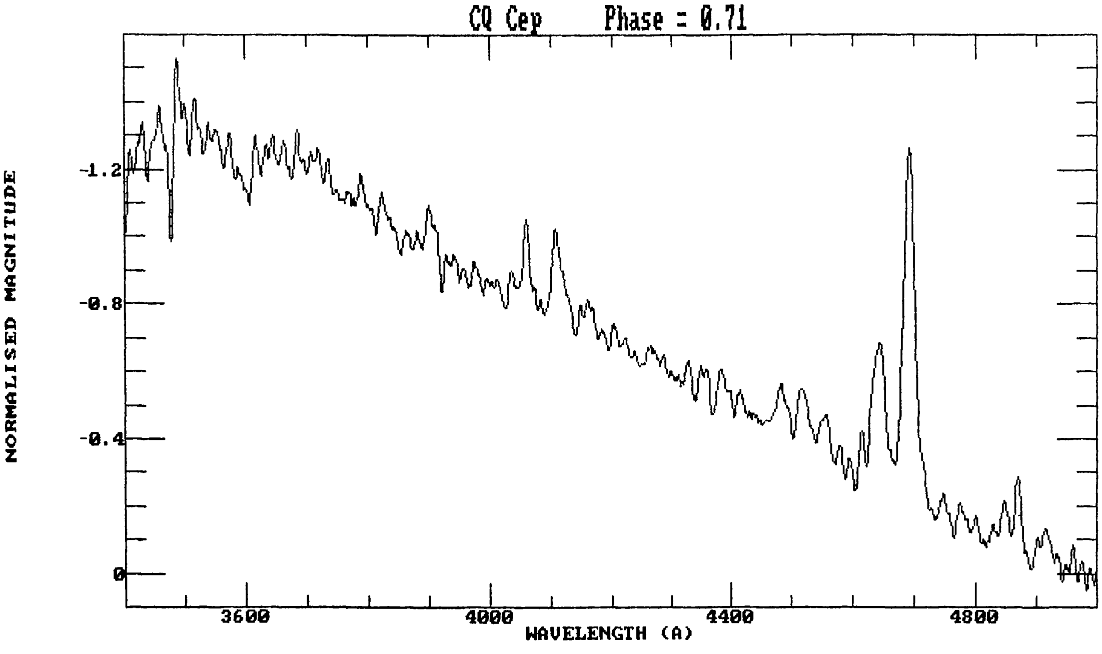

Fig. 2. Dereddened spectrum of CQ Cep normalised to λ5000 and converted to magnitude scale.

Table 1 and plotted in Figs. 3–7, which may have a simple explanation of being a printing error as the value of exponent differs. But there is no explanation for a strange line intensity ratios resulting from her values. For instance the flux of NIV λ4058 line is often greater then the flux of NIII λ4640, which is contradictory to catalogue classification of a WN7 type star (van der Hucht *et al.* 1981). Finally, the equivalent widths of HeII λ4861 and NIV λ4058 are about two times bigger

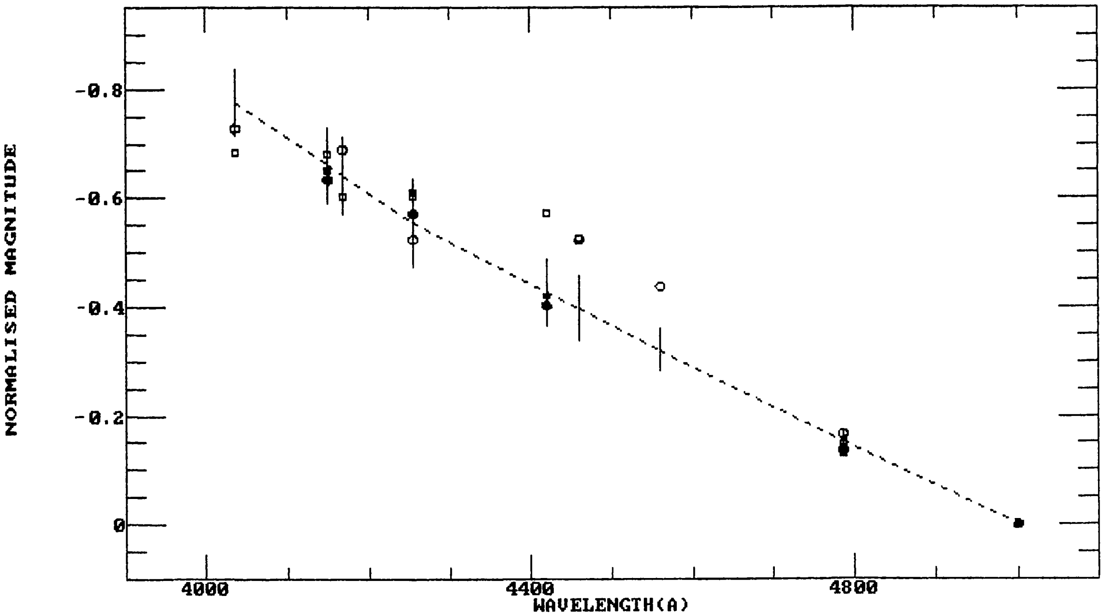

Fig. 3. Dereddened energy distributions from various studies: full circles – Cohen *et al.* (1975), open circles – Hua *et al.* (1982), full squares – Stickland *et al.* (1984), open squares – Shylaja (1986). Values corresponding to present study are connected by broken line with error bars marked by vertical dashes.

than those of HeII $\lambda4686$ line – the strongest known emission of WN7 stars.

We can compare equivalent widths determined from our spectra with those published by Conti and Massey (1989). For HeII $\lambda4686$ line we confirmed the $\log EW$ to change in the range 1.48 – 1.77 and for NIII in the range 0.98 – 1.28 for $\lambda4640$ line. Conti and Massey (1989) give the $\log EW$ value of 1.53 for HeII line and 1.07 for NIII line. Shylaja, after Bappu, claimed changes in $\log EW$ of HeII $\lambda4686$ line in the range 0.30 – 0.65. Thus, it is necessary to provide a consistent set of emission line fluxes.

Continuum was fitted using splines to line free points selected from the spectrum of a WN7 star (Smith and Kuhi 1981). Fluxes of emission lines were measured by numerical integrations of the profiles. Lines are often blended due to a relatively low dispersion of the spectra. We had to fit three Gauss profiles to resolved blends at $\lambda\lambda4058, 4100, 4121$ and at $\lambda\lambda4604, 4640$ and 4686. 18 lines and 2 HeII+NIII blends were measured, the weaker of them not in all spectra because of the noise. The results are given in Table 2.

Observed (in units of 10^{-12} ergs $\mathrm{cm}^{-2}\mathrm{s}^{-1}$) and dereddened (in units of 10^{-11} ergs $\mathrm{cm}^{-2}\mathrm{s}^{-1}$) fluxes of measured lines can be found in the table, both being determined independently. From independently processed and measured scans of the same spectra we derive error of single measurement around 15 – 20 %.

An example of the nature of these changes is given in Fig. 5. All line fluxes show enhancement at phases 0.0 and 0.5, except for the NV $\lambda4604$ line, blended and too weak to ascertain any firm statement. Shylaja (1986) also claimed that

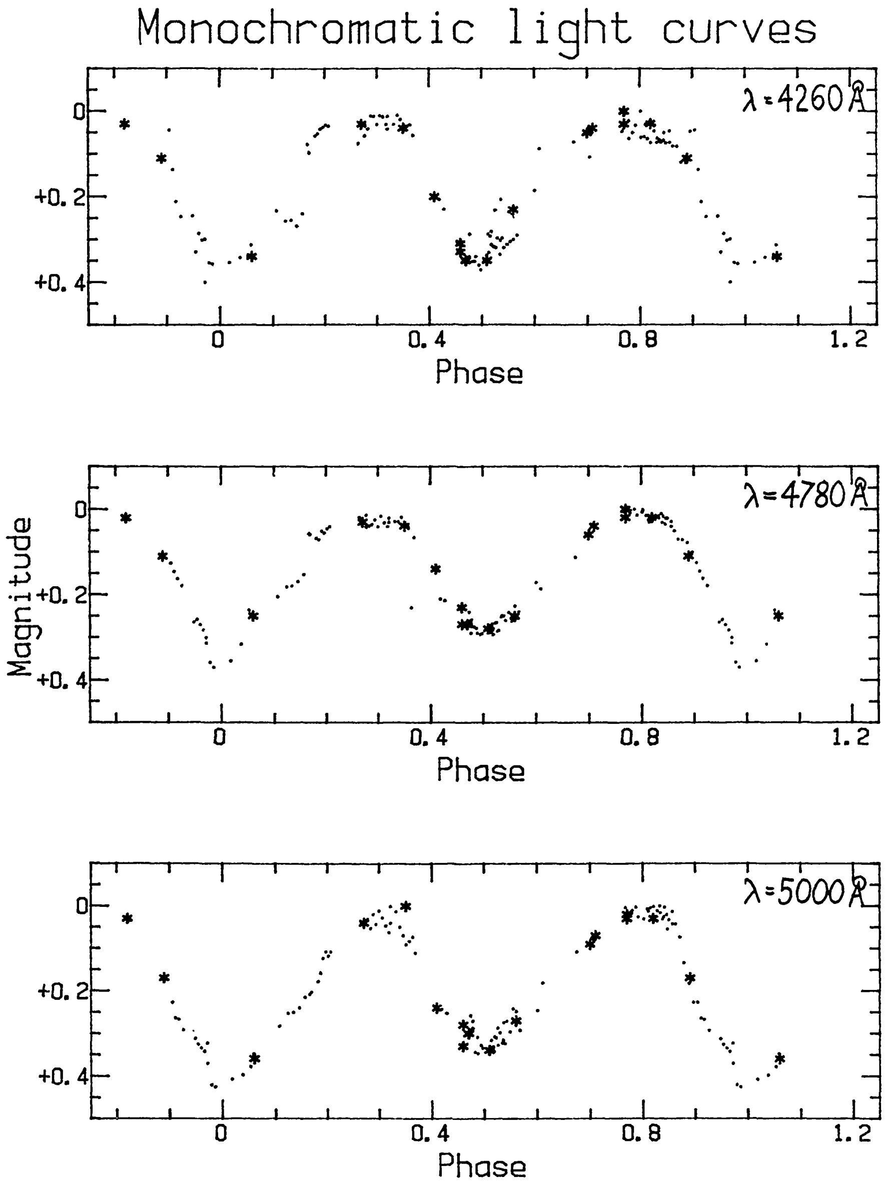

Fig. 4. (a – c) Monochromatic light curves at three wavelengths free of emission line effects. Points are values from Shylaja (1986), crosses correspond to present study.

intensities of all lines increase during eclipses, except for the NV λ4604 line, which shows eclipse effects. Our data cannot confirm that effect, but – taking into account other results – the majority of her analysis and conclusions is still valid. We only notice a more pronounced shift of the maxima to phases 0.4 and 0.9 practically for all lines and their unequal run, the one closer primary minimum being weaker and flattened comparing to the maximum around phase 0.4 – 0.5, which is narrow and sharp, especially for HeI lines.

Table 2

Emission line fluxes of CQ Cep

JD		N IV	3479 Å	He I	3705 Å	He I	3733 Å	N III	3755 Å
2440000	Phase	obs	der	obs	der	obs	der	obs	der
+		×e-12	×e-11	×e-12	×e-11	×e-11	×e-12	×e-11	×e-12
6557.53	0.56	3.18	8.19	1.07	1.62	1.39	1.27	2.11	3.18
6627.48	0.18	2.10	5.48	0.27	0.98	0.53	0.79	1.57	2.33
6643.50	0.94	3.58	8.83	1.04	1.62	-	-	1.87	4.42
7279.54	0.47	3.69	8.74	-	-	1.28	1.91	2.25	2.53
7291.40	0.70	2.25	6.37	-	-	0.97	1.69	1.96	3.61
7291.51	0.77	1.10	2.64	0.32	0.56	0.68	1.56	1.45	3.10
7297.38	0.35	1.42	3.91	-	-	0.77	1.49	1.97	2.24
7297.49	0.41	3.53	6.37	1.00	1.34	-	-	2.03	5.71
7307.41	0.46	4.08	6.74	1.13	2.08	1.57	2.36	2.20	4.40
7307.50	0.51	4.09	9.72	0.99	1.66	1.18	1.83	2.45	4.04
7309.47	0.71	1.87	7.16	0.68	0.93	0.89	1.20	-	-
7326.46	0.06	3.44	8.20	0.71	1.37	1.19	1.97	2.38	4.01
7328.45	0.27	-	-	0.48	1.22	0.69	-	1.50	2.88
7457.28	0.77	2.05	4.54	-	-	0.54	1.22	1.52	3.30
7457.37	0.82	1.47	4.25	0.85	1.02	-	-	1.85	2.74
7457.48	0.89	3.31	7.77	0.83	1.49	0.60	1.88	1.72	3.78
7691.46	0.46	4.07	9.40	1.12	1.93	-	-	2.30	4.10

JD		He I	3889 Å	N III	4002 Å	He I	4026 Å	N IV	4058 Å
2440000	Phase	obs	der	obs	der	obs	der	obs	der
+		×e-12	×e-11	×e-12	×e-11	×e-11	×e-12	×e-11	×e-12
6557.53	0.56	1.30	3.97	0.53	0.83	0.59	1.02	6.00	10.27
6627.48	0.18	1.45	2.90	0.64	0.71	0.24	1.32	6.50	10.29
6643.50	0.94	1.63	4.46	1.11	1.05	0.69	1.20	8.16	11.30
7279.54	0.47	2.08	5.52	0.90	1.05	1.98	2.51	6.81	10.29
7291.40	0.70	1.99	3.28	0.58	0.93	0.67	1.34	6.30	8.36
7291.51	0.77	1.50	3.10	-	-	0.97	1.71	7.07	9.51
7297.38	0.35	3.04	4.55	0.62	1.00	1.97	3.04	7.03	11.29
7297.49	0.41	3.00	4.83	0.91	1.29	1.66	3.01	8.19	12.52
7307.41	0.46	2.69	6.05	-	-	1.86	3.24	7.59	11.43
7307.50	0.51	1.63	5.19	0.69	1.01	1.53	2.36	7.22	9.85
7309.47	0.71	1.55	3.00	0.20	0.98	0.61	1.51	5.21	8.27
7326.46	0.06	1.69	3.68	1.15	1.03	1.20	1.82	7.85	12.34
7328.45	0.27	1.76	2.99	0.63	0.69	0.10	1.19	6.57	10.66
7457.28	0.77	1.36	1.95	-	-	0.14	1.17	6.73	9.02
7457.37	0.82	2.08	3.43	0.62	0.97	0.67	1.04	5.39	8.42
7457.48	0.89	1.73	3.73	0.81	1.18	0.85	1.47	7.50	11.35
7691.46	0.46	2.96	5.49	-	-	1.67	2.87	7.90	11.60

Table 2

continued

JD		Blend	4100 Å	Blend	4200 Å	N III	4321 Å	He II	4339 Å
2440000	Phase	obs	der	obs	der	obs	der	obs	der
+		×e-12	×e-11	×e-12	×e-11	×e-11	×e-12	×e-11	×e-12
6557.53	0.56	8.68	13.35	0.91	1.47	-	-	2.06	1.86
6627.48	0.18	8.35	12.17	-	-	-	-	1.64	1.68
6643.50	0.94	7.60	13.33	1.23	1.97	0.81	1.20	2.71	3.01
7279.54	0.47	9.59	14.39	-	-	-	-	1.82	3.01
7291.40	0.70	8.31	11.40	-	-	-	-	0.65	1.38
7291.51	0.77	8.07	12.69	1.01	0.98	-	-	1.55	2.04
7297.38	0.35	8.91	14.40	-	-	0.39	1.33	1.38	2.80
7297.49	0.41	9.20	13.89	1.27	2.08	0.76	1.35	2.48	3.15
7307.41	0.46	11.41	18.82	1.17	1.94	0.57	1.27	3.02	2.97
7307.50	0.51	9.67	15.12	1.21	2.31	0.80	1.19	-	-
7309.47	0.71	9.11	14.26	0.97	1.36	0.68	0.99	1.34	1.59
7326.46	0.06	10.40	15.81	1.17	1.98	0.67	0.92	2.42	3.40
7328.45	0.27	10.41	16.42	1.09	1.33	-	-	1.44	1.91
7457.28	0.77	8.57	13.07	1.17	1.36	-	-	1.22	1.81
7457.37	0.82	9.68	14.94	0.58	1.28	0.53	0.96	1.29	3.09
7457.48	0.89	10.93	16.27	0.96	1.91	0.78	1.11	2.13	2.70
7691.46	0.46	8.11	12.57	1.00	1.59	0.89	1.12	2.64	2.62
JD		N III	4379 Å	He I	4471 Å	N III	4511 Å	He II	4542 Å
2440000	Phase	obs	der	obs	der	obs	der	obs	der
+		×e-12	×e-11	×e-12	×e-11	×e-11	×e-12	×e-11	×e-12
6557.53	0.56	0.67	1.36	1.32	1.54	3.92	3.59	2.68	1.93
6627.48	0.18	-	-	1.07	1.73	3.27	3.11	2.36	2.06
6643.50	0.94	1.37	1.84	1.04	1.91	3.78	3.85	3.00	2.46
7279.54	0.47	-	-	-	-	3.83	3.31	3.07	2.63
7291.40	0.70	1.12	1.23	0.74	1.75	2.94	2.73	2.09	1.68
7291.51	0.77	0.59	1.12	0.76	1.45	2.80	2.50	1.82	1.94
7297.38	0.35	1.08	1.70	0.76	1.59	3.09	2.87	2.71	2.89
7297.49	0.41	1.19	1.72	1.93	2.55	3.45	3.39	3.28	3.21
7307.41	0.46	1.59	1.56	1.11	-	3.51	3.19	3.28	2.58
7307.50	0.51	1.78	2.20	-	-	3.65	4.23	3.17	2.60
7309.47	0.71	1.33	1.27	-	-	3.19	3.09	1.93	1.91
7326.46	0.06	0.92	0.53	1.40	1.80	3.95	4.08	2.18	2.89
7328.45	0.27	0.26	0.58	1.04	1.41	3.14	3.04	3.17	2.50
7457.28	0.77	0.69	1.10	0.92	1.93	3.12	3.23	-	-
7457.37	0.82	1.63	1.13	1.31	1.95	3.08	3.38	2.28	2.41
7457.48	0.89	-	-	1.20	2.10	3.86	3.55	2.86	2.83
7691.46	0.46	-	-	1.36	2.27	3.46	3.19	3.03	2.62

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Table 2

concluded

JD 2440000 +	Phase	N V 4604 Å obs ×e-12	 der ×e-11	N III 4640 Å obs ×e-12	 der ×e-11	He II 4686 Å obs ×e-11	 der ×e-12	He II 4861 Å obs ×e-11	 der ×e-12
6557.53	0.56	0.74	0.87	18.14	21.46	51.20	57.75	7.35	7.93
6627.48	0.18	0.10	0.10	16.68	19.32	46.35	52.96	4.36	4.40
6643.50	0.94	0.68	0.83	17.25	21.51	53.11	60.72	8.57	9.85
7279.54	0.47	-	-	17.13	22.30	57.27	63.91	9.62	8.97
7291.40	0.70	0.33	0.12	16.06	18.84	40.96	48.46	3.49	2.77
7291.51	0.77	0.44	0.31	15.89	19.25	45.73	51.98	5.44	4.07
7297.38	0.35	0.36	0.15	16.95	20.83	53.82	61.19	8.03	8.20
7297.49	0.41	-	-	17.58	22.02	56.21	62.66	9.28	8.87
7307.41	0.46	0.76	0.45	17.33	22.75	56.42	62.09	9.25	8.67
7307.50	0.51	0.53	0.57	17.75	22.16	53.97	61.89	8.06	7.83
7309.47	0.71	-	-	15.83	18.85	42.63	47.67	2.89	2.89
7326.46	0.06	0.64	0.50	17.56	21.29	50.42	59.34	8.55	8.61
7328.45	0.27	0.43	0.33	16.64	19.22	49.15	56.08	6.42	6.37
7457.28	0.77	-	-	16.29	19.16	44.54	51.35	4.37	3.71
7457.37	0.82	0.39	0.43	16.51	19.09	45.96	52.49	5.97	3.60
7457.48	0.89	-	-	17.23	21.51	51.07	61.30	6.77	7.02
7691.46	0.46	0.22	0.27	17.22	22.87	55.50	61.31	9.10	8.60

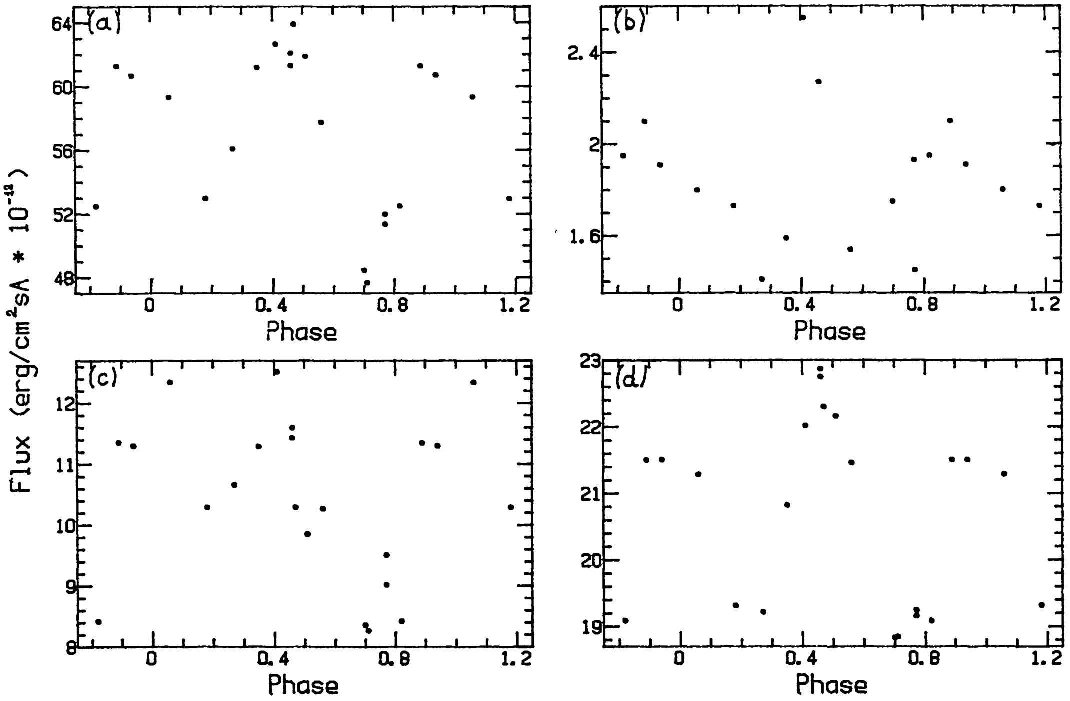

Fig. 5. (a – d). Fluxes of emission lines measured from dereddened spectra: (a) HeII λ4686, (b) HeI λ4471, (c) NIV λ4058, (d) NIII λ4640.

6. H/He ratio

Since even the low dispersion spectra may be useful at least for a rough estimate of hydrogen content in the envelopes of WN stars (Niedzielski 1989) we tried to apply a simple method for CQ Cep.

Several lines of HeII Pickering $(n-4)$ series appear in all spectra. Due to intristic broadening the lines with the even principal quantum number n are blended with HI Balmer $(n-2)$ lines. If any hydrogen in an envelope of a W-R star is present, these lines will appear stronger than the odd lines of the Pickering series. Thus the H/He ratio can be determined by comparing the even and odd Pickering lines.

Assuming that the lines are formed in an optically thin envelope $(n > 10)$ we have (Castor and Van Blerkom 1970):

$$F(\mathrm{H{+}He})/F(\mathrm{He}) = N(\mathrm{H}^{+})/N(\mathrm{He}^{++}) + 1 \qquad (12)$$

where F(H+He) and F(He) are fluxes measured from the blended and unblended Pickering lines.

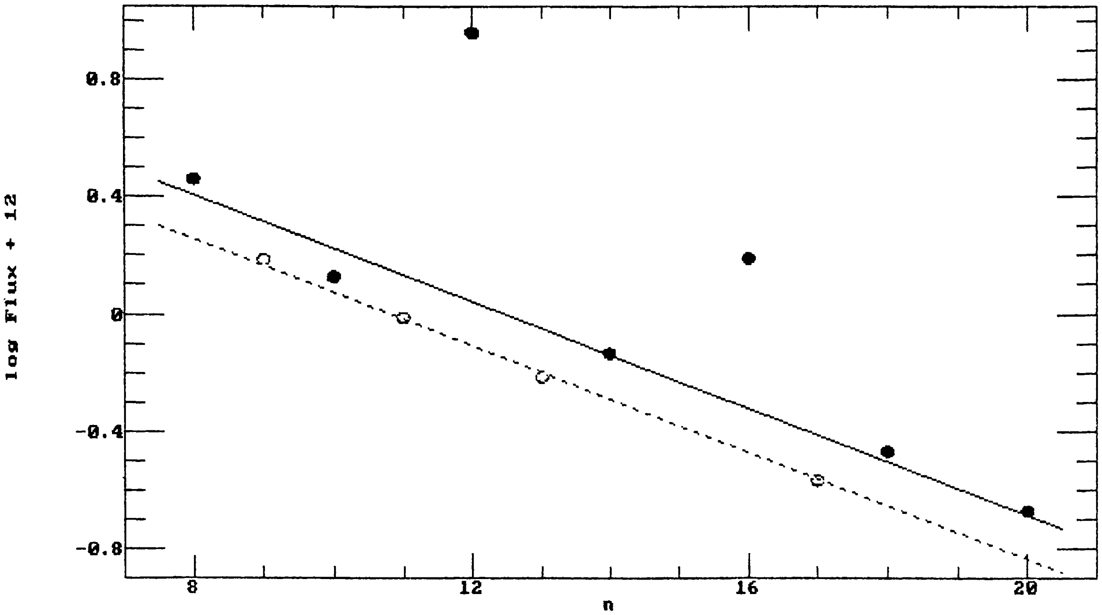

Fig. 6. Balmer-Pickering decrement for one of CQ Cep spectra. Full and open circles correspond to even and odd Pickering line fluxes; solid line is the best fit to even and dashed one to odd line fluxes. Lines with $n = 12$ and $n = 16$ are strong blends and were not used for fitting.

Usually it was possible to measure the fluxes of lines with $8 \leq n \leq 18$. Fig. 6 shows the observed Balmer-Pickering decrement for one of the spectra. Lines with $n = 12$ (λ4100) and $n = 16$ (λ3889) are strong blends (of NIII and HeI, respectively) – they give flux values useless for H/He determination. We had to draw two parallel lines – solid one as the best fit to even (full circles), and dashed one to odd line fluxes (open circles). The distance between the lines defines H/He ratio. From all our spectra we derive a mean value H/He = 0.66 ± 0.08 (standard error of a mean value), which is the first H/He determination for CQ Cep. Adopting Eq. (12) we assume that helium appears only as HeII; neglecting the contribution of HeI may cause an overestimation of H/He ratio. It is possible to estimate the influence of HeI by comparing two lines – according to Conti *et al.* (1983) we have in the optically thin case:

$$N(\mathrm{He}^{++})/N(\mathrm{He}^{+}) \approx 4 \times EW(4541)/EW(4471) \qquad (13)$$

For CQ Cep we find

$$EW(4541)/EW(4471) \approx 2.2$$

and hence

$$N(\mathrm{He}^{++})/N(\mathrm{He}^{+}) \approx 9$$

It means that our value of H/He should be approximately 10 % lower, *i.e.* H/He=0.60.

This result is in a good agreement with the estimates of Conti *et al.* (1983) for Galactic and Magellanic WN stars; they claim the hydrogen to appear more often for later WN subtypes (WN6 – WN9), deriving the H/He ratio for these stars being in the range 0.3 – 4.0. The H/He ratio obtained here can be treated as a rough estimate, thus we do not give precise error discussion.

7. Conclusions

Our spectrophotometric study of CQ Cep provides a set of data based on new spectral observations, supplementary for earlier investigations. Our results are not contradictory to a similar research made by Shylaja (1986), except for the numerical values of emission line fluxes. However, the nature of changes, *i.e.* enhancement of fluxes at minima, is confirmed: thus a model explaining observable characters remains valid and will not be discussed here.

The energy distributions obtained by us at various phases do not show a clear evidence of the change of slope of continuum, which could have been caused by an early-type companion. Thus, no signature of the companion is detectable in continuous spectrum.

Finally, in the optically thin case, we derive H/He ratio, H/He ≈ 0.60, which is the first abundance determination for CQ Cep.

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