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ULTRAVIOLET LIGHT CURVES OF U GEMINORUM AND VW HYDRI

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ABSTRACT. Ultraviolet light curves have been obtained for the quiescent dwarf novae U Gem and VW Hyi. The amplitude of the hump associated with the accretion hot spot is much smaller in the UV than in the visible. This implies that the bright spot temperature is roughly 12000 K if it is optically thick. A hotter spot would have to be optically thin in the near UV. The flux distribution of U Gem in quiescence cannot be fitted by model spectra of steady state, viscous accretion disks. The absolute luminosity, the flux distribution, and the far UV spectrum suggest that the primary star is visible in the far UV. The optical-UV flux distribution of VW Hyi could be matched roughly by our model accretion disks, but the fitting is poorly constrained due to the uncertainty in its distance.

I. INTRODUCTION

The optical light curves of dwarf nova systems often show a prominent hump which is attributed to a bright spot at the point where the gas stream from the late type secondary strikes the accretion disk around the white dwarf primary. We have used the observed amplitudes of the hump in the ultraviolet and optical light curves to derive the temperature of the bright spot of U Gem for the optically thick and thin cases. We have also estimated the temperature and luminosity of the accretion disk of U Gem and VW Hyi by matching the observed flux distribution (UV+ optical) with that predicted by the steady state, viscous disk model computations. All of the results here refer to the quiescent (non-outburst) state.

II. OBSERVATIONS

The UV light curves of U Gem and VW Hyi (Fig. 1 and 2 respectively) were obtained with the 5-channel spectrophotometer on board the Astronomical Netherlands Satellite (ANS) (van Duinen et al 1975). 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. Most of the observations were made with the offset (sky chopping) mode which had a duration of about 10 minutes. The magnitudes in Figures 1 and 2 are defined such that, for all channels, m = 0.00 for f = 3.64 x 10^{-9} ergs cm^{-2} S^{-1} $Å^{-1}$. Spectra of U Gem were obtained with the International Ultraviolet Explorer (IUE) with both the short wavelength prima (SWP) and long wavelength redundant (LWR) cameras. The spectra were taken through the large aperture in the low dispersion mode with a resolution of about 5 and 8 Å respectively for SWP and LWR (Boggess et al. 1978). The exposure time for the images was about 35 minutes. The absolute calibration of Bohlin and Holm (1980) was adopted.

III. THE BRIGHT SPOT OF U GEM

It is obvious from Fig. 1 and 2 that the bright spot is not prominent in the ultraviolet. From the ANS light curves the hump amplitude is estimated to be 0.18, 0.26, 0.39, 0.35, and 0.69 at 1550, 1800, 2200, 2500, and 3300 A respectively. From optical light curves (Krzeminski 1965), the amplitude is 0.64, 0.87, and 0.66 mag at U,B, and V, respectively. To obtain quantitative estimates for the spot, we have calculated amplitudes for several assumed spot models (Fig. 3). These calculations are normalized to the observed amplitude at V. The assumed spot flux distribution plus the flux distribution of the disk then determines the amplitudes in the other bands. The flux distribution of the disk is taken as the average of the ANS fluxes at orbital phases 0.15-0.55 for which the spot is assumed to be hidden behind the disk. In Fig. 3 we see that the observed low amplitude of the hump in the UV indicates that an optically thick spot must have a temperature near 12000 K. If the spot gas temperature is 30000 K it must be optically thin in the UV. A free-free opacity provides reasonable agreement if the optical depth at V is about 2. Also in Fig. 3, we see that the amplitudes derived from the IUE spectra confirm the ANS results. If the bright spot is a 12000 K blackbody, it has a luminosity of 9 x 10^{-3} $L_\odot$ and a diameter of 3.2 x 10^9 cm. If it is a 30000 K gas with free-free opacity τ(5500 Å) = 2, it has a luminosity of 8 x 10^{-3} $L_\odot$ and a diameter of 1.4 x 10^9 cm. These values are consistent with the 2.9 x 10^9 cm estimated by Warner and Nather (1971) from eclipse geometry.

IV. THE ACCRETION DISK

To calculate model spectra for the disk, we adopt the structure of a steady-state, optically thick, viscous accretion disk as used in several recent detailed comparisons to observations (e.g. see the review by Mayo et al. 1980). The principal novelty of our technique is to represent the energy radiated by each segment of the disk by the empirical flux of a main sequence star of the same effective temperature. The visual brightness is determined from the empirical relation between T_{eff} and bolometric correction (Code et al. 1976), and the flux at the other wavelengths from the relation between T_{eff} and (B-V) and the colors of Wu et al. (1980) and Johnson (1966). The surface gravity of main sequence stars is appropriate for the disks (see the discussion by Mayo

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et al.). Also, the average inclination of a stellar disk is reasonable for the moderately inclined VW Hyi and U Gem. Our calculations of absolute visual magnitude can reproduce the results of Mayo et al., and we also reproduce the fluxes of the coolest disk model of Herter et al. (1979), except at 1550 A, to within the expected accuracy of 0.1 to 0.2 mag. Spectra for 3 representative models are shown in Fig. 4. These demonstrate the manner in which $\dot{M}$, the mass flux, can be traded against disk size to obtain a variety of energy distributions of a given visual luminosity.

a. The Disk of U Gem

As discussed above, the UV flux distribution of the disk is assumed to be the average over the phase interval 0.15-0.55. This is shown in Fig. 5, along with the optical data of Wade (1979) which should also be representative of the quiescent disk. The UV fluxes were scaled up by 0.3 mag to match the optical data at 3300 A. No reddening correction should be necessary.

The distance of U Gem is estimated as 75 pc from the direct observation of the secondary star (Wade 1979). This provides a valuable constraint in fitting to disk models by fixing the absolute magnitude. Comparison with the model disk spectra of Fig. 4 shows that the models are unable to reproduce the turnup of the flux distribution at the shortest wavelengths. Furthermore, the disks must be quite small in order not to exceed the relatively low absolute visual magnitude of U Gem. The disk with $\dot{M}$ = 0.25 would provide the closet fit. This disk has a radius less than 1/10 the radius vector for the spot as derived from the optical eclipse (Smak 1976).

Our IUE spectra confirm the result of Fabbiano et al. (1981) that the upturn in flux persists down to 1250 A. However, comparison with stellar spectra (Wu et al. 1981) shows that the far UV energy distribution of U Gem resembles a 30000 K main sequence star. If we assume that the disk contributes nothing at 1250 A, the corresponding visual magnitude for the central star is 15.6 or absolute 11.2. This is a reasonable value for a hot white dwarf primary star. Such a star could be responsible for the observed strong Lyman alpha absorption (see Fig. 7 of Fabbiano et al.). Thus, we feel that a large contribution to the far UV flux by the primary star is a reasonable alternative for nuclear surface reactions (Fabbiano et al. 1981).

b. The Disk of VW Hyi

We assume that the hotspot is hidden behind the disk at orbital phases 0.25-0.75 (the phase convention puts phase zero at the optical spot maximum), so that the flux distribution of the disk is obtained as the average of the ANS fluxes over this interval. This is shown in Fig. 5, along with the optical fluxes of Panek (1979) which should also be representative of the quiescent disk. The UV fluxes were scaled up by 0.3 mag to match the optical flux at 3300 A. Bath et al. (1980) have demonstrated the absence of reddening in VW Hyi. The fitting to VW Hyi is much less constrained because the distance is very poorly known.

The flux distribution shown in Fig. 5 could be obtained with a variety of models if the absolute magnitude is unconstrained. However, we note that the red flux (Panek 1979) and the infrared flux (Sherrington et al. 1980) suggest that the flat spectrum persists to quite long wavelengths. This would require a very large disk to yield low enough temperatures to avoid the Rayleigh Jeans behavior, and would make VW Hyi much more luminous than U Gem.

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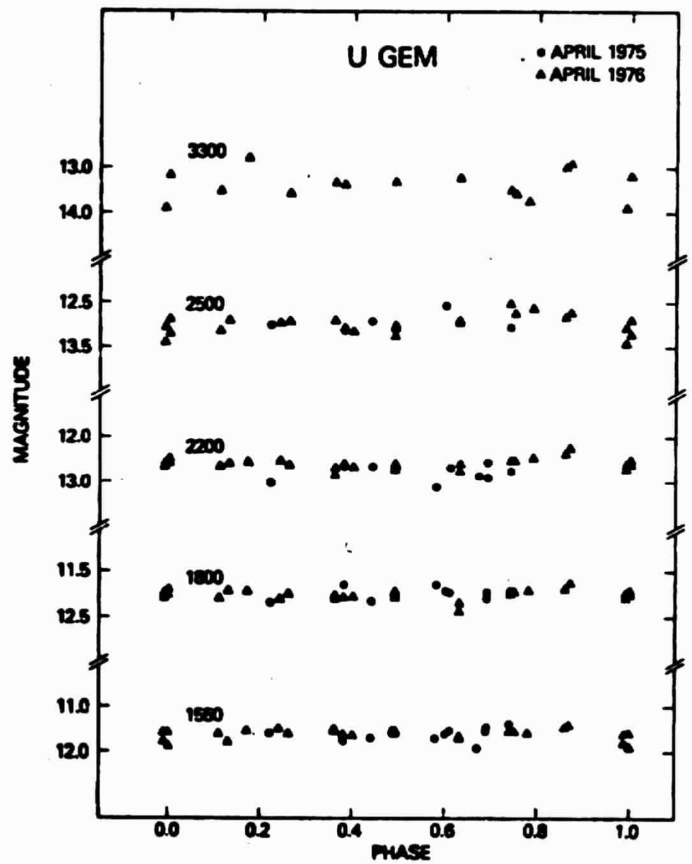

Fig. 1 The Ultraviolet light curves of U Gem. The central wavelength for each bandpass is labelled for each curve.

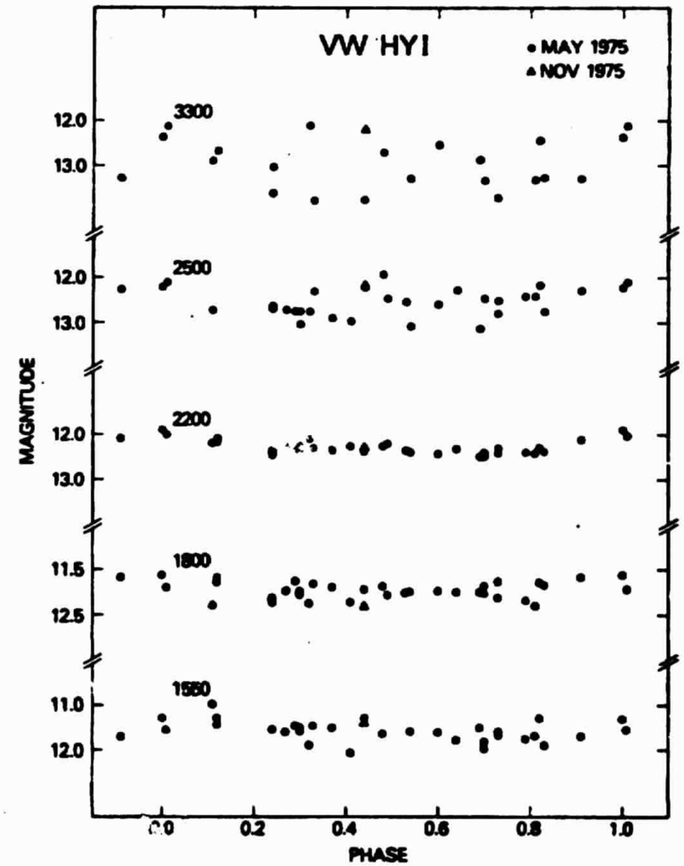

Fig. 2 The Ultraviolet light curves of VW Hyi. The central wavelength for each bandpass is labelled for each curve.

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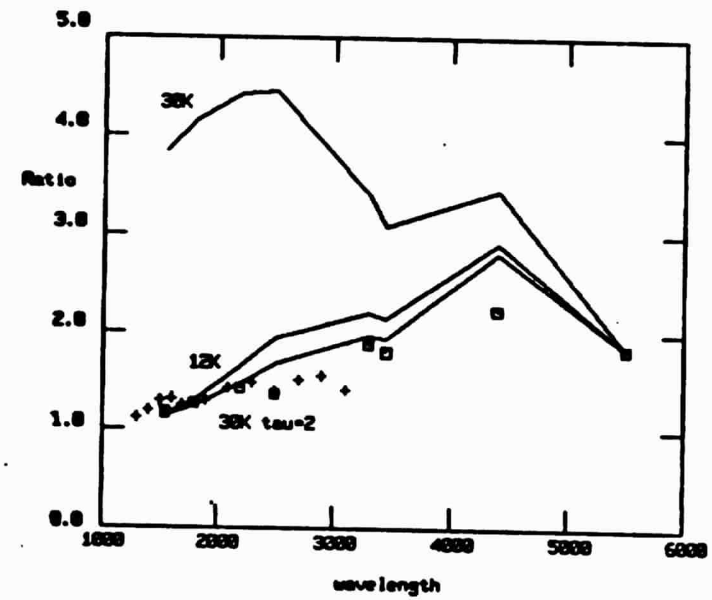
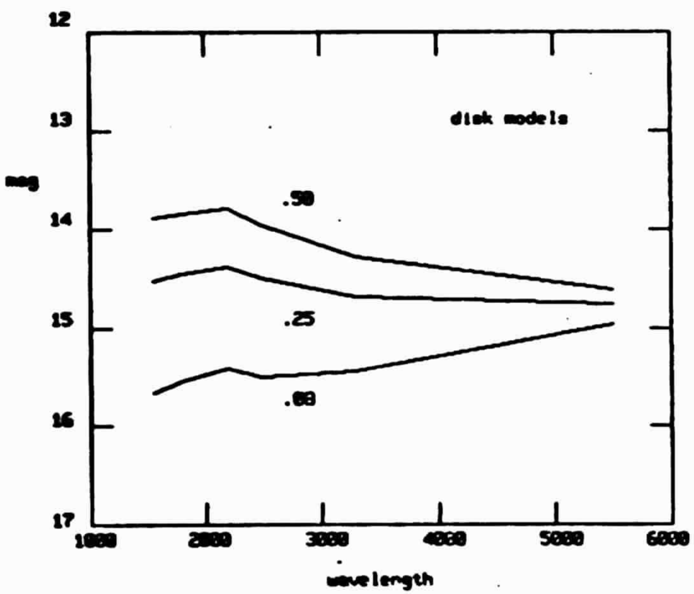


Fig. 3 Ratio of flux distributions for hotspot maximum / hotspot minimum. The squares are derived from the ANS photometry, the plus symbols from the IUE spectra. The solid curves define the expected results for 3 assumed flux distributions for the hotspot: a 30000 K blackbody, a 12000 K blackbody, and a 30000 K hotspot which has an optical depth of 2 at 5500 A.



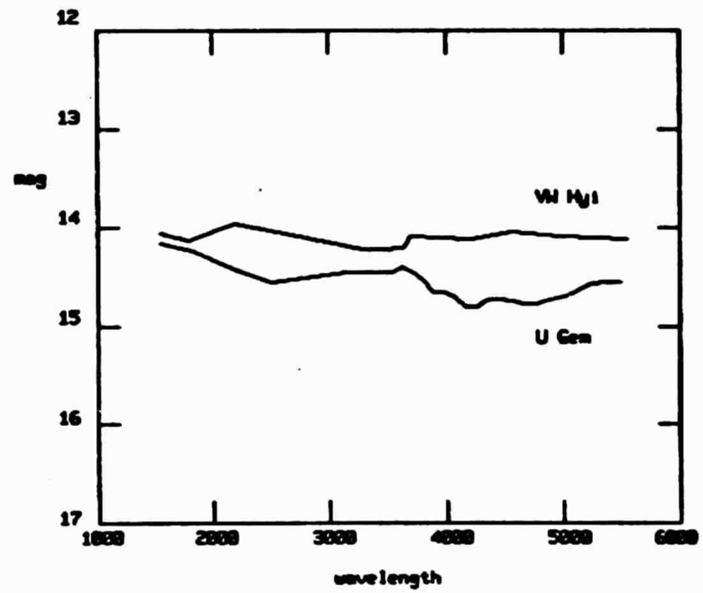


Fig. 4 Flux distributions for 3 representative disk models, in the units of Fig. 5. The disks are identified by their mass flux $\dot{M}$ (units of 10^{16} g/s). The other disk parameters are radius 1.6 10^9 cm and luminosity 0.07 L_o for the model with $\dot{M}$ = 0.50; 1.9 10^9 cm and 0.04 L_o for $\dot{M}$ = 0.25; and 2.4 10^9 cm and 0.02 L_o for $\dot{M}$ = 0.08. The models have been placed at the distance and inclination of U Gem.

Fig. 5 Observed flux distributions for VW Hyi and U Gem, shown as magnitude per unit frequency vs wavelength in A. The ultraviolet (ANS) data has been scaled to match the groundbased fluxes at 3300 A.

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