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SPECTROPHOTOMETRY OF CATACLYSMIC VARIABLES WITH THE MEPSICRON SYSTEM[1]

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RESUMEN

Se ha obtenido espectrofotometría de baja resolución con el sistema *Mepsicron* de quince variables cataclísmicas, como parte de un programa general para determinar con precisión flujos de líneas de emisión y de contínuo. Se muestran flujos obtenidos de V Sge, AE Aqr, SS Cyg, V426 Oph y FO Aqr, y se presenta evidencia de la presencia de una secundaria K tardía en V426 Oph y posiblemente de una K temprana en V Sge. Como resultado adicional de este programa se presentan espectros de estrellas de tipo espectral K y M.

ABSTRACT

Low resolution spectrophotometry of fifteen cataclysmic variables have been obtained with the *Mepsicron* system as part of a general program to obtain accurate fluxes of emission lines and continua. Emission line fluxes are given for V Sge, AE Aqr, SS Cyg, V426 Oph and FO Aqr, and evidence is presented for a late K star in V426 Oph, and possibly an early K star in V Sge. As a by-product of this program, we present spectra of K and early M dwarfs.

Key words: SPECTROPHOTOMETRY – STARS-CATACLYSMIC VARIABLES

I. INTRODUCTION

Cataclysmic variables are a class of interactive binaries which have semidetached late-type secondaries undergoing mass transfer onto a white-dwarf primary. Peculiar phenomena like outbursts, flickering and pulsar-like beaming are observed in these systems, properties which are thought to arise from an accretion disc, or an accretion column associated with the white dwarf (see recent review by Wade and Ward 1985).

The spectra of cataclysmic variables are rather complex; at minimum light (or low state) most of them show strong and broad H and He I emission lines; while at maximum light (or high state) absorption at the same lines is sometimes seen. Systems with high orbital inclination usually show a double-peaked profile. The absorption features of late-type components are visible at minimum (or low state), for long orbital period systems. Early spectra of these objects date back to the 1940's, when Joy (1940) and Elvey and Babcock (1943) made the first spectral survey on photographic plates. This pioneering task was soon followed by a number of contributions, devoted primarily to the analysis of radial velocities, and which has continued to date (e.g., Kraft 1962, 1964; Stover, Robinson, and Nather 1981). Further spectral surveys made with digital detectors include: Bond (1981, unpublished); Oke and Wade (1982); Echevarría and Costero (1983), and Williams (1983). A number of double-peak systems have been observed with great care by various groups (e.g., Young and Schneider 1980; Bailey and Ward 1981). These authors have measured continua, line fluxes or line profiles, which can be compared with data from theoretical models; thus gaining insight into the physical mechanisms producing such bizarre behavior. To continue with these efforts, we have observed several objects at low dispersion, and the results are presented here. A complete analysis

1. Based on observations collected at the Observatorio Astronómico Nacional of San Pedro Mártir, B.C., México.

of the emission lines in cataclysmic variables, including the data in this paper, has been published by Echevarría (1988), and therefore we will only discuss here individual objects, particularly those which present evidence of the secondary star.

II. OBSERVATIONS

Spectrophotometric observations of fifteen cataclysmic variables were obtained in 1985 August 13 – 17 with the echelle spectrograph in its low-dispersion mode and with the *Mepsicron* system at the Cassegrain f/7.5 focus of the 2.12-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, Baja California, México. In the low dispersion mode the echelle grating is substituted by a plane mirror, with the cross dispersor used as the principal grating. A 300 groves mm^{-1} grating was selected, to give a dispersion of 96 A mm^{-1}. A 400 μm x 2000 μm slit was used, to allow all light to pass through it, corresponding to 5 x 26 arcsec, oriented EW. The *Mepsicron* system was used at the f/1.46 camera plane of the spectrograph. The detector consists of an S25 photocathode coupled with two arrays of microchannel plates and an anode plate where electron cloud events are detected through the Pulse Position Analyser, by measuring the electric currents produced at the four corners of the anode (Firmani *et al.* 1982, 1984). The linearity and stability of the detector have been tested both at the laboratory and telescope, and ensure accurate flux calibrations.

The spectra were reduced at the STARLINK/VAX node at University College London. The eight pixel wide spectra were converted to one dimension using a program developed by one of us (FD) which follows an algorithm of maximum intensity search, channel by channel. All subsequent reductions were made with the SPICA package. Flux calibrations were derived from the standard star BD+28° 4211 and Kopff 27 (Stone 1977). The instrumental response derived from each star is the same, within 10 percent, for most of the covered spectral range, except at both ends where the optical and electronic response of the system declines rapidly. The log of observations is shown in Table 1. Visual magnitudes were taken whenever possible from AAVSO Circulars. Magnitude estimates of the continuum at λ5500 A for all objects have been derived from the expression

$$m_{5500} = -2.5 \log F_\lambda - 21.10 \quad .$$

Figures 1 to 4 show the spectra of all the observed objects. A He-Ar arc lamp was used to provide wavelength calibration. Due to the small number of arc lines in the blue region (λ < 3888 A), the calibration in that region is not very accurate. The spectral resolution, measured from the FWHM of isolated He-Ar lines is 9 A. A number of well known late-type standards were observed to compare possible absorption features from the

TABLE 1

LOG OF OBSERVATIONS

Name	Type	UT (mid) h	UT (mid) m	Exp. time s	Date Aug. 1985	Optical State: Spectra m_{5500}	Optical State: AAVSO m_V
T CrB	RN	06	15	1800	16	10.15	9.98
V Sge	NL	08	07	3600	15	11.15	...
AE Aqr	NL	08	39	3900	14	11.15	11.18
SS Cyg	DN	10	44	3600	13	11.40	minimum
V426 Oph	NL	04	23	3600	15	12.65	...
RW Tri	NL	11	20	2400	15	12.90	...
RX And	DN	09	11	3600	16	11.53	standstill 11.6
V3885 Sgr	NL	05	23	1800	17	10.65	...
UX UMa	NL	04	20	3600	17	12.90	...
FO Aqr	NL	10	51	3600	17	13.65	...
CM Del	DN?	07	52	4200	17	12.40	...
AO Psc	NL	09	26	3600	17	13.15	13.2
0623+71	N?	11	43	3000	16	12.65	...
V603 Aql	N	05	58	3600	15	12.15	11.5
TT Ari	NL	10	30	3600	16	11.40	10.69

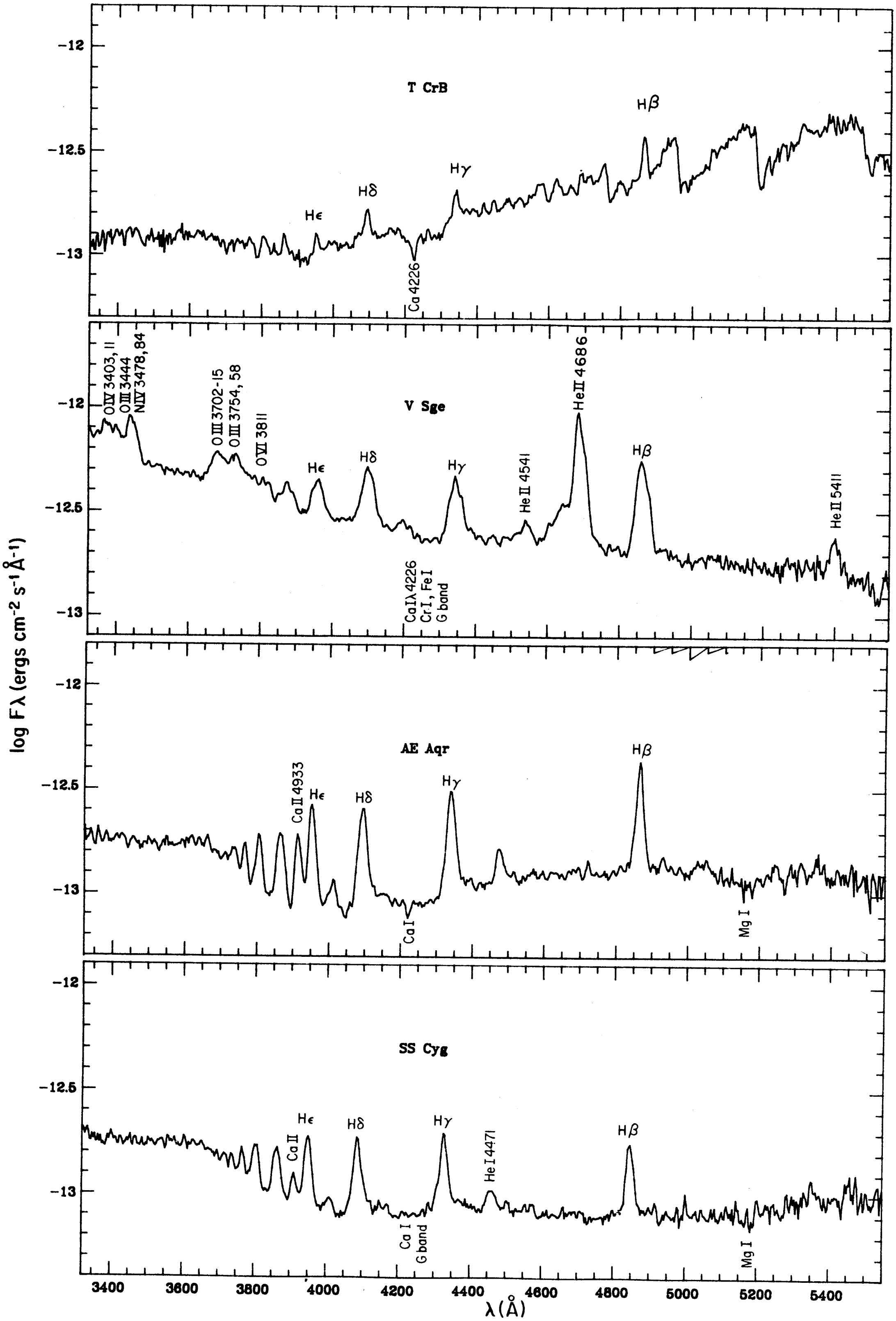

Fig. 1. Mepsicron spectra of T CrB, V Sge, AE Aqr and SS Cyg.

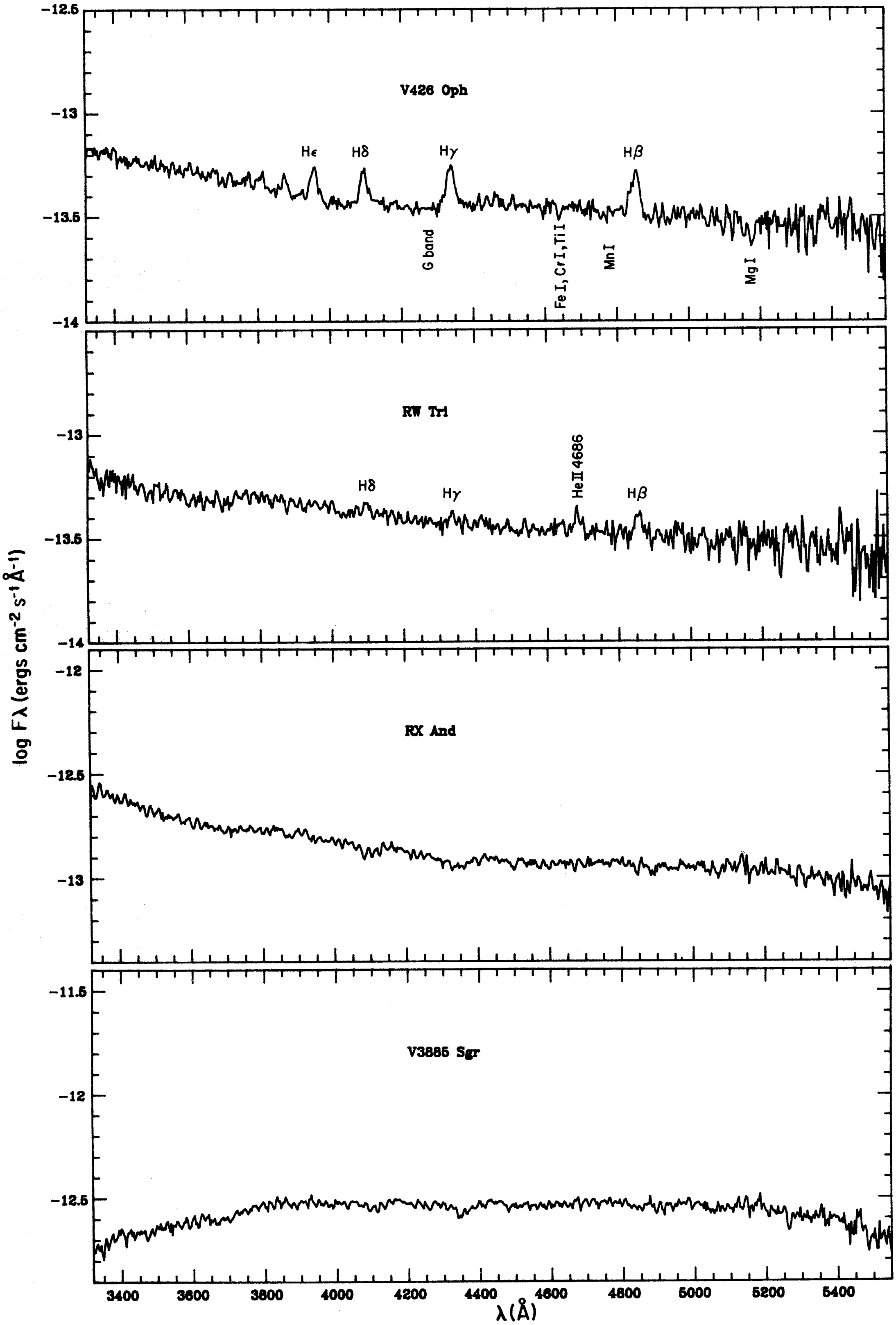

Fig. 2. Mepsicron spectra of V426 Oph. RW Tri, RX And and V3885 Oph.

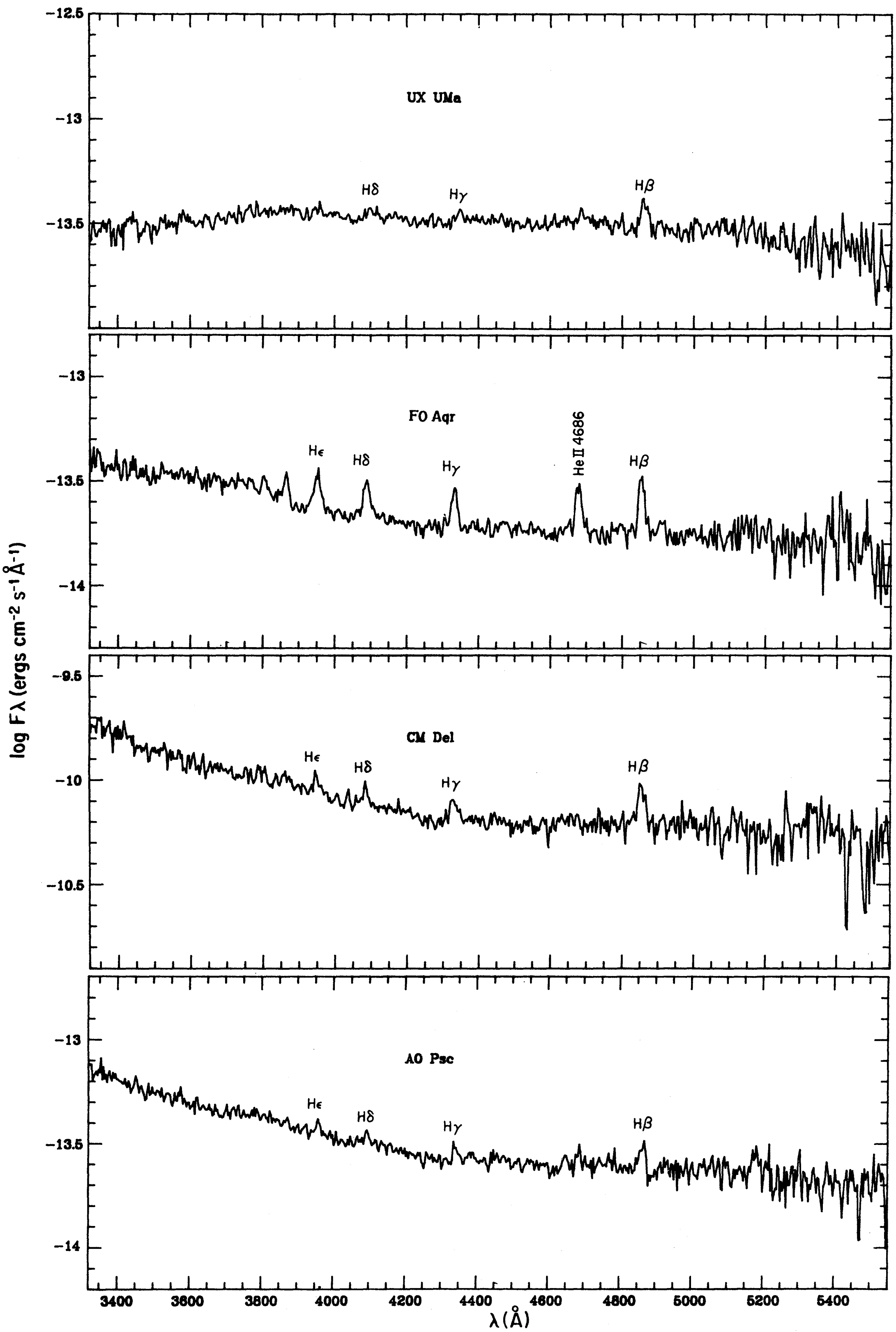

Fig. 3. Mepsicron spectra of UX UMa, FO Aqr, CM Del and A0 Psc.

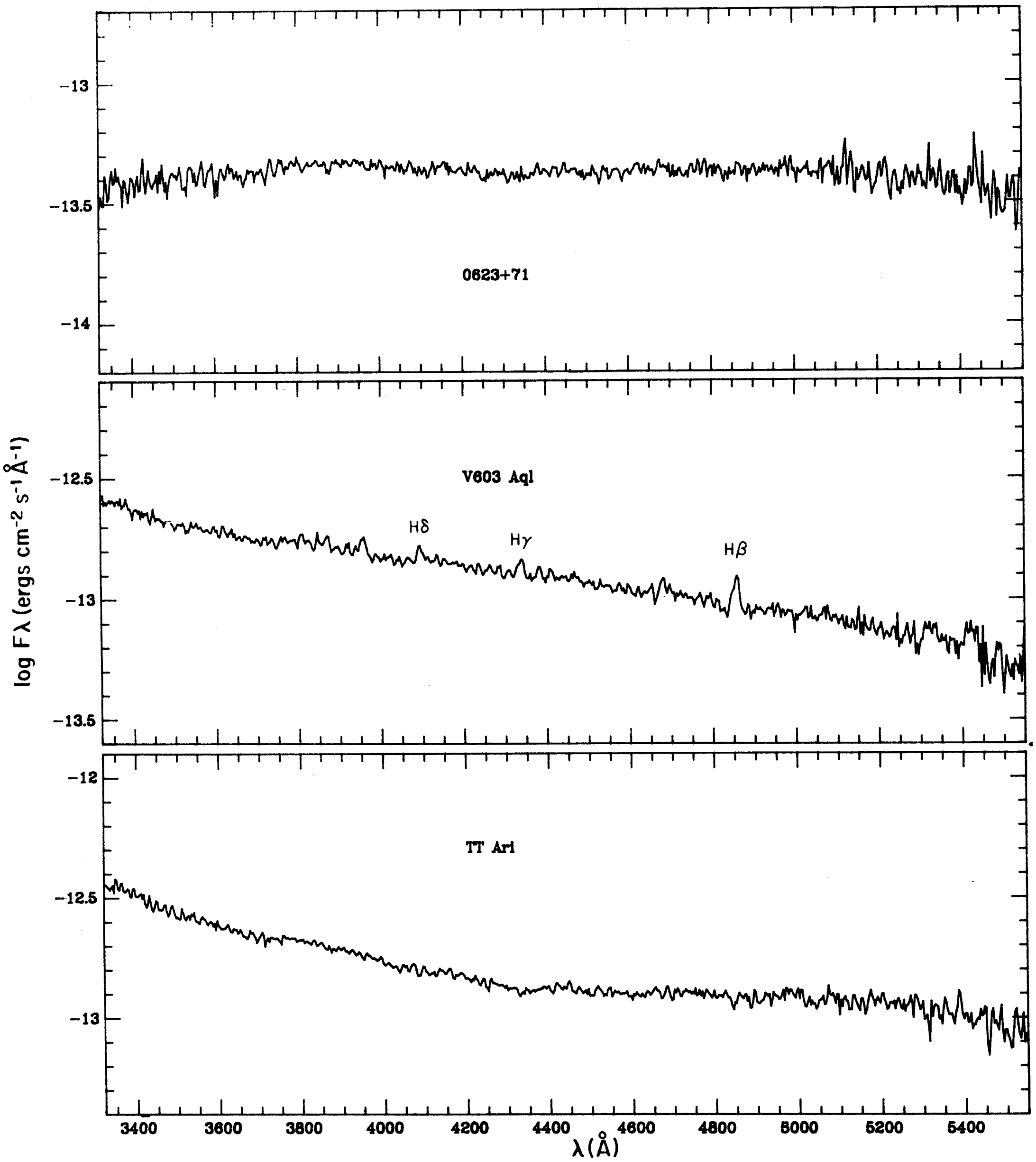

Fig. 4. Mepsicron spectra of 0623+71, V603 Aql and TT Ari.

program stars. The log of these observations is shown in Table 2, while the observations are plotted in Figures 5 and 6.

III. DISCUSSION AND CONCLUSIONS

a) *Objects with Balmer Lines in Emission or Absorption*

A few objects were observed in a state where Balmer lines and the Balmer jump were all in absorption, like V3885 Sgr, 0623+71, RX And and TT Ari, while others showed a mixture of lines and Balmer jump in emission and absorption, like RW Tri, UX UMa, CM Del, AO Psc and V603 Aql. Emission-line fluxes were measured for V Sge, AE Aqr, SS Cyg, V426 Oph and FO Aqr, which were the only five objects in our sample with strong emission lines at the time of observation. The relative intensities with respect to Hβ are shown in Table 3, together with Hβ absolute fluxes and equivalent widths. These five objects are included in a more complete discussion about the statistical properties of cataclysmic variables with emission lines (Echevarría 1988).

TABLE 2

THE SIX DWARFS

Name	Sp. Type	UT (mid-exp) h	UT (mid-exp) m	Exposure Time (s)	Date of Observation	Visual Magnitude
HD 224618	K0V	09	48	2100	14AUG85	8.72
HD 223778	K3V	10	33	600	14AUG85	6.41
G1 689	K4V	06	57	1800	16AUG85	8.62
61 Cyg A	K5V	09	43	600	15AUG85	5.23
61 Cyg B	K7V	10	01	900	15AUG85	6.02
G1 617 A	M1V	06	59	1800	15AUG85	8.62

TABLE 3

EMISSION LINE INTENSITIES RELATIVE TO Hβ

Line	λ (A)	V Sge	AE Aqr	SS Cyg	V4426 Oph	FO Aqr
O IV	3403-11	0.02	...	...	...	...
O III	3444	0.09	...	...	...	...
N IV	3478-84	0.38	...	...	...	...
O III	3702-15	0.17	...	...	...	...
H13	3734	...	...	0.05	...	...
H12	3750	...	...	0.13	...	...
O III	3754-59	0.11	...	...	...	...
H11	3771	...	0.09	0.12	...	...
H10	3798	...	0.13	0.24	0.16	0.20
H9	3835	...	0.26	0.63	0.22	0.39
H8	3889	0.28	0.41	0.76	0.43	0.66
Ca II	3933	...	0.34	0.25	0.09	...
Hε	3970	0.38	0.63	0.98	0.78	...
He I	4026	...	0.09	0.19	...	...
Hδ	4101	0.65	0.69	1.35	0.71	0.60
Hγ	4340	0.56	0.85	1.17	0.93	0.52
He I	4471	...	0.20	0.30	...	...
He II	4541	0.16	...	...	...	...
He II	4686	2.14	...	...	...	0.81
Hβ	4861	1.00	1.00	1.00	1.00	1.00
Log F(Hβ)		−10.90	−11.19	−11.67	−12.25	−12.49
EW (Hβ)		61	50	25	18	19

b) *Systems which Show the Presence of the Secondary Star*

i) T CrB

The spectrum is dominated by a giant M star. In contrast to the observations by Kraft (1958) we no longer observe forbidden lines, not even [Ne III]λλ3868,3967. In fact, the only emission lines present are the Balmer lines visible to H10. The strength of the TiO bands suggests, together with the narrow emission lines, the presence of an M5e III star, similar to that of the Mira type star R Crv (Keenan and Mc Neil 1976). Since T CrB is clas-

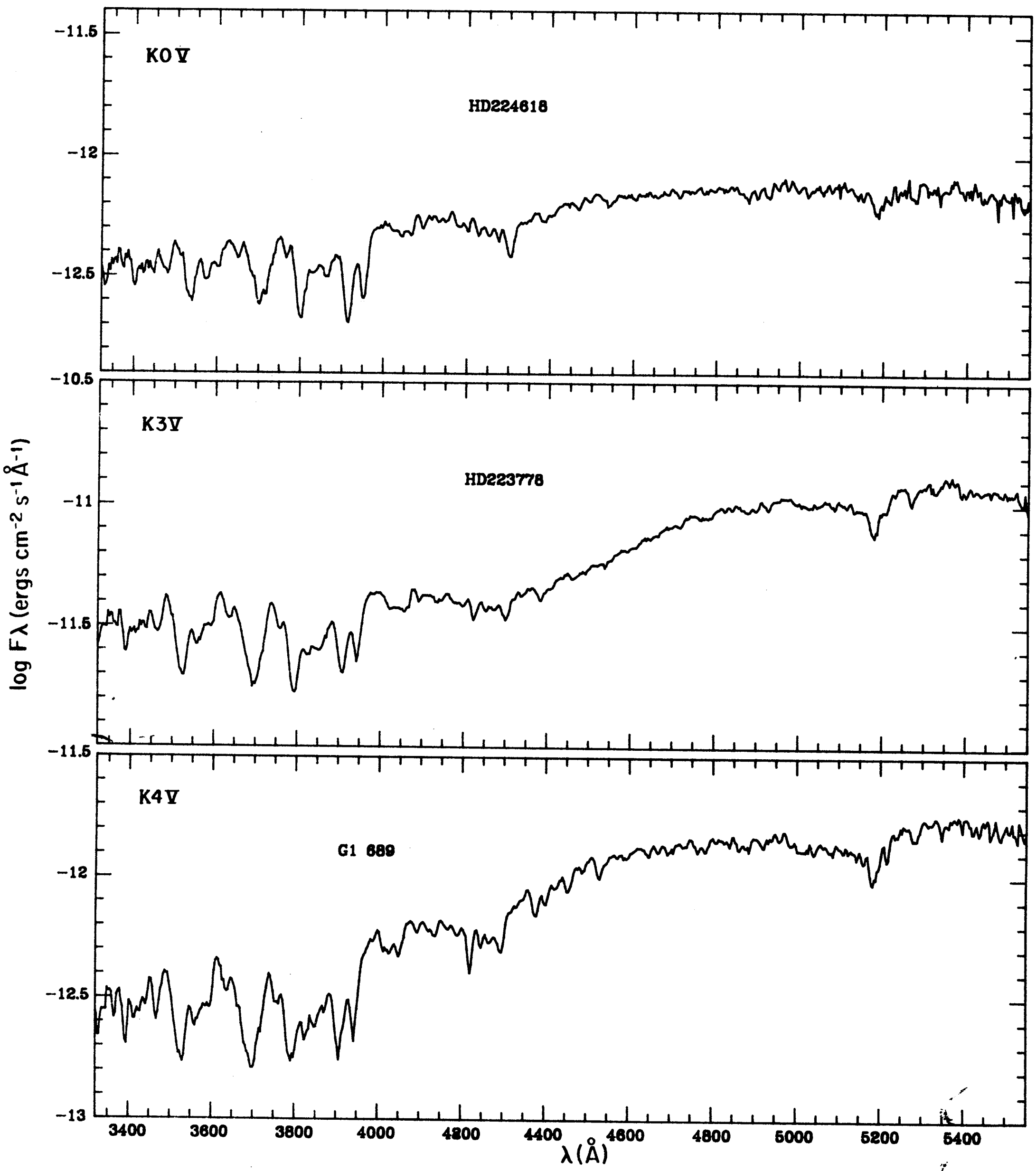

Fig. 5. Mepsicron spectra of spectral standards.

sified as a recurrent nova, we conclude that we are not dealing with a true cataclysmic variable; this view is further supported by its large period and the high mass of the system (Kraft 1958).

ii) V Sge

Our spectrum was obtained when the system was between orbital phases 0.86 and 0.94 which correspond to eclipse ingress. Although eclipses are not very deep during high states (Herbig *et al.* 1965), it is at these phases when the secondary star should be more prominent. We found very weak traces of the G band, Ca λ4226 and the blends of Cr I, Fe I around λλ4250–60 and λλ4271–74. Other absorption features are comparable to those seen in HD 224618 (Figure 5). The Mg I λ5172 line is not clearly visible, but our spectra are in general very noisy in this region, and even in AE Aqr and SS Cyg this feature is not very conspicuous. The observed lines are too

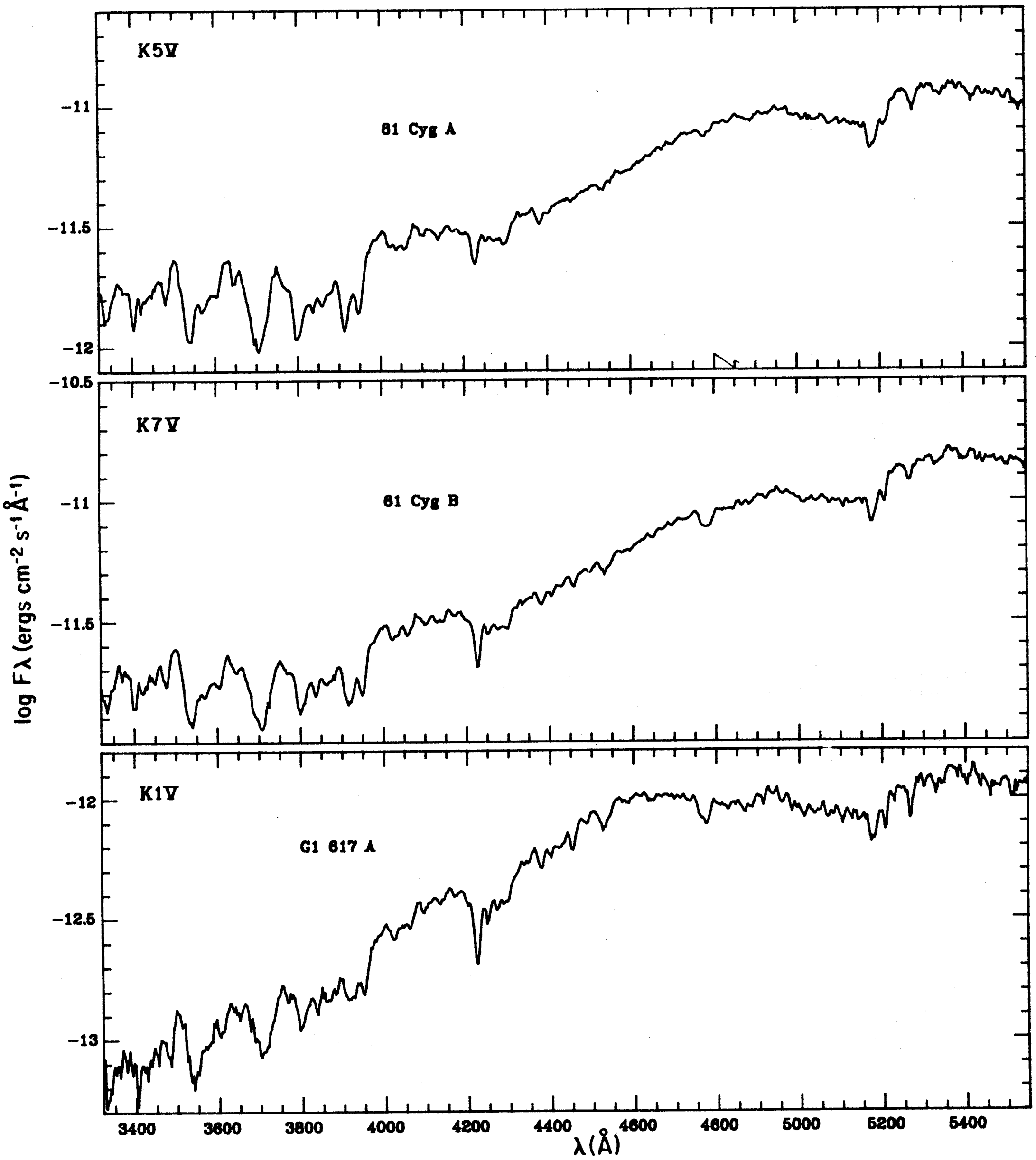

Fig. 6. Mepsicron spectra of spectra standards.

weak to attempt a good spectral classification, but the secondary could be an early K star as judged from the absence of a strong red continuum.

V Sge has been studied extensively by Herbig *et al.* (1965), who proposed a strong and explosive ejection of semi-opaque material to explain the complex behaviour of the emission lines. They attribute the doubling of the fluorescent O III and other lines to the presence of two evolved stars. However, our marginal detection of a late type secondary (see below), the similarity to the old nova BT Mon, both spectroscopically (Williams and Ferguson 1982) and photometrically (Robinson, Nather, and Kepler 1982), and the fact that both systems show deep eclipses and have very strong He II λ4686 emission, suggest a cataclismic variable in which a very large and luminous disc is seen at a high inclination angle. It would be very interesting to obtain time-resolved spectroscopy of V Sge with modern detectors, and to search for the existence of a faint optical nebula, which might be responsible for some of the high excitation O III lines.

iii) AE Aqr

The classification of AE Aqr is uncertain. Although no clear outbursts have been seen like those in dwarf novae, its spectrum is very similar to that of SS Cyg. The X-ray modulation suggests a DQ Her type (Patterson *et al.* 1980), but judging from the width of the emission lines a full disc is expected. The absorption spectrum of AE Aqr is noticeably strong and has all the features of a K5V star in agreement with the classification by Chincarini and Walker (1981), in particular the strength of the Ca I λ4226 line compared with the weak G band indicates that this is not an early K star like HD 224618 and HD 223778 shown in Figure 5.

iv) SS Cyg

In this object, the G band is stronger than the Ca I λ4226 line. A comparison of the absorption features and the continuum in SS Cyg, with the spectral standards, and with AE Aqr, indicate a spectral type around K2, earlier than previous classifications (e.g., Stover *et al.* 1980), but in agreement with the spectral type seen at high dispersion by Echevarría *et al.* (1989).

Our observations show that the Balmer lines in our spectrum have a very flat decrement with peak flux at Hδ and line ratios which are much higher than other published values (see the compilation by Echevarría 1988).

v) V426 Oph

V426 Oph is another system whose classification is in doubt. Szkody (1986) suggests a DQ Her type based on the observed X-ray modulation. Shugarov (1983) has found 1.5 mag flares, but no clear indication of dwarf nova outbursts. The low EW values found for the system at a low state support a nova-like membership. The total absence of He II λ4686 however, favours a dwarf nova interpretation although there are some intermediate polar stars like AO Psc, in which λ4686 is also very weak. V426 Oph was observed near minimum light and shows for the first time the absorption lines from the secondary star. We see the blend of Fe I, Cr I, Ti I around λλ4637–46, and the lines of Mn I λλ4754–83 and Mg I λλ5167–83. A general comparison with the standard spectral stars suggest a late K or an early M star. Since the TiO band head λ5167 is not well developed, we favour a K7 spectral type. A radial velocity study of V426 Oph has been published by Hessman (1988), who favours a K3 spectral type.

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