Astron. Astrophys. 321, 213–219 (1997)

ASTRONOMY AND ASTROPHYSICS

UV Observations of dwarf novae in quiescence – effects of evaporation?

C. la Dous[1], **F. Meyer**[2] **and E. Meyer-Hofmeister**[2]

[1] Sternwarte Sonneberg, Sternwartestr. 13, D-96515 Sonneberg, Germany
[2] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild Str. 1, D-85740 Garching, Germany

Received 30 May 1996 / Accepted 5 September 1996

Abstract. IUE spectra of dwarf novae in quiescence provide information on the inner part of the accretion disk. In the framework of the evaporation model the mass flow of about $10^{-11} M_{\odot}/y$ is understood as accretion via a hot corona above the cool inert disk. The UV radiation originates from the transition region between disk and corona, and from the white dwarf. If it is possible to separate the radiation from white dwarf and disk, the remaining disk spectrum allows conclusions on where the dominant emitting disk area is located. We compare results from observations of different systems with the prediction of the evaporation model.

Key words: accretion disks – ultraviolet: stars – cataclysmic variables – white dwarfs

1. Introduction

Dwarf novae show alternating phases of low and high luminosity, quiescence and outburst. In these binaries mass flows over from a Roche Lobe filling main sequence star via an accretion disk onto the white dwarf. During quiescence mass is accumulated in the disk until the next outburst is triggered and the material flows at a rate of about $10^{-9} M_{\odot}/yr$ towards the compact object, resulting in a significant increase of luminosity. The phases of low luminosity have been less studied in the past. But the accumulation of material in the disk is important for our understanding of the outburst cycle. An analysis of the physics of the inner cool accretion disk is of interest also in connection with similar features of disks in galactic black hole candidates and AGN.

In the standard model for dwarf nova outbursts the mass flow rate through the cool disk during quiescence is only $10^{-12} M_{\odot}/y$ to $10^{-13} M_{\odot}/y$. But accretion via a hot corona above the cool disk allows mass flow rates of $10^{-11} M_{\odot}/y$. Such values are indeed indicated by X-ray and UV observations (e.g. van der Woerd & Heise 1987, Szkody et al. 1991). The inclination dependence of the equivalent widths of the UV emission lines (la Dous 1991) also hints at an optically thin hot layer close to the orbital plane. Theory predicts a self-sustained corona above the cool inner accretion disk (Meyer & Meyer-Hofmeister 1994, Liu et al. 1995). The mass flow through the corona and a possible evaporation of the inner disk during quiescence is an essential additional feature of the standard outburst model. It also provides a natural explanation for the delay between optical and UV radiation at rise to outburst as observed for several systems (la Dous 1994, Verbunt 1987).The inner evaporated part of the disk has to be filled in on the diffusion timescale before it can display the hot UV temperatures during the early outburst (Meyer & Meyer-Hofmeister 1989). We note that such a hole can also be created by a weak magnetic field of the white dwarf, sweeping away the innermost part of the disk (Livio & Pringle, 1992).

It is the aim of this paper to learn about the situation in the inner accretion disk from UV observations. We give a short description of the evaporation model in Sect. 2. In Sect. 3 we discuss the observational data selected for our investigation and special features of these spectra, as well as the fit to black body effective temperatures. We further analyse the contributions of white dwarf and disk and show in Sect. 4 how properties of the disk can be evaluated under certain assumptions for the temperatures of white dwarf and disk.These results are discussed with respect to the evaporation model in Sect. 5. We further analyse the flux ratios evaluated by Deng et al. (1994) for numerous dwarf novae in the context of the evaporation model. Finally, related X-ray observations are discussed.

2. The evaporation model

The interaction of a hot corona with the underlying cool disk in dwarf nova systems leads to an evaporation of the inner disk around the white dwarf. In contact with the corona, material evaporates at higher gravitational potential and accretes on to the compact white dwarf at lower gravitational potential. Due to angular momentum this mass flow takes the form of a coronal accretion disk, which is heated by friction. The process works

Send offprint requests to: E. Meyer-Hofmeister

strongest close to the white dwarf, thus evaporating the innermost part of the disk first. If a hole in the inner disk is formed by this process, the evaporation then becomes less efficient during later times. This then also implies a decrease of the mass flow rate. Whether or not this happens depends on the amount of mass contained in the inner disk.

The evaporation model gives typical mass flow rates of about 10^{-11} to 3 $10^{-11} M_{\odot}/y$. Part of it leaves the system as a very hot wind, the remaining part is accreted onto the white dwarf. X-rays are produced mainly in the optically thin thermal conductive boundary layers of the white dwarf (main part of the radiation) and above the accretion disk (a small fraction). This irradiates regions below, so that the UV radiation originates from both, the disk and the white dwarf surface. The effective temperature of the white dwarf thus depends on the accretion rate. The accretion rate depends itself on the distance between the white dwarf and the inner edge of the cool disk. The rate might therefore change due to two effects: (1) after the innermost part is evaporated the process works less efficient and the accretion rate decreases; (2) the location of the inner edge of the disk is determined by a balance between progressing evaporation of material and accumulation of mass in the disk during quiescence, which could result in changes of the accretion rate either way.

3. UV observations of dwarf novae in quiescence

3.1. Selection of appropriate data

Optical observations of dwarf nova outbursts show that details of the lightcurves vary from cycle to cycle. For an investigation of the evolution of the accretion disk during quiescence it is therefore important to use data from a single quiescent phase. The IUE archive provides such observations for several dwarf nova systems. Further constraints are, that the system be seen at low inclination, so that the disk contribution be recognizable, that the mass of the white dwarf be known, and that its temperature can be deduced from IUE observations. Only systems can be used for the analysis where a separation of contributions to the spectrum from disk and white dwarf is possible. Of the currently available IUE spectra of quiescent dwarf novae (on the order of 400), these limitations leave only the few systems listed in Table 1.

3.2. The UV emission lines

A remarkable feature is the inclination dependence of the equivalent widths of UV emission lines. At low inclinations all lines are strongly in emission; as the inclination increases, the equivalent widths decrease and at angles larger than 60^o or 70^o only an essentially featureless continuum can be seen [1] (la Dous, 1991). From this it can be concluded that there is an optically thin emission source radiating at UV wavelengths and that this source is predominantly confined to the orbital plane of the system. A cool optically thin disk would not radiate in the UV.

[1] except for the $Ly\alpha$ absorption line which, if present, has its origin in the white dwarf, and when in emission is at least partly of geocoronal origin; this line, thus, cannot be used for our purposes

3.3. The white dwarf spectrum

It has been demonstrated that, on the basis of the SWP spectrum alone, it is possible to roughly determine the temperature of the white dwarf in quiescent dwarf novae (Hassall & la Dous, 1996). The white dwarf spectrum then can be subtracted from the observed integral spectrum. What remains is interpreted as the spectrum of the quiescent accretion disk. To zeroth approximation this can be fitted with a single black body having a temperature between 9000 and 15000 K. We find for all objects for which more than one quiescence spectrum is available that the flux level is not constant with time. Rather for UV continua spectra and emission line fluxes the changes are consistent with a simple change of the white dwarf and disk temperatures. A temperature decrease during quiescence was found e.g. for U Gem (Long et al. 1994) and this was interpreted as due to cooling of the outer layers of the white dwarf after an outburst. Various different processes had been discussed (for a recent discussion see Long et al. (1994)). A decreasing mass flow rate due to evaporation has the same effect. Probably the temperature changes are related to cooling and ongoing accretion with decreasing rate, the accretion being necessary to explain the X-rays.

In Table 1 we give continuum fluxes of IUE spectra used below for further evaluation.

4. Evaluation of disk properties

Under the assumption that it is possible to separate the contributions of white dwarf and disk to the spectrum and to attribute black body temperatures to both parts, we can use the fluxes at selected wavelengths to determine the size of the dominant emitting disk area and to estimate the mass flow rate through the corona.

4.1. Emitting disk area

The evaluation is based on assumed values for the inclination i and white dwarf mass m_{wd} with the white dwarf radius, r_{wd}, determined according to the formula of Nauenberg (1972) (see Table 2). We take r_d as the distance between the dominant emitting disk area and the center of the white dwarf. The observed radiation in a certain wavelength range is proportional to the size of the emitting region, that is proportional to r_{wd}^2 for the white dwarf and to r_d^2 for the disk.

The luminosity of the white dwarf at frequency ν is given by

$$(L_\nu)_{wd} = 4\pi r_{wd}^2 (\mathscr{F}_\nu)_{wd} \quad (1)$$

where $(\mathscr{F}_\nu)_{wd}$ is the flux density at the white dwarf, energy per cm^2 and sec, in the frequency range $\nu \pm d\nu/2$. The flux density received at distance D is

$$(f_\nu)_{wd} = (L_\nu)_{wd}/4\pi D^2 \quad (2)$$

Table 2. Estimated inner disk radii r_d and coronal mass accretion rates $\dot{M}_d$ for quiescent dwarf novae. M_{wd} and i from Ritter and Kolb (1995), R_{wd} after Nauenberg (1972), T_{wd} as in Table 1, r_d, $\dot{M}_d$ evaluated, according to formulae (8) and (9), in the text. Cgs units, except $\dot{M}_d$.

object	$M_{wd}/M_\odot$	i°	log R_{wd}	T_{wd}	T_d	log r_d	log $\dot{M}_d$ ($M_\odot/yr$)
SS Cyg	1.19 ± 0.02	37 ± 5	8.56	25000 ± 1000	11000-13000$\pm$1000	9.38-9.64	-10.5
RU Peg	1.21 ± 0.19	33 ± 5	8.54	21600 ± 200	14000 ± 1000	9.1	-11.2
SS Aur	1.08 ± 0.4	38 ± 16	8.66	23000 ± 1000	15000 ± 1000	9.1	-11.2

We take $(f_\nu)_d = (f^0_\nu)_d cos\ i$ as the flux received per cm^2 from a disk at distance D, seen under inclination i. The total luminosity of the disk (both sides together) is $(L_\nu)_d$. Half of the disk luminosity is emitted into the half space

$$0.5(L_\nu)_d = D^2 \int_{i=0}^{\pi/2} \int_{\varphi=0}^{2\pi} d\varphi (f^0_\nu)_d cosi\ sini\ di = \pi D^2 (f^0_\nu)_d \quad (3)$$

Thus the observed flux $(f_\nu)_d$ at earth is related to the total luminosity as

$$(f_\nu)_d = (L_\nu)_d \cdot 2cosi/4\pi D^2. \quad (4)$$

This means that an observer at $i = 0$ sees twice the flux of an isotropic source of the same luminosity.

For our analysis we use the ratio of observed fluxes from disk and white dwarf

$$\frac{(f_\nu)_d}{(f_\nu)_{wd}} = \frac{2cosi(L_\nu)_d}{(L_\nu)_{wd}} \quad (5)$$

We write $(\mathscr{F}_\nu{}^0)_d$ for the flux (energy per cm^2 and sec) from the disk in the frequency range $\nu \pm d\nu/2$ and take r_d both for the mean distance of the dominant emitting disk area from the white dwarf and for a representation of the size of this area, πr^2_d. Then the luminosity in the frequency range is

$$(L_\nu)_d = 2\pi r^2_d (\mathscr{F}_\nu{}^0)_d \quad (6)$$

and the ratio of fluxes observed is

$$\frac{(f_\nu)_d}{(f_\nu)_{wd}} = \frac{4\pi cosi \cdot r^2_d (\mathscr{F}_\nu{}^0)_d}{4\pi r^2_{wd} (\mathscr{F}_\nu)_{wd}} \quad (7)$$

and using the black body approximation it follows that

$$\frac{(f_\nu)_d}{(f_\nu)_{wd}} = \frac{r^2_d cosi}{r^2_{wd}} (e^{hc/k\lambda T_{wd}} - 1)/(e^{hc/k\lambda T_d} - 1). \quad (8)$$

With values for the temperatures of the white dwarf and the disk (Sect. 3), derived from fits to observations, and the value r_{wd}, as derived from the star's mass, we find the radius r_d from relation (8) (see Table 2). The uncertainty of the temperature yields a large uncertainty in the values of r_d. We show the results with error bars corresponding to $\pm 1000K$ in T_d. The uncertainty in T_{wd}, which is smaller if the star is less hot, produces, further errors. An additional error could arise, if the UV radiating layers would be optically thin and the spectra would deviate significantly from black body. But the contributions from the optically thin layers above the photosphere are very small due to the existence of the corona and the white dwarf thermal boundary layer. This can be seen from the emission measures given in Liu et al. (1995). Despite the crudeness of this procedure it is clear the resulting values r_d on the order of 5-10 white dwarf radii, indicate that the dominant emitting disk areas are not close to the white dwarf, i.e., that a hole exists. First results were presented by la Dous et al. (1995).

In addition to the evaluation based on simple one-temperature black body disk spectra we also used a superposition of black body spectra with T proportional to $r_d^{-9/8}$. But this produces only little changes of the result.

Important information comes from HST observations of dwarf novae. These spectra allow more elaborate conclusions. First results for VW Hydri point to a disk edge close to the white dwarf at the time of observation (Huang et al. 1996).

The evaporation model predicts that this process works best close to the white dwarf, and therefore the hole should first be created in the innermost part of the disk and then grow, depending on how much mass is contained in the disk. Later accumulation of mass from the outside might again shift the edge of the hole inward. Observations of several systems such as VW Hydri (Verbunt et al. 1987), WX Hydri (Hassall et al. 1985), U Gem (Szkody & Kiplinger 1985) show a decline of the UV radiation during quiescence. From our own evaluation of SS Cyg we find non-monotonic changes as shown in Fig. 1. We do not yet know whether heating of the cool disk by the hot corona above might initiate higher mass flow rates in the disk which then in turn might influence the extent of the hole created by evaporation. But we would not expect an essential change of the situation due to the heating.

4.2. Mass flow rate

We can use the determined values r_d to derive the mass flow rate $\dot{M}_d$ through the corona. If we interprete the disk temperature as due to frictional heating

$$\sigma T^4_d \cdot 2\pi r^2_d = \frac{GM_{wd}\dot{M}_d}{2r_d} \quad (9)$$

we find values on the order of $10^{-11} M_\odot/y$, as given in Table 2. These mass flow rates would yield white dwarf temperatures higher than actually found in the fit. This might suggest, that not all mass arrives at the white dwarf. But the amount of material in the wind lost from the corona is not enough to explain this discrepancy. However, if part of the UV radiation, interpreted

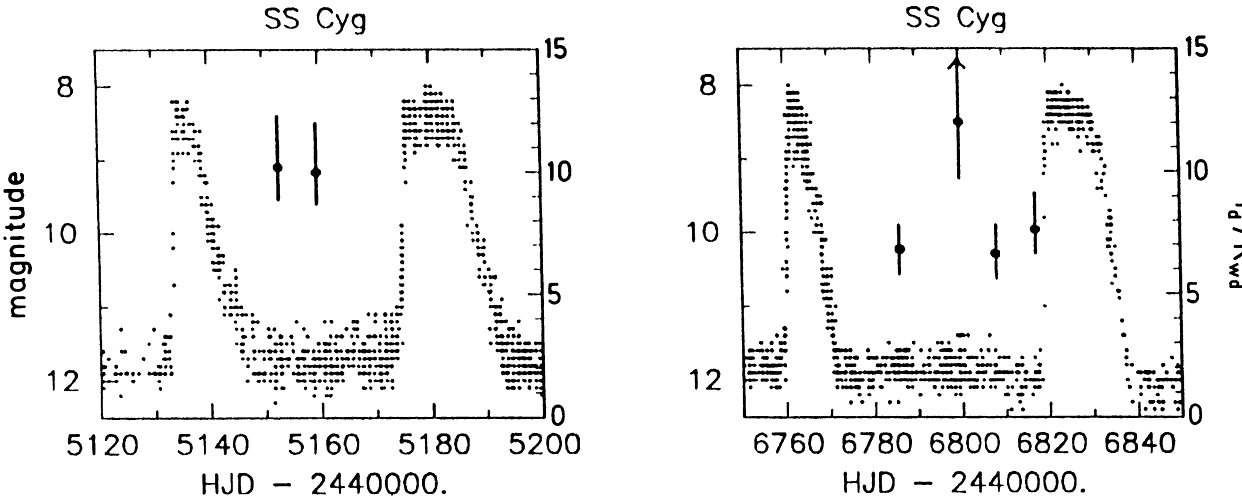

Fig. 1. Variations of the inner disk radius during the course of two quiescent intervals of SS Cyg. The error bars shown are those resulting from uncertainties of $\pm 1000K$ in the temperature of the optically thick accretion disk. The photometric data are courtesy of the AAVSO.

as originating from the disk, would come from the bright spot or the secondary (as discussed in the following section) this problem might be resolved. This would affect also the radial distance estimate r_d.

We investigated the question whether the transition layer below the disk corona could provide a significant contribution to the UV radiation. The emission measures determined from the vertical structure (Liu et al. 1995) allow a detailed evaluation. But the contributions turned out to be low, less than one per cent.

5. Comparison of our results with other observations and conclusions

5.1. UV observations

Besides the data concerning single quiescent phases, as used for the evaluations in Sect. 4, we want to include in our comparison the statistical study by Deng et al. (1994) on dwarf novae in quiescence, based on 1200 IUE spectra. Ratios of continuum fluxes, averages of 80Å bins, centered on 1460Å, 1800Å and 2880Å were used to characterize the ultraviolet radiation. Verbunt (1987) had determined these ratios for different types of cataclysmic variables, including dwarf novae in quiescence, and had found in his investigation that the slopes of spectra differ from system to system. In Fig. 2a we show the flux ratios f_{1460}/f_{1800} and f_{1460}/f_{2880} as determined by Deng et al. (1994, Fig. 1). In the original figure all numbers were given in colors defined as c1 = -2.5 log f_{1460}/f_{2880} and c2 = -2.5 log f_{1460}/f_{1800}. There is a surprisingly large scatter of the values of flux ratios away from the band which white dwarfs of different mass and temperature would populate. The investigation of Deng had already shown that f_{1460}/f_{2880} increases with the inclination. This suggests that a sizeable part of the flux at 2880Å comes from the accretion disk, which is less recognizable for higher inclinations. The flux at 1460Å should come from the white dwarf.

To analyse this scatter of observed ratios we determine the flux ratios expected due to evaporation of the inner disk during one single quiescent phase. The efficiency of the evaporation depends on the distance of the edge of the inner disk from the white dwarf, as well as on the white dwarf mass. We therefore expect a high rate of evaporation and accretion in the early quiescence and a decrease once a hole is created. In Fig. 2b we show the change of the flux ratio due to the temperature decrease of white dwarf and disk as predicted by the evaporation model for a $1M_\odot$ white dwarf. The relations of M_{wd}, $\dot{M}$, r_d are taken from Liu et al. (1995). This means that $\dot{M}$ decreases from $10^{15.12}$ g/s to $10^{14.62}$ g/s and r_d increases from $10^{9.33}$ cm to $10^{9.74}$ cm. The size of the UV emitting disk area is taken as πr_d^2, the disk temperature according to formula (9). For the flux of the disk we assume black body radiation. For the white dwarf we take fluxes from the pure hydrogen LTE model atmospheres by Wesemael et al. (1980). Because of the finer temperature grid we use the unblanketed model data. For the temperature range of interest to us the difference between these and the blanketed models is small. We assume log g = 8. Our evaluation shows that during one single quiescent interval the flux ratios can change, depending on the inclination, as depicted in Fig. 2b. We calculated the flux ratios for four consecutive stages of evaporation, which are depicted in Fig. 2b and were connected by lines 1 and 2. We see that we expect for one dwarf nova system during a single quiescence quite a variation of the flux ratios. For example the ratio f_{1460}/f_{2880} might increase by about a factor of 2 if the inclination is 30°.

An additional possible source of UV radiation is the bright spot. Its contribution is higher for small orbital periods as the stream material falls more deeply into the potential well of the primary (Lin 1975). The bright spot contribution can be seen best in high inclination systems. Temperatures of 11000 to 16000K have been found from observations for IP Peg (Marsh 1988), Z Cha (Wood et al. 1986), OY Car (Shoembs & Hartmann, 1983; Wood et al. 1989) and WZ Sge (Robinson et al.

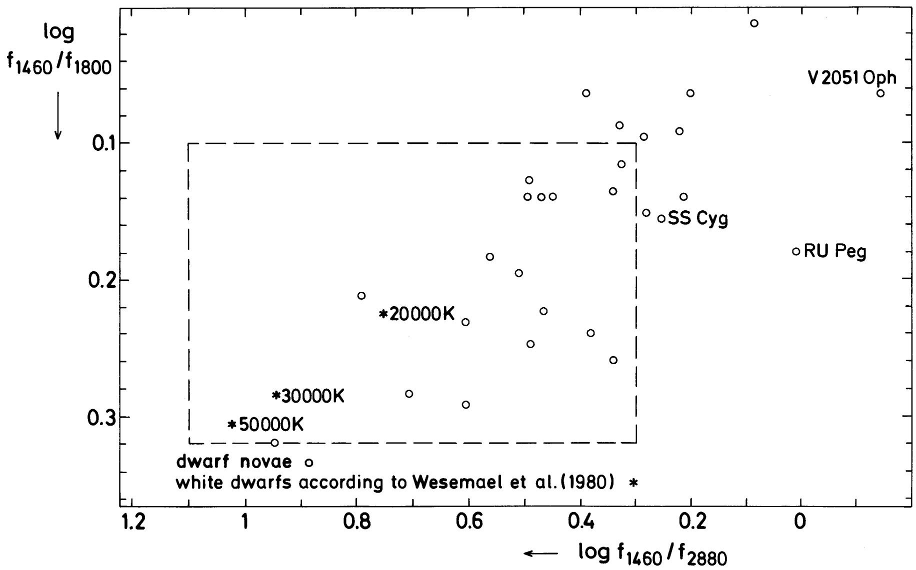

Fig. 2a. Flux ratios of dwarf novae in quiescence, observed with IUE, and the positions of white dwarfs (taken from Deng et al. (1994), Fig. 1). Dashed lines show the area given in Fig. 2b. Three systems with low values of f_{1460}/f_{2880} are indicated.

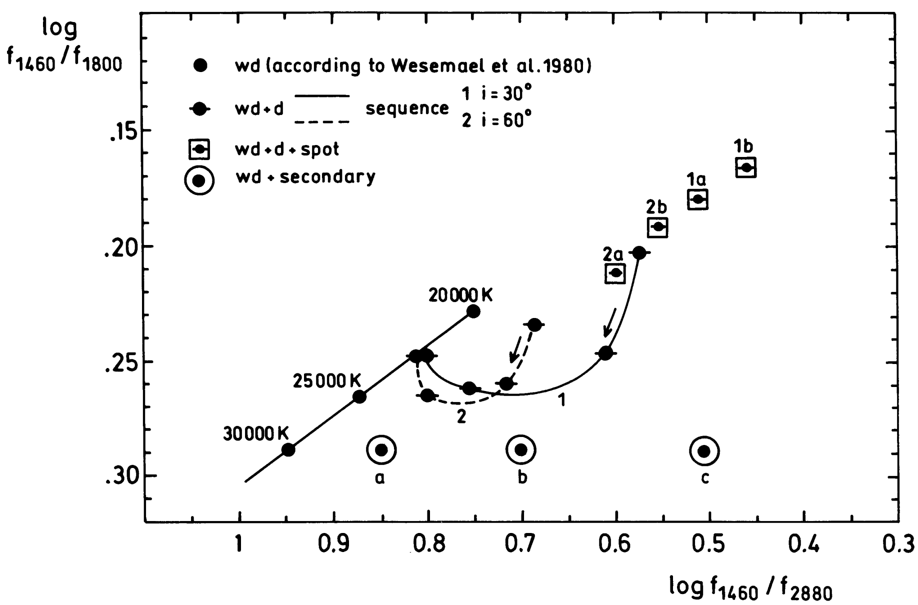

Fig. 2b. Theoretically determined traces of flux ratios of one dwarf nova system during a single quiescent interval, contributions of white dwarf ($1M_\odot$) and accretion disk, seen under inclination 30° (solid line 1) or 60° (hatched line 2). Accretion rates and sizes of the emitting disk area taken as expected from the evaporation model (see text). This infers temperatures for white dwarf and disk as follows: 30 000K + 12 445 K (early quiescence), 27500K + 9290 K, 25000K + 6607 K, 22500 K + 4603 K (late quiescence), arrow marks direction of change. In addition, given flux ratios including a contribution of a bright spot: white dwarf (30000 K) and disk (12445 K) plus bright spot (1a: 12000 K, 1b: 14000 K, i = 30°; 2a, 2b same for i = 60°). Further, ratios for white dwarf (30000 K) plus secondary star (a: $0.7M_\odot$, 4000 K; b: $0.7M_\odot$, 4500K; c: $0.94M_\odot$, 4500 K), see text.

1978). The angular extent of the bright spot is different for different systems and seems to vary (for a review see Warner 1995). As an example we assume a spot size of $1.2 \cdot 10^9 cm$ times $1.8 \cdot 10^9 cm$ which compares to a disk height of 1/30 of disk radius and a slight elongation of the spot along the outer edge of the disk and temperatures of 12000K and 14000K. We show in Fig. 2b how the flux ratio (early quiescence) would be changed if a bright spot of temperature 12000 or 14000 K would also contribute to the fluxes (squares 1a and 1b belong to line 1, 2a and 2b to line 2).

An even further contribution to the fluxes might come from the secondary if it is of relatively hot. The large size of the star compared to the white dwarf can cause a change of flux ratios. As an example we give the flux ratio for a white dwarf plus the radiation (assumed to be a black body) from $0{\cdot}7M_\odot$ and $0{\cdot}94M_\odot$ main sequence stars. The second mass was chosen according to the secondary in RU Peg. This system has an extremly low value of log f_{1460}/f_{2880} (compare Deng et al. 1994). Due to the low inclination of about 33° this position in the flux ratio diagram can be understood as resulting from disk and secondary star contributions. Because of the spectral type of the secondary star (K5V) we expect similar features for SS Cygni. But these contributions put a question mark on the results in Sect. 4, where we interprete the total flux as contributions from white dwarf plus disk.

As described we determined the position in the flux ratio diagram for different contributions of white dwarf, disk, bright spot and eventually secondary star for systems with a $1M_\odot$ white dwarf. For smaller white dwarf mass the radius is larger and, for a given accretion rate, the temperature would be lower. We then would find other flux ratios. This means that the traces would fill another area in the flux ratio diagram. For a whole sample of dwarf novae then the observed scatter in the flux ratio diagramm, (Fig. 2a), can be understood as a consequence of evaporation.

An additional cooling of the white dwarf following from other processes would show up only as decreasing white dwarf temperatures.

5.2. X-ray observations

The radiation from the corona and the white dwarf boundary layer is seen partly in UV and partly in X-rays, whereby the larger part of the X-rays originates from the white dwarf (Liu et al. 1995). X-ray observations of dwarf novae during quiescence also show a considerable spread in a diagram of PSPC count rates vs. hardness ratio (Beuermann & Thomas, 1993). The decreasing X-ray flux observed for VW Hydri (van der Woerd & Heise 1987) is related to decreasing UV flux. We interprete both as due to the less effective evaporation after a hole has already been created. ASCA observations of VW Hydri (Mauche and Raymond 1994) and of HT Cas (Mukai et al. 1995) demonstrate that accretion goes on during quiescence at a rate of $6 \cdot 10^{-12} M_{\odot}/y$ and $10^{-11} M_{\odot}/y$. The X-ray eclipse of HT Cas (Wood et al. 1995, Mukai et al. 1995) shows that either the amount of X-rays from the disk corona is very small (the evaporation model predicts about 1/6 of the total amount, Liu et al. 1995) or that the inner edge of the disk, where the X-rays originate, is close to the white dwarf. In their analysis of Ginga observations of SS Cygni Yoshida et al. (1992) found indications for an evaporation-accretion flow.

6. Conclusions

UV observations of dwarf novae systems during a single quiescence would be most suitable to learn about the disk evolution. But such an evaluation suffers from the fact, that only few observations are available under these constraints and also from uncertainties in separating the flux contributions from white dwarf and disk as well as the lack of adequate theoretical spectra. Having these problems in mind, we find from the data of 4 systems, that probably a hole exists in the inner disk. The observed flux evolution does not show a monotonic change of the inner disk radius, as would be deduced from monotonic changes of UV and X-rays observed for VW Hyi.

Another piece of information is the scatter of flux ratios f_{1460}/f_{1800} and f_{1460}/f_{2880} in the compilation of Deng et al. (1994). We show that the mass accretion rate change according to evaporation causes a change of the flux ratios during quiescence, resulting from decreasing temperatures of white dwarf and disk and an increasing emitting disk area at larger distance from the white dwarf. We have evaluated the expected traces in the flux ratio diagram for a system containing a $1 M_{\odot}$ white dwarf. For a sample of systems with different white dwarf masses we then get different values for the flux ratios. This analysis allows to understand the changing disk temperatures and white dwarf temperatures as the physical cause of the scatter. We have also shown that further contributions from a bright spot or, in a few cases, even from the secondary star influence the flux ratios. This makes it even more difficult to analyse the spectra. If the decrease of the white dwarf temperature would result from cooling only, the disk would not be affected by this process. Accumulation of mass during quiescence results in an increase of the temperature, but not high enough to show up as UV radiation. So cooling only would give variations along the white dwarf positions in a color color diagramm and not a scatter as in the observed data (Fig. 2a).

References

Beuermann, K., Thomas, H.C., 1993, Adv. Sp. Res. **13** (12) 115

Deng, S.B., Zhang, Z.Y., Chen, J.S., 1994, A&A **281**, 759

Hassall, B.J.M., Pringle, J.E., Verbunt, F., 1985 Mon. Not. R. astr. Soc. **216**, 353

Hassall, B.J.M., la Dous, C. 1996, in Cataclysmic variables and related objects,IAU Coll. 158, Keele, eds. A. Evans and J.H. Wood, Kluwer Astroph. and Space Science Library, p.85

Huang M., Sion E.M., Hubeny, I., Cheng F.H. Szkody P. 1996, in Cataclysmic variables and related objects,IAU Coll. 158, Keele, eds. A. Evans and J.H. Wood, Kluwer Astroph. and Space Science Library, p.247

la Dous, C. 1991, *A& A*, **252**, 100

la Dous, C. 1994, Space Science Reviews **67**

la Dous, C., Meyer-Hofmeister, E., Meyer, F. 1995, in Cataclysmic variables and related objects,IAU Coll. 158, Keele, eds. A. Evans and J.H. Wood, Kluwer Astroph. and Space Science Library, p.81

Lin, D.N.C. 1975 Mon. Not. R. Astr. Soc. **170**, 379.

Liu, F.K., Meyer, F., Meyer-Hofmeister, E. 1995, *A & A*, **300**, 823

Livio, M., P, Pringle J.E., 1992, Mon. Not. R. Astr. Soc., **259**, 23p

Long, K.S., Sion, E.M., Huang, M., Szkody, P., 1994, Ap.J. **424**, L 49

Marsh, T.R. 1988, Mon. Not. R. Astr. Soc. **231**, 1117.

Mauche, C.W., Raymond, J.C., 1994, in New Horizon of X-ray Astronomy, Universal Academy Press Inc., p. 399

Meyer, F., Meyer-Hofmeister, E., 1989, *A & A*,**221**, 36

Meyer, F., Meyer-Hofmeister, E., 1994, *A & A*, **288**, 175

Mukai, K., Schlegel, E.M., Swank, J.H., Naylor, T., Wood, J.H., 1995,in Cataclysmic variables and related objects, IAU Coll. 158, Keele, eds. A. Evans and J.H. Wood, Kluwer Astroph. and Space Science Library, p.269

Nauenberg, M., 1972, Astrophys. J. **175**, 417

Ritter H., Kolb, U., 1995, in: X-Ray Binaries, ed. Lewin W.H.G. et al. Cambridge Astrophysic Series Vol. **26**, p.578

Robinson E.L., Nather R.E., Patterson J. 1978 ApJ **219**, 168

Schoembs R., Hartmann K. 1983, A&A **128**, 37

Szkody, P., Kiplinger, A., 1985, Bull. Astron. Soc. **17**, 839

Szkody, P., Mattei, J.A., Waagen, E.O., Staeblein C. 1991, Astr.J.Suppl. **76**,359.

van der Woerd, H., Heise, J. 1987, *Month.Not.R. Astr.Soc.* **225**, 141.

Verbunt, F., 1987, Astron. Astrophys. Suppl. **71**, 339

Verbunt, F., Hassall, B.J.M., Pringle, J.E., Warner, B., Marang, F.: 1987 Mon. Not. R. Astr. Soc. **225**, 113

Warner, B. 1995 Cataclysmic Variable Stars, Cambridge Astrophysics Series, Vol. **28**

Wesemael F., Auer, L.H., van Horn, H.M., Savedoff, M.P. 1980, ApJ Suppl. **43**, 159

Wood, J., Horne, K., Berriman G., et. al, 1986, Mon. Not. R. Astr. Soc. **219**, 629

Wood, J., Marsh, T.R. Robinson, E.L., et. al, 1989, Mon. Not. R. astr. Soc. **239**, 809.

Wood, J., Naylor, T., Hassall B.J.M., Ramseyer T.F., 1995, Mon. Not. R. astr. Soc. **273**, 772

Yoshida K., Inoue H. Osawi, Y. 1992, Publ. Astron. Soc. Japan **44**, 537

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.