

## ULTRAVIOLET PHOTOMETRY OF DWARF NOVAE IN OUTBURST

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### ABSTRACT

We present *ANS* broad-band photometry of five dwarf novae at 1550, 1800, 2200, 2500, and 3300 Å. The Balmer continuum of AR And and Z Cam in outburst is well approximated by a power law  $F_\lambda \propto \lambda^\alpha$  with index  $\alpha = -1.9$ . Z Cam has the same flux distribution about 1 mag fainter in standstill. EM Cyg in standstill shows a flux excess at 3300 Å. At minimum, SS Aur and SU UMa have  $\alpha \approx -0.5$ . The lack of a strong extinction feature at 2200 Å indicates that the reddening is small toward all five systems. Using an independent estimate of the distances, we are able to derive mass flux rates  $\dot{M}$  by fitting steady state, optically thick accretion disk models to the observed UV luminosity. We find  $\dot{M} = 3 \times 10^{17} \text{ g s}^{-1}$  for Z Cam and EM Cyg in outburst, and a factor of 3 smaller for Z Cam in standstill. However, the models do not reproduce the slope of the Balmer continuum. Of particular interest are the observations of outburst rises of SS Aur, SU UMa, and EM Cyg. SS Aur showed an exponential increase at a rate of 3.5 mag in 0<sup>d</sup>.5. The outburst in EM Cyg also showed an exponential rise but at a rate of only 1.2 mag per day. SU UMa showed an initial, very red outburst followed within 0<sup>d</sup>.5 by a second, bluer outburst. This might indicate precursor activity in the outer, cool parts of the disk.

*Subject headings:* stars: dwarf novae — ultraviolet: general

### I. INTRODUCTION

The characteristic feature of the dwarf nova class of cataclysmic variables is the recurrence of outbursts at semiregular intervals. While there is considerable individuality among the members, these outbursts tend to be about 3 mag in amplitude with a recurrence interval of weeks to months. The discovery of their binary nature and the recognition of processes of mass transfer in such systems have led to a model in which the outburst energy arises through the release of gravitational energy in an accretion disk as gas falls into the potential well of the compact star in the system (Pringle 1981). Recent ultraviolet observations have been useful in testing the applicability of this model to the dwarf novae (e.g., Kiplinger 1979, 1980; Bath, Pringle, and Whelan 1980; Szkody 1981; Wu and Panek 1982). The principal theoretical tool has been the model of the optically thick, steady state, viscous accretion disk for which the radiated flux is readily calculated in a few-parameter family. The more general problem of the complete description of the behavior of the dwarf novae in terms of the fundamental parameters of the binary system is frustrated by the complexity of the accretion processes. In particular, the mechanism of the instability toward outbursts remains to be established. In the accretion model, it still remains to be decided whether the outburst is caused by some instability in the mass-losing star which temporarily increases its rate of mass loss (e.g., Bath

1975; Papaloizou and Bath 1975; Wood 1977; Bath and Pringle 1981), or whether the disk itself produces outbursts from the input of a steady mass flux (e.g., Osaki 1974; Paczyński and Schwarzenberg-Czerny 1980; Meyer and Meyer-Hofmeister 1981). We note the variety of behavior within the class, both qualitatively and quantitatively. For example, subtypes are recognizable according to the pattern of outbursts: the U Gem type stars, with regularly recurring outbursts; the Z Cam type stars, in which the outburst cycle is interrupted by a “standstill” at an intermediate brightness; and the SU UMa type stars in which extraordinarily bright and long-lasting “super-outbursts” are interspersed among ordinary outbursts.

Given the incompleteness of the theory, much remains to be learned from observational exploration of the variety among the dwarf novae in the different stages of the outburst cycle. Here, we present UV broad-band photometry of five dwarf novae. Of particular importance is the observation of three of these through the initial stages of an outburst.

### II. OBSERVATIONS AND REDUCTIONS

Observations were made with the University of Groningen Ultraviolet experiment on board the *Astronomical Netherlands Satellite (ANS)*. The instrument consisted of a 22 cm Cassegrain telescope, followed by a

five-channel grating spectrophotometer (van Duinen *et al.* 1975). The entrance aperture was  $2.5 \times 2.5$ , and the pointing accuracy was better than 0.5. The channels had almost rectangular response functions with central wavelengths and full widths (given in parentheses) at 1549(149), 1799(149), 2200(200), 2493(150) and 3294 (101) Å. In addition, the 1550 channel could be narrowed to a width of 50 Å to facilitate the measurement of the C iv  $\lambda 1550$  line. The absolute calibration of the channels was derived by comparing the flight instrument with a Groningen standard phototube which, in turn, was calibrated with a standard maintained at the Space Astronomy Laboratory of the University of Wisconsin (Aalders *et al.* 1975).

The satellite attitude control system allowed two modes of observations. The pointing mode kept the shutter opened for stellar observations and closed for dark measurements. The offset mode chopped between the star and a sky position  $5' - 64'$  away. A typical pointing observation consisted of a DARK-STAR-DARK-STAR-DARK sequence of measurements. Each DARK contained six 8 s samples and each STAR contained ten 1 s or 8 s samples. A typical offset observation had six to ten STAR-SKY pairs. The integration time for the STAR measurement was usually 32 s and that for SKY was 16 s with 16 s allowed for slewing between the star and the sky.

A second-degree polynomial was fitted to the DARK or SKY samples and subtracted from the STAR to obtain the net count rates. The net count rates were then corrected for the sensitivity change of the instrument which was monitored by daily observations of  $\epsilon$  Dor or  $\nu$  Dor. In the 18 month lifetime of the *ANS*, the 1550 channel became more sensitive by 18% and the sensitivity of the other four channels changed by less than 4% (Aalders and Wesselius 1976). The corrected *ANS* net count rates were converted into absolute fluxes by using the laboratory calibration (Aalders *et al.* 1975; Wesselius *et al.* 1980). Magnitudes were derived by adopting the definition  $m_\lambda = 0.00$  for  $f_\lambda = 3.64 \times 10^{-9}$  ergs  $\text{cm}^{-2} \text{s}^{-1} \text{Å}^{-1}$  (Oke and Schild 1970).

TABLE 1  
SUMMARY OF OBSERVATIONS

Object	Type	<i>ANS</i>	
		Observations	State
AR And.....	U Gem	1975 Jan	Outburst maximum
SS Aur.....	U Gem	1975 Mar	Start of outburst
		1975 Sep	Minimum
		1976 Mar	Minimum
SU UMa....	SU UMa	1975 Apr	Minimum
		1975 Oct	Minimum
		1976 Apr	Start of outburst
		1976 Apr	Standstill
Z Cam.....	Z Cam	1975 Apr	Standstill
		1975 Oct	Standstill
		1976 Apr	Outburst maximum
EM Cyg.....	Z Cam	1975 Oct	Minimum
		1976 Apr	Start of outburst

The *ANS* described a polar orbit around the Earth. The orbital plane was perpendicular to the axis joining the satellite and the Sun. The optical axis lay close to the orbital plane with maximum offset from the plane of  $\pm 0.9/\cos \beta$ , where  $\beta$  is the ecliptic latitude. Therefore, a star could be observed by the *ANS* every 6 months when it was  $\sim 90^\circ$  from the Sun, with an observing window of  $1.8/\cos \beta$  days.

We have investigated the possibility of contamination of the photometry by stars which might be included in the  $2.5$  square aperture. There are no stars bright enough to affect the observations in the outburst state. The fluxes of the objects at minimum light compare very well with *IUE* observations in all five bands (see § III). Thus, there should be no significant error introduced from surrounding stars.

The observations are summarized in Table 1. The outburst activity around the dates of observation was available from the visual monitoring by the AAVSO (Mattei 1975, 1976, 1977; J. Mattei 1982, private communication). The *ANS* photometry is presented in Tables 2–6. For each set of observations in the pointing or offset mode, we give the mean time in Julian Date and the results for each band in the form  $m_\lambda \pm (\text{p.e.}/\bar{x})$ ,

TABLE 2  
OBSERVED ULTRAVIOLET MAGNITUDES OF AR ANDROMEDAE

JD 2,442,000. +	$m_\lambda$				
	1550	1800	2200	2500	3300
1975 January					
440.746.....	9.99 ± 0.03	10.27 ± 0.02	10.69 ± 0.02	10.99 ± 0.03	11.60 ± 0.03
440.884.....	9.96 ± 0.02	10.21 ± 0.02	10.64 ± 0.02	10.90 ± 0.03	11.49 ± 0.03
441.564.....	10.18 ± 0.02	10.41 ± 0.02	10.91 ± 0.02	11.16 ± 0.03	11.85 ± 0.03
441.835.....	10.25 ± 0.05	10.48 ± 0.04	11.15 ± 0.04	11.38 ± 0.06	12.82 ± 0.09
441.907.....	10.31 ± 0.03	10.53 ± 0.02	10.99 ± 0.02	11.22 ± 0.03	11.77 ± 0.03
441.974.....	10.36 ± 0.02	10.52 ± 0.02	11.06 ± 0.02	11.28 ± 0.03	11.79 ± 0.03

TABLE 3  
OBSERVED ULTRAVIOLET MAGNITUDES OF SS AURIGAE

JD 2,442,000. +	$m_\lambda$				
	1550	1800	2200	2500	3300
1975 March					
494.057 .....	12.82 ± 0.17	13.76 ± 0.28	13.75 ± 0.14	13.32 ± 0.15	14.04 ± 0.88
494.261 .....	12.94 ± 0.37	13.69 ± 1.13	14.22 ± 0.30	13.93 ± 0.70	14.28 ± 1.57
494.463 .....	12.78 ± 0.35	13.48 ± 0.26	14.14 ± 0.27	13.65 ± 0.31	13.47 ± 0.64
494.668 .....	12.57 ± 0.16	13.43 ± 0.20	13.89 ± 0.13	13.71 ± 0.32	14.38 ± 1.44
494.751 .....	12.88 ± 0.69	13.51 ± 0.92	14.07 ± 0.64	13.11 ± 0.52	12.72 ± 1.11
494.872 .....	12.69 ± 0.15	13.52 ± 0.30	13.98 ± 0.14	13.48 ± 0.23	15.05 ± 2.09
494.886 .....	12.27 ± 0.38	12.38 ± 0.31	14.10 ± 0.57	14.30 ± 1.64	13.53 ± 1.09
495.076 .....	12.21 ± 0.09	12.60 ± 0.10	12.73 ± 0.05	12.81 ± 0.17	12.34 ± 0.24
495.159 .....	11.93 ± 0.29	11.73 ± 0.20	12.11 ± 0.10	12.06 ± 0.21	12.17 ± 0.53
495.294 .....	10.52 ± 0.09	10.61 ± 0.09	10.77 ± 0.04	11.12 ± 0.11	11.22 ± 0.14
495.349 .....	10.23 ± 0.06	10.31 ± 0.04	10.64 ± 0.03	10.75 ± 0.05	10.86 ± 0.06
1975 September					
680.434 .....	13.07 ± 0.40	13.72 ± 0.73	13.84 ± 0.45	13.69 ± 0.48	13.40 ± 0.88
681.177 .....	12.91 ± 0.24	13.35 ± 0.02	13.93 ± 0.24	13.49 ± 0.27	13.85 ± 0.66
681.241 .....	12.52 ± 0.29	13.37 ± 0.69	14.14 ± 0.50	14.42 ± 1.08	14.41 ± 1.63
681.247 .....	N11.87 ± 0.27	13.38 ± 0.31	14.19 ± 0.27	13.51 ± 0.28	...
681.376 .....	12.45 ± 0.20	12.89 ± 0.24	13.16 ± 0.15	14.01 ± 0.71	13.52 ± 0.55
681.383 .....	N11.97 ± 0.26	13.30 ± 0.27	13.75 ± 0.16	13.38 ± 0.23	14.19 ± 1.07
682.119 .....	12.31 ± 0.19	13.28 ± 0.43	14.19 ± 0.37	13.55 ± 0.51	12.85 ± 0.45
Mean .....	12.65 ± 0.09	13.28 ± 0.06	13.85 ± 0.10	13.57 ± 0.07	13.69 ± 0.30
1976 March					
859.298 .....	13.38 ± 0.37	13.56 ± 0.40	14.58 ± 0.33	14.28 ± 0.60	13.59 ± 0.54
859.630 .....	13.48 ± 0.42	14.20 ± 0.53	14.07 ± 0.18	13.35 ± 0.27	...
860.298 .....	13.10 ± 0.70	13.13 ± 0.59	14.07 ± 0.35	13.42 ± 0.58	...
860.431 .....	13.13 ± 0.36	13.27 ± 0.38	13.62 ± 0.19	13.07 ± 0.30	14.12 ± 1.78
Mean .....	13.33 ± 0.07	13.72 ± 0.19	14.11 ± 0.13	13.57 ± 0.16	13.67 ± 0.17

where  $m_\lambda$  is the magnitude derived from the mean count rate  $\bar{x}$  and p.e. is the probable error of the mean as estimated from the dispersion of the  $n$  individual measures  $x_i$

$$\text{p.e.} = 0.67 \left[ \sum_{i=1}^n (x_i - \bar{x})^2 / n(n-1) \right]^{1/2}.$$

At epochs where the star was not changing over the period of *ANS* observations, e.g., for 1975 September SS Aur, we give the mean of all the sets using (p.e.)<sup>-2</sup> as the weight. Of the five *ANS* channels, the 3300 channel was most susceptible to background particles which often dominated the measurement noise. Hence, it has the largest uncertainties. The accuracy of measurements in a given channel varied considerably because of the different depths of penetration by the spacecraft into the high background South Atlantic Anomaly. All the 1550 measurements were made with the wide (150 Å) band except two sets on SS Aur in 1975 September marked "N" in Table 3. In Table 6, we include phases

from the ephemeris of the optical eclipses of EM Cyg (Mumford 1980) with the phase zero at mid-eclipse thought to mark eclipse of the compact star by the red star.

### III. RESULTS FOR THE INDIVIDUAL SYSTEMS

Here we discuss the five systems individually. It is convenient to parameterize the flux distribution in the form  $F_\lambda \propto \lambda^\alpha$ , and in most cases this form matches the observed fluxes within the observational error. We use a least squares fitting with the probable errors of the individual magnitudes used as weights and in the determination of the probable error of  $\alpha$  (Bevington 1969). The interpretation of the 1550 band requires some information about the strength of the C IV line, which can be in emission very strongly, especially in the nonoutburst state. For a line with equivalent width  $W_\lambda$ , the magnitude in a band of width  $\Delta\lambda$  will be biased from the continuum flux level by an amount  $\Delta m = 2.5 \log(1 + W_\lambda/\Delta\lambda)$ . Since  $W_\lambda$  can reach 100 Å and  $\Delta\lambda = 150$  Å, this bias can be substantial. In outburst the emission

TABLE 4  
OBSERVED ULTRAVIOLET MAGNITUDES OF SU URSAE MAJORIS

JD 2,442,000. +	$m_\lambda$				
	1550	1800	2200	2500	3300
1975 April					
511.402 .....	12.39 ± 0.42	12.98 ± 0.59	13.39 ± 0.35	...	...
511.798 .....	12.29 ± 0.22	12.66 ± 0.20	12.96 ± 0.10	12.72 ± 0.17	...
511.933 .....	13.09 ± 0.27	13.00 ± 0.18	13.32 ± 0.11	13.48 ± 0.21	...
512.001 .....	12.09 ± 0.13	12.95 ± 0.35	13.01 ± 0.07	13.48 ± 0.23	13.27 ± 0.29
512.150 .....	11.92 ± 0.22	12.80 ± 0.66	12.59 ± 0.14	12.43 ± 0.32	13.30 ± 1.00
512.351 .....	12.15 ± 0.30	12.34 ± 0.25	13.02 ± 0.17	12.71 ± 0.29	13.13 ± 0.91
512.556 .....	12.18 ± 0.35	12.20 ± 0.27	13.04 ± 0.22	12.71 ± 0.37	...
512.626 .....	12.42 ± 0.37	12.37 ± 0.26	12.98 ± 0.16'	13.61 ± 0.70	12.59 ± 0.69
512.895 .....	12.26 ± 0.34	12.31 ± 0.28	12.76 ± 0.17	12.97 ± 0.43	13.23 ± 0.73
512.952 .....	12.32 ± 0.13	12.68 ± 0.14	12.10 ± 0.07	13.24 ± 0.21	13.15 ± 0.62
513.020 .....	12.59 ± 0.28	12.93 ± 0.18	13.35 ± 0.29	13.12 ± 0.19	...
513.168 .....	12.75 ± 0.72	12.42 ± 0.33	13.24 ± 0.26	12.38 ± 0.36	12.05 ± 0.49
513.367 .....	12.11 ± 0.33	...	13.01 ± 0.22	12.23 ± 0.27	...
Mean .....	12.40 ± 0.05	12.74 ± 0.07	13.02 ± 0.04	13.16 ± 0.13	13.16 ± 0.20
1975 October					
698.521 .....	12.13 ± 0.14	12.75 ± 0.19	13.16 ± 0.12	13.25 ± 0.25	13.26 ± 0.27
698.587 .....	12.14 ± 0.12	13.25 ± 0.27	13.21 ± 0.10	13.06 ± 0.22	13.84 ± 0.67
698.778 .....	12.58 ± 0.38	...	13.31 ± 0.20	12.80 ± 0.30	...
698.845 .....	12.27 ± 0.32	13.64 ± 0.99	13.27 ± 0.21	...	...
698.918 .....	12.45 ± 0.24	13.49 ± 0.50	13.30 ± 0.15	13.31 ± 0.40	12.79 ± 0.47
699.046 .....	12.35 ± 0.28	12.87 ± 0.32	13.02 ± 0.13	13.21 ± 0.33	12.82 ± 0.56
699.115 .....	...	12.89 ± 0.39	13.08 ± 0.15	12.90 ± 0.42	12.98 ± 0.41
699.124 .....	11.94 ± 0.16	13.08 ± 0.22	12.90 ± 0.13	12.89 ± 0.19	13.47 ± 0.68
699.182 .....	11.95 ± 0.26	...	13.01 ± 0.24	13.10 ± 0.55	12.33 ± 0.32
699.259 .....	12.42 ± 0.19	12.79 ± 0.23	13.08 ± 0.10	13.13 ± 0.21	13.26 ± 0.44
699.492 .....	12.64 ± 0.27	12.90 ± 0.28	13.32 ± 0.16	13.09 ± 0.38	...
699.589 .....	12.20 ± 0.29	12.46 ± 0.32	12.56 ± 0.11	13.59 ± 0.65	12.32 ± 0.25
Mean .....	12.26 ± 0.04	12.92 ± 0.06	13.13 ± 0.05	13.11 ± 0.06	13.11 ± 0.13
1976 April					
876.716 .....	12.09 ± 0.36	...	13.11 ± 0.26	11.70 ± 0.17	11.57 ± 0.29
876.852 .....	10.51 ± 0.10	10.83 ± 0.13	11.03 ± 0.07	10.48 ± 0.10	9.81 ± 0.14
876.985 .....	11.39 ± 0.18	11.69 ± 0.17	11.37 ± 0.06	11.38 ± 0.12	10.40 ± 0.10
877.1163 .....	12.02 ± 0.27	11.94 ± 0.22	11.74 ± 0.09	11.54 ± 0.13	11.40 ± 0.20
877.1178 .....	11.68 ± 0.21	12.01 ± 0.23	11.56 ± 0.07	11.54 ± 0.14	11.30 ± 0.21
877.183 .....	12.02 ± 0.28	13.09 ± 0.76	12.06 ± 0.11	11.74 ± 0.19	11.36 ± 0.20
877.382 .....	10.71 ± 0.10	10.91 ± 0.10	10.99 ± 0.05	11.08 ± 0.09	11.04 ± 0.14
877.447 .....	10.85 ± 0.11	10.96 ± 0.06	11.19 ± 0.05	11.52 ± 0.12	11.83 ± 0.28

lines are usually very weak (Heap *et al.* 1978; Szkody 1981). In several cases, we have information from spectra obtained with the *International Ultraviolet Explorer* (IUE).

#### a) AR Andromedae

AR And is a U Gem type dwarf nova, with a mean interval between outbursts of about 26<sup>d</sup>. The peak visual magnitude reported for outburst ranges from 11.5 to 13.3 mag. Visual estimates by the AAVSO show that an outburst occurred between JD 2,442,436.55 (fainter than  $m_v = 14.0$ ) and 2442.70 ( $m_v = 13.0$ ). The ANS observations show that the variable was bright already at JD 2,442,440.8, so that the peak visual brightness probably

exceeded  $m_v = 13.0$ . The changes during the span of 1<sup>d</sup>2 of the ANS observations indicate a fading at the rate of  $0.30 \pm 0.03$  mag per day. The flux distributions across the 5 ANS bands are well represented by a power law with  $\alpha = -1.95 \pm 0.05$  (p.e.) (see Fig. 1). The *B* and *V* magnitudes reported for an outburst by Markarian (1967) fit the extrapolation of this relation at maximum UV brightness. At minimum light, Markarian found  $V = 17.0$ . The orbital period of AR And is unknown.

#### b) SS Aurigae

SS Aur is a well-known dwarf nova of the U Gem type, showing a mean interval between outbursts of

TABLE 5  
OBSERVED ULTRAVIOLET MAGNITUDES OF Z CAMELOPARDALIS

JD 2,442,000. +	$m_\lambda$				
	1550	1800	2200	2500	3300
1975 April					
507.591 .....	9.17 ± 0.03	9.43 ± 0.04	9.78 ± 0.02	10.02 ± 0.06	10.61 ± 0.09
507.661 .....	9.19 ± 0.05	9.42 ± 0.03	9.73 ± 0.03	10.12 ± 0.03	10.68 ± 0.06
508.342 .....	9.16 ± 0.03	9.41 ± 0.03	9.77 ± 0.01	10.14 ± 0.03	10.79 ± 0.10
508.479 .....	9.18 ± 0.04	9.43 ± 0.03	9.77 ± 0.03	10.11 ± 0.04	10.98 ± 0.12
508.819 .....	9.23 ± 0.04	9.51 ± 0.04	9.83 ± 0.02	10.13 ± 0.07	10.53 ± 0.09
508.876 .....	9.15 ± 0.02	9.46 ± 0.02	9.81 ± 0.01	10.19 ± 0.04	10.69 ± 0.03
508.944 .....	9.18 ± 0.02	9.45 ± 0.02	9.81 ± 0.02	10.12 ± 0.02	10.75 ± 0.03
509.079 .....	9.25 ± 0.02	9.44 ± 0.03	9.80 ± 0.01	10.12 ± 0.02	10.78 ± 0.04
509.091 .....	9.19 ± 0.04	9.51 ± 0.05	9.82 ± 0.02	10.17 ± 0.05	10.57 ± 0.08
509.431 .....	9.19 ± 0.04	9.45 ± 0.04	9.80 ± 0.02	10.21 ± 0.05	10.80 ± 0.12
509.702 .....	9.23 ± 0.04	9.46 ± 0.04	9.79 ± 0.02	10.10 ± 0.04	10.79 ± 0.15
509.895 .....	9.19 ± 0.03	9.49 ± 0.02	9.83 ± 0.02	10.09 ± 0.02	10.74 ± 0.04
509.906 .....	9.29 ± 0.04	9.55 ± 0.05	9.86 ± 0.02	10.10 ± 0.05	10.57 ± 0.71
509.963 .....	9.22 ± 0.02	9.49 ± 0.02	9.85 ± 0.02	10.19 ± 0.04	10.81 ± 0.03
510.098 .....	9.20 ± 0.02	9.46 ± 0.02	9.81 ± 0.01	10.10 ± 0.04	10.76 ± 0.05
510.105 .....	9.25 ± 0.06	9.47 ± 0.05	9.88 ± 0.03	10.09 ± 0.11	10.90 ± 0.14
Mean .....	9.20 ± 0.01	9.46 ± 0.01	9.81 ± 0.01	10.12 ± 0.01	10.73 ± 0.02
1975 October					
694.881 .....	9.14 ± 0.05	9.28 ± 0.04	9.72 ± 0.03	9.92 ± 0.06	10.83 ± 0.11
696.365 .....	9.19 ± 0.05	9.36 ± 0.03	9.73 ± 0.03	9.92 ± 0.06	10.70 ± 0.26
696.500 .....	9.09 ± 0.05	9.31 ± 0.04	9.73 ± 0.03	9.99 ± 0.06	11.01 ± 0.12
Mean .....	9.14 ± 0.03	9.31 ± 0.02	9.73 ± 0.00	9.95 ± 0.02	10.84 ± 0.08
1976 April					
873.398 .....	8.11 ± 0.01	8.37 ± 0.01	8.74 ± 0.01	9.08 ± 0.02	9.76 ± 0.04
873.863 .....	8.13 ± 0.02	8.39 ± 0.01	8.78 ± 0.01	9.11 ± 0.02	9.82 ± 0.09
874.062 .....	8.13 ± 0.01	8.43 ± 0.01	8.80 ± 0.01	9.11 ± 0.01	9.74 ± 0.06
874.329 .....	8.18 ± 0.01	8.45 ± 0.02	8.84 ± 0.01	9.18 ± 0.02	9.87 ± 0.04
874.527 .....	8.18 ± 0.01	8.48 ± 0.02	8.84 ± 0.01	9.14 ± 0.03	9.74 ± 0.06
Mean .....	8.16 ± 0.02	8.42 ± 0.02	8.80 ± 0.02	9.13 ± 0.02	9.80 ± 0.03

TABLE 6  
OBSERVED ULTRAVIOLET MAGNITUDES OF EM CYGNI

JD 2,442,000. +	PHASE	$m_\lambda$				
		1550	1800	2200	2500	3300
1975 October						
713.264 .....	0.50	12.21 ± 0.10	12.53 ± 0.10	12.73 ± 0.07	12.87 ± 0.15	12.41 ± 0.05
713.467 .....	0.19	...	12.42 ± 0.12	12.77 ± 0.05	12.94 ± 0.06	12.68 ± 0.07
1976 April						
891.663 .....	0.74	11.56 ± 0.11	12.08 ± 0.17	12.09 ± 0.08	12.19 ± 0.11	12.20 ± 0.16
891.725 .....	0.96	11.68 ± 0.08	11.72 ± 0.09	11.94 ± 0.05	12.10 ± 0.07	12.15 ± 0.07
891.857 .....	0.41	11.66 ± 0.09	11.78 ± 0.11	11.95 ± 0.04	12.11 ± 0.08	12.14 ± 0.12
891.924 .....	0.64	11.40 ± 0.11	11.80 ± 0.10	11.94 ± 0.06	11.96 ± 0.08	11.74 ± 0.11
892.060 .....	0.11	11.36 ± 0.07	11.49 ± 0.11	11.63 ± 0.06	11.85 ± 0.11	11.82 ± 0.09
892.127 .....	0.34	11.08 ± 0.04	11.28 ± 0.06	11.62 ± 0.03	11.67 ± 0.05	11.63 ± 0.09
892.260 .....	0.79	11.04 ± 0.04	11.19 ± 0.06	11.53 ± 0.02	11.73 ± 0.07	11.81 ± 0.06
892.324 .....	0.01	11.08 ± 0.05	11.14 ± 0.04	11.41 ± 0.03	11.58 ± 0.05	11.74 ± 0.11
892.393 .....	0.25	10.72 ± 0.04	10.98 ± 0.04	11.25 ± 0.03	11.50 ± 0.06	11.77 ± 0.10
892.459 .....	0.48	10.79 ± 0.04	11.00 ± 0.04	11.27 ± 0.02	11.46 ± 0.04	11.61 ± 0.06
893.588 .....	0.36	10.34 ± 0.04	10.60 ± 0.04	10.89 ± 0.03	11.18 ± 0.05	11.48 ± 0.09

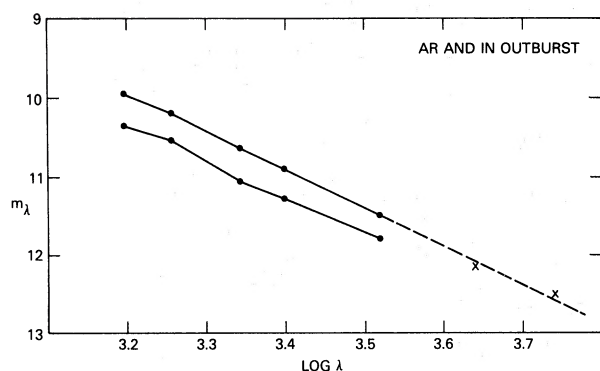


FIG. 1.—The flux distributions of AR And in outburst, from Table 2. The  $B$  and  $V$  magnitudes reported for an outburst by Markarian (1967) are shown as X. The probable errors of the *ANS* magnitudes are all less than 0.05 mag.

about 56<sup>d</sup>. The optical outbursts have a very abrupt rise, covering about 4 mag in less than a day. Like U Gem, it tends to have two types of outbursts, characterized by their duration at maximum light as “long” or “short.” SS Aur is a spectroscopic binary with a period of 4<sup>h</sup>33 (Kraft and Luyten 1965). The *ANS* observations in 1975 September and 1976 March were obtained between outbursts. The observations in 1975 September cover about one-half the orbital period but show no variability within the rather large probable error (typically 0.5 mag). The fluxes at the two epochs are similar, though a bit redder in 1976 March. The flux distribution in 1975 September clearly reveals a large contribution by C IV line emission

to the 1550 band. An *IUE* spectrum of SS Aur obtained by J. B. Oke and R. Wade on 1980 February 15 showed C IV emission with  $W_\lambda = 80 \text{ \AA}$  at minimum light. This would bias the *ANS* 1550 band by  $\Delta m = 0.46$  mag over the continuum flux distribution with  $\alpha = -0.2 \pm 0.6$ . Two measurements with the 50  $\text{\AA}$  wide 1550 band in 1975 September indicate  $\Delta m = 0.71$  ( $W_\lambda = 138 \text{ \AA}$ ) but with a large uncertainty.

The *ANS* observations in 1975 March include the start of an outburst (Fig. 2). At 2200  $\text{\AA}$ , a range of 3.5 mag is covered in 0<sup>d</sup>.5. The flux distribution apparently steepens as the light increases, although the measurement is not very precise (Fig. 3). Omitting the 1550 band, we find  $\alpha = 0.0 \pm 0.3$  when  $m_\lambda(2200) = 12.7$ ;  $\alpha = -0.9 \pm 0.7$  at  $m_\lambda(2200) = 12.1$ ;  $\alpha = -1.1 \pm 0.2$  at  $m_\lambda(2200) = 10.8$ ; and  $\alpha = -0.88 \pm 0.1$  at  $m_\lambda(2200) = 10.64$ . At the brightest, the 1550  $\text{\AA}$  band is consistent with the flux distribution determined by the 1800–3300 bands, as expected if the C IV equivalent width decreases in the outburst. The AAVSO observations constrain the time of the visual outburst to be between JD 2,442,494.70 ( $V = 14.1$ ) and 2495.57 ( $V = 11.4$ ).

### c) *SU Ursae Majoris*

SU UMa is the prototype of the class of dwarf novae which show supermaxima, occasional outbursts which are brighter and last longer than the ordinary outbursts. Objects in this class tend to have three other characteristics: a short interval between the ordinary outbursts, a

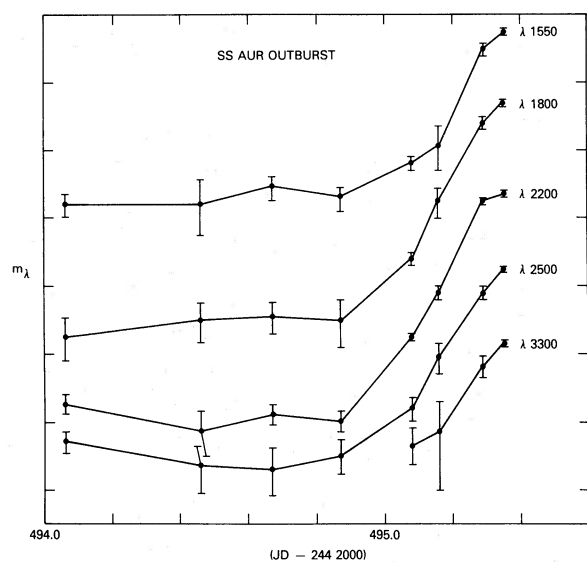


FIG. 2

FIG. 2.—The light curves of the outburst of SS Aur in 1975 March (Table 3). The vertical scale ticks mark 1 mag intervals. The light curves for the five bands have been shifted vertically. Error bars show the probable errors.

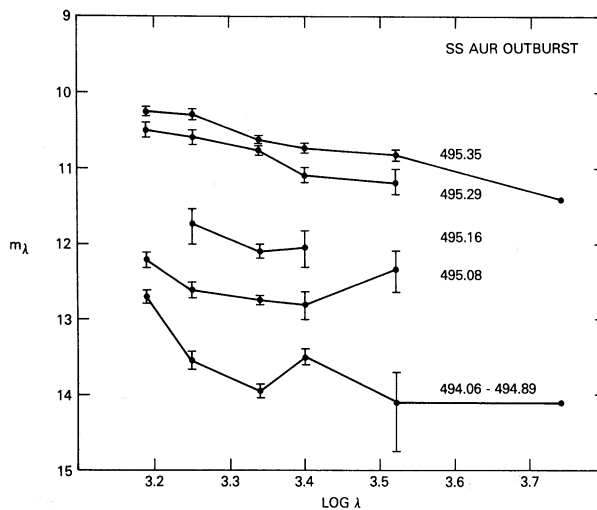


FIG. 3

FIG. 3.—The flux distributions of SS Aur during the outburst on JD 2,442,494. The error bars show probable errors.

short orbital period (around 2 hours or less), and optical light curves during the supermaxima with recurring humps (superhumps) with a period which is several percent longer than the orbital period. The time between the ordinary outbursts of SU UMa averages about 16 days. These outbursts last a few days, with a rapid rise and a fairly rapid decline. The supermaxima occur about every 6 months. They last about 20 days and peak near  $m_v = 11.2$ , about 1 mag brighter than the ordinary outbursts. For SU UMa itself the orbital period remains unknown, and the occasion to observe the superhumps has not yet arisen (Barwig and Schoembs 1981).

The ANS observations in 1975 April and October occurred between recorded outbursts. At these times, the UV fluxes were constant within the errors of several tenths of a mag, and the average fluxes at these two epochs are equal within the errors. Excepting the 1550 band, the UV flux distribution is rather flat,  $\alpha = -0.7 \pm 0.3$ . The 1550 band is obviously influenced strongly by C IV line emission. Szkody (1981) reports a C IV equivalent width of 91 Å in emission at minimum light. This will bias the 1550 band by  $2^{m5}$  over the continuum. The

mid-UV continuum slope found by Szkody,  $\alpha = -1.0$ , agrees with our result.

The ANS observations in 1976 April occurred at the time of an ordinary outburst as reported by the AAVSO:  $m_v = 14.5$  at JD 2,442,876.69; 12.2 at 2877.00; 12.0 at 2877.56; 12.2 at 2878.56; and 14.1 at 2880.64. The UV behavior is quite remarkable. Labeling the individual times of observations 1 to 8 (Fig. 4), we see an initial peak (2) with a very red flux distribution followed by a fall to an intermediate level (4,5,6), also with a red flux distribution (see Fig. 5). Then the flux at 1550–2200 Å recovers to the level of the initial peak, the fall and recovery having occupied  $0^d.5$ , whereas the flux at 2500–3300 Å holds at the intermediate level. Extrapolation of the flux distribution 1550–3300 Å at the peak 8 and extrapolation of the flux distribution for  $\lambda \leq 2200$  Å at the peak 3 are consistent with the visual magnitudes. At the peak 2 we find  $\alpha = -2.8 \pm 0.4$  for  $\lambda \leq 2200$  Å and  $\alpha = +1.3 \pm 0.3$  for  $\lambda \geq 2200$  Å. At the levels 4 and 7, a single slope fits within the uncertainties  $\alpha = +0.85 \pm 0.3$  at the intermediate level 4 and  $\alpha = -0.5 \pm 0.2$  at the peak 7.

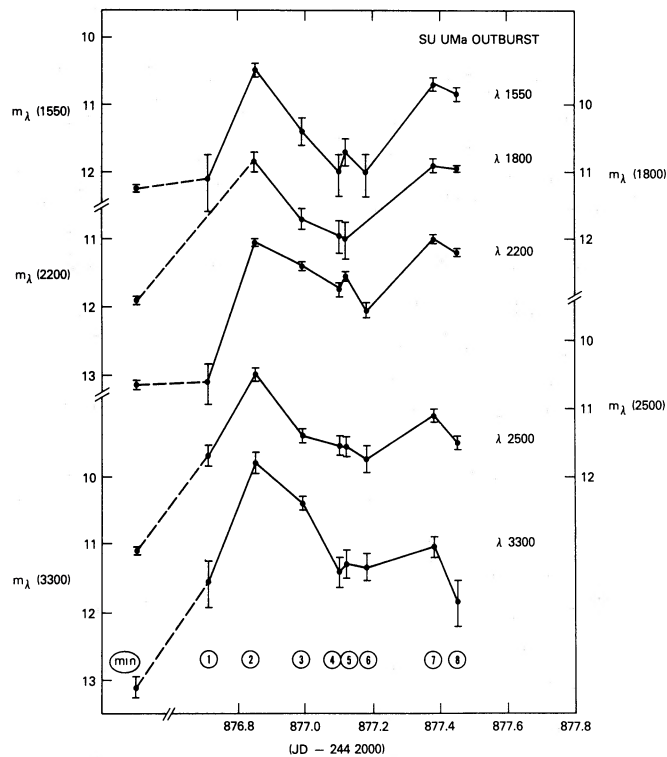


FIG. 4

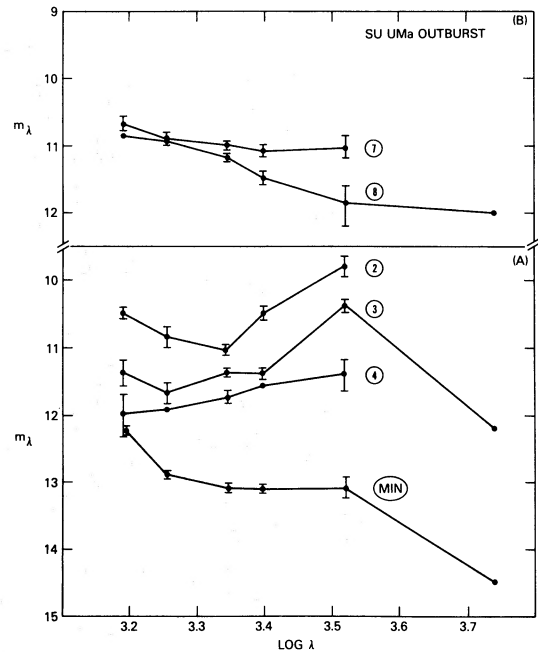


FIG. 5

FIG. 4.—The light curves of the outburst of SU UMa in 1976 April (from Table 4). The vertical axis is broken to show the scales for the 5 ANS bands. The horizontal axis is broken to include the minimum light (average for 1975 October). The eight times of measurement in 1976 April are numbered consecutively for reference in the text.

FIG. 5.—The flux distributions of SU UMa for selected times in the outburst of 1976 April and for the minimum light (1975 October). For clarity the display is separated into two panels, Fig. 5a covering the first outburst peak, and Fig. 5b, the second. Error bars show the probable errors.

d) *Z Camelopardalis*

*Z CAM* is the well-known prototype of the class of dwarf novae with standstills in the outburst cycle. *Z Cam* itself is a spectroscopic binary with a period of 6<sup>h</sup>96 (Kraft, Krzeminski, and Mumford 1969). The *ANS* observations of 1975 April and October came during a year-long standstill which began in 1974 November. The 16 measurements over a 2<sup>d</sup> interval in 1975 April are well distributed in orbital phase but show no significant variations. The UV flux distribution over 1550–3300 Å conforms reasonably well to a power law with  $\alpha = -1.81 \pm 0.002$  for April and  $\alpha = -1.76 \pm 0.06$  for October (Fig. 6). Extrapolation to 5500 Å comes close to the *V* mag (AAVSO). Szkody (1981) has observed *Z Cam* in standstill with the *IUE*. C IV is relatively weak and in absorption ( $W_\lambda = 4$  Å). The mean *ANS* fluxes agree to within 10% with the *IUE* fluxes during the standstill in 1979 December.

The *ANS* observations in 1976 April occurred about 2 days after *Z Cam* reached maximum ( $V = 10.8$ ) of an ordinary outburst. *Z Cam* was about 1 mag brighter than in standstill, though the slope of the flux distribution,  $\alpha = -1.84 \pm 0.04$ , is identical. During the 1<sup>d</sup> interval of observations, the magnitudes fit closely to a decline at the rate of  $0.084 \pm 0.007$  mag per day.

e) *EM Cygni*

*EM Cyg* is an important system, being an eclipsing binary (Mumford and Krzeminski 1969) and a double-lined spectroscopic binary (Kraft 1964) with the period 6.98 hr. Therefore, its mass is relatively well determined (Robinson 1974, 1976; Stover, Robinson, and Nather 1981). It is a *Z Cam* type dwarf nova with visual outbursts of about 2 mag at an interval of about 25<sup>d</sup>, though the light curve is often rather irregular. It is the only dwarf nova in which the compact star,  $M = 0.6 M_\odot$ , is known to be less massive than the secondary (mass ratio 0.75).

The *ANS* observations in 1975 October show *EM Cyg* at two orbital phases at a flux level about 0.5 mag brighter than at midway on the decline to minimum (Szkody 1981). AAVSO estimates at this time show *EM Cyg* holding at  $V = 13.4$ , following an outburst on JD 2,442,692. This appears to be a sort of standstill level, about 1 mag above minimum. The steep increase in flux at 3300 Å confirms the upturn reported by Szkody (1981). The 1550 Å band indicates strong C IV line emission, consistent with the measurement of  $W_\lambda = 47$  Å at the midway level (Szkody 1981). Over the limited range 1800–2500 Å, we find  $\alpha = -0.94 \pm 0.5$ .

The observations in 1976 April cover a 2<sup>d</sup> interval of rising light (Fig. 7). Over the first day, the magnitude change is approximately linear (i.e., exponential flux change) at a rate of  $1.23 \pm 0.08$  mag per day at 1550 Å;  $1.22 \pm 0.09$  at 1800 Å;  $1.07 \pm 0.09$  at 2200 Å;  $0.92 \pm 0.08$

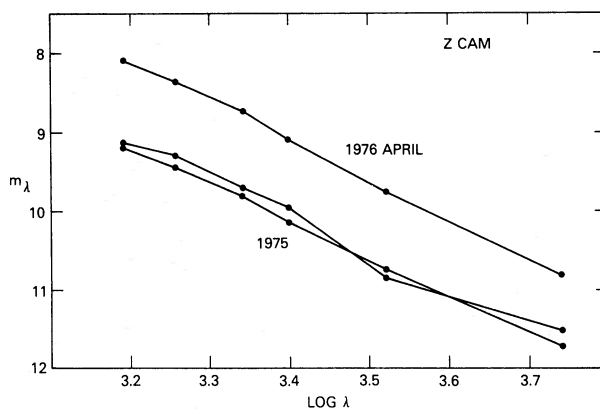


FIG. 6.—The flux distributions of *Z Cam* from *ANS* photometry (Table 5) and from the AAVSO visual estimates. The values for 1975 April and October are the means from observations during a long-lived standstill. The 1976 April values are observations of an outburst. Except for  $\lambda 3300$  (p.e. up to 0.08 mag), the errors are less than 0.03 mag.

at 2500 Å; and  $0.64 \pm 0.10$  at 3300 Å. There is no dependence on orbital phase. The continuum change at 1550 Å would be larger since the C IV flux does not share the increase seen in the continuum (a factor of 2 versus a factor of 16; Szkody 1981). The smaller change at 3300 Å suggests that the source of light producing the flux upturn there does not participate strongly in the outburst. The changes in the flux distribution are shown in Figure 8. At the brightest level, the power law flux distribution is an adequate approximation from 1550 to 3300 Å with  $\alpha = -1.53$ , close to what is seen by Szkody

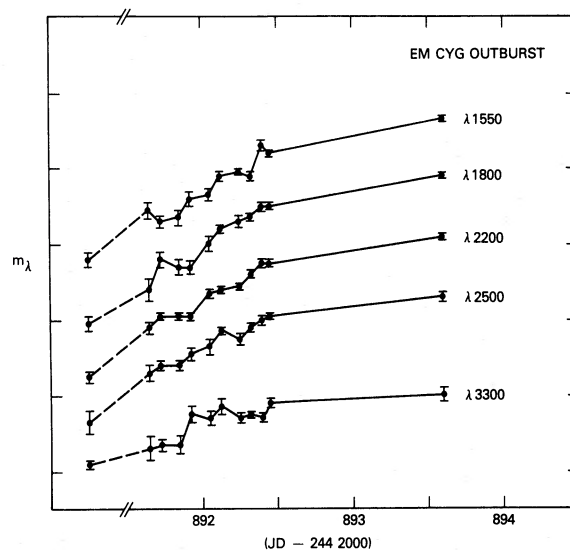


FIG. 7.—The light curve of the outburst of *EM Cyg* in 1976 April (Table 6). The vertical scale ticks mark 1 mag intervals. The horizontal axis is broken to include JD 2,442,713 as well as the outburst rise (JD 2,442,891–893). The light curves for the five bands have been shifted vertically.

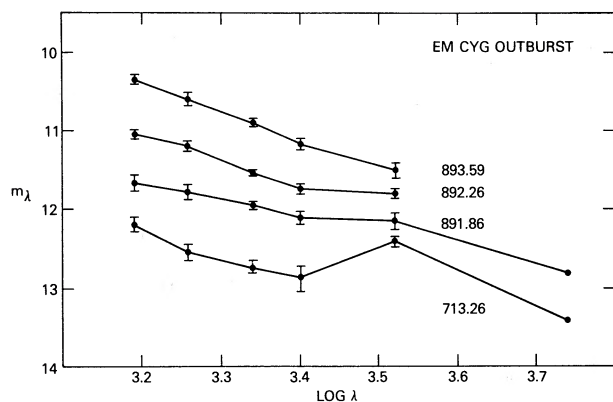


FIG. 8.—Representative flux distributions of EM Cyg, labeled by JD 2,442,000.

(1981) at outburst maximum. A single estimate by the AAVSO,  $V = 12.8$  at JD 2,442,891.87, confirms an optical outburst at this time.

#### IV. COMPARISON TO MODEL DISKS

There are three requirements for the astrophysical interpretation of the broad-band photometry: correction of the effects of interstellar reddening, calculation of realistic models, and identification of a model with a particular system to verify the validity of the theory and to derive parameters for the system. We discuss these requirements below.

Whenever the intrinsic ultraviolet flux distribution is smooth, the interstellar reddening can be estimated by the appearance of the 2200 Å extinction feature. If we compare the depression at 2200 Å relative to a linear interpolation between 1800 and 2500 Å, in the  $m_\lambda$  versus  $\log \lambda$  plane, we find  $\Delta m(2200) \approx 2 \times E(B - V)$ . Roughly speaking, we find that the change in the power law index  $\alpha$  is about  $\Delta \alpha = 7 \times E(B - V)$ . We suppose that our assumption of intrinsic smoothness sets a lower limit to the accuracy of measurement of  $\Delta m(2200)$  at about 0.05 mag, with a corresponding uncertainty of 0.025 mag in  $E(B - V)$  or  $\pm 0.2$  in  $\alpha$ . Observational imprecision can increase these uncertainties substantially. Using the most accurate observations for the five systems, we estimate as follows: AR And,  $E(B - V) = 0.00 \pm 0.03$ ; SS Aur,  $E(B - V) = 0.05 \pm 0.03$ ; SU UMa,  $E(B - V) = 0.00 \pm 0.05$ ; Z Cam,  $E(B - V) = 0.00 \pm 0.03$ ; EM Cyg,  $E(B - V) = 0.00 \pm 0.05$ . These small reddening values are consistent with independent estimates of luminosities of dwarf novae. Since  $A_\lambda(2200) \approx 10 \times E(B - V)$ , we will accept a minimum uncertainty of about  $\pm 0.5$  mag in comparisons with absolute model fluxes and of about  $\pm 0.3$  in comparisons with the power law index  $\alpha$  due to the uncertainty in the determination of reddening.

#### a) Steady State Models

We adopt the basic model in which an accretion disk radiates the observed UV flux when it is heated by the viscous dissipation of gravitational energy as mass flows through it into the potential well of the compact star (white dwarf). We will assume a steady state, optically thick disk. The disk structure and radiated spectrum then depend upon five parameters: the mass of the compact star  $M_\star$ , the inner radius and outer radius of the disk, the mass flux ( $\dot{M}_{16}$ , in units of  $10^{16} \text{ g s}^{-1}$ ) through the disk, and the inclination of the disk to the observer. The assumption of optical thickness is incorrect in the outer regions of the disk, where  $T < 10,000 \text{ K}$ . While this necessitates more complex models to treat the visual and infrared continuum and the emission lines (Williams 1980; Tylanda 1981), these cool regions do not radiate significant UV flux. Similarly, the outer radius of the disk is unimportant for the UV flux as long as it is large enough that the outer temperature falls below 10,000 K. The steady state approximations should be valid for Z Cam and EM Cyg in standstill. We assume that this holds also for AR And and Z Cam during the outburst, and that for SS Aur, EM Cyg, and SU UMa the flux distribution observed just at the end of the outburst rise is representative of the outburst steady state.

Much of the accretion luminosity must be radiated in the boundary zone between the disk and the white dwarf. However, most of this energy should appear in the far-UV and X-ray spectrum (Pringle and Savonijje 1979). Since the disk is not flat, it absorbs and reradiates some of this energy. However, this effect is insignificant except in the cool, outer regions of the largest disks (Tylanda 1981; Pacharintanakul and Katz 1980). Thus, we can ignore the boundary zone. To further simplify the calculation of the model spectra, we have assumed that each portion of the disk radiates like a main-sequence star of the corresponding effective temperature, except for  $T > 50,000 \text{ K}$  for which we assume blackbody radiation. The geometrical projection of the disk is explicitly included in the determination of the absolute flux. These assumptions should be adequate when the inclination is not extreme (Wu and Panek 1982).

We have calculated a family of models in which the disk size is determined by the condition that the temperature at the edge is 10,000 K and the inner radius is the radius of the white dwarf,  $R_\star$ . The flux distributions can be approximated well enough for our purposes in terms of the absolute magnitude in the 2200 Å band,  $M_{2200}$ , and the index  $\alpha$  of the best fit power law over the 1550–3300 Å range. For  $M_\star = 1.2 M_\odot$  and  $R_\star = 5 \times 10^8 \text{ cm}$ , we find that over the range  $\dot{M}_{16} = 1-100$ ,  $M_{2200} = 4.72 - 2.01 \times \log(\dot{M}_{16}) \pm 0.05$ ,  $\alpha = -2.29 - 0.225 \times \log(\dot{M}_{16}) \pm 0.05$ . If we assume that the surface radiates like a blackbody at all temperatures, we find

$\alpha_{\text{BB}} = -1.63 - 0.284 \times \log(\dot{M}_{16}) \pm 0.1$ . For  $M_{\star} = 0.6 M_{\odot}$  and  $R_{\star} = 1.0 \times 10^9$  cm, we find over the same range of  $\dot{M}$ ,  $M_{2200} = 6.46 - 2.522 \times \log(\dot{M}_{16}) \pm 0.1$ ,  $\alpha = -1.77 - 0.381 \times \log(\dot{M}_{16}) \pm 0.05$ , and  $\alpha_{\text{BB}} = -0.55 - 0.795 \times \log(\dot{M}_{16}) \pm 0.2$ . We note that the disks which radiate like stars are bluer than the blackbody disks. This occurs because of the Balmer continuum absorption in stellar atmospheres. This opacity decreases toward shorter wavelengths and forces redistribution of flux, with the result that stellar fluxes peak well shortward of the Planck maximum at the effective temperature of the atmosphere. The flux distributions of disks of this size and mass flow rate differ from the well-known result for an infinitely large disk with infinitely large  $\dot{M}$ , which has  $\alpha = -2.3$  (Lynden-Bell 1969).

The change in color over the range of  $10^2$  in  $\dot{M}$  is small compared with observational errors and uncertainties introduced by the assumptions in the theory. Thus, to make a comparison with a model we rely on an independent determination of the distance to the system. This is possible when the cool star is visible in the integrated light and its spectral type and luminosity class can be determined. This is possible only for Z Cam, distance modulus  $DM = 6.5 \pm 0.5$  (Szkody and Wade 1981), and for EM Cyg,  $DM = 7.7 \pm 0.5$  (Bailey 1981).

#### i) Z Cam

Robinson (1974) has estimated the white dwarf mass to be  $1.2 M_{\odot}$ . The inclination must be close to  $55^{\circ}$  (Kraft, Krzeminski, and Mumford 1969). We find that the model with  $\log(\dot{M}_{16}) = 1.02 \pm 0.25$  provides the required absolute magnitude  $M_{2200} = 3.2 \pm 0.5$  in standstill. The predicted power law index  $\alpha = -2.5$  is much bluer than the observed. Our analysis is consistent with Kiplinger (1980), the difference arising from the slightly larger distance and considerably larger interstellar extinction estimates he adopted. In outburst the  $M_{2200} = 2.2 \pm 0.5$  requires  $\log(\dot{M}_{16}) = 1.54 \pm 0.25$ , and again the predicted index is bluer than observed.

#### ii) EM Cyg

Adopting the white dwarf mass of  $0.6 M_{\odot}$  and inclination at  $63^{\circ}$  (Stover, Robinson, and Nather 1981), we find that  $M_{2200} = 3.2 \pm 0.5$  at the brightest level requires  $\log(\dot{M}_{16}) = 1.63 \pm 0.20$ . At the standstill level of 1975 October,  $M_{2200} = 5.0 \pm 0.5$  and  $\log(\dot{M}_{16}) = 0.92 \pm 0.20$ . Again, however, the predicted index  $\alpha = -2.4$  is bluer than observed.

#### iii) AR And, SS Aur, and SU UMa

We do not have any good basis for distance estimate, but 500 pc seems a firm upper limit given the lack of reddening. Further assuming  $M_{\star} = 1.2 M_{\odot}$  and  $R_{\star} = 5 \times 10^8$  cm for the white dwarf and an inclination of  $45^{\circ}$ ,

we can set an upper limit to  $\dot{M}$ . For AR And in outburst we find  $\log(\dot{M}_{16}) < 1.5$ . For SU UMa at minimum,  $\log(\dot{M}_{16}) < 0.3$  with  $\Delta \log \dot{M} = 1.0$  in outburst. For SS Aur at minimum,  $\log(\dot{M}_{16}) < -0.2$  with  $\Delta \log(\dot{M}_{16}) = 1.7$  in outburst.

#### b) Nonsteady Disks

In the accretion model the outbursts might be imposed upon the disk by a sudden, temporary increase in the rate at which mass is fed to the disk, mandated by some instability of the mass-losing star. Alternatively, one could envision mass buildup in the disk during the quiescent interval, to be released by a sudden increase in viscosity. The behavior and appearance of nonsteady disks depends upon the nature of the viscosity. Since this is not known even approximately, theoretical investigations are necessarily ad hoc (Bath and Pringle 1981, 1982).

Extensive optical photometry and spectroscopy during the outburst rise exists only for SS Cyg and VW Hyi (Bailey 1980). Marked changes occur in SS Cyg. As the system brightens, strong absorptions in the Balmer lines and Balmer jump appear in place of the strong emission seen at minimum light. The absorptions then weaken as SS Cyg reaches maximum until the spectrum is nearly featureless. Photometrically, SS Cyg follows a loop in the  $(U - B, B - V)$  plane, with  $U - B$  getting redder during the initial rise, then bluer again as SS Cyg approaches maximum. VW Hyi shows similar photometric behavior. These observations are consistent with the idea that the increased mass flux occurs initially in the outer region of the disk. The line and bound free emission which originates there is suppressed as the continuum optical depth increases, due to the higher mass flux (Tylanda 1981). The strong Balmer lines and Balmer jump in absorption are expected for the relatively cool temperatures ( $T \approx 10,000$  K) in the outer disk. As the enhancement of local mass flux diffuses inward, the hotter regions brighten also, and the flux distribution evolves toward the spectrum of a steady state disk. The complexity of the Balmer emission spectrum hinders precise interpretation of the  $UBV$  broadband photometry. The span of the ANS bands, 1550–3300 Å, is well suited to discrimination of changes over the range expected to be involved in the outburst phenomena in the outer disk, 10,000–15,000 K. Each of the three systems we observed on the outburst rise presents a unique behavior.

#### i) SS Aur

The outburst rise is exponential with an  $e$ -fold time of  $0^{\text{d}}13$  and a total rise time of about  $0^{\text{d}}5$ . The AAVSO estimates bracketing the observed rise confirm that the UV outburst coincides with the optical within one rise time. The excess in the 1550 band is consistent with the

dilution of an unchanging emission line flux by the rising continuum near minimum light. An excess appears marginally at 3300 Å when the system is 1 mag above minimum light (Fig. 3). This could indicate brightening first in the cool outer region of the disk. It is interesting that this flux distribution resembles EM Cyg, which also presents an excess at 3300 Å when 2 mag below maximum light.

#### ii) *SU UMa*

As discussed above, a very red precursor outburst occurred about 0<sup>d</sup>.5 before *SU UMa* evolved to a power law outburst flux distribution. The outburst rise was not monotonic at any wavelength. The precursor might be a pulse of enhanced mass loss from the companion, or some sort of relaxation or feedback mechanism operating in the disk.

#### iii) *EM Cyg*

The outburst rise is very slow, being exponential with an  $e$ -fold time of 0<sup>d</sup>.9 over the first day of observation. As discussed above, *EM Cyg* when at the standstill level shows a flux excess at 1550 and at 3300 Å over a power law distribution. The source of the excess red flux does not appear to participate in the outburst, however. For such a slow outburst, one might expect the disk structure to remain close to the steady state for increasingly higher mass flux (Bailey 1980). The power law component, evidenced at 1800–2500 Å at standstill, becomes bluer during the outburst, as expected for a hotter disk.

### V. CONCLUSIONS

Our results add to the observations of dwarf novae in the various stages of the outburst cycle. We find that a power law  $F_{\lambda} \propto \lambda^{\alpha}$  is mostly a good approximation to the Balmer continuum, allowing for the effect of C IV line emission in the 1550 channel. One exception is *EM Cyg*, which shows a pronounced flux excess at 3300 Å when at standstill about 2 mag below maximum light.

The lack of a dip at 2200 Å shows that the interstellar reddening must be small. Using the accretion model of the dwarf nova outburst, we have estimated mass fluxes  $\dot{M}$  by fitting steady state, geometrically thin, optically thick disk models to the observed UV luminosity. This depends on an independent estimate of the distance. We find  $\dot{M} \approx 3 \times 10^{17} \text{ g s}^{-1}$  for *Z Cam* and *EM Cyg* in outburst. The mass flux increases by about a factor of 3 in *Z Cam* from standstill to outburst. We find, however, that the observed flux distributions are definitely redder than predicted. This is true even for *Z Cam* in a year-long standstill, so that it is not just a failure of the steady state assumption.

Of particular interest is the observation of the outburst rise of *SS Aur*, *SU UMa*, and *EM Cyg*. *SS Aur* had a fast rise, exponential at the rate of 3.5 mag in 0<sup>d</sup>.5. There is an indication of a flux excess at 3300 Å at the start of the rise. *SU UMa* showed a very red precursor outburst 0<sup>d</sup>.5 before it reached a blue maximum. The flux distributions of *SS Aur* and *SU UMa* are not very steep near the end of the outburst rise,  $\alpha \approx -1$ . *EM Cyg* showed a much slower outburst rise, but reached a bluer slope  $\alpha = -1.5$  at the end. The source of the flux excess at 3300 Å does not participate in the outburst, nor does the 1550 Å line emission. The observation of red sources in the initial rise of *SU UMa* and *SS Aur* is in line with expectations that the outburst activity begins in the cooler, outer regions of the disk.

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