Rev. Mexicana Astron. Astrof., 8, 141-145 (1983)

SPECTROPHOTOMETRY OF DWARF NOVAE

J. Echevarría

Astronomy Centre, University of Sussex and
Royal Greenwich Observatory

and

R. Costero

Instituto de Astronomía
Universidad Nacional Autónoma de México
Received 1983 March 24

RESUMEN

La espectrofotometría de siete novas enanas fue obtenida en la región λλ3800-5200 A; tres objetos fueron observados en erupción y cuatro cerca del mínimo. Las líneas de Balmer en emisión y absorción tienen anchos similares (∿ 4540 km s^{-1}). RU Peg, SS Cyg y AB Dra muestran emisión débil de C II λ 4267. En erupción, EM Cyg presenta emisión fuerte de He II λ4686. CY Lyr y UU Aql tienen, cerca del máximo, anchos equivalentes similares a los de una estrella B3 III.

Los cocientes de líneas de emisión, calculados por modelos de discos de acreción ópticamente delgados en estado estacionario, son menores que los cocientes observados. Estos últimos son ∿ 3 veces mayores que los del Caso B de recombinación. Los cocientes He I/H I observados son consistentes con los valores predichos por Williams y Ferguson (1982) para modelos con altas abundancias de helio.

ABSTRACT

The spectrophotometry of seven dwarf novae was obtained from λλ 3800-5200 A; three objects were observed during outburst and four near minimum. The Balmer lines in emission and absorption have similar widths (∿4540 km s^{-1}). RU Peg, SS Cyg and AB Dra show weak C II λ4267 in emission. EM Cyg shows strong He II λ 4686 in emission during outburst. CY Lyr and UU Aql have, near maximum, equivalent widths comparable with those of a B3 III star.

The emission line ratios from optically thin steady state accretion disc models are lower than the observed values. The latter are ∿ 3 times greater than Case B recombination values. The observed He I/H I flux ratios are consistent with the predicted values by Williams and Ferguson (1982) for models with high helium abundance.

Key words: SPECTROPHOTOMETRY – STARS-DWARF NOVAE – STARS-EMISSION LINES

I. INTRODUCTION

The first spectra of dwarf novae obtained by Adams and Joy (1921) and Joy (1940) showed a striking contrast between minimum and outburst stages; a strong continuum and weak absorption lines were observed at maximum, while at minimum, strong emission lines of H I were present, superimposed on a weak continuum. At this stage, the red continuum of a late type star was present in some systems and occasionally some absorption features. Later Elvey and Babcock (1940, 1943) identified lines of He I, He II and Ca II (H and K). A description of most of the spectra obtained by these and later authors can be found in the review by Warner (1976). These qualitative studies of the continuum and the emission and absorption lines provided essential understanding in the dwarf novae phenomena.

Theoretical models of accretion discs (Lynden-Bell 1969; Pringle 1974) in the now accepted standard model (see reviews by Robinson 1976 and Warner 1976), predict flux distributions which have been tested by photometric and spectrophotometric observations (cf. Bath, Pringle, and Whelan 1980; Echevarría and Jones 1983). Optically thin accretion disc models have been discussed by Williams (1980), Tylenda (1981) and Williams and Ferguson (1982), which include flux distributions and emission line ratios.

An observational program is currently in progress at the observatory in San Pedro Mártir, to obtain accurate spectrophotometry of dwarf novae, to compare the emission and absorption line fluxes with those predicted by theory. As part of this program we report here preliminary results on seven dwarf novae.

II. OBSERVATIONS

The observations were made on 1981 July 5-10 and August 3-8 with the 2.12 m telescope of the Observatory in San Pedro Mártir, using the Optical Multichannel Analyser (OMA) described by Firmani and Ruíz (1981) consisting of a WL30677 Westinghouse image intensifier

TABLE 1

JOURNAL OF SPECTROSCOPIC OBSERVATIONS OF DWARF NOVAE

Name	Date 1981	Ut Mid	Exposure	Exposure Time (s)	Run Number
SS Cyg	Jul 5	11	36	400	SP239
RU Peg	Jul 7	11	31	1200	SP245
	Aug 3	7	09	960	SP486
	Aug 3	7	39	960	SP487
	Aug 3	10	54	960	SP490
	Aug 4	6	53	960	SP494
	Aug 4	8	56	960	SP497
	Aug 4	10	46	1600	SP501
	Aug 5	10	00	1440	SP519
EM Cyg	Jul 8	9	49	1280	SP249
	Jul 8	10	47	3840	SP250
	Jul 9	9	08	1200	SP253
	Jul 10	7	33	3000	SP262
WW Cet	Aug 6	10	38	1440	SP520
AB Dra	Aug 7	10	03	1440	SP525
UU Aql	Aug 7	8	29	1200	SP524
	Aug 8	6	25	800	SP531
CY Lyr	Aug 7	7	30	2240	SP523
	Aug 8	6	58	1440	SP532

described by Ruíz (1974) and a SIT device described by Solar (1977). The OMA was coupled to a Boller and Chivens spectrograph with a 200 $\mathrm{l\,mm^{-1}}$ grating and gave a spectral resolution of about 4 Å $\mathrm{channel^{-1}}$ in its second order. The spectral region λλ 3800-5200 Å was covered. A wide entrance slit of 3 X 16.5 arcsec was used, where the first value is along and the second perpendicular to the dispersion, and gave an estimated spectral resolution of 25 Å; a second slit 7 arcsec east was used alternately for sky subtraction. The spectrophotometric standards BD + 28°4211, BD + 40° 4032 (Stone 1977) and LDS 749B (Oke 1974) were observed on the same nights. The DA white dwarf GRW + 70°8031 (Oke 1974) was also observed. An He-Ar arc lamp was used to obtain a linear calibrated wavelength scale.

The Journal of observations is given in Table 1. The seven dwarf novae reported here were constantly monitored by the AAVSO, and we have examined their light curves kindly given to us by J. Mattei. All spectra were reduced using the SPICA package, available on the STARLINK VAX Computer code at the Royal Greenwich Observatory.

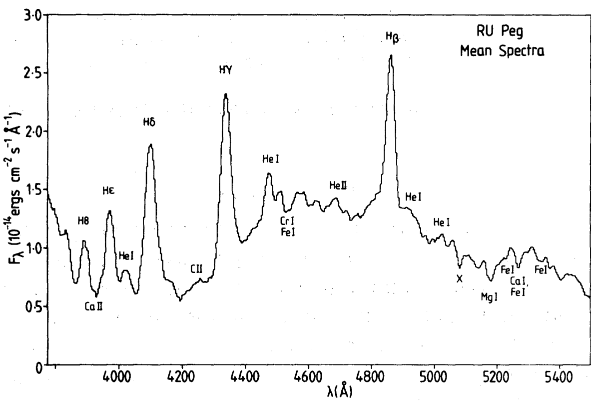

Fig. 1. Mean spectra of RU Peg during minimum light (∿ 12. mag, AAVSO). Note the absorption lines around λ 5200 from th late type secondary. The feature X is a spot in the detector.

III. RESULTS

Figures 1-4 show the four dwarf novae observed near minimum. Strong and broad Balmer lines in emission are visible down to H8. Their relative intensities ar tabulated in Table 2. The full width at zero intensit (FWZI) of the H I lines for all systems is 4570 ± 830 kn $\mathrm{s^{-1}}$ (mean value over all lines). Also present in the spec tra are broad emission lines of He I λλ4026, 4471, 492 and 5015. The relative intensities of λλ4026 and 447

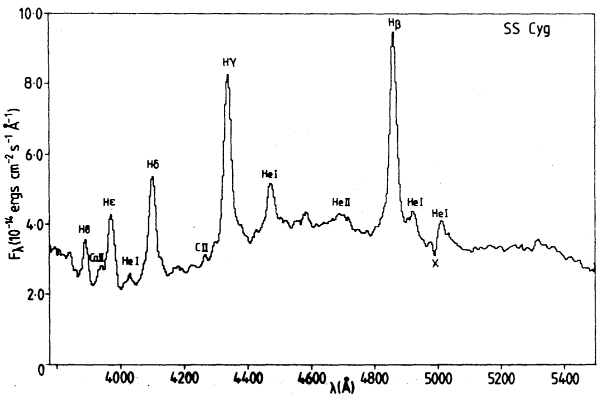

Fig. 2. SS Cyg observed on July 5, one magnitude above minimum.

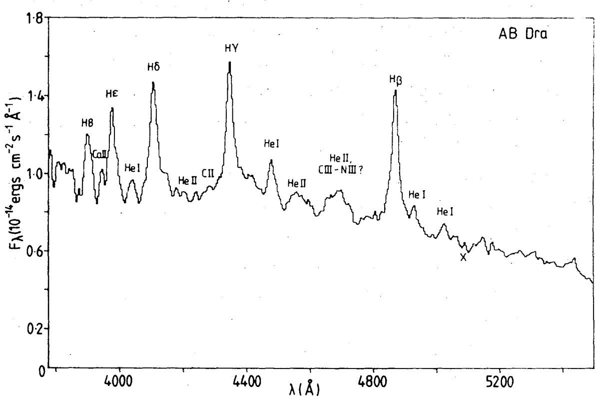

Fig. 3. Spectrum of AB Dra taken on August 7. The He II λ4686 line may be contaminated by the C III-N III λ4650 group.

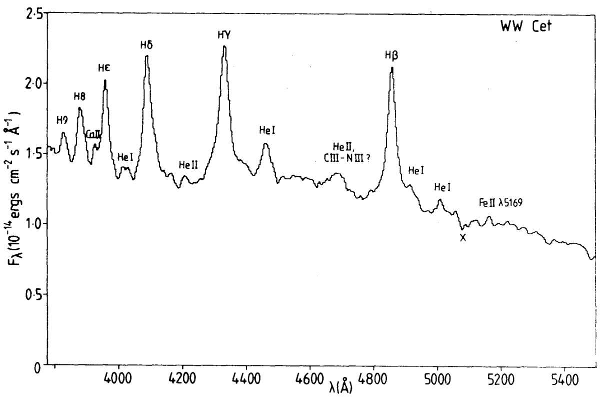

Fig.4. Spectrum of WW Cet obtained on August 6. The He II λ4686 may be contaminated by C III-N III as in Figure 3. The Balmer lines are clearly visible down to H9.Fe II λ 5169 is present in emission.

are also shown in Table 2. In addition to the H I and He I lines, some objects show emission lines of Ca II λ 3933, He II λ 4200, 4540, 4686, C II λ 4267 and Fe II λ 5169. RU Peg also shows some absorption lines from the secondary star like Ca II λ 3933, Mg I λ5167-83, Fe I λ5227, 5328 and the Ca I, Cr I, Fe I, Mi I, Ti I blend around λ5267. None of the other dwarf novae shows clear absorption lines. The AAVSO light curve shows that SS Cyg was observed one magnitude above minimum and, therefore, we may expect the continuum to mask the absorption lines. RU Peg and SS Cyg show evidence of a red continuum from a late G or K star. This is particularly evident near λ4200 where the flux distribution increases rapidly towards the red. We found no evidence of any such increase in WW Cet or AB Dra.

EM Cyg, CY Lyr and UU Aql were observed during outburst after an alert from AAVSO (J. Mattei, private communication). EM Cyg was followed three consecutive nights during a short outburst. On July 8 the AAVSO estimated maximum brightness (∿ 12.5) was only 1.5 mag above minimum. Due to non-photometric conditions during the night, the spectrum was not properly calibrated, and has been shifted arbitrarily to the top of Figure 5 to show the evolution of the outburst.

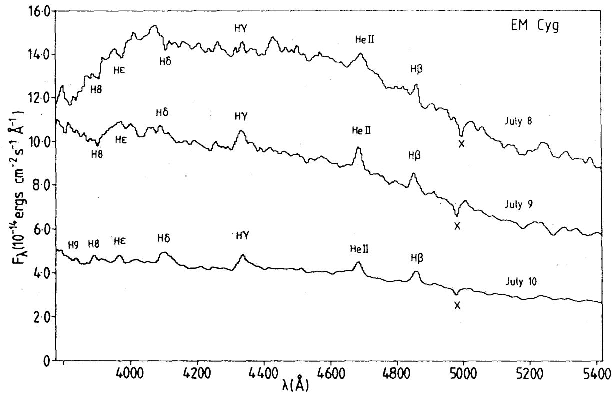

Fig. 5. EM Cyg during outburst observed on July 8, 9 and 10. The first spectrum is not properly calibrated and has been shifted arbitrarily to show the evolution of the continuum and lines. Strong He II λ4686 is visible in emission while some Balmer lines change from absorption to emission during decline.

Hβ and Hδ are seen in emission while the other H I lines appear in shallow absorption. The most prominent feature is He II λ4686 in emission. On July 9, the higher members of the Balmer series are weaker and Hδ has changed into emission. On July 10 all the Balmer lines are seen in emission while He II λ4686 is still strong.

CY Lyr was observed at maximum during two consecutive nights, with no apparent change in its spectra. The first spectrum taken on July 7 is shown in Figure 6. It has deep Balmer lines visible down to H10, and weak He I and Ca II absorption lines. The Balmer lines have a mean FWZI of 4466 ± 299 km s^{-1}.

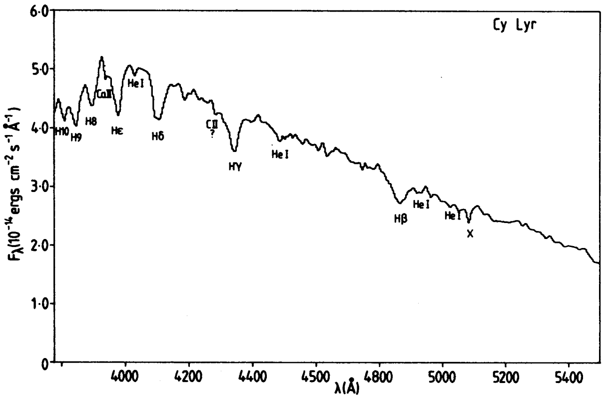

Fig. 6. Spectrum of CY Lyr during maximum on August 7.

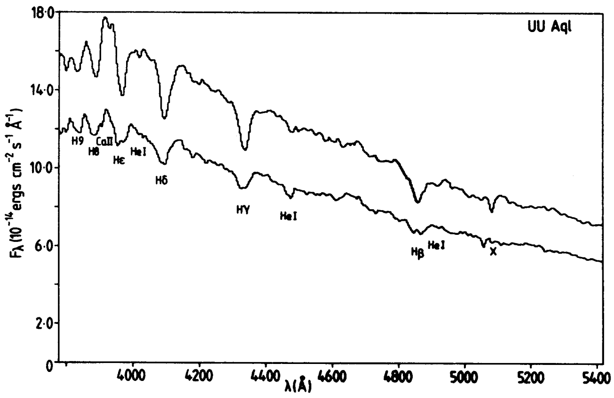

Fig. 7. Two spectra of UU Aql taken on August 7 and 8 show the decline from maximum of this object. All Balmer lines are in strong absorption and sometimes there is emission filling the absorptions.

UU Aql was observed near maximum and during decline (see Figure 7). On August 7 the Balmer lines were all in absorption with a mean FWZI of 4543 ± 756 km s^{-1}. Weak lines of He I and Ca II are also present. On August 8 the intensity of the H I lines have decreased and Hβ is now filled with some emission.

The Balmer line equivalent widths of CY Lyr and UU Aql are shown in Table 3. The mean FWZI of the H I lines for both systems is 4505 ± 543 km s^{-1}.

IV. DISCUSSION AND CONCLUSIONS

The contribution of He I λ3888 to H8 is not easy to estimate, because the relative strengths of the He I lines are very different from those found in H II regions or planetary nebulae. In Case B recombination, for instance, at a temperature of 10^4°K λλ4026/4471 = 0.47 (Osterbrock 1974), while our observations show a mean ratio λλ4026/4471 = 0.35. Hε is also contaminated with Ca II λ3970, but its contribution is probably small as judged by the intensity of the Ca II λ3933 line. Other He I lines blended with H I lines at the observed dispersion are λλ4120, 4143 and 4388. However, high dispersion spectrograms of other dwarf novae show that these lines are very weak (e.g. Cowley, Hutchings, and Crampton 1981). He II λ4686 is present in all our objects. In AB Dra and WW Cet the line is very broad and may be contaminated with C III-N III λ4650.

The observed emission line strengths are compared in Table 2 with theoretical line ratios from optically thin steady state accretion disc (Tylenda 1981; Williams and Ferguson 1982). They are, in general, greater than the theoretical values. The observed Hβ equivalent widths are also greater than that predicted by theory. Other models computed by Tylenda (not shown in Table 2) have comparable EW(Hβ), but they have very low mass transfer rate ∿10^{14} gr s^{-1}, and the relative line intensities are smaller than those for higher mass loss rates. Williams and Ferguson have computed some models with EW(Hβ) ∿ 20 Å, but they have extremely high He/H

TABLE 2

EMISSION LINE INTENSITIES RELATIVE TO Hβ

Line	λ (Å)	SS Cyg	RU Peg[a]	AB Dra	WW Cet	Case B (T = 10^4°K)	Tylenda[b]	Williams[c]
H8	3889	0.16	0.49	0.51	0.35	0.10	0.39	...
Hε	3970	0.43	0.59	0.80	0.61	0.16	0.46	...
He I	4026	0.06	0.09	0.18	0.10	...	...	0.20
Hδ	4102	0.49	1.49	0.90	1.09	0.26	0.56	0.79
Hγ	4340	0.98	1.19	0.89	1.14	0.47	0.71	0.89
He I	4471	0.22	0.26	0.33	0.40	...	...	0.28
Hβ	4861	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Log F(Hβ)[d]		−11.87	−12.09	−12.79	−12.62			
EW (Hβ)		32	16	20	18		0.83	14

a. August 3 (SP486)
b. Model with log Ṁ = 16 in Tylenda's Table 1.
c. Model 4 in Williams and Ferguson's Table 1.
d. In erg cm^{-2} s^{-1}.

abundance. The observed He I/H I ratios are consistent with the models of Williams and Ferguson for high helium abundances. Also shown in Table 2 are the Case B Balmer line ratios for $T = 10^4$ °K. They are ∿3 times smaller than the observed ratios.

The equivalent widths of the Balmer lines in UU Aql and CY Lyr are compared in Table 3 with those of the B3 III star BD + 40°4032 and with the DA white dwarf GRW + 70°8031. The first shows lines with a FWZI ∿ 3598 ± 804 km s^{-1}, while the second has FWZI ∿ 8665 ± 3735 km s^{-1} (see Figure 8). The equivalent widths of UU Aql and CY Lyr are similar to those of the B3 III star and much less than those of the DA white dwarf. These results are compatible with the idea that the absorption lines in dwarf novae are produced in the "atmosphere" of a disc rather than in the degenerate matter of white dwarf (cf. Warner 1976). This explanation is supported by Mayo, Wickramasinghe and Whelan (1980), who found that theoretical profiles produced by accretion discs agree reasonably well with observations. The equivalent widths in the DA white dwarf are similar to those found in emission lines of dwarf novae at minimum. It is unlikely that DA white dwarfs are present in dwarf novae because the wide and strong absorptions would be visible at the wings of the emission lines.

We are indebted to the personnel of the Observatory at San Pedro Mártir for the invaluable help in obtaining the data. JE wishes to thank CONACYT, México for scholarship support.

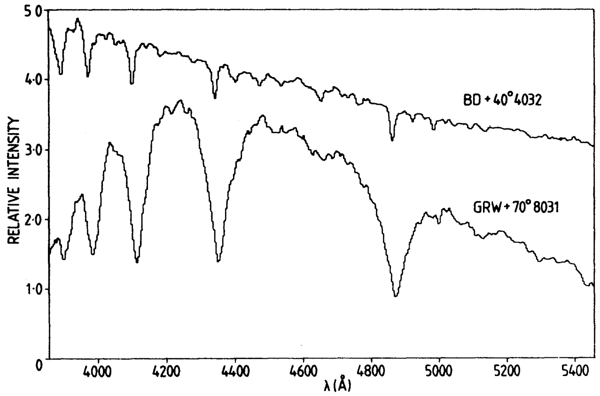

Fig. 8. Spectra of the B3 III star BD + 40°4032 and the DA white dwarf GRW + 70°8031.

REFERENCES

Adams, W.S. and Joy, A.H. 1921, *Pub. A.A.S.*, 4, 305.
Bath, G.T., Pringle, J.E., and Whelan, J.A.J. 1980, *M.N.R.A.S.*, **190**, 185.
Cowley, A.P., Hutchings, J.B., and Crampton, D. 1981, *Ap. J.*, **246**, 489.
Echevarría, J. and Jones, D.H.P. 1983, *Rev. Mexicana Astron. Astrof*, 5, 301.
Elvey, C.T. and Babcock, H.W. 1940, *Pub. A.A.S.*, **10**, 51.
Elvey, C.T. and Babcock, H.W. 1943, *Ap. J.*, **97**, 412.
Firmani, C. and Ruíz, E. 1981, *Symposium on Recent Advances in Observational Astronomy*., eds. H.L. Johnson, and C. Allen, (México: Univ. Nacional Autónoma de México), p. 25.
Joy, A.H. 1940, *Pub. A.S.P.*, **52**, 324.
Lynden-Bell, D. 1969, *Nature*, **223**, 690.
Mayo, S.K., Wickramasinghe, D.T., and Whelan, J.A.J. 1980, *M.N.R.A.S.*, **193**, 793.
Oke, J.B. 1974, *Ap. J. Suppl.*, **27**, 21.
Osterbrock, D.E. 1974, *Astrophysics of Gaseous Nebulae*, (San Francisco: W.H. Freeman and Co.).
Pringle, J.E. 1974, Ph.D. Thesis, University of Cambridge.
Robinson, E.L. 1976, *Ann. Rev. Astr. and Ap.*, **14**, 119.
Ruíz, E., 1974, BSc Thesis, Universidad Nacional Autónoma de México.
Solar, A. 1977, BSc Thesis, Universidad Nacional Autónoma de México.
Stone, R.P.S. 1977, *Ap. J.*, **218**, 767.
Tylenda, R. 1981, *Acta Astr.*, **31**, 127.
Warner, B. 1976, in *IAU Symposium No. 73, Structure and Evolution of Close Binary Systems*, eds. P. Eggleton, S. Mitton, and J. Whelan, P. 85.
Williams, R.E. 1980, *Ap. J.*, **235**, 939.
Williams, R.E. and Ferguson, D.H. 1982, *Ap. J.*, **257**, 672.

TABLE 3

EQUIVALENT WIDTHS OF BALMER LINES (Å)

Name	Date	H8	Hε	Hδ	Hγ	Hβ
UU Aql	Aug 7	4.3	4.6	6.6	5.7	3.7
	Aug 8	3.3	4.0	4.8	3.6	3.3
CY Lyr	Aug 7	3.4	5.2	5.0	4.0	3.3
	Aug 8	1.5	3.5	5.0	3.9	4.2
BD + 40°4032	...	3.6	3.8	3.0	2.4	2.3
GRW + 80°8031	...	7.	15.	26.	39.	35.

Rafael Costero: Instituto de Astronomía, UNAM, Apartado Postal 70-264, 04510 México, D.F. México.
Juan Echevarría: Observatorio Astronómico Nacional, UNAM, Apartado Postal 877, 22860 Ensenada, B.C., México.