Optical variability in compact sources
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A spectrophotometric study of RW Trianguli

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On the basis of spectrophotometric observations we reconstruct the accretion disk of the eclipsing novalike cataclysmic variable RW Tri in the wavelength region 3600-7000Å. We show that the mass-accretion rate in RW Tri is $(1.0 \pm 0.1) \times 10^{-8} \, M_\odot/\text{yr}$ and that the radial temperature profile is consistent with that expected on the basis of the theory of optically thick, steady state accretion disks. We further show that the decrease of the line strength of the Balmer lines, as is often observed in high inclination novalike CVs, is caused by a layer of gas that surrounds the hot-spot and accretion disk region and which is optically thick in the lower Balmer and neutral helium lines: a Balmer Bubble. In our observations RW Tri shows a number of features that are characteristic of the SW Sex sub-class of novalike stars. Instead of classifying RW Tri as 'yet-another' SW Sex star we propose to abandon the division of novalikes in the UX UMa and SW Sex sub-classes altogether since there appears to be no physical distinction between members of these two classes.

7.1 Introduction

Although RW Tri is one of the longest known cataclysmic variables (CVs), discovered by Protitch (1937), and has been studies extensively photometrically, it has been largely neglected in spectroscopic studies. To our knowledge only two extensive optical spectrophotometric studies, by Kaitchuck, Honeycutt and Schlegel (1983) and Still, Dhillon and Jones (1995) have been made of this system. RW Tri is generally assumed to be a
standard novalike CV (see Warner, 1995 for a general overview of CVs), but both spectroscopic studies have shown that the phase dependence and the light curves of the emission lines show features that are difficult to explain in a standard CV picture.

RW Tri was included in the broad-band photometry eclipse mapping studies of Rutten, Van Paradijs and Tinbergen (1992) who showed that its radial temperature profile is consistent with the $T \propto R^{-3/4}$ dependence expected on the basis of accretion disk theory (see e.g. Frank, King and Raine, 1992). RW Tri is in this respect similar to UX UMa (Rutten et al., 1993; 1994) that has been shown spectrophotometrically to follow the same temperature profile.

Apart from the emission line behaviour, RW Tri is also known to undergo irregular variations of up to one magnitude in its out-of-eclipse brightness, as was first shown by Walker (1963) and occasionally increases even to more than three magnitudes from its faint brightness level at AB~13.5, as was seen in the spectrophotometric study of Still et al. (1995). This irregular behaviour, most likely caused by a variation in the mass-transfer rate from the mass-losing secondary star, is not unique for RW Tri (see e.g. the recent results on GS Pav; Groot et al., 1998), although it is the best documented case.

The radial temperature profile and the peculiar emission line behaviour prompted us to a spectrophotometric study of RW Tri.

### 7.2 Observations

On the nights of 22-26 October 1994, we have obtained a total of 671 low-resolution spectra using the Intermediate Dispersion Spectrograph with the R300V grating and a 1k×1k Tek CCD. A wide slit (2.5") and a second star on the slit (48" NW of RW Tri) were used to obtain differential photometry. An absolute flux calibration was obtained by observing the spectral flux standard BD +28 (Oke, 1990) using a 5" wide slit for both the spectral flux standard as well as RW Tri and its local comparison star.

All data is reduced in the standard fashion using the ESO-MIDAS package, with additionally written software. All stars were optimally extracted using the technique developed by Horne (1986). All spectra were obtained with a 50s on-target integration time. With a ~60s dead-time for CCD readout and data storage, we obtained an effective time resolution of 110s, or 1/182nd of the orbital period of 5h34m. A total of five eclipses were observed. Throughout the nights CuAr arc spectra were taken for the wavelength calibration.

Based on the colour excess given by Rutten et al., (1992) of $E(B - V)=0.1$ we have dereddened all our spectra using the galactic reddening coefficients given by Cardelli, Clayton and Mathis (1990), assuming a standard $R_V=3.1$. 
Figure 7.1. The average spectrum of RW Tri, divided in three phase intervals. The bottom curve shows the spectrum in mid-eclipse (0.995 < $\varphi$ < 0.005), the middle curve the spectrum outside eclipse and outside the phase interval that a hot-spot can be visible (0.005 < $\varphi$ < 0.75) and the top curve shows the spectrum during the hot-spot phase (0.75 < $\varphi$ < 0.995). All the emission lines appear single-peaked which can be due to our low-resolution. The Balmer lines remain largely un eclipsed. In the higher Balmer lines strong underlying absorption troughs can be seen. The absorption feature at 6160Å is the strongest absorption line of the Ca triplet between 6100-6160Å. The Hei λ4471 is in absorption during the complete orbit, except the eclipse, where it shows up in emission. The top two curves are displaced by 1 mJy with respect to each other.

7.3 Ephemeris and System Parameters

We have phase folded all spectra using the ephemeris given by Robinson, Shetrone and Africano (1991). Trial eclipse maps using the system parameters given in Table 7.1 showed a phase shift in the phase of minimum light. Shifting the phases by −0.0046 of an orbital period as has been found before by Smak (1995), corrected this. A revised ephemeris is given in Eq. 7.1

$$HJD_{mid, ecl} = 2441129.36380(10) + 0.231883297E$$ \hspace{1cm} (7.1)

The system parameters of RW Tri are rather uncertain, especially the $(q, i)$ pair. Values
Table 7.1. System parameters of RW Tri.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>20034.717 s</td>
</tr>
<tr>
<td>$M_{WD}$</td>
<td>0.7 $M_\odot$</td>
</tr>
<tr>
<td>$M_{sec}$</td>
<td>0.6 $M_\odot$</td>
</tr>
<tr>
<td>Inclination</td>
<td>75°</td>
</tr>
<tr>
<td>Distance</td>
<td>330 pc</td>
</tr>
</tbody>
</table>

for $i$ range between 67° (Kaitchuck, 1983) to as high as 80° (Mason, Drew and Knigge, 1997), with the component masses varying accordingly. It is clear that the mass ratio in RW Tri is rather close to unity, and Smak (1995) even argued that the mass-ratio is larger than unity (e.g. the secondary is more massive than the white dwarf primary). It is, however, unclear if a system with a mass-ratio larger than unity can maintain stable Roche-lobe overflow on a nuclear timescale, as observed in RW Tri. For this reason we have opted to use the values as given in Rutten et al., (1992), with a mass-ratio smaller than unity and, consequently, a relatively high inclination: $i=75°$. We will comment on the distance choice in Sect. 7.8.3 on the other system parameters in Sect. 7.9.

### 7.4 Average Spectrum

In Fig. 7.1 we show the average flux calibrated spectrum of RW Tri during our observations. The spectrum shows the usual emission lines of H, HeI and HeII. We see that the HeII and Bowen blend of NiIII and CiIII, which are not visible in the spectra of Kaitchuck et al. (1983) and Still et al. (1995), merge together in one broad feature. All lines appear single peaked. Although RW Tri is supposed to have double-peaked emission lines, these will show up as single peaked in our low-resolution spectra. We see that the continuum emission is deeply eclipsed, but that the majority of the emission lines are not so deeply eclipsed, indicating that the emission lines are formed in a different region than the continuum. We see that the spectrum of RW Tri does not change dramatically between phases $0.005 < \varphi < 0.75$ and phases $0.75 < \varphi < 0.995$ when a hot-spot could be visible and during which interval SW Sex showed deep absorption lines in the blue (Groot, Rutten and Van Paradijs, 1999).

The higher Balmer lines, especially HeI and H$\delta$ can be seen to consist of two components in the out-of-eclipse spectra. Underlying the emission lines we see absorption troughs, that are caused by optically thick parts of the disk. They could also be photospheric absorption lines from the white-dwarf, although they appear to be too narrow for that.

It is evident from a comparison of the HeI $\lambda 4471$ line between the three spectra displayed here, that the behaviour of this line is unusual: almost non-existent in the phase interval $0.005 < \varphi < 0.75$, in absorption in the interval $0.75 < \varphi < 0.995$, and in emission during mid-eclipse. We will further discuss this line in the next section.
The red part of the spectrum shows the atmospheric features at 6300Å and 6900Å. A clear absorption line is visible at 6160Å, caused by the K7 secondary in RW Tri.

7.5 Trailed spectra

The trailed spectra of the Balmer and He lines as presented by Kaitchuck et al. (1983) and Still et al. (1995) already show that the emission line behaviour in RW Tri is complex. The main emission lines have a relatively low orbital velocity modulation of $<200$ km s$^{-1}$. In Fig. 7.2 we show the trailed spectra of the, continuum subtracted, main lines in RW Tri and in Fig. 7.3 we show the corresponding light curves. We see from these figures that a total of five components can be identified:

- The strongest component in the lines is an emission component that has a small velocity dependence with phase. This component dominates the main emission in the Balmer lines. We can also see that in the Balmer lines this component decreases in strength between phase 0.75 and phase 0.1. The He$\text{II}$ $\lambda 4686$ line is unaffected by this decrease in strength.

- The second component has a considerable velocity dependence with phase and is best seen in the He$\text{I}$ $\lambda 6678$ line. It reaches maximum blueshift around phase 0.25 and maximum redshift around phase 0.75-0.8. In the Balmer lines and He$\text{II}$ $\lambda 4686$ this component is visible throughout the complete orbit and does not seem to suffer from either the decrease of the main component in the Balmer lines or the primary eclipse by the secondary. It is this same component that we see in absorption during most of the orbit in He$\text{I}$ $\lambda 4471$ and He$\text{I}$ $\lambda 4026$. The strength of the absorption in these two He$\text{I}$ lines diminishes between orbital phases $0.15 < \varphi < 0.5$.

- The third component is an emission component that is only visible during mid-eclipse. This component is best seen in He$\text{I}$ $\lambda 4471$, where the line profile changes from absorption to emission, and in the higher Balmer lines. This clearly indicates that (part of) the emission site of the Balmer lines and the He$\text{I}$ lines is not eclipsed. Only the He$\text{II}$ $\lambda 4686$ line is unaffected by this mid-eclipse emission and shows a strong eclipse, similar to the continuum (see next Section).

- The fourth component are the absorption troughs in the higher Balmer lines, best seen in H$\delta$ and H$\epsilon$. These originate most likely in an optically thick part of the accretion disk.

- The fifth component is the primary eclipse. It is seen as a decrease of the emission strength in He$\text{II}$ $\lambda 4686$ only. Paradoxically the primary eclipse is seen as an increase of the linesstrength in most of the other lines.
7.5.1 Radial velocity curve of the secondary

The interpretation of the place of origin of these lines is helped by the absorption lines around 6160Å. We can see in Fig. 7.4 that there is more than one absorption line in this region; at ~6160Å the strongest one is visible, at ~6120Å the second is visible and a trace can be seen of a third line around 6100Å. These three wavelengths uniquely identify this set of lines as the CaI triplet at 6102, 6122 and 6162 Å, which are indeed among the strongest lines in a late K-type star. The radial velocity curve of the CaI λ6162 is shown in Fig. 7.5. We see that the phasing of the line coincides with that of the secondary and the derived amplitude is consistent with that derived by Smith et al. (1994). The strength of the absorption lines reaches a minimum between phase 0.45< φ <0.55, which indicates that they are influenced by a secondary eclipse.
7.5 Trailed spectra

Figure 7.3. The light curves of the same lines as showed in Fig. 7.2. All lines, except HeII λ4686, decrease in their strength at phases $\varphi > 0.75$. The HeII λ4686 line closely resembles the continuum light curves. Apart from Hα, HeII λ4686 and HeI λ6678, all lines show a significant brightening during mid-eclipse, indicative that a strong emission source is left uneclipsed.

7.5.2 Origin of the emission lines

The main emission component has been attributed to emission from the irradiated inner half of the secondary star by Still et al. (1995). Fig. 7.6 shows the radial velocity curve that has been derived by fitting a single Gaussian, with variable width, to the total line profile. We see that both the phasing as well as the amplitude of the radial velocity curve are in good agreement with those found by Still et al. (1995) and Kaitchuck et al. (1983). We do however, not agree with the conclusion by Still et al. (1995) that the bulk of the emission line originates on the heated side of the secondary. For the system parameters used here, which are identical to the ones used by Still et al. (1995) the center-of-mass of the system lies in the Roche-lobe of the white dwarf, but rather close to the $L_1$ point. If the inner side of the secondary is the place of origin of the bulk of the Balmer emission, one would expect the radial velocity curve to show a maximum blueshift near $\varphi \sim 0.75-0.8$, and not a maximum redshift, as observed. This locates the emission site on the white-dwarf side of the center-of-mass. The same result, but with higher scatter on the radial velocity curve, is obtained when only the core of Hα line is used in the Gaussian fit. We
conclude that the bulk of the Balmer emission originates in the accretion disk region.

7.5.3 The behaviour of the HeI lines

It is rather peculiar the we see the high velocity component in emission in the HeI $\lambda 5875$ and $\lambda 6678$ lines and in absorption in the $\lambda 4026$ and $\lambda 4471$ lines. The trio of lines ($\lambda 5875$, $\lambda 4471$, $\lambda 4026$) belong to the same triplet group of transitions to the $2s$ ground state, with the $\lambda 5875$ line coming from the $3d$ level, the $\lambda 4471$ line from the $4d$ and the $\lambda 4026$ line from the $5d$ level. In LTE we would expect that all three lines would be either in emission or in absorption, since their common velocity and phasing properties indicate that in RW Tri they originate in the same physical location. An explanation for the emission of the $\lambda 5875$ line based on either a different geometry for the line formation site, or on a different temperature regime for the line formation sites of the different lines, is therefore not valid.
7.6 An explanation for the Balmer absorption effects

We have seen in Sect. 7.5 that the main component of the emission lines suffers from a strong decrease in the line strength between $0.75 < \varphi < 0.1$. This feature appears to be a consistent part of high inclination novalike systems and has been seen before in RW Tri in the studies of Still et al. (1995) and Kaitchuck et al. (1983). In Sect. 7.5 we have already concluded that the main emission component does not have its origin on the secondary. The behaviour of the emission line light curve can be explained if we assume that the line emission region is optically thick in the lines, but not in the continuum. This means that in the continuum our line of sight always end on the continuum source, i.e. the accretion disk. In the emission lines, however, the continuum source is not seen, because the lines are optically thick and our line of sight ends at the line emission region. In Fig. 7.7 we show a schematic picture of this geometry. In further we will call the emission site region that is optically thick in the lines, but optically thin in the continuum, the Balmer Bubble. The existence of such a Balmer Bubble causes the total amount of flux that is emitted in the continuum and the lines to be decoupled. If the continuum strength varies, the lines do not have to follow this behaviour. In Fig. 7.8 we show the average flux calibrated spectrum of RW Tri in five phase intervals, ranging from bottom to top: $0.1 < \varphi < 0.2$, 

![Graph showing radial velocity curve](image)

**Figure 7.5.** The radial velocity curve of the Ca i absorption line at 6162Å. The phasing and amplitude of the radial velocity curve correspond well with a place of origin on the secondary star. The decrease of absorption around $\varphi \sim 0.5$ shows that a secondary eclipse affects the absorption line.

![Diagram](image)
Chapter 7. A Spectrophotometric study of RW Trianguli

\[ \gamma = -22.2 \pm 5.2 \text{ km/s} \]
\[ \text{Ampl} = -116.3 \pm 7.7 \text{ km/s} \]
\[ \varphi_0 = 0.112 \pm 0.009 \]

**Figure 7.6.** The radial velocity curve of H\(\alpha\), determined by fitting a single Gaussian to the complete profile. The phasing of the curve shows that the main emission site is *inconsistent* with an origin on the heated side of the secondary. Velocities in the phaseinterval \(0.8 < \varphi < 0.1\) have not been taken into account for the sinusoidal fit. The errors on the velocities have been set to 25 km/s (~1/6 of a wavelength bin at H\(\alpha\)).

\(0.5 < \varphi < 0.6, 0.6 < \varphi < 0.7, 0.7 < \varphi < 0.8\) and \(0.8 < \varphi < 0.9\). A number of important results can be seen from this figure:

- The continuum rises from an almost constant level between \(0.1 < \varphi < 0.6\) to a maximum between \(0.8 < \varphi < 0.9\).

- The Balmer lines from H\(\beta\) to H\(\epsilon\) show a constant total flux. Although the continuum is rising, the Balmer lines do not increase in strength.

- The He\(\text{II} \lambda4686\) and C\(\text{II} \lambda4267\) flux does rise simultaneously with the continuum.

- For H\(8\) and higher up the Balmer series the line flux is not constant, but rises together with the continuum.

The rising continuum is caused by the optically thick hot spot coming into view on the optically thick rim of the accretion disk. We can clearly see that a number of photospheric absorption lines of the accretion disk and hot-spot area are present in the spectrum of RW Tri. The aforementioned He\(\text{I} \lambda4471\) and He\(\text{I} \lambda4026\) lines are two of them. This rise of the continuum is caused by a temperature difference between the ‘hot’ hot-spot region and
7.6 An explanation for the Balmer absorption effects

The hot spot, seen in continuum, is located on the rim of the disk, where the accretion stream (not shown) from the secondary impacts on the disk. This region is surrounded by a gas cloud or ‘Balmer Bubble’ that is optically thick in the lower Balmer and H\textsc{e} lines and hides the hot-spot from view in these lines, and is optically thin in the higher Balmer and H\textsc{e} lines and in the continuum.

Figure 7.7. Schematic view of the hot-spot region in RW Tri. The hot spot, seen in continuum, is located on the rim of the disk, where the accretion stream (not shown) from the secondary impacts on the disk. This region is surrounded by a gas cloud or ‘Balmer Bubble’ that is optically thick in the lower Balmer and H\textsc{e} lines and hides the hot-spot from view in these lines, and is optically thin in the higher Balmer and H\textsc{e} lines and in the continuum.

The ‘cool’ remaining part of the accretion disk rim. This can e.g. be seen by the increasing strength of the H\textsc{e} absorption lines, that increase in strength with increasing temperature. The lower Balmer lines, up to H\textsc{e}, however, do not rise with the continuum, but stay at a constant flux. This means that the continuum radiation from the hot spot that we see rising towards $\varphi \sim 0.8-0.9$ at any wavelength other than the Balmer lines is not able to reach us in the Balmer lines. In the Balmer lines the hot-spot region is hidden from our view because an optical depth of unity is reached before the hot spot continuum layer is seen. The fact that there is no variation in the total amount of flux received in the lower emission lines means that the Balmer Bubble must surround the emission site at all sides. It not only intersects our line of sight, which is rather close to the orbital plane, when the hot-spot continuum radiation is in full view, but also half an orbit later. The constancy of the flux in the Balmer lines, independent from the continuum variations, does not allow for a partial coverage of the hot spot region by this layer of gas.

The observed phase lag of the H\textsc{a} radial velocity curve seems to indicate that the Balmer Bubble does not encompass the complete accretion disk, since in this case we would expect no phase lags with respect to the white dwarf. The Balmer Bubble, which is the line emission region, must be confined to a small part of the accretion disk. The phase lag identifies the hot-spot region as the center of the Balmer Bubble. This means that the radial velocity of the H\textsc{a} line reflects the orbital motion of the hot-spot region. We will further discuss the consequences of this in Sect. 7.9. The dominance of the hot-spot region in the line emission was already concluded for SW Sex where both the Balmer lines as well as the H\textsc{ii} $\lambda 4686$ lines are emitted in a region above the hot-spot (Groot et al., 1999).
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Figure 7.8. The flux calibrated average spectrum of RW Tri in the phase intervals $0.1 < \varphi < 0.2$, $0.5 < \varphi < 0.6$, $0.6 < \varphi < 0.7$, $0.7 < \varphi < 0.8$ and $0.8 < \varphi < 0.9$, running from bottom to top. We see that the continuum rises when the hot spot comes into view, and that the HeII $\lambda 4686$ and CII $\lambda 4267$ lines rise with it. The Balmer lines up to He, however, stay at a constant flux. This indicates that these lines are optically thick and that the hot-spot continuum is hidden from view at these wavelengths. From H8 on the Balmer lines become optically thin.

The fact that the total amount of flux received in the Balmer lines is constant, but that at the same time the surrounding continuum rises in strength because the hot-spot comes into view, explains the, continuum subtracted, line strength behaviour seen in Fig. 7.3. The HeII $\lambda 4686$ line does rise together with the continuum, which indicates that the Balmer Bubble is not optically thick in the HeII $\lambda 4686$ line. This shows that the temperature of the Balmer Bubble is too low to contain an appreciable amount of ionized helium. Since the line strength is also not rising when the hot-spot comes into view (Fig. 7.3), it means that the emission site of the HeII $\lambda 4686$ is equally well visible at all phases. The apparent increase in the, continuum subtracted, strength of the emission lines during mid-eclipse indicates that the Balmer Bubble extends to an appreciable height above the accretion disk. The observed origin of the Balmer Bubble at the hot-spot region and the radial velocity curve of the H$\alpha$ line indicate that the gas in the Balmer Bubble is decoupled...
from the gas flow in the disk which is assumed to be Keplerian. Studies of these lines that interpret them as coming from the plane of the disk, e.g. Doppler mapping, will therefore give erroneous results.

### 7.6.1 Optically thin higher Balmer lines

We have seen in Fig. 7.8 that the Balmer lines of H8 and higher do follow the continuum in its rise towards maximum. From this we can conclude that between He and H8 the gas layer changes from optically thick to optically thin. In the higher Balmer lines the hot-spot continuum is no longer hidden from view. The reason that the higher Balmer lines are not rising together with the continuum analogous to the HeII λ4686 lines is caused by two secondary effects of the high hot spot temperature and the vertical extension of the emission region. The first of these effects is that the depth of the photospheric Balmer absorption lines, underlying the emission lines, will, at the temperatures encountered in the hot-spot region (≈10000 K), increase with increasing temperature. The second of these effects is that continuum radiation that originates in the accretion disk as seen to be located behind the Balmer Bubble above the hot spot region will scatter out of our line-of-sight due to a non-zero optical depth in the higher Balmer lines. This will lead to an increase of the absorption line depth. These secondary effects will cause an increase of the absorption line depth, which, together with the constant Balmer emission from the Balmer Bubble will cause the higher Balmer lines to go into absorption as seen in Fig. 7.8.

### 7.6.2 The HeI line appearance

This same optical depth effect can also explain the puzzling behaviour of the HeI lines as described in Sect. 7.5.3. The lower HeI λ6678 and λ5875 lines are optically thick and our line-of-sight ends in a similar ‘Helium Bubble’ as in the ‘Balmer Bubble’ for the lower Balmer lines. For the higher helium lines, the optical depth decreases to less than unity. Since we can see that the HeI λ4471 line is almost non-existent in the phase-interval 0.1< φ <0.5, while the HeI λ5875 line is clearly in absorption and the HeI λ4026 clearly in absorption, we can deduce that τ_{He} > 1 for the helium lines >4471Å, τ_{He} < 1 for the helium lines <4471Å and τ_{He} ~1 for HeI λ4471.

### 7.7 Continuum light curves

The continuum light curves of RW Tri (Fig. 7.9) show that the system varied from night to night up to ~30% in its out-of-eclipse light level. These short term variations of RW Tri have been long known (Walker 1963, Smak 1995), but are not unique to RW Tri. The novalike system GS Pav has been shown to exhibit similar variations on similar timescales
of days to weeks (Groot et al., 1998). Almost all well studied novalike systems show slow variations in their average out-of-eclipse levels. RW Tri is rather extreme, since it has been shown to vary by more than three magnitudes from the very high state at AB~10.1 in the observations of Still et al., (1995) to the low states at AB~13.5 as seen by Walker (1963). In our observations the system varied, at 4500 Å, between AB=13.2 (18.5 mJy) on the night of October 23, to AB=12.9 (23 mJy) on October 26.

We see from Fig. 7.9 that the light curves show a round bottomed eclipse profile which is intermediate between the V-shaped eclipse profiles seen in many novalike systems, and the U-shaped profiles common to dwarf nova systems. This indicates a strong dominance of the inner accretion disk. A clear egress feature is visible in all the light curves, but no corresponding strong orbital hump is seen just before the onset of the eclipse. This shape of the light curve is not uncommon in novalikes and has been seen before in RW Tri and UX Uma (see Smak, 1995; 1994 and references therein). Smak (1994) has designated the light curves that do show a clear egress delay caused by a hot-spot, but no orbital hump, to be of the peculiar type and he argues that the lack of an orbital hump is caused by circumbinary material, which invalidates the use of these light curves for eclipse and

![Figure 7.9. The continuum light curves of RW Tri between 4400Å and 4600 Å, from bottom (22 October) to top (26 October). The light curves are offset by steps of 10 mJy per night, with no offset for the bottom curve.](image-url)
accretion disk analysis. We would like to argue, however, that there is no further support for the presence of circumbinary material, that has to be optically thick in the continuum to affect the continuum light curves. The HeII $\lambda 4686$ line, which most closely resembles the continuum light curve is not affected by any absorption in the phase interval just before eclipse. If any optically thick circumbinary material is the cause of a lack of an orbital hump, this would most certainly also influence the HeII $\lambda 4686$ line.

### 7.8 Spectral Eclipse Mapping

For the eclipse mapping procedure, we used the run-combined light curve to obtain sufficient phase resolution and phase coverage. Analysis of the light curves showed that the profile of eclipse of October 23 deviated in its shape from the rest of the eclipse profiles, especially in the steepness of the egress feature. This eclipse profile has therefore been excluded from the run-combined average which is based on the other four eclipses. One of the assumptions of the eclipse mapping program is that no variation on the light curve occurs outside eclipse. We have therefore applied a correction to the observed light curves and brought them to a common scale, which was chosen to be the brightness of RW Tri on the first night, which is, at AB=13.0 at 4500Å, average for the four eclipse curves used here. We would like to note that the results from the eclipse maps should be viewed as the average state of the accretion disk of RW Tri during our observation. Any information on the time dependence of the accretion disk is lost.

The spectrum of RW Tri has been divided in 80 narrow band light curves, each 40Å wide, except around the spectral lines, which were taken as one bin each. In Fig. 7.10 we show the corrected light curves in three narrow band wavelength regions, distributed over the wavelength range covered. We see that, despite the variation of the out-of-eclipse light, the eclipse profiles do not vary strongly, especially in the blue. We also see that the amount of asymmetry of the light curves, caused by the hot-spot egress feature, diminishes from the blue to the red. The amount of scatter on the narrow-band light curves increases when going to the red. This indicates that it is the cool outer layer of the accretion disk that varies mostly when the out-of-eclipse brightness varies. We can also see that the phasing of the four eclipses used in these lightcurves, is rather unlucky in the sense that they bunch together and do not make a smooth profile. In the eclipse mapping procedure this limits the phase-bin size that can be used in the reconstruction.

For the reconstruction we have used a $51 \times 51$ pixel map, phasebins of 0.005 in phase and the system parameters as given in Table 7.1.

### 7.8.1 Disk size

To measure the size of the accretion disk at different wavelengths we have used the distance ($R_{0,1}$) where the intensity on the disk has fallen to 10% of the central intensity. This
measure was used by Rutten et al. (1992) to compare the relative sizes of the disks in six different novalike systems. We find from our eclipse maps that $R_{0,1} = 0.25 \pm 0.10 R_{L_1}$ at 4420Å. The rather large error is caused by a relatively flat run of the reconstructed intensity with radial distance at this wavelength. For 6270Å the disk size has increased to $R_{0,1} = 0.45 \pm 0.05 R_{L_1}$. Both values are comparable to the values found by Rutten et al. (1992) at 4410Å ($R_{0,1} = 0.28 \pm 0.03 R_{L_1}$) and 8010Å ($R_{0,1} = 0.43 \pm 0.03 R_{L_1}$).

### 7.8.2 Accretion disk annuli spectra

We have defined seven regions in the accretion disk of RW Tri, shown in Fig. 7.11, and labeled ‘A’ through ‘H’. The spectra of these regions are shown in Fig. 7.12. We see that there is a strong change in the slope of the spectrum when going from the white dwarf to the outside of the accretion disk. The emission lines are in absorption in the inner disk, and changing to emission when going outwards. Not surprisingly the non-eclipsed light (region H) shows the emission lines strongly in emission on top of a continuum level that strongly rises to the red. This change of the reconstructed accretion disk spectrum is very
similar to that of UX Uma as shown by Rutten et al. (1994).

Figure 7.11. Schematic view of the white dwarf Roche lobe, showing the subdivision of the Roche lobe in seven regions, labeled 'A'-'G', which increase outwards in steps of 0.1RL, except region 'G' that covers the annulus from 0.5RL-0.75RL. The uneclipsed light is denoted by region 'H', tentatively placed on the secondary.

7.8.3 Distance to RW Tri

In order to convert the reconstructed fluxes to specific intensities, from which temperatures can be derived by e.g. blackbody fitting, it is imperative to have a good estimate of the distance to the system. The distance of RW Tri was recently determined by parallax measurements using the HST Fine Guidance Sensor to be 341±35 pc (McArthur et al., 1999).

The distance of RW Tri can also be estimated by allowing the distance as well as the temperature to vary in blackbody fits to the reconstructed accretion disk spectra. Blackbody fitting in the wavelength region 4000-6200Å gives a distance to RW Tri of 330±40 pc, in excellent agreement with the parallax measurements and also with the estimate of the fractional contribution of the secondary by Rutten et al. (1992). We refer to McArthur et
Figure 7.12. The reconstructed spectrum of the accretion disk in RW Tri in the regions defined in Fig. 7.11. Fluxes are in fluxes per surface element. We see that the slope of the spectrum changes dramatically from very blue in the inner parts, to red in the outer parts. The hot-spot area (region ‘G’) is more blue than the rest of the outer disk. The fluxes of the uneclipsed light component (region ‘H’) are plotted on a logarithmic scale, all others on a linear scale.

al. (1999) for a comparison with other distance estimates. We will use the value of 330 pc in the further analysis.

7.8.4 The Radial temperature profile

The radial temperature profile of the accretion disk can now be determined. For this we have used the wavelength region of 4000Å-6200Å, from which the emission lines have been omitted. The blue cut-off has been chosen to avoid any influence of the Balmer jump and the red cut-off has been chosen because trial blackbody fits showed that the reconstructed intensities at these wavelengths strongly deviated from the expected values based on the trend in the bluer part of the wavelength which generally agreed well with the blackbody fits. We cannot say whether this is caused by an incorrect flux calibration
in this wavelength region or by a physical reason which causes the accretion disk spectra in this region to deviate from approximately blackbody.

We show the radial temperature profile of the accretion disk in RW Tri in Fig. 7.13, which also shows the theoretical predictions for the radial temperature profile based on optically thick, steady state accretion disks. We see that the reconstructed radial temperature profile follows the theoretical prediction rather well in the radial distance range of 0.55–0.15 \( R_{L1} \). Inside 0.15\( R_{L1} \), the temperature profile flattens with respect to the theoretical prediction. Comparing the temperature profile derived here with those derived by Rutten et al. (1992) on the basis of four-colour photometry and by Horne and Stiening (1985) on the basis of brightness temperature estimates of their B band photometry, we see that our radial temperature profile already levels off at a larger distance from the white dwarf (at \( \sim 0.15R_{L1} \) here and at \( \sim 0.06R_{L1} \) in Rutten et al., 1992 and Horne and Stiening, 1985). The derived mass-transfer rates are almost the same, although the one of Rutten et al. (1992) is somewhat lower, but this will partly be caused by the lower distance (270 pc) used in that study.

Comparing the radial temperature profile of RW Tri as derived here with those of other novalike systems, we see that it most closely resembles the profile of UX Uma as derived by Rutten et al. (1992), but also shows some aspects of the profiles displayed by the SW Sex stars (Rutten et al., 1992 and Groot et al., 1999), especially the flattening of the temperature profile.

### 7.8.5 Position of the hot-spot

We have seen in Fig. 7.12 that the hot-spot is blue and peaks at \( \sim 4000 \)Å. To better determine the position of the hot-spot we have taken the ratio of the continuum intensity maps at 4060Å, at the peak of the hot-spot, and one at 6270Å, where the hot spot influence is much less. We see in Fig. 7.14 that the hot spot peaks at a position (in radial coordinates, \( r, \phi \)) of (0.5\( R_{L1} \), 0.875).

### 7.9 RW Tri system parameters

We have seen in the previous paragraph that the radial velocity curve of the Balmer lines most likely reflects the orbital motion of the hot-spot: \( K_{HS} = 120 \pm 15 \) km s\(^{-1}\) after correction for the inclination \( (i=75^\circ) \). We have also determined the position of the hot spot at \( (r, \phi) = (0.5R_{L1}, 0.875) \). Using this position we can now check if the radial velocity derived from the H\( \alpha \) profile is indeed a good reflection of the orbital motion of material at the position of the hot spot, for the parameters we have used for RW Tri (see Table 7.1). For \( M_1 = 0.7 \) M\(_{\odot} \) and \( M_2 = 0.6 \) M\(_{\odot} \) and an orbital period of 20034.72 s, the position of the center-of-mass is located just inside the Roche-lobe of the white dwarf at \( (r, \phi) = (0.895, 0.0) \). From simple geometry it then follows that the distance of the hot spot from
Figure 7.13. The radial temperature profile of RW Tri, as deduced from the spectral eclipse mapping. The average mass-accretion rate in the radial distance range of $0.55R_L < r < 0.15R_L$ is $(1.0 \pm 0.1) \times 10^{-8} M_\odot/yr$. The dashed lines show the theoretical prediction of the radial temperature profile based on the theory of optically thick, steady state accretion disks.

The center-of-mass is $0.65R_L$, and using the orbital period the orbital velocity at this position is $\sim 125$ km s$^{-1}$. This agrees very well with the $120 \pm 15$ km s$^{-1}$ as found from the H$\alpha$ profile. This also shows that the gas causing the H$\alpha$ emission must be completely decoupled from the velocity field, normally assumed to be Keplerian, in the accretion disk itself.

The velocity expected for the center of the secondary for these system parameters is $225$ km s$^{-1}$, again in excellent agreement with the observed value of $210 \pm 50$ km s$^{-1}$ (after correction for the inclination) as found from the rather noisy radial velocity curve of the CaII $\lambda 6162$ line. Future, higher resolution observations should be able to constrain both values, and therefore the system parameters to higher accuracy.

7.9.1 RW Tri as an SW Sex star?

During our observations RW Tri shows some features that are commonly used as identifiers of the SW Sex sub-class of novalike CVs (see Thorstensen, 1991 and Groot et al., 1999): single-peaked emission lines, low radial velocities, phase lags and shallow eclipses of the Balmer lines, a flat radial temperature profile, HeII $\lambda 4686$ emission and an apparent decrease in emission line strength before the eclipse in the Balmer lines. It is,
however, striking to see that the same system did not show a number of these in earlier observations. In the observations presented by Horne and Stiening (1985) and Rutten et al. (1992) the radial temperature profile only flattened at a distance much closer to the white dwarf. In the spectroscopic observations of Still et al. (1995) and Kaitchuck et al. (1983) the HeII λ4686 emission was not seen. It appears that in our observations RW Tri behaved ‘SW Sexier’ than normal.

On the other hand Groot et al. (1999) showed that in recent observations of SW Sex in a low state, this system behaved less ‘SW Sexy’ than normal, not showing e.g. the phase 0.5 absorption. Combined with the RW Tri observations presented here it appears that the boundary between UX UMa-like novalikes (such as RW Tri) and SW Sex stars is vague and depends on the brightness of the system at the moment of observation, i.e. it most likely depends on the mass-transfer rate from the secondary. We would therefore like to suggest that there is no clear physical distinction between SW Sex stars and UX UMa stars, and that the behaviour that is ‘standard’ for the two sub-classes are the extremes of a sliding scale. How we classify a system between these sub-classes depends on the spectroscopic state at the time of a particular observation and can change from epoch to epoch.

We will therefore not classify RW Tri, based on our current observations, as an SW Sex star. We argue that the SW Sex stars are not a different sub-class of the novalikes. The classification suffices to describe, in general terms, the spectroscopic behaviour of a no-
valike system, but should not be used to denote a physically different sub-class.

7.10 The structure of RW Tri

From the evidence given above we conclude that the RW Tri system consists of an $0.7M_\odot$ white dwarf and an $0.6M_\odot$ late K-type secondary, which is transferring mass to the white dwarf at a rate of $(1.0\pm0.1)\times10^{-8} M_\odot$/yr. The accretion disk around the white dwarf is optically thick, as evidenced by the absorption features seen in its spectrum. The radial temperature profile of the accretion disk is consistent with the prediction of steady state accretion disk theory up to a distance of $0.15 R_{L,1}$ from the white dwarf. Within this distance the radial temperature profile levels off. This radial temperature profile is a case in between the previous observations of RW Tri (Horne and Stiening, 1985; Rutten et al., 1992) and UX UMa (Rutten et al., 1992), where the radial temperature profile continues to follow the theoretical prediction up to distances of $0.06R_{L,1}$ from the white dwarf, and the observations of the SW Sex stars, where the radial profile already flattens at distances $>0.2R_{L,1}$ (Groot et al., 1999; Rutten et al., 1992).

The hot-spot region is a bright region on the rim of the accretion disk. The hot spot region is surrounded by a gas layer, or ‘Balmer Bubble’ that is optically thick in the lower Balmer and HeI lines, and is the cause of the transient absorption of the Balmer lines, also seen in other novalike systems (e.g. SW Sex, Groot et al., 1999, Dhillon, Marsh and Jones, 1997). The gas seen in the emission lines is decoupled from the velocity field of the accretion disk and we can estimate the orbital velocity of the hot-spot region from the emission line radial velocity curves. Together with the radial velocity curve of the secondary these confirm the system parameters of RW Tri as given above.

RW Tri shows some characteristics that are commonly attributed to SW Sex stars. Instead of classifying RW Tri as ‘yet-another’ SW Sex star we argue that the whole division of novalike systems into the SW Sex and UX UMa sub-classes should be disregarded and all the systems should be considered as one class: the novalikes. The spectroscopic appearance of an eclipsing novalike depends on brightness of the system at the particular epoch of the observations and further study should clarify why, and how, the accretion disk structure changes with a varying brightness.

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