

IUE ULTRAVIOLET OBSERVATIONS OF W UMa STARS*

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ABSTRACT

Four W UMa eclipsing binary systems have been observed with IUE: 44 Boo, VW Cep, W UMa, and ϵ CrA. They generally show large surface fluxes of high temperature lines (C II, C IV, N V, Si IV) which may result from the high rotational velocities forced by synchronous rotation. High dispersion spectra of the 44 Boo system in the Mg II line enable the individual stellar components to be identified. The line widths and phase variations are consistent with the optically determined spectroscopic orbit. Circumstellar absorption of Mg II may be present at selected phases.

INTRODUCTION

The W UMa systems are eclipsing binaries composed of late-type dwarf stars with an orbital period of less than one day. Their high spatial frequency means such a configuration is an important phase in the main sequence evolutionary process. The two components of these systems are of unequal mass implying that mass transfer has undoubtedly played a role in the evolution of these systems. There are indications of sudden changes in orbital periods over a few months as well. Light wave effects are found in some systems suggestive of stellar surface activity.

Early results from IUE (ref. 1, ref. 2) showed that these systems are rich sources of ultraviolet emission and suggested that binaries of shorter orbital period had a higher surface flux of UV lines than those of longer period. Most recently the discovery from HEAO-1 (ref. 3) that one member of this class is an X-ray source and the subsequent detection of many of these systems with the *Einstein* Observatory (ref. 4) show that these stars contain extensive coronae as well.

Much theoretical work has been done on structural models for these systems. It is generally thought that a large flux of energy is transferred from the more massive primary to the secondary star. Models suggest that the components share a common envelope in which transfer of energy from primary to secondary must occur by the action of circulation currents in a manner similar to convection.

Since we believe that convection plays a crucial role in generating solar chromospheric activity, we might well expect enhancement over single stars. These binaries are rapidly rotating and enhancement and concentration of magnetic fields must occur. This may well lead also to increased heating and radiative losses. In addition, one structural theory - the thermal relaxation

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oscillation theory - (ref. 5, 6) predicts phases of mass exchange between components. So in the ultraviolet we might search for the spectroscopic signatures of circumstellar material and mass flow.

These W UMa systems are valuable objects with which to investigate coronal structure, stellar surface activity, and the dynamics of mass transfer or mass loss. It is also important to pursue the effect of rotation on chromospheric structure. It has long been known that the Ca K flux is enhanced in binary systems and apparently the extension of such enhancement is found in high chromospheric and coronal regions as well.

OBSERVATIONS - LOW DISPERSION

IUE spectra have been obtained of several W UMa type systems listed in Table 1. Short wavelength spectra (figure 1) exhibit the typical spectral features of high temperature chromospheric and transition region lines, namely O I, C II, Si IV, C IV, and N V. In ϵ CrA, the strong continuous emission at long wavelengths results from the high effective temperature of the components. Similar continuous emission is found in the system 44 Boo. This is a visual binary with one component being the W UMa system (G2 V) and the other an F4 V star. The continuum in this case arises from the F dwarf which is only $\sim 2''$ away from the W UMa system at present and hence unresolvable with IUE. The strong He II ($\lambda 1640$) line is notable in all of these systems. Its presence underscores the X-ray detections as the $\lambda 1640$ transition can be increased through photoionization of He I by X-rays followed by recombination (ref. 7).

Surface fluxes in the emission lines (figure 2) are substantially higher than those found in the quiet solar spectrum and display an increasing enhancement with temperature of formation. Although the enhancement is more than an order of magnitude higher, this behavior is similar to that found in solar active regions suggesting a structure dominated by a constant conductive flux. Since we assume that the flux is homogeneously distributed over the stellar surface, these values may well be a lower limit to the true surface flux above active areas.

The surface flux of the C IV transition ($\lambda 1550$) is a convenient index of enhancement and radiative losses in the stellar atmosphere at temperatures of 2×10^5 K. Inspection of the relation between emergent flux and stellar rotational velocity (figure 3) shows a clear correlation. The four W UMa systems have velocities $\geq 100 \text{ km s}^{-1}$, and exhibit the highest surface flux in the C IV line. Both the velocities and fluxes are higher than those of the RS CVn systems included for comparison. The correlation suggests a continuity in the effect of rotation upon the radiative losses; however there are still substantial variations in fluxes at a given rotational velocity. Some of this variation may result from activity on the stellar surface similar to that found for λ And (ref. 8) in which the ultraviolet flux correlates with the V light modulation. The extreme values found for ϵ CrA may be associated with the earlier spectral type of the system or the larger mass ratio (ref. 9) between the components.

OBSERVATIONS - HIGH DISPERSION

The system 44 Boo has been observed at various epochs with high dispersion at long wavelengths (figure 4). In this figure, the continuum and photospheric lines arise in the F dwarf companion and the central emission reversal from the W UMa component. The sample spectra at four phases show the variation of individual profiles with phase; the central emission reversal shows the orbital motion of the members of the W UMa system with an amplitude in agreement with the optical spectroscopic orbit (ref. 10, ref. 11). The breadth of each emission component at elongation (phase 0.28) is consistent with the rotational velocity expected from synchronous motion, namely $\pm 1.5 \text{ \AA}$ and $\pm 1.1 \text{ \AA}$ for the primary and secondary star respectively. The flux ratio is consistent with the surface area presented at elongation and supports a relatively uniform distribution of surface flux. There are phase changes in the profile from epoch to epoch; the flux attributed to the primary star remains approximately constant, whereas the secondary appears to fluctuate by 10 to 20% in the Mg II k line flux. This seems reasonable if the secondary is merely the recipient of the luminosity generated principally on the primary star.

There is a suggestion of absorption features in the Mg II k profile that have a variable velocity of about -100 km s^{-1} ; these appear to be present at various epochs and may indicate the presence of circumstellar material in the system. Confirmation of this, and in particular its appearance with orbital phase, suggests that mass transfer occurs between the components of contact systems.

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TABLE 1

Observations and Parameters of W UMa Systems

System	Spectrum	Period (days)	Image*	Phase	Exposure (minutes)	References
44 Boo	G2, F4 (primary)	0.268	Average of 9 SWP	Many	23 to 45	11
			LWR 3197	0.28	25	
			LWR 5834	1.00	19	
			LWR 5836	0.40	15	
			LWR 5838	0.78	15	
VW Cep	G2	0.278	SWP 6534	0.84-0.46	150	11
W UMa	F8	0.334	SWP 6881	0.45	75	13
ε CrA	F0	0.591	SWP 6830	0.79	2	9
			SWP 6831	0.85	40	

* All exposures were made using the Large Aperture.

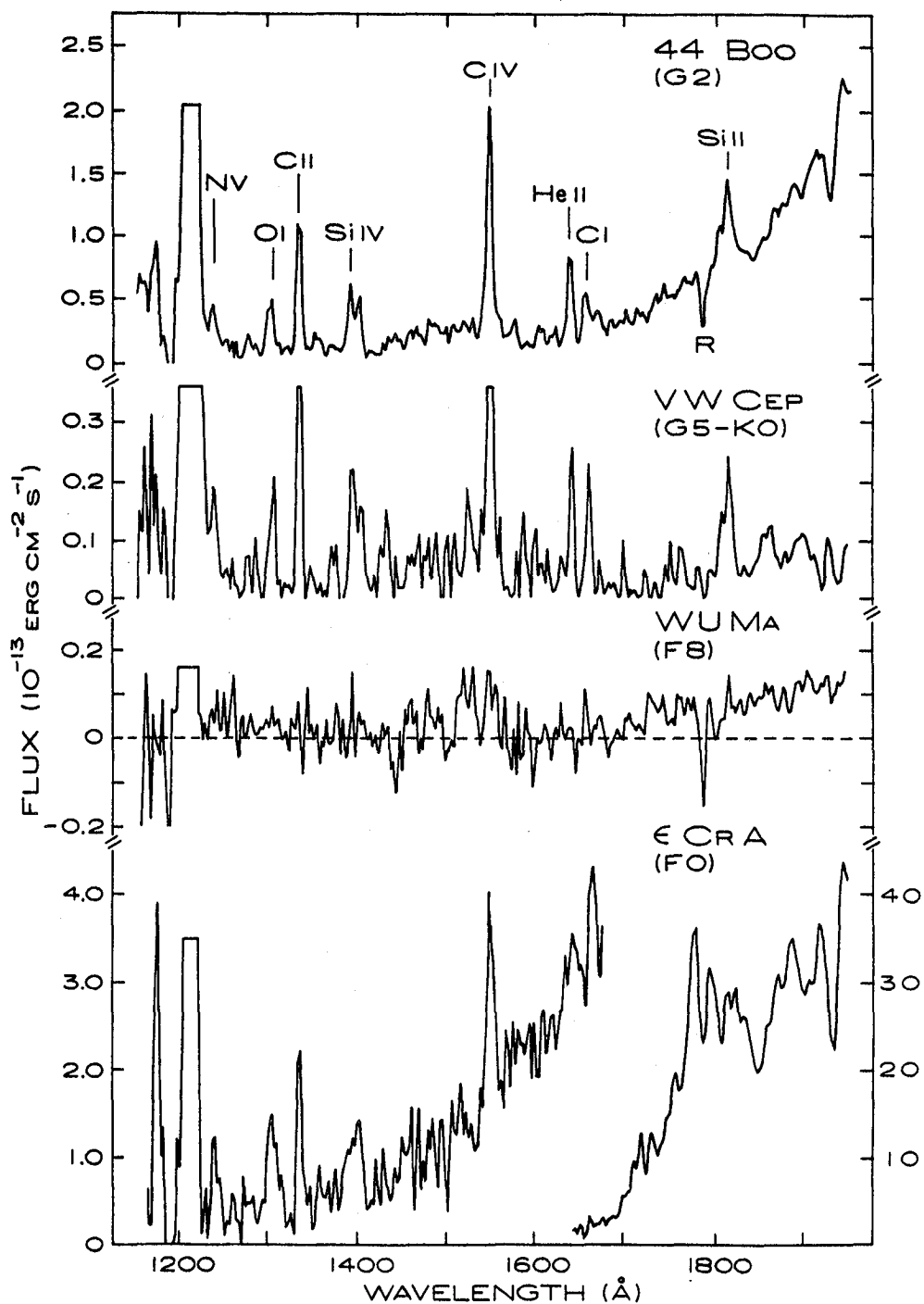


Figure 1. Short wavelength spectra of 4 W UMa systems. The spectrum of 44 Boo represents an average of 6 images. The spectrum of W UMa is underexposed and serves only to provide an upper limit to the C IV lines at $\lambda 1550 \text{ \AA}$. The spectrum of $\epsilon \text{ CrA}$ is a composite of a long exposure (40 min.) to detect the high temperature lines at short wavelengths and a shorter exposure (20 min.) to measure the continuum near $\lambda 1800$.

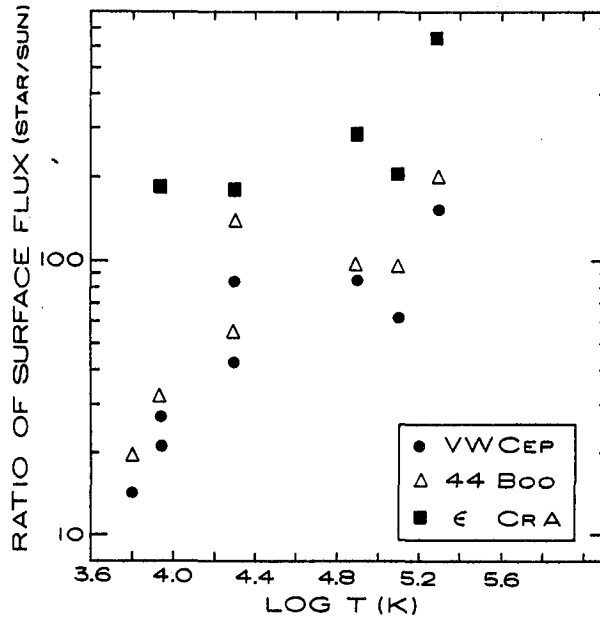


Figure 2. The ratio of surface flux in selected emission lines to that in the quiet Sun. All three systems show a similar pattern of enhancement which is generally the highest found to date in late-type stars.

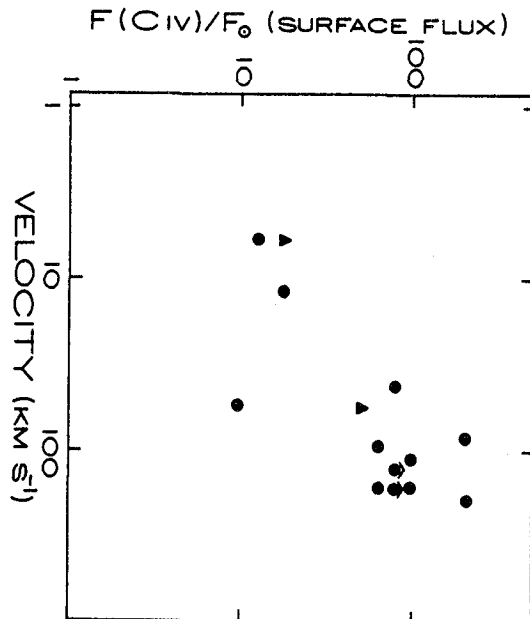


Figure 3. The surface flux in the C IV ($\lambda 1550$) transition as a function of velocity of the components for several binary systems. Synchronous rotation was assumed for those systems with orbital period less than 5 days. The four W UMa systems have $V \geq 100 \text{ km s}^{-1}$. Upper limits for the components of W UMa itself are shown. Several RS CVn systems are also included. The triangles indicate the position for Capella with attribution of the total flux to the secondary (ref. 12) or to the primary star.

44 Boo

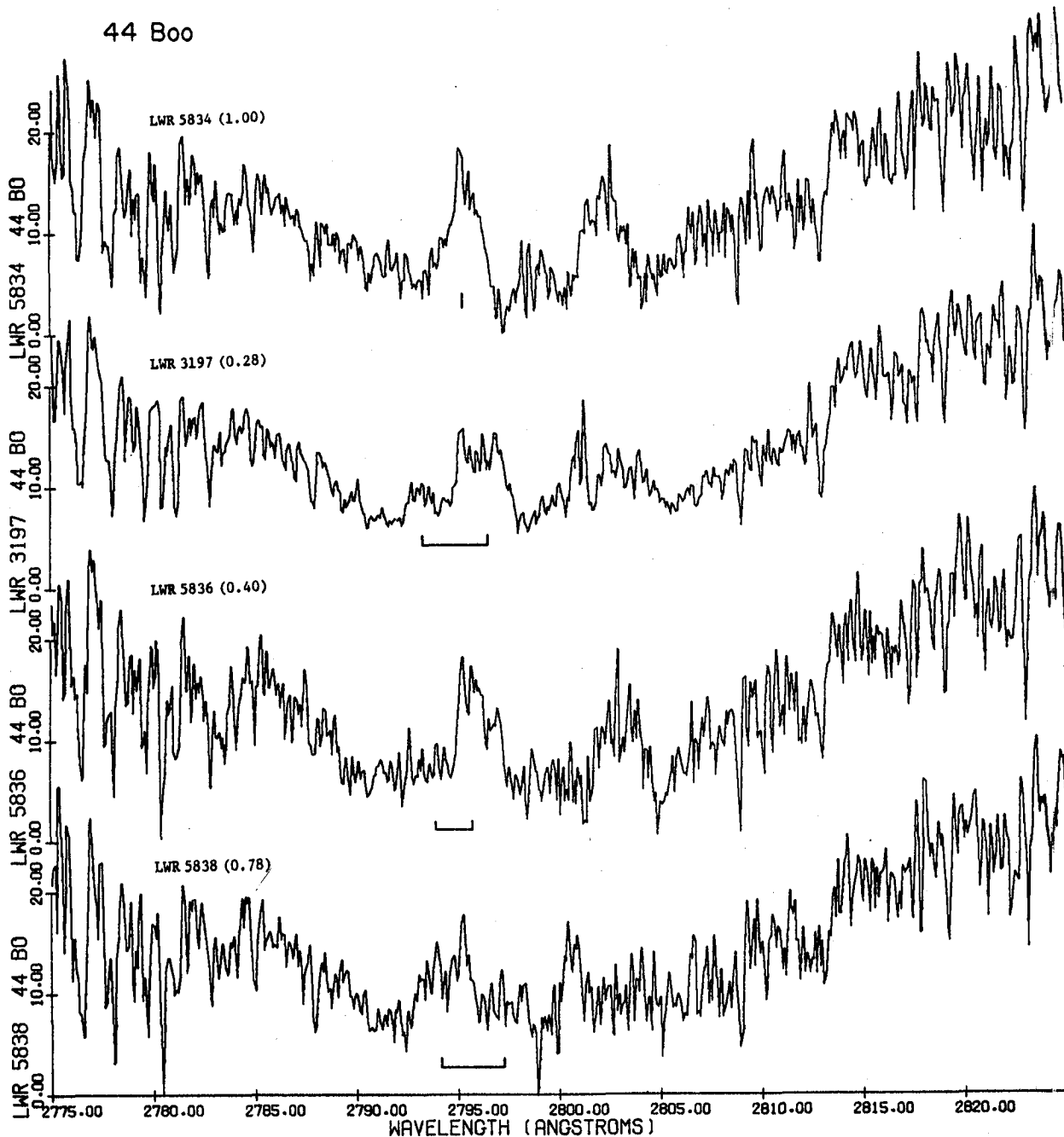


Figure 4. Samples from the high dispersion observations of the Mg II spectral region in 44 Boo. The F4 V component contributes the narrow photospheric absorption lines. The emission cores show the phase dependent behavior expected from the optically determined spectroscopic velocity curve (ref. 10, ref. 11) marked by the solid lines. At phase 0.28 the primary star has the maximum redshift; at phase 0.78 the primary star is approaching.