Reconstruction of the accretion disk in six cataclysmic variable stars

R.G.M. Rutten 1, J. van Paradijs 1, and J. Tinbergen 2

1 Astronomical Institute “Anton Pannekoek”, University of Amsterdam, and Center for High Energy Astrophysics, NIKHEF-H, Kruislaan 403, NL-1098 SJ Amsterdam, The Netherlands
2 Leiden University and Kapteyn Observatory, Mensingheweg 20, NL-9301 KA Roden, The Netherlands

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Abstract. Four-color eclipse light curves of the nova-like variable stars RW Tri, UX UMa, SW Sex, LX Ser, V1315 Aql, and V363 Aur are analyzed with the maximum-entropy eclipse-mapping algorithm to reconstruct images of the accretion disks. The two-dimensional disk intensity maps deduced from the light curves reveal the size of the disk and its radial intensity dependence. The disk radius appears unrelated to the binary system parameters such as the orbital period, mass ratio and mass of the white dwarf. The position and luminosity of the bright spot are obtained from the intensity maps, and it is shown that the fractional luminosity of the bright spot is related to the ratio of the disk radius to the white-dwarf radius.

Black-body temperature maps deduced from the intensity maps at different wavelengths show that the disks in RW Tri, UX UMa and V363 Aur have a radial temperature dependence which closely matches the fundamental theoretical run of the effective temperature with radial distance from disk center: \( T_{\text{eff}} \propto R^{-3/4} \). In these cases a mass-transfer rate can be deduced. The systems V1315 Aql and SW Sex, however, exhibit a much flatter run of \( T(R) \) in the inner region of the disk, while LX Ser appears to hold a position in between these two extremes. We discuss the consequences of our results for accretion disk models.

We show that the eclipse-mapping technique also serves as a tool to isolate the light from the secondary star (or any other light source unrelated to the disk); this allows us to estimate the distance of the system.

Key words: accretion: accretion disks – stars: binaries: close – stars: individual: RW Tri, UX UMa, SW Sex, LX Ser, V1315 Aql, V363 Aur – stars: novae and cataclysmic variables

1. Introduction

The UX UMa-type nova-like variable stars are a class of non-magnetic cataclysmic variables (CVs) which are characterized by a relatively bright and stable accretion disk, as opposed to the highly variable dwarf novae. In these nova-like systems the accretion disk dominates the optical spectrum. According to theories on accretion disk structure the high mass transfer rate in nova-like variables puts the disk in a stable state in which gravitational potential energy is released through viscous heating and is balanced by radiative cooling; these systems are frozen in a state of permanent outburst (see the reviews by Smak 1984; Meyer-Hofmeister & Ritter 1991, and references therein). This makes UX UMa-type nova-like systems particularly suitable objects for a study of steady-state accretion disk structure and for comparing the observations with theoretical disk models.

A fundamental property of accretion disk structure has been deduced from energy balance arguments: if material in the disk is rotating at Keplerian velocities throughout the disk, half of the available gravitational potential energy is released in the disk by viscous friction. The other half of the gravitational-energy budget is released in the boundary layer between inner disk and white dwarf, provided that the surface rotation rate of the white dwarf is much less than the orbital velocity of the accreting material (Bath & Pringle 1981). An implication of this steady-state disk model is that locally the effective temperature, \( T_{\text{eff}} \), depends on the radial distance from the center of the disk, \( R \), as

\[
T_{\text{eff}}(R) = \frac{3G M_{\text{wd}} \dot{M}}{8 \pi \sigma R^3} \left[ 1 - \left( \frac{R_{\text{wd}}}{R} \right)^{1/2} \right],
\]

where \( R_{\text{wd}} \) is the radius of the white dwarf and \( \dot{M} \) is the mass-accretion rate (Bath & Pringle 1981, 1985). For radial distances \( R \gg R_{\text{wd}} \), Eq. (1) reduces to \( T_{\text{eff}} \propto R^{-3/4} \). This prediction is, in principle, open to observational tests.

In some cataclysmic variable stars the binary system is viewed under such a high inclination that at superior conjunction the cool, Roche-lobe filling secondary star obscures light coming from the white dwarf and the accretion disk. The shape of the eclipse light curve contains information on the spatial intensity structure of the accretion disk. Horne (1985) describes a method to derive the 2-D disk intensity map from the eclipse light curve: the so-called eclipse-mapping technique. A very appealing feature of this method is that it does not have to enforce a specific model for the accretion disk. The basic assumptions made are that the disk is not changing during eclipse, is geometrically thin and lies in the orbital plane, and that the Roche model is valid. A short description of the technique is given in Sect. 3.

Horne & Stening (1985) employed the eclipse-mapping technique to analyze the eclipse light curve of the nova-like variable RW Trianguli. From the intensity map, a reconstructed image of the accretion disk, they derive a map of the brightness temperature, \( T_{\text{bright}} \). It is found that for RW Tri the radial temperature dependence fits the theoretical dependence \( T \propto R^{-3/4} \) very well. A similar study of the eclipsing dwarf nova Z Cha during outburst (Horne & Cook 1985) also showed that the radial temperature...
structure closely follows the theoretical prediction. However, ZCha in quiescent state (Wood et al. 1986) as well as the quiescent disk in the dwarf nova OY Car (Wood et al. 1989) both indicate a remarkably flat run of $T_{\text{bright}}$ with $R$. This has been attributed by Wood et al. (1989) to the disk being optically thin in quiescence. Before general conclusions may be drawn from a comparison between observational results and theory a larger sample of well-studied objects is required. Therefore, we embarked on a project with the aim to investigate the steady-state accretion disk structure from analysis of eclipse light curves. To avoid inconsistencies introduced by instrumentation or by the method of analysis we obtained observations of a sample of nova-like variables using the same equipment and analyzed them in an identical fashion.

In this paper we report on photometric observations of the eclipse light curves of the six nova-like variables RW Trianguli, UX Ursae Majoris, SW Sextantis, LX Serpentis, V1315 Aquilae and V363 Aurigae. These objects have been identified as UX Uma-type nova-like variables, with the exception of LX Ser, which in the latest version of Ritter's (1990) catalogue of cataclysmic variable stars is listed as an anti-dwarf nova. The light curves in four colors have been analyzed using the eclipse-mapping technique. We shall concentrate on the radial temperature structure of the accretion disk and investigate the dependence of basic disk characteristics on binary system parameters.

2. Observational details

2.1. Instrumentation

The observations were obtained with the Multi-Purpose Photometer (MPF, see Tinbergen 1987) on the 1-m Jacobus Kapteyn Telescope at the Observatorio del Roque de los Muchachos$^1$ on the island of La Palma. The MPF is a 12-channel photopolarimeter which allows one to split the incoming light into 12 beams using dichroic and neutral beam splitters. Filters are used to further define the passband. To obtain optimal efficiency over a wide wavelength range the MPF is equipped with six bluesensitive bi-alkali photomultiplier tubes (type RCA 8850) and six red-sensitive gallium-arsenide tubes (type RCA C-31034-02). All channels are operated simultaneously. The MPF has a halfwave plate permanently rotating in the beam at high frequency to allow polarimetric measurements. For photometric measurements the halfwave plate acts as a depolarizer; this is required to eliminate errors caused by polarization properties of the beam splitters.

For the eclipse observations only 4 out of the 12 available channels were used. The passbands combined the largest possible wavelength coverage with high photon efficiency, at the expense of not using "standard" passbands. Details of the passbands are given in Table 1. The effective wavelengths have been obtained by folding the instrumental response (of optics and detector) with spectra of flux standard stars (see Table 1).

Timing of the integrations was controlled by an internal clock; the absolute time was obtained from broadcast time signals.

Table 1. Details of MPF channels

<table>
<thead>
<tr>
<th>MPF channel no.</th>
<th>8</th>
<th>5</th>
<th>3</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.M. tube type</td>
<td>Bi-alkali</td>
<td>Ga-As</td>
<td>Ga-As</td>
<td>Ga-As</td>
</tr>
<tr>
<td>$\lambda_{\text{eff}}$ (Å)</td>
<td>4410</td>
<td>5700</td>
<td>6870</td>
<td>8010</td>
</tr>
<tr>
<td>$\lambda_{\text{peak}}$ (Å)</td>
<td>4200</td>
<td>5200</td>
<td>7100</td>
<td>8200</td>
</tr>
<tr>
<td>FWHM (Å)</td>
<td>900</td>
<td>1400</td>
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<td>Peak efficiency (%)</td>
<td>19</td>
<td>11</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

2.2. Observations and data reduction

A single recording of a light curve consisted of a long time series of individual 11 second integrations and typically covered up to half an orbital cycle. The observations were regularly interrupted for sky background measurements (including dark current) and for measurements of a local comparison star (within 2' distance from the target). A time series was usually preceded and followed by sky and comparison star observations, and measurements of a second comparison star as a check on the stability of the main one. From this check we find the main comparison stars to be stable to better than a few percent from night to night.

The size of the aperture was usually set to 14" (larger in poor seeing). The position of the target within the aperture was checked regularly by eye, and corrected if necessary. All integrations were screened for loss of signal by clouds or by poor centering due to tracking errors; such integrations have been purged.

The count rates for individual integrations were corrected for sky background. Next, the count rates of the target were divided by the count rates of the nearby comparison star, obtained by linear interpolation to the time of observation. The resulting relative intensities are not sensitive to (slow) variations in sky transparency and instrumental response.

In order to establish an absolute flux scale the local comparison stars were calibrated against two flux standard stars. These flux calibration observations were always performed under excellent sky conditions and, to minimize extinction differences, the time of observation was such that the comparison star and the flux standard star were at nearly the same airmass. The AB magnitudes (Oke 1974) derived for our target stars outside eclipse are given in Table 2. From a comparison of calibration measurements on different flux standard stars we estimate the accuracy to be 0.05 mag. However, systematic errors of up to $\sim 0.1$ mag may have been introduced by differences in effective wavelength due to color differences between the flux standard stars (mainly of spectral type B or A) and the target.

Gaps in the time series caused by calibration measurements are filled in by combining several eclipse light curves. Fluctuations caused by unstable sky transparency and by "flickering" of the target are reduced in the average light curve. A journal of the eclipse observations is given in Table 3. In order to bring the eclipses to a common phase scale the eclipse minima in each passband were obtained by fitting a parabola to the deepest part of the eclipse. The minimum of the parabola, averaged for the four passbands, was taken to be zero orbital phase. Published orbital periods (see Table 4) are used to convert time to phase. In the case of SW Sex it was found during later analysis that the minimum of the light curve does not correspond to the zero orbital phase, due to substantial influence of the bright spot. In this case a phase

$^1$ The Jacobus Kapteyn Telescope is operated by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias on behalf of the Science and Engineering Research Council and the Netherlands organization for scientific research.
Table 2. AB magnitudes in the different passbands. Values on the first line represent the total brightness of the system, whereas on the second line a correction for the secondary star has been applied. Magnitudes are not corrected for interstellar extinction.

<table>
<thead>
<tr>
<th>Object</th>
<th>4410 Å</th>
<th>5700 Å</th>
<th>6870 Å</th>
<th>8010 Å</th>
</tr>
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<tbody>
<tr>
<td>RW Tri</td>
<td>13.6</td>
<td>13.5</td>
<td>13.4</td>
<td>13.3</td>
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<td></td>
<td>13.6</td>
<td>13.5</td>
<td>13.6</td>
<td>13.6</td>
</tr>
<tr>
<td>UX UMa</td>
<td>12.6</td>
<td>12.8</td>
<td>12.9</td>
<td>12.9</td>
</tr>
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<td></td>
<td>12.6</td>
<td>12.8</td>
<td>13.0</td>
<td>13.1</td>
</tr>
<tr>
<td>SW Sex</td>
<td>14.5</td>
<td>14.6</td>
<td>14.6</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>14.5</td>
<td>14.6</td>
<td>14.6</td>
<td>14.7</td>
</tr>
<tr>
<td>LX Ser</td>
<td>14.6</td>
<td>14.6</td>
<td>14.5</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>14.6</td>
<td>14.6</td>
<td>14.5</td>
<td>14.5</td>
</tr>
<tr>
<td>V1315 Aql</td>
<td>14.8</td>
<td>14.6</td>
<td>14.4</td>
<td>14.4</td>
</tr>
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<td></td>
<td>14.8</td>
<td>14.7</td>
<td>14.5</td>
<td>14.5</td>
</tr>
<tr>
<td>V363 Aur</td>
<td>14.6</td>
<td>14.3</td>
<td>14.2</td>
<td>14.1</td>
</tr>
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<td></td>
<td>14.9</td>
<td>14.7</td>
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Table 3. Journal of eclipse observations and mid-eclipse timings

<table>
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<tr>
<th>Object</th>
<th>Date (UT)</th>
<th>HJD - 2440000</th>
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<tr>
<td>RW Tri</td>
<td>23 Sep. 1989</td>
<td>7792.5293</td>
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<tr>
<td></td>
<td>24 Sep. 1989</td>
<td>7793.6895</td>
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<td></td>
<td>25 Sep. 1989</td>
<td>7794.6161</td>
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<tr>
<td></td>
<td>26 Sep. 1989</td>
<td>7795.5444</td>
</tr>
<tr>
<td></td>
<td>2 Oct. 1989</td>
<td>7801.5736</td>
</tr>
<tr>
<td></td>
<td>3 Oct. 1989</td>
<td>7802.5002</td>
</tr>
<tr>
<td>UX UMa</td>
<td>16 Mar. 1989</td>
<td>7601.5122</td>
</tr>
<tr>
<td></td>
<td>16 Mar. 1989</td>
<td>7602.4954</td>
</tr>
<tr>
<td></td>
<td>17 Mar. 1989</td>
<td>7603.4792</td>
</tr>
<tr>
<td></td>
<td>22 Mar. 1989</td>
<td>7607.6089</td>
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<tr>
<td></td>
<td>23 Mar. 1989</td>
<td>7608.5922</td>
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<td>29 Mar. 1989</td>
<td>7614.6888</td>
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<td></td>
<td>1 Apr. 1989</td>
<td>7618.4259</td>
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<td></td>
<td>5 Apr. 1989</td>
<td>7621.5726</td>
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<td>6 Apr. 1989</td>
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<td></td>
<td>8 Apr. 1989</td>
<td>7624.5226</td>
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<td>SW Sex</td>
<td>9 Feb. 1989</td>
<td>7566.5676</td>
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<tr>
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<td>30 Mar. 1989</td>
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<td>2 Apr. 1989</td>
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<td>5 Apr. 1989</td>
<td>7622.4320</td>
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<tr>
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<td>7621.6891</td>
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<tr>
<td></td>
<td>7 Apr. 1989</td>
<td>7623.5903</td>
</tr>
<tr>
<td></td>
<td>12 Apr. 1989</td>
<td>7628.6604</td>
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<tr>
<td></td>
<td>15 June 1990</td>
<td>8058.4874</td>
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<tr>
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</tr>
<tr>
<td></td>
<td>27 June 1990</td>
<td>8069.5770</td>
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<td>V1315 Aql</td>
<td>18 Sep. 1989</td>
<td>7788.3753</td>
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<td></td>
<td>20 Sep. 1989</td>
<td>7790.4714</td>
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<td></td>
<td>23 Sep. 1989</td>
<td>7793.4041</td>
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<td>30 Sep. 1989</td>
<td>7800.3891</td>
</tr>
<tr>
<td></td>
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<td>7801.3669</td>
</tr>
<tr>
<td></td>
<td>22 June 1990</td>
<td>8064.6826</td>
</tr>
<tr>
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<td>8065.6604</td>
</tr>
<tr>
<td></td>
<td>23 June 1990</td>
<td>8066.4980</td>
</tr>
<tr>
<td>V363 Aur</td>
<td>8 Feb. 1989</td>
<td>7566.3817</td>
</tr>
<tr>
<td></td>
<td>9 Feb. 1989</td>
<td>7567.3466</td>
</tr>
<tr>
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</tr>
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<td></td>
<td>20 Sep. 1989</td>
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<tr>
<td></td>
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<td></td>
<td>29 Sep. 1989</td>
<td>7798.6401</td>
</tr>
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</table>

3. The eclipse-mapping method

This section briefly describes the eclipse-mapping method pioneered by Horne (1985), which employs the maximum-entropy optimization scheme described by Skilling & Bryan (1984; see also Skilling & Gull 1985). In this method for analyzing eclipse light curves one adjusts the intensity distribution in the orbital plane around the white dwarf, searching for that distribution which reproduces the observed eclipse light curve. The model used in the eclipse-mapping procedure assumes that the cool, mass-donating star fills its Roche lobe and that the orbital motion is circularized. The disk is assumed to be of negligible thickness and to have a stationary intensity distribution (in the rotating frame of the binary system). It is assumed that all the observed light is from the disk and the white dwarf.

These assumptions, together with the orbital inclination, the stellar masses and the orbital period, constrain the intensity distribution in the plane of the disk. In practice, a grid of points is defined in the orbital plane centered on the white dwarf and intensities are assigned to each grid point. We shall call such a set, \( f_i \), of intensity values an intensity map. The individual intensities on the map are adjusted in order to fit the light curve to a reduced-\( \chi^2 \) of 1. The constraints on this fitting problem are,
Table 4. System parameters

<table>
<thead>
<tr>
<th>Object</th>
<th>Period (s)</th>
<th>Inclination (deg)</th>
<th>(M_\text{wd} \ (M_\odot))</th>
<th>(M_\text{sd} \ (M_\odot))</th>
<th>(E(B-V))</th>
<th>References*</th>
</tr>
</thead>
<tbody>
<tr>
<td>RW Tri</td>
<td>20035</td>
<td>75</td>
<td>0.7</td>
<td>0.6</td>
<td>0.1</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>UX UMa</td>
<td>16992</td>
<td>71</td>
<td>0.45</td>
<td>0.45</td>
<td>0.0</td>
<td>4, 5</td>
</tr>
<tr>
<td>SW Sex</td>
<td>11659</td>
<td>79</td>
<td>0.44</td>
<td>0.30</td>
<td>0.0</td>
<td>3, 6</td>
</tr>
<tr>
<td>LX Ser</td>
<td>13689</td>
<td>75</td>
<td>0.40</td>
<td>0.35</td>
<td>0.0</td>
<td>3, 7, 8</td>
</tr>
<tr>
<td>V1315 Aql</td>
<td>12069</td>
<td>81.5</td>
<td>0.9</td>
<td>0.4</td>
<td>0.0</td>
<td>6, 9</td>
</tr>
<tr>
<td>V363 Aur</td>
<td>27755</td>
<td>73</td>
<td>0.86</td>
<td>0.77</td>
<td>0.1</td>
<td>10</td>
</tr>
</tbody>
</table>


however, not sufficiently tight to yield a unique solution; many different intensity maps reproduce the observed light curve equally well and therefore an additional constraint is required. This additional constraint is found in optimizing the “smoothness” of the intensity distribution. A measure for the smoothness is given by the entropy, \(S\), of an intensity map, \(f_i\), which is defined by the following summation over all disk elements:

\[
S = - \sum_{i=1}^{n} f_i \ln \left( \frac{f_i}{d_i} \right)
\]

(see Burch et al. 1983; Skillings & Bryan 1984; Horne 1985), where \(d_i\) is a default map (\(f_i\) and \(d_i\) are normalized to the total intensity on the grid). By maximizing \(S\) the discrepancies between \(f_i\) and \(d_i\) for all disk elements \(i\) are minimized and hence \(f_i\) would equal \(d_i\) if there were no observational constraints. Choice of the default map gives a certain flexibility to steer the final maximum-entropy solution. Horne (1985) showed that the default map which optimizes the smoothness in the azimuthal direction produces optimal results for this type of study which aims at revealing the radial disk structure; we follow Horne’s method.

For the maximization of entropy we used the MEMSYS software package, developed by S.F. Gull and J. Skillings, and kindly made available through the STARLINK computer network facility in the United Kingdom.

Throughout this study we use a square grid of 43 \(\times\) 43 pixels with the white dwarf at its center and the inner Lagrangian point L1 at the center of one side (pixels with radial distance from the white dwarf larger than \(R_{\text{L1}}\) are forced to zero intensity). In the fitting procedure the light curves are rebinned to phase intervals of 0.002. The uncertainties in the measured light curve play an essential role through the \(\chi^2\) measure. If (part of) the light curve is fitted more tightly than warranted by the uncertainty on the data the resulting intensity map will exhibit spurious structure like bright spots or ridges. In some of our light curves occasional flaring or strong flickering before or after the eclipse results in deviations which cannot be fitted and thus contribute substantially to \(\chi^2\). In these cases the constraint of unity reduced-\(\chi^2\) is too tight, and to compensate for this effect we allow a slightly larger \(\chi^2\) for the fit.

4. Results

We have employed the eclipse-mapping algorithm to analyze the light curves in each of the passbands separately. Eclipse light curves at 4410 Å for the six objects are shown in Fig. 1. The orbital period and stellar masses have been taken from the literature; see Table 4 for an overview and for references. The orbital inclination is deduced from the width of the eclipse, given the mass ratio (Horne 1985). These basic parameters set the geometry of the binary system.

4.1. Uncertainties

The maximum-entropy eclipse-mapping method, described in Sect. 3, is a non-linear algorithm which does not allow one to calculate uncertainties in the intensity map directly from standard deviations in the measured light curve. An alternative way to derive uncertainties is by statistical simulation: all data points in a light curve were independently varied according to a Gaussian distribution with a standard deviation corresponding to the standard deviation on that point. This “randomized” light curve was then fitted with the eclipse-mapping algorithm to produce an intensity map. By randomizing the original light curve and fitting an intensity map several times the uncertainty on each pixel of the intensity map was obtained. The results of this exercise show that uncertainties on the map are not uniform or random, but that regions with correlated uncertainties exist. Note also that this method brings out the statistical uncertainties, but does not yield information on systematic errors. The uncertainties are used later, when temperatures are derived from intensities in different passbands (Sect. 5).

4.2. The secondary star

One of the uncertainties in interpreting the light curve is the unknown contribution of the secondary star (or, in fact, any other field star which happens to be in the aperture but was not corrected for with the sky measurement). In principle, this contribution should be subtracted in order to isolate the light from the disk (including the white dwarf). The deepest point of the eclipse sets an upper limit to the contribution of the secondary star. For the systems SW Sex, LX Ser and V1315 Aql the eclipses are very deep and the secondary star can at most contribute a few percent to the total light in the system. The eclipses of RW Tri, UX UMa and V363 Aur are shallower; in UX UMa this is mainly due to the relatively low inclination which causes the disk to be only partially eclipsed, whereas in RW Tri and V363 Aur the
Fig. 1a-f. Normalized light curves at 4410 Å. The thin curves show the measured light curves, and the fits produced by the eclipse-mapping algorithm are indicated by a thick, smooth curve. The standard deviations on the measured light curves are shown at the bottom of each panel, over the range in phase that was used in the fit. a RW Tri, b UX UMa, c SW Sex, d LX Ser, e V1315 Aql, f V363 Aur. Note that in the case of V1315 Aql (panel e) and V363 Aur (panel f) a (small) offset has been applied, to correct for the contribution of the secondary star.

The secondary star is responsible for the shallow eclipse, as we shall show below.

To examine the effect of contamination of the light curve by the secondary star, we first performed simulations to investigate

the response of the eclipse-mapping reconstruction method to an

offset in the zero-intensity level. To this end, we defined a smooth,

azimuthally symmetric intensity structure representing the accre-

tion disk and calculated the eclipse light curve for a given mass

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a: simulation

b: RW Tri (8010 Å)

Fig. 2. a Reconstructed intensity map of a simulation in which the light curve from an azimuthally symmetric disk structure was artificially offset to simulate the effect of contamination by the cool secondary star. b Reconstruction of the light curve of RW Tri at 8010 Å before the correction for light from the secondary star is applied. Note the similarity of the spurious partial ring structures in panels a and b.

ratio, inclination and orbital period. A positive phase-independent offset was then introduced to mimic a constant contribution from the secondary star. The reconstructed map from this light curve (Fig. 2a) shows (apart from the main central disk structure) a spurious ring-like structure in the outer regions of the orbital plane, which is most strongly present on the side opposite to the L1 point, the section of the plane which is least eclipsed (see also Horne 1985). The strength of this additional structure, and hence the entropy measure, is correlated with the fractional contribution of the secondary star to the total light. When a negative offset is introduced to the light curve, also additional structure in the outer regions of the grid appears and the main disk structure tends to become asymmetric, forcing the entropy value to become smaller.

These simulations indicate that the eclipse-mapping algorithm is also a powerful tool for isolating the fraction of the light which originates from places other than the orbital plane around the white dwarf, e.g. from the secondary star. This can be understood in the following way: suppose all light is coming from the accretion disk plane and that at phase zero the disk is fully eclipsed, then a narrow and steep eclipse light curve results, which reaches zero intensity at mid-eclipse. Such an implicit connection exists between eclipse depth and duration and shape of the eclipse also when the disk is not fully eclipsed at any instant. A contribution from the secondary star prevents the eclipse from reaching zero intensity and consequently the eclipse-mapping algorithm cannot reconcile the duration and steepness of the eclipse light curve with the non-zero eclipse depth. The excess light becomes visible as a spurious structure in that section of the disk plane which is least obscured by the secondary star (and is azimuthally smeared out). The entropy measure, as an indicator for the amount of structure on the intensity map, serves as a means for finding the true zero-intensity level, thereby isolating the fraction of the total light which is not coming from the accretion disk plane. Note that if this spurious structure on the disk is not recognized erroneous conclusions may result.

Ring structures on the disk maps very similar to the one obtained from the simulations are readily seen in the reconstructions of the 8010 Å light curves of RW Tri (shown in Fig. 2b) and of V363 Aur. The structure is very pronounced in the reconstruction from the long-wavelength eclipse light curves and gets progressively weaker towards shorter wavelengths, which is the signature of an additional source of red light in the system, most likely the secondary star. By subtracting the appropriate level from the observed light curve, one can make the spurious structures vanish completely and the entropy of the map becomes larger, indicating an improved optimization of the smoothness of the map. Note that the reconstructed R-band map of RW Tri published by Horne & Stiening (1985) also shows the spurious structure due to the secondary star, but was not recognized by them.

For light curves at 8010 Å we find that the contribution of the secondary star to the total light of the system is 46 ± 10% in V363 Aur, 22 ± 5% in RW Tri, 12 ± 5% in UX UMa and 9 ± 5% in V1315 Aql. These percentages decrease towards shorter wavelengths. Table 2 lists the magnitudes of each object before and after the contribution of the secondary star has been subtracted.

4.3. Distances

Distances of CVs are a major uncertain factor in the determination of intrinsic flux densities. There are several ways to estimate the distance (see Patterson 1984) of which the most direct ones are parallax measurements and detection of the secondary star in the infrared (Bailey 1981). Other methods rely on assumptions
concerning the intrinsic shape of the spectral energy distribution of the accretion disk or on its intrinsic absolute luminosity. The interstellar material may provide a distance measure through spectral absorption features or interstellar polarisation, but the local distance scale will remain uncertain due to inhomogeneities in the interstellar medium.

For the objects studied here we have estimated the distance by fitting a black-body curve to the fluxes in the four passbands, at each pixel on the intensity maps independently, both temperature and distance being free parameters. To relate intensities on a map to flux densities at the disk surface first a correction for interstellar extinction had to be applied to the total disk magnitudes. The wavelength-dependent interstellar extinction has been derived from the color excess \( E(B-V) \) using the standard extinction curve (Scheffler 1982). The broad and shallow interstellar absorption band at 2200 Å was used to estimate \( E(B-V) \). For the systems in our sample we retrieved low-resolution IUE spectra from the IUE archive for inspection of the 2200 Å absorption feature. We followed Verbunt’s (1987) method and combined pairs of low-resolution short- and long-wavelength IUE spectra, and applied Seaton’s (1979) wavelength-dependent UV extinction correction for a number of color excess values (but note that extinction in the 2200 Å feature may not be related unambiguously to extinction at other wavelengths; see Somerville 1991). The spectra were judged by eye for the presence of the extinction feature. Although the IUE spectra available to us are not of sufficient quality to estimate \( E(B-V) \) accurately, they are at least good enough to signal the presence of substantial interstellar absorption. Our estimates of \( E(B-V) \) for RW Tri and UX UMa agree with those obtained by Verbunt (1987). The UV spectra of UX UMa, SW Sex, LX Ser and V1315 Aql do not show any indication of (substantial) interstellar extinction, and hence \( E(B-V)=0.0 \) is assumed here. V363 Aur provides marginal evidence for extinction; we take \( E(B-V)=0.1 \). The magnitudes in our passbands are corrected for interstellar extinction corresponding to the color excess \( E(B-V) \) specified in Table 4.

The flux densities \( F_{\nu,i} \) at a specific pixel \( i \) on the disk surface may be obtained from

\[
F_{\nu,i} = \frac{d^2}{A \cos i} \frac{1}{I_{\text{disk}}} 10^{-0.4m_{\text{AB}}-19.44},
\]

(3)

where \( m_{\text{AB}} \) is the total, disk-integrated magnitude corrected for interstellar extinction (and for the contribution of the secondary star; see Sect. 4.2) and \( I_{\text{disk}} \) specifies the fractional contribution of that disk element to the total disk luminosity. \( A \) is the surface area of the disk element and \( \cos i \) the fore-shortening factor introduced by the inclination \( i \) of the disk relative to the line of sight. Finally, the flux density scales with the square of the distance \( d \). The Planck function \( B(\nu d) \) was fitted to these flux densities whereby both \( T_{\text{eff}} \) and \( d \) were optimized. To avoid large uncertainties in the fit we only used pixels with intensities exceeding a threshold of 25% of the maximum intensity. This selection criterion also ensures that the inner, optically thick part of the disk is selected where the spectrum better resembles that of a black body than the outer, optically thin regions. The average of the individual distance measures over all pixels is given in Table 5, column [a].

Another clue to the distance has been obtained from the luminosity of the secondary star. As explained in Sect. 4.2, the fractional luminosity of the secondary star, and hence its magnitude, has been deduced from the light curve at 8010 Å. Given the mass of the secondary star its absolute magnitude may be estimated under the assumption that the star is on the main sequence [absolute AB magnitudes at 8010 Å derived from \( M_V \) using color tables for K- and M-type main-sequence stars from Schmidt-Kaler (1982), conversions between \( (B-V) \), \( (V-R) \) and \( (R-I) \) colors given by Barnes et al. (1978), and magnitude-to-flux conversion factors given by Lamla (1982)]. The distance modulus is obtained from the difference \( m_{\text{AB}}-M_{\text{AB}} \) and the resulting distances are listed in Table 5, column [b]. Note that, with the exception of V1315 Aql, these distances agree remarkably well with those obtained from the spectral fit described above.

Our distance estimates are in good agreement with those obtained by Bailey (1981) from infra-red photometry of the cool secondary star (see Table 5). Patterson (1984) and Warner (1987) have made a compilation of distance estimates for many CVs, which are also listed in Table 5. We adopt the distances given in the last column of Table 5.

### 4.4. Light curves and their intensity maps

The intensity maps reconstructed from the light curves at 4410 Å are shown in Fig. 3. The corresponding fits to the light curves are indicated by the smooth curves in each panel of Fig. 1. The light curves in the other three passbands and the corresponding

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**Table 5. Distance estimates (parsec)**

<table>
<thead>
<tr>
<th>Object</th>
<th>[a]</th>
<th>[b]</th>
<th>[c]</th>
<th>[d]</th>
<th>[e]</th>
<th>Adopted</th>
</tr>
</thead>
<tbody>
<tr>
<td>RW Tri</td>
<td>270</td>
<td>330</td>
<td>247</td>
<td>224</td>
<td>(250)</td>
<td>270</td>
</tr>
<tr>
<td>UX UMa</td>
<td>330</td>
<td>290</td>
<td>216</td>
<td>300</td>
<td>340</td>
<td>250</td>
</tr>
<tr>
<td>SW Sex</td>
<td>460</td>
<td>&gt;440</td>
<td>&gt;360</td>
<td>&gt;300</td>
<td>(210)</td>
<td>340</td>
</tr>
<tr>
<td>LX Ser</td>
<td>320</td>
<td>&gt;360</td>
<td>&gt;300</td>
<td>&gt;300</td>
<td>(210)</td>
<td>340</td>
</tr>
<tr>
<td>V1315 Aql</td>
<td>150</td>
<td>550</td>
<td>720</td>
<td>(1000)</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>V363 Aur</td>
<td>530</td>
<td>720</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Explanation of columns:** (a) derived from black-body fit to spectrum of central part of disk (see Sect. 4.3); (b) derived from fractional contribution of secondary star (see Sect. 4.3); (c) derived from infrared luminosity of secondary star (Bailey 1981); (d) taken from the compilation by Warner (1987); (e) taken from the compilation by Patterson (1984), brackets indicating uncertain values

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intensity maps show structures similar to those at 4410 Å. We shall discuss each system individually:

**RW Tri**: the light curve of RW Tri is quite symmetric (Fig. 1a). At disk ingress there appears to be a slight dip, due to only one of the six available light curves which happens to dominate the sampling locally; this section of the light curve was not used in the fit.

**UX UMa**: shows a comparatively shallow eclipse which is due to the fact that the secondary star does not fully obscure the disk. The part which is not obscured is optimized as a smooth azimuthally symmetric structure. The shoulder in the light curve at egress is due to the bright spot, which is indeed apparent in the intensity map in Fig. 3b.

**SW Sex**: the eclipse of SW Sex is relatively wide, exhibits a steep

---

![Fig. 3a-f. Grey-scale representation of the intensity maps reconstructed from the light curves at 4410 Å. The grid center coincides with the white dwarf and the I1 point is located at the center of the lower boundary of each panel. The grey tones are equidistant on a linear scale.](image-url)

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ingress and a much more gradual egress. As a result the reconstructed intensity map is asymmetric and has a comparatively strong bright spot (Fig. 3c).

**LX Ser:** the eclipse exhibits a slight asymmetry indicative of a bright spot, as is confirmed by the reconstructed intensity map (Fig. 3d). In this case it is seen that the bright spot is smeared out in the azimuthal direction and gives the impression of a (partial) ring. As a result of this smoothing, the fit produces systematic residuals around phase $-0.07$, which is, however, not dramatic considering the relatively large uncertainties on the light curve at that phase.

**V1315 Aql:** has a very symmetric light curve and thus a featureless symmetric intensity map (Fig. 3e).

**V363 Aur:** the disk depicted in Fig. 3f shows an inconspicuous bright spot which is responsible for the gradual light curve egress.

In an attempt to quantify the disk size we measure its radius where the intensity is down to 10% of the peak intensity, $R_{0.1}$, both on the 4410 Å and 8010 Å maps, but ignoring the bright spot; these measures are listed in Table 6. The level of 10% is somewhat arbitrary but it provides a consistent measure of the disk size at an intensity level which is high enough to be reliably reproduced by the eclipse-mapping technique. In general $R_{0.1}$ at 8010 Å is larger than at 4410 Å indicating that the outer regions of the disk are red compared to the inner disk. The disk is very large in SW Sex, reaching up to 60% of the distance to L1. At the other extreme RW Tri, UX UMa and V363 Aur have relatively small disk radii $\sim 0.3R_{\odot}$, depending on wavelength.

---

**Table 6.** Parametrization of some disk characteristics

<table>
<thead>
<tr>
<th>Object</th>
<th>$R_{L1}$ (cm)</th>
<th>$R_{0.1}/R_{L1}$</th>
<th>Ingress phase</th>
<th>$R_{ ingress}/R_{L1}$</th>
<th>$\dot{M}$ ($M_\odot$/yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RW Tri</td>
<td>$6.2 \times 10^4$</td>
<td>0.28</td>
<td>0.03</td>
<td>-0.07</td>
<td>0.29</td>
</tr>
<tr>
<td>UX UMa</td>
<td>$4.8 \times 10^4$</td>
<td>0.27</td>
<td>0.04</td>
<td>-0.06</td>
<td>0.31</td>
</tr>
<tr>
<td>SW Sex</td>
<td>$3.8 \times 10^4$</td>
<td>0.6</td>
<td>0.01</td>
<td>-0.07</td>
<td>0.25</td>
</tr>
<tr>
<td>LX Ser</td>
<td>$4.0 \times 10^4$</td>
<td>0.43</td>
<td>0.07</td>
<td>-0.07</td>
<td>0.29</td>
</tr>
<tr>
<td>V1315 Aql</td>
<td>$5.0 \times 10^4$</td>
<td>0.47</td>
<td>0.04</td>
<td>-0.09</td>
<td>0.44</td>
</tr>
<tr>
<td>V363 Aur</td>
<td>$8.3 \times 10^4$</td>
<td>0.28</td>
<td>0.02</td>
<td>-0.06</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Timing of the start and end of eclipse provides an alternative way to estimate the disk radius and the radial extent of the bright spot. The limiting ingress and egress phases from the light curves at 4410 Å are given in Tables 6 and 7, respectively. At each of these phases we have calculated the boundary of the area in the plane of the accretion disk which is obscured by the secondary star. The position on this boundary nearest to the white dwarf is adopted as the disk radius, \( R_{\text{ingress}} \), for the ingress phase, and as the largest radial extent of the bright spot, \( R_{\text{egress}} \), for the egress phase; all are listed in Tables 6 and 7. The values of \( R_{\text{ingress}} \) are consistent with those of \( R_{0.1} \), except for SW Sex where the disk is strongly asymmetric.

Another feature of the disk is the bright spot, presumed to be where the mass accretion stream from the secondary collides with the disk. Of the systems we investigated, UX UMa, SW Sex, LX Ser and V363 Aur show a bright spot. For these systems the distance of the bright spot to the center of the disk and its position angle relative to the line connecting both stars are presented in Table 7. Note that the position angle is somewhat uncertain due to the optimized smoothing in the azimuthal direction.

In addition to the position of the bright spot we estimate its fractional luminosity by isolating the relevant pixels on the 4410 Å map (by visual inspection) and adding the intensities. These intensities, as a fraction of the total intensities, are given in Table 7.

5. The radial temperature profile

As described in the previous section, we have obtained intensity maps for each system in four passbands. We combine these maps into a single (color-) temperature map by fitting a black-body curve at every pixel. Again we use Eq. 3 to convert intensity on the map to flux density at the disk surface, but we now keep the distance fixed at the adopted value given in Table 5. In Fig. 4 \( T_{\text{eff}} \) is plotted against the radial distance to the center of the disk, scaled with the radial distance of the L1 point. In each case, not surprisingly, the temperature is highest close to the white dwarf, with typical values of 10000–30000 K, and it decreases gradually towards the outer regions of the disk. The bright spot shows up as a hump in the temperature profile, accompanied by a somewhat larger spread. The temperature of the bright spot is higher than the disk temperature at the same radial position by a few thousand K. However, since the eclipse-mapping algorithm tries to smear out intensity in the azimuthal direction, the peak temperature is underestimated.

The run of \( T(R) \) for RW Tri is in good agreement with Horne & Stiebing's (1985) findings, except for an offset of 0.15 dex which is due to the different value adopted for the color excess \( E(B-V) \).

The Planck function does not represent the observed spectrum well in every case. In V1315 Aql the outer region of the disks appears substantially bluer than the black-body curves, while in the inner disk the opposite holds. This systematic trend is depicted in Fig. 5, where the brightness temperature profiles at 4410 and 8010 Å are plotted for V1315 Aql. In SW Sex a similar though less pronounced trend is observed, but in the other systems systematic deviations from the Planck curve are much less obvious. More detailed modeling of the fluxes at different wavelengths will be necessary to explain these discrepancies, but this is not attempted here.

6. Discussion

6.1. The radial temperature dependence

The accretion disks in RW Tri, UX UMa, SW Sex, LX Ser, V1315 Aql and V363 Aur show distinctly different characteristics in their radial temperature structure (Fig. 4). To facilitate comparison with the canonical disk model, Fig. 4 includes the theoretical dependence of Eq. (1) for different levels of the mass-accretion rate \( \dot{M} \). The radius of the white dwarf is derived from its mass using Nauenberg's (1972) parametrization of stellar models calculated by Hamada & Salpeter (1961). For RW Tri, UX UMa and V363 Aur the deduced temperature profiles closely follow the theoretical curves (Figs. 4a, b and f), with the exception of the inner few pixels of the grid where \( T_{\text{eff}} \) appears to level off somewhat. In these three cases the mass-accretion rate can be fitted with some confidence. The mass-accretion rates found are (in \( M_\odot \) yr\(^{-1} \): RW Tri, 3 \( 10^{-9} \); UX UMa, 8 \( 10^{-9} \); V363 Aur, 3 \( 10^{-9} \). The estimate of \( \dot{M} \) for RW Tri is consistent with the upper limit to the mass-transfer rate of \( 5.6 \times 10^{-9} M_\odot \) yr\(^{-1} \) deduced by Robinson et al. (1991) from the timescale of changes in the orbital period.

The situation is less clear for LX Ser; the bright spot produces a hump in the temperature profile which confuses the general trend. In the inner few pixels of the grid the temperature profile appears to be flat, but the white dwarf may contribute substantially here and a clear conclusion cannot be drawn.

In SW Sex and V1315 Aql \( T_{\text{eff}} \) decreases more slowly with \( R \) than predicted by the standard model (Fig. 4c and e), and \( \dot{M} \) can only be estimated to order of magnitude accuracy (see Table 6). The large spread in temperatures at a given radius in SW Sex reflects the asymmetric disk shape and the pronounced bright spot.

Could the flat run of \( T_{\text{eff}} \) with \( R \) in SW Sex and V1315 Aql be induced by the method of analysis? We offer the following arguments in favor of its applicability:

<table>
<thead>
<tr>
<th>Object</th>
<th>Radial distance</th>
<th>Azimuthal position (deg)</th>
<th>Fractional luminosity</th>
<th>( R_{wd}/R_{\text{spot}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( R_{\text{spot}}/R_{L1} )</td>
<td>( R_{\text{egress}}/R_{L1} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UX UMa</td>
<td>0.57 ± 0.05</td>
<td>0.60</td>
<td>35 ± 10</td>
<td>0.07</td>
</tr>
<tr>
<td>SW Sex</td>
<td>0.51 ± 0.03</td>
<td>0.59</td>
<td>35 ± 10</td>
<td>0.13</td>
</tr>
<tr>
<td>LX Ser</td>
<td>0.48 ± 0.02</td>
<td>0.55</td>
<td>35 ± 15</td>
<td>0.11</td>
</tr>
<tr>
<td>V363 Aur</td>
<td>0.57 ± 0.05</td>
<td>0.65</td>
<td>35 ± 10</td>
<td>0.03</td>
</tr>
</tbody>
</table>

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In the eclipse-mapping method structure is smoothed primarily in the azimuthal direction; radial dependences are largely left intact. Simulations performed by Horne (1985) and by us show that the radial structure in a map can be recovered accurately. In order to show how the $T(R)$ dependence is reflected in the light curve we have simulated the light curve of V1315 Aql at 4410 Å for the case that $T(R)$ follows the theoretical dependence of Eq. (1), and for the flat temperature profile depicted in Fig. 5. The resulting light curves are compared in Fig. 6 and are clearly different; the theoretical $T(R)$ profile produces a steeper ingress and egress, and the deepest part of eclipse is much more rounded than the light curve corresponding to the flat $T(R)$

---

**Fig. 4a-f.** Radial dependence of disk temperature. Each point represents a single grid element. The point at disk center ($R=0$) is plotted at $log R = -1.9$. The curves show the canonical prediction of Eq. (1) for $T_{eff}(R)$; values of $log M$ (in $M_{\odot}$ yr$^{-1}$) are indicated. a RW Tri, b UX UMa, c SW Sex, d LX Ser, e V1315 Aql, f V363 Aur
Fig. 5. Brightness temperatures at 4410 Å (dots) and 8010 Å (crosses) against radius (logarithmic scale) for V1315 Aql. The curves show the canonical prediction of Eq. (1) for \( T_{\text{eff}}(R) \); values of log \( M \) (in \( M_\odot \) yr\(^{-1}\)) are indicated.

profile. The accuracy of the actually measured light curves allows us to distinguish between these two cases with ease. Consequently, \( T(R) \) can be obtained with confidence, provided the light curve is well sampled and measured with sufficient accuracy.

— Underestimating interstellar reddening results in \( T(R) \) curves which are too flat. Simulations show that for V1315 Aql and SW Sex \( E(B-V) > 0.5 \) would be required to bring the observations into accord with theory. Such large values for the color excess are inconsistent with the weak 2200 Å interstellar absorption feature.

— It is suspect that SW Sex and V1315 Aql are the two systems in our sample with the largest orbital inclination, where the assumption of a disk with negligible thickness may not be a reasonable approximation. We investigated the effect of a thick disk by assuming, rather arbitrarily, that the height of the disk surface above the orbital plane goes as 0.05\( R \) (Mayo et al. 1980). The intensities on the disk of V1315 Aql which results from this shape of the disk surface differ from the original map by only a few percent. This test shows that the assumption of a thin disk cannot be held responsible for the flat radial temperature distribution.

These arguments above strongly suggest that the radial disk temperature dependences deduced from the eclipse light curves are a good representation of the true situation. If so, we require a physical explanation for the different runs of \( T_{\text{eff}} \) with \( R \) between different systems and for the discrepancy with respect to the canonical theoretical model.

For the quiescent disks in the dwarf novae Z Cha and OY Car, Wood et al. (1986, 1989) found a radial temperature profile that is much flatter than the theoretical \( R^{-3/4} \) dependence. Wood (1990) tried to reproduce the white-light brightness temperature curves by fitting optically thin spectra, combining continuum and line opacities by assuming that the total energy radiated at each radial position equals \( \sigma T^4 \), where \( T_{\text{eff}} \) is given by the steady-state model [Eq. (1)]. Wood was able to reproduce the brightness temperature curve, but unreasonably large viscosities were required in some parts of the disk. Although the results of these fits are not completely satisfactory in the case of Z Cha and OY Car, Wood’s scheme supplemented with optically thick model spectra may prove useful in understanding the flat \( T(R) \) curves of SW Sex and V1315 Aql. In these systems line blanketing may be (partly) responsible for the discrepancies between brightness temperature profiles at different wavelengths. Brightness temperature curves in our four passbands will put much tighter constraints on the models than the white-light information. Such modeling is outside the scope of this paper.

Fig. 6. Simulated light curves of V1315 Aql. The bold curve is derived from an azimuthally symmetric disk intensity structure with a radial structure as observed at 4410 Å (see Fig. 5). The thin curve results from the radial intensity structure of the theoretical steady-state disk model [Eq. (1), i.e. \( T \propto R^{-3/4} \)] at 4410 Å.

Here we briefly suggest a few alternative explanations for the flatness of the \( T(R) \) curves in SW Sex and V1315 Aql: (i) It has been suggested that some non-magnetic nova-like CVs may in fact harbor a magnetic white dwarf whose magnetic field disrupts the inner part of the disk (Williams 1989; Dhillon et al. 1991). In such a case, the inner disk material will not rotate at Keplerian velocities and thus Eq. (1) will not be valid. (ii) An alternative violation of the \( T_{\text{eff}} \propto R^{-3/4} \) law would occur if the boundary layer between the disk and the white dwarf were radially extended to a substantial fraction of the disk (Duschl & Tscharnuter 1991). (iii) The inner disk temperatures may also indicate that energy is lost in some other way than by radiation, e.g. by a wind driven from the inner disk region.

Finally, we note that the two systems with clearly discordant temperature profiles, SW Sex and V1315 Aql, are also known for their unusual behavior of the Balmer lines. In both objects the Balmer lines exhibit large phase shifts relative to the motion of the white dwarf, they show a peculiar transient absorption at phases roughly opposite to eclipse, but near zero phase they are much less eclipsed than the continuum light, and the lines are not double-peaked as would be expected from the basic picture of a Keplerian rotating disk (Honeycutt et al. 1986; Thorstensen et al. 1991, Dhillon et al. 1991). The flat temperature profiles could be related to these peculiar emission-line characteristics.

6.2. Global disk properties

Light curves of nova-like CVs are comparatively stable, which indicates that the disk is replenished by steady mass overflow from the secondary star. The mass overflow is thought to be driven by loss of angular momentum from the system through magnetic braking and, to a lesser extent, through gravitational radiation. From this perspective, the accretion disk is an integral
part of the binary star system and we may expect that some of the
global disk characteristics will depend on binary system para-
eters such as the orbital period $P$, the mass ratio $q$, or the mass
of the white dwarf $M_{\text{wd}}$. For instance, model calculations of
binary star evolution (e.g. Rappaport et al. 1983; Hameury et al.
1988; McDermott & Taam 1989) predict that for systems above
the period gap the mass-transfer rate decreases towards shorter
orbital periods.

Patterson (1984) in a statistical study has searched for corre-
lations between several characteristics of the accretion disk and of
the binary system. One of Patterson’s findings is indeed a crude
relationship between $M$ and $P$, with $M$ obtained from luminosity
arguments based on the visual magnitude of the disk. Patterson’s
values for $M$ are systematically lower than the current values
obtained from the fit to $T(R)$. The present sample on its own does
not show an obvious relation between $M$ and $P$. Apparently,
the relationship found by Patterson (1984) is of a statistical nature
rather than an exact dependence (see the discussion in Warner 
1987). Neither do the values for the disk radius (Table 5) show any
obvious dependence on $P$, $q$ or $M_{\text{wd}}$.

The nova-like cataclysmic variables discussed here have
steady-state, bright disks. However, models of time-dependent
accretion disks, for the outburst behavior of dwarf-novaae, also
constrain steady-state disk models. The most promising set of
outburst models predicts that, below a certain critical mass-
transfer rate from the secondary star, the accretion disk will
alternate between bright stages characterized by a high mass
accretion rate and faint stages of low mass accretion (see the
reviews by Smak 1984; Meyer-Hofmeister & Ritter 1991). Several
outburst models have been calculated, each providing an estimate
for the critical mass-transfer rate $M_{\text{crit}}$, as a function of some
combination of physical parameters. Shafer et al. (1986) gave an
overview of these formulae and deduced a simple relationship
between $M_{\text{crit}}$, the disk radius and the mass of the white dwarf,
which reflects the general results from individual model calcula-
tions. We use this formula to calculate $M_{\text{crit}}$ for the systems
studied here. The critical mass-transfer rates for RW Tri, UX UMa,
SW Sex and V363 Aur indeed fall well below $M$ obtained from the
$T(R)$ curves for LX Ser and V1315 Aql, $M$ is slightly less than $M_{\text{crit}}$, but given the appreciable uncertainty on both quanti-
ties we conclude that the mass-transfer rates deduced here do not
conflict with current lower limits set by models for dwarf nova
outbursts.

The bright spot is a feature readily recognized from the
reconstructed intensity maps of UX UMa, SW Sex, and V363
Aur, and somewhat less clear in LX Ser. The luminosity of the
bright spot will be proportional to the amount of potential energy
which is liberated when the material strikes the disk, and thus be
proportional to $1/R_{\text{spot}}$, $R_{\text{spot}}$ being the radial position of the
bright spot. Likewise, the total disk luminosity will be propor-
tional to $1/R_{\text{wd}}$, and hence the luminosity ratio $L_{\text{spot}}/L_{\text{disk}}$
$\approx R_{\text{wd}}/R_{\text{spot}}$. In Table 7 these ratios are compared (thereby
implicitly assuming that the bolometric correction for the bright
spot and the disk are the same) and indeed the two numbers are
related although the relative brightness of the spot appears to be
about twice the ratio of the radii. This factor of two may be
explained by the disk being optically thick and thus self-ob-
scuring half the radiation while the bright spot is optically thin.

The question remains why the bright spot is not visible in RW
Tri and V1315 Aql. If we assume that the bright spot would be
located on the outer edge of the disk, then the ratio $R_{\text{wd}}/R_{\text{spot}}$
becomes 0.039 and 0.023 for RW Tri and V1315 Aql, respectively,
from which we would expect to see at least the spot in RW Tri. A
possible explanation is that the spot is hidden from view, e.g. due
to penetration of the gas stream into disk (Bath et al. 1983).

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