

High-speed photometry of the eclipsing dwarf nova OY Carinae

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Accepted 1985 January 29. Received 1985 January 29; in original form 1984 October 11

Summary. High-speed photometry of the eclipsing dwarf nova OY Car in the quiescent state is presented. OY Car becomes highly reddened during eclipse, with minimum flux colours inconsistent with optically thick emission in the *U* and *B* bandpasses. Mass ratios in the range 6.5 to 12 are required to reconcile the eclipse structure with theoretical gas stream trajectories. Primary eclipse timings reveal a significant decrease in the orbital period and the duration of primary eclipse indicates the presence of a luminous ring about the white dwarf. The hotspot eclipse reveals a hotspot which is elongated along the rim of the accretion disc, with optical emission being non-uniformly distributed along the rim. The location of the hotspot in the accretion disc implies a disc radius larger than that of an inviscid disc, with variation in the position of the hotspot being consistent with a fixed stream trajectory.

1 Introduction

OY Car is a member of the SU UMa class of dwarf novae, which are a subset of the class of interacting binaries containing a Roche lobe filling secondary star and a mass-gaining white dwarf (cataclysmic variables, Warner 1976). In dwarf novae, matter is first transferred from the secondary on to an accretion disc via a well-defined stream trajectory (Lubow & Shu 1975), then by viscous forces, through the disc and on to the white dwarf. The impact of the gas stream on to the accretion disc gives rise to a hotspot, which is responsible for the orbital modulation (hump) seen in the optical light curves of many of these systems. The accretion rate through the disc in dwarf novae varies in a quasi-periodic manner on time-scales of 10 days to several years. This produces large optical flare-ups known as outbursts which last several days. SU UMa systems, which are the dominant type of dwarf novae with orbital periods less than ~ 2 hr, are distinguished from other dwarf novae by the existence of two distinct types of optical outbursts, each with their own typical amplitudes, durations, and recurrence time-scales (Vogt 1980; Warner 1984).

OY Car is of particular importance the study of dwarf novae as both the hotspot and the white

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dwarf are eclipsed by the secondary star. There are only three other known dwarf novae which undergo such eclipses: Z Cha (Warner 1974), HT Cas (Patterson 1981), and V2051 Oph (Warner & Cropper 1983; Cook & Brunt 1983). Studies of the better known system Z Cha (Cook & Warner 1984, and references therein) have shown that several properties of the binary system, for example the mass ratio ($q=M_1/M_2$), can be determined without the need to employ radial velocities obtained from various components of the broad emission lines of these systems. The connection between these radial velocities and the radial velocity of the white dwarf is often very unclear (Schoembs & Hartman 1983; Wade 1981).

OY Car was discovered to be an eclipsing system by Vogt *et al.* (1981). From the eclipse structure, and the radial velocity data of Bailey & Ward (1981), they determined a white-dwarf mass of $0.95 \pm 0.15 M_\odot$ and a secondary star mass of $0.14 \pm 0.05 M_\odot$, the latter obtained from a theoretical, low-mass main-sequence star mass–radius relation. The hotspot was found to be at a distance of 0.327 ± 0.002 from the white dwarf (unit=orbital separation), which is more than 50 per cent larger than that expected of an inviscid accretion disc. Further eclipse observations and analysis by Vogt (1983) have shown that a normal (short) outburst of OY Car commences in the outer regions of the accretion disc and propagates inward towards the white dwarf.

Spectroscopic data were first published by Bailey & Ward (1981), which revealed the typical double-peaked Balmer emission lines of a highly inclined quiescent dwarf nova. A more extensive analysis of the behaviour of these emission lines by Schoembs & Hartman (1983, hereafter denoted by [SH]) has shown that the emission region which produces these lines has a non-uniform azimuthal distribution about the white dwarf, and does not rotate around the white dwarf in a simple Keplerian manner. The result of this is that the connection between the radial velocity amplitudes of various parts of the emission lines and the radial velocity amplitude of the white dwarf is highly uncertain. Infrared observations (Berriman 1984a) indicate a distance of 100 to 200 pc for OY Car.

This paper presents new high-speed photometry of OY Car in the quiescent state. The eclipse analysis techniques used previously for Z Cha (Cook & Warner 1984, hereafter denoted [CW]) are employed to determine the mass ratio, inclination, position and structure of the hotspot, and the size and nature of the central source responsible for the primary eclipse. The techniques used here are based on determining which parts of the orbital plane are obscured from view by the secondary star and are discussed in more detail in [CW].

2 Observations and the light curves

OY Car was observed with the 0.9-m and 1.5-m telescopes of the Cerro Tololo Interamerican Observatory (CTIO), La Serena, Chile, between 1983 March 3 and March 24. These telescopes were equipped with the CTIO three-channel photometer, with *U* (blocked CuSO_4) and *B* filters on channels 1 and 3 respectively. A filter slide on channel 2 was used to place *V* or *R* filters in the light path, or positioned to allow unfiltered light to pass into the photomultiplier. On most nights all three channels employed S20 photometers with dry-ice cold boxes, but on the 9th, 10th and 11th a thermoelectrically cooled super S20 photometer had to be employed in place of one of the dry-ice-cooled photometers, increasing the dark count from $\sim 4 \text{ counts s}^{-1}$ to $\sim 32 \text{ counts s}^{-1}$, the latter being comparable to typical sky count rates through a 10-arcsec aperture and various filters. This photometer was placed on channel 1 on the 9th, but on channel 2 on the 10th and 11th. A dichroic beam splitter was used to send 60 per cent of the *U* light to channel 1, 60 per cent of the *B* light to channel 3, and the remaining light to channel 2. The beam splitter could be moved out of the light path to enable single-channel white-light operation. Some time series observations were performed in simultaneous *UBR*, however the subsequent low count rates and the need for good time resolution of the critical phases of the eclipse required that most observations were obtained

in white light. In all cases there was a minimum time resolution of 0.5 s with no dead time losses during data logging. In almost all cases snapshot *UBV* observations of OY Car and a nearby comparison star were obtained before or after a time series observation. Extinction and colour transformation coefficients were determined from a nearby comparison star and from standard stars listed in Landolt (1973). Spot *UBV* measurements and other details of the observation runs are given in Tables 1 and 2. Observations of OY Car by members of the variable star section of the Royal Astronomical Society of New Zealand, showed that OY Car was in quiescence during 1983 March and April, and most of 1983 February. In the latter month, an increase in luminosity was observed on 1983 February 3, but had decayed away two days later.

The light curve of OY Car obtained on 1983 March 4 (cycle 22246) is shown in Fig. 1, details of the eclipse structure are shown in Fig. 2, and all the fully observed eclipses are shown in Fig. 3. The time resolution is 3 s, except in Fig. 3, where the time resolution of eclipse cycles 22339, 22515, 22561 and 22563 is 5 s, and 10 s for eclipse 22357. All the eclipses in Fig. 3 have been smoothed by a three-point running average to bring out the eclipse structure. Following the analysis of the eclipse structure of Z Cha by [CW], the eclipse contacts of the primary eclipse are denoted ϕ_{p1} , ϕ_{p2} , ϕ_{p3} and ϕ_{p4} (Fig. 2). Mid-ingress and mid-egress have been denoted ϕ_{pi} and ϕ_{pe} . Corresponding phases for the hotspot have been denoted ϕ_{h1} , ϕ_{h2} , ϕ_{h3} , ϕ_{h4} , ϕ_{hi} and ϕ_{he} respectively. The light curve is very similar to that of Z Cha (Bailey 1979; [CW]), having an orbital hump which contributes 40 per cent of the light at maximum and lasts for approximately half the orbit, and showing the distinct double eclipse of the white dwarf/inner accretion disc and the hotspot. In OY Car however, the standstill between ϕ_{p2} and ϕ_{h1} was usually better defined. All the hotspot eclipses showed well-defined rapid egresses, which usually were preceded by long standstills in intensity. On the 7th and 18th (cycles 22294, 22468 and 22469) a slow rise in intensity was observed prior to the egress of the hotspot. Using the interpretation by [CW] of Z Cha eclipse

Table 1. Journal of observations. White-light observations are denoted by the symbol W, simultaneous *U*, *B*, *R*, filter observations by *UBR*. Superscript 1 indicates two eclipses were observed during a run, superscript 2 indicates that a super S20 thermoelectrically cooled photomultiplier had to be employed on channel 1 (*U* filter) instead of a dry-ice-cooled S20 photomultiplier. Superscript 3 indicates that the thermoelectrically cooled photomultiplier was employed on channel 2 (*V* and *R* filters).

Date	HJD start	Duration	Tel.	Filters
(3/83)	(2445000+)	(hr)		
3	396.73084	1.84	.9m	W ¹
4	397.69741	1.37	.9m	W
5	398.67718	0.76	.9m	W
5	398.72043	1.09	.9m	W
6	399.68527	0.66	.9m	W
6	399.74768	0.71	.9m	W
7	400.75651	0.66	.9m	W ²
9	402.53092	0.38	.9m	W ²
10	403.59628	0.71	.9m	UBR ³
11	404.73683	0.94	.9m	UBR ³
13	406.80770	0.85	.9m	W
14	407.76882	0.57	.9m	W
15	408.52731	0.38	.9m	W
16	409.78263	0.61	.9m	W
17	410.67310	0.47	.9m	W
18	411.73113	0.85	.9m	W
18	411.80994	0.43	.9m	W
19	412.75636	0.61	.9m	W
21	414.69952	1.04	1.5m	UBR
24	417.61598	0.43	1.5m	UBR
24	417.54578	0.38	1.5m	UBR

Table 2. Isolated *UBV* measurements of OY Car. Typical errors are 0.05 mag for *V*, 0.02 mag for *B-V*, 0.03 mag for *U-B*. The time of measurement has been converted into orbital phase using the quadratic ephemeris given in the text. The asterisk denotes values determined from a local comparison star.

Date		V	B-V	U-B	Phase
3/3/83		15.4	0.20	-0.89	.92
4/3/83		14.83	0.10	-0.47	.83
		15.90	0.24	-0.95	.18
5/3/83		16.14	0.06	-0.94	.52
		15.75	0.12	-0.67	.33
6/3/83		15.76	0.07	-0.71	.22
7/3/83		15.61	0.11	-0.86	.73
9/3/83		-----	----	----	---
10/3/83	*	16.00	0.00	-0.70	.23
11/3/83	*	16.11	-0.15	-0.77	.21
13/3/83		16.00	-0.01	-0.73	.19
14/3/83	*	15.92	-0.23	-0.52	.23
15/3/83		-----	----	----	---
16/3/83	*	15.84	-0.33	-0.59	.71
	*	16.22	0.13	-0.88	.17
17/3/83		15.60	-0.27	-0.69	.82
18/3/83		16.02	0.01	-0.85	.19
19/3/83		16.08	-0.16	-0.71	.27
21/3/83	*	16.04	0.15	-0.84	.33
24/3/83	*	-----	----	-0.82	.86

data, these OY Car hotspot eclipses correspond to a compact hotspot at the rim of the accretion disc, with faint extensions to the inner regions of the accretion disc in the case of those eclipses with a slow rise preceding rapid egress.

An additional feature of the light curve in Fig. 1 is a shallow minimum at phases -0.5 to -0.35 , which has been previously reported by Vogt (1983) who suggested it to be caused by the

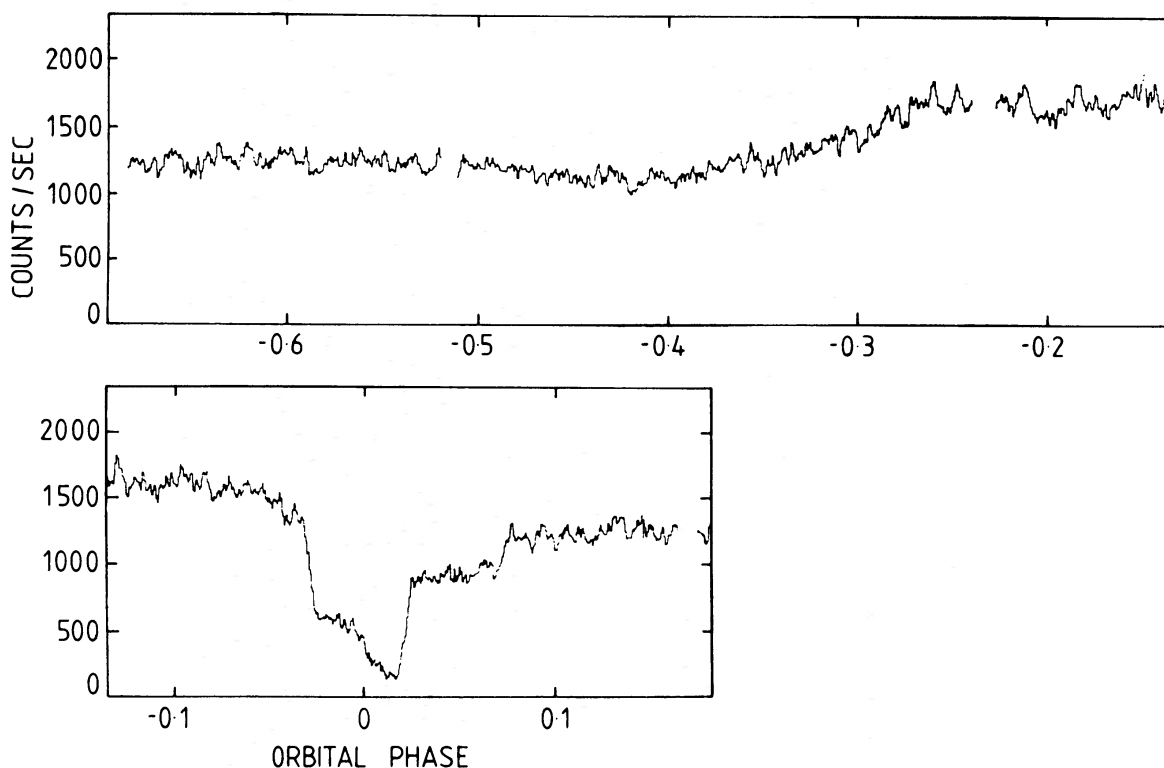


Figure 1. Light curve of OY Car observed on 1983 March 4 (cycle 22246) in unfiltered light.

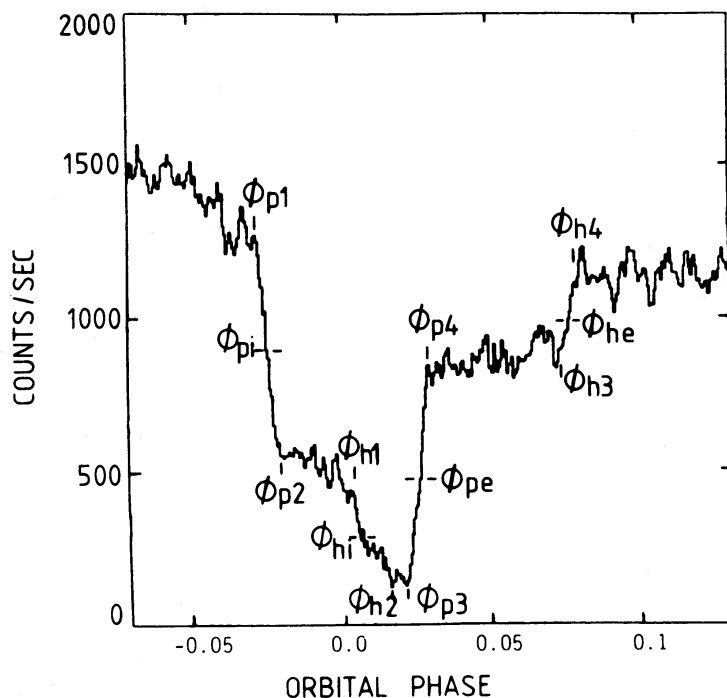


Figure 2. Critical phases of the eclipse structure of OY Car. The primary eclipse contacts are denoted by ϕ_{p1} , ϕ_{p2} , ϕ_{p3} and ϕ_{p4} respectively, with mid-ingress denoted by ϕ_{pi} , mid-egress by ϕ_{pe} . The ϕ_{hn} , $n=1, 2, 3, 4, i, e$, denote the equivalent critical phases of the hotspot eclipse.

obscuration of the gas stream by the accretion disc. The previous night's data showed a strong interhump between phases 0.3 and 0.5, not seen on the 4th and in Vogt's data, but has been previously reported by [SH]. No other observations presented here cover this phase range.

Simultaneous U , B , R observations of OY Car showed marked $U-R$ colour changes during eclipse. A smoothed example of the $U-R$ colour variation is shown in Fig. 4. The $U-B$ colour tended to follow that of $U-R$, with the $B-R$ colour often showing little significant variation. Only for one eclipse, on the 11th, did $B-R$ vary in a manner similar to that shown in Fig. 4. The pattern of variability of $U-R$ is similar to that seen by [SH] for $B-R$ and $B-I$, in that the system reddens rapidly during primary ingress, undergoes a small standstill, then reddens further during hotspot ingress. The colours then tend to rapidly return to near pre-eclipse values during the primary egress, with little colour variation during hotspot egress. Estimates of the magnitude and colours at pre-eclipse, 1st (intensity) standstill, minimum light, 2nd (intensity) standstill and post-eclipse are given in Table 3.

Interpretation of the colours in terms of stellar and accretion disc temperatures is difficult due to the highly variable values between eclipses and during eclipses. The $U-B$ colour during the second intensity standstill is consistent with the hot white-dwarf models of Wesemael *et al.* (1980). The colours at minimum light are the least well defined due to the low count rates. However, the $U-R$ and $B-R$ colours are respectively -0.09 to 0.26 and 0.44 to 1.03 , which are too blue for the flux at minimum light to come from the cool secondary star (spectral class M5V or later). Interpretation in terms of optically thick disc emission would require disc temperatures of 8500 – 9500 K (Allen 1973), which taking a distance of 100 – 300 pc for OY Car (Berriman 1984a) and a typical dimension of $\sim 10^{10}$ cm for the uneclipsed part of the accretion disc, would imply visual magnitudes of 8 to 10, inconsistent with the observed magnitudes of 17 to 18. It is therefore likely that the residual emission at minimum light in the U and B bands originates from an optically thin emission region. This supports the view of an infrared study of OY Car by Berriman

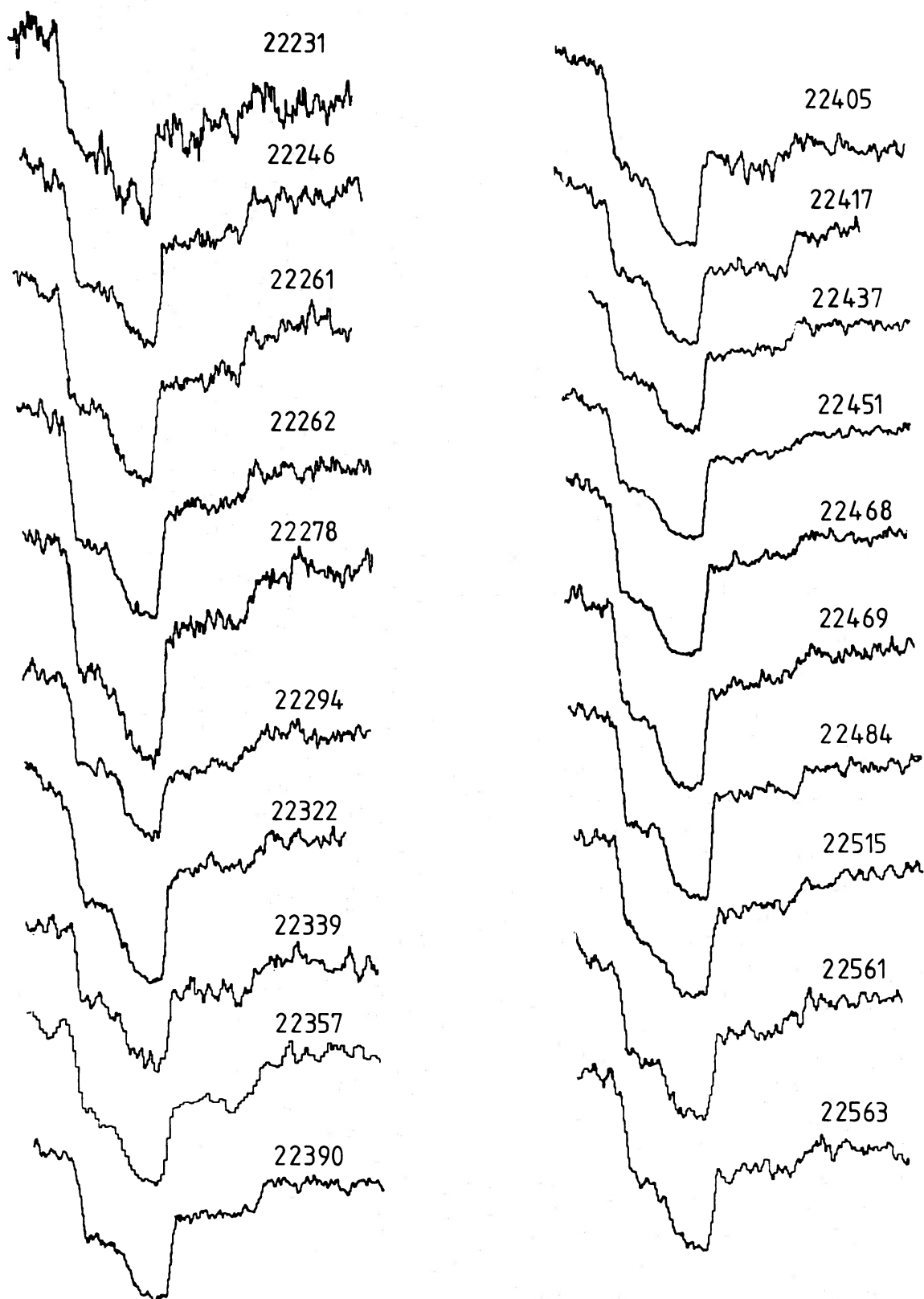


Figure 3. All the fully observed eclipses of OY Car. The cycle number is given against each eclipse.

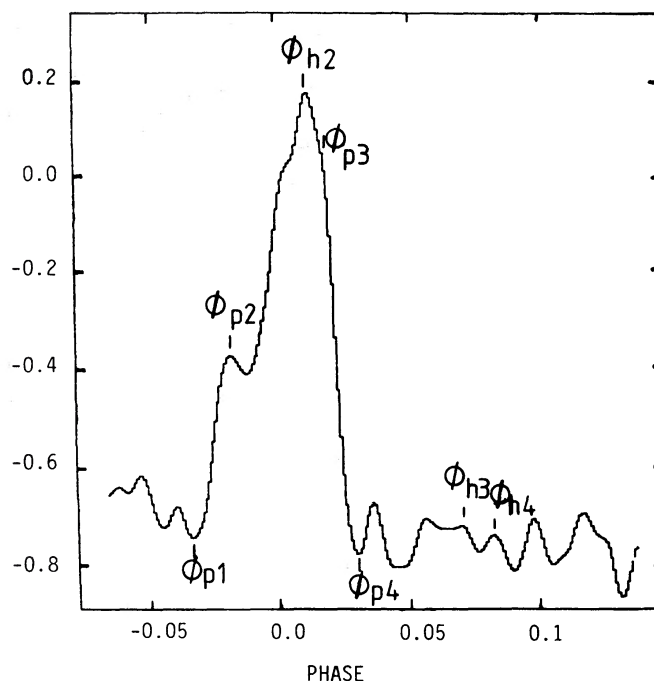


Figure 4. The smoothed $U-R$ colour curve for the eclipse cycle 22563, observed on 1983 March 24.

(1984b), but goes against the views of [SH], based on their $B-R$, $B-I$ colours, that the outerparts of the accretion disc forms a cool optically thick torus of temperature 4000 to 5000 K. It may be that such a feature, if real, may be transitory.

3 The primary eclipse

The primary eclipse of OY Car, like that of Z Cha, is a highly stable feature of the quiescent light curve. Typically the time of primary mid-eclipse can be determined to an accuracy of less than 3 s (0.0006 in orbital phase) from either the four eclipse contact times or the times of mid-ingress and mid-egress. To attain this accuracy of measurement for the individual contact times the light curves were typically binned at 3 s and then smoothed by performing a 2- or 3-point running average over the data. This removed most of the uncorrelated photon noise, whilst retaining the eclipse structure and intrinsic rapid flaring of OY Car. Those eclipses which were observed in simultaneous UBR were binned at 5 s (10 s for cycle 22357). The individual U , B and R light curves were combined and smoothed to improve the eclipse structure. The actual measurements of the times of the eclipse contacts were made visually with the aid of an interactive computer graphics package. The intensity levels of mid-ingress and mid-egress were calculated from visual estimates of the intensity levels at the eclipse contacts, and then used to position horizontal lines which intersected the eclipse curves. The time coordinates at the points of intersection were again measured visually.

The times of mid-eclipse are listed in Table 4. When these times are combined with those of Vogt *et al.* (1981) and [SH], raising the total to 44 (Vogt's first eclipse was not employed), the following linear and quadratic ephemerii are obtained:

$$\text{HJD}(\text{mid-eclipse}) = 2443993.553266 + 0.06312092138 E \quad (1)$$

$\pm 12 \qquad \qquad \pm 74$

Table 3. *UBR* colour–magnitude measurements at various stages of the eclipse. Colours and magnitudes have been listed for just prior to eclipse, at the intensity standstill at the end of primary eclipse, minimum light, the second standstill after primary eclipse, and the post-eclipse values. There are some discrepancies between the colours measured from the *U–B*, *B–V*, and *U–R* curves, which arises primarily from the weaker signal in the *B* filtered light.

Date	R	B–R	U–B	U–R
(a) Pre-eclipse				
10/3/83	15.6	0.04	-0.75	-0.85
11/3/83	15.2	0.22	-0.93	-0.71
21/3/83	15.6	0.12	-0.90	-0.83
24/3/83	15.5	0.15	-1.00	-0.81
	15.3	0.16	-0.79	-0.72
(b) 1st standstill				
10/3/83	16.3	----	-----	-0.56
11/3/83	15.9	0.51	-----	-0.36
21/3/83	16.8	0.12	-0.70	-0.68
24/3/83	16.5	0.33	-0.83	-0.52
	16.1	0.41	-0.54	-0.39
(c) Minimum				
10/3/83	17.1	0.44	-----	0.16
11/3/83	16.7	1.03	-0.79	0.26
21/3/83	18.6	0.12	-0.70	-0.68
24/3/83	18.3	----	-0.06	-----
	17.4	0.58	-0.29	0.14
(d) 2nd standstill				
10/3/83	----	----	-----	-1.07
11/3/83	15.9	0.26	-----	-0.76
21/3/83	16.3	0.12	-1.05	-0.76
24/3/83	16.2	----	-1.00	-----
	16.1	----	-----	-----
(e) Post-eclipse				
10/3/83	15.9	0.04	-0.80	-0.85
11/3/83	15.4	0.37	-0.93	-0.54
21/3/83	15.9	----	-0.94	-0.84
24/3/83	15.9	0.09	-1.00	-0.90
	15.8	0.16	-0.96	-0.77

Standard error = 4.26×10^{-5}

$$\text{HJD}(\text{mid-eclipse}) = 2443993.553216 + 0.0631209352 \text{ E} - 5.3 \times 10^{-13} \text{ E}^2 \quad (2)$$

$\pm 17 \qquad \pm 39 \quad \pm 1.5$

Standard error = 3.76×10^{-5} .

An F test procedure based on the standard deviations about the regression curves (Pringle 1975) showed that the linear fit could be rejected at significance levels of less than 2.5 per cent. The quadratic term, differing from zero by 3.5σ , implies a period evolution time-scale of $2.1 \pm 0.6 \times 10^7$ yr. This is in line with such time-scales for other systems (Cook & Warner 1981; and references therein). As the white dwarf is more massive than the secondary star (see below) the decrease in the orbital period could not be attained by conservative mass transfer. Possible

Table 4. Times of mid-primary eclipse in UT. These were obtained by taking the mean of the times of mid-ingress and mid-egress.

Cycle	mid eclipse (HJD 2440000+)
22231	5396.79442
22246	5397.74122
22261	5398.68814
22262	5398.75122
22278	5399.76109
22294	5400.77109
22322	5402.53847
22339	5403.61154
22357	5404.74774
22390	5406.83064
22405	5407.77752
22417	5408.53497
22437	5409.79734
22451	5410.68107
22468	5411.75411
22469	5411.81719
22484	5412.76397
22515	5414.72085
22561	5417.62445
22563	5417.75066

explanations for such a change in orbital period include: mass loss from the system, systematic transfer of orbital angular momentum from the orbit to the accretion disc over the past four years of monitoring, or a third body in the system.

Employing the quadratic ephemeris to convert time into orbital phase, the orbital phases corresponding to the primary eclipse contact times and the times of mid-ingress and mid-egress have been listed in Table 5. From these phases the following parameters may be computed:

Half width at zero primary intensity ($HWZI$)= $0.5 \times (\phi_{p3} - \phi_{p2})$

Table 5. Orbital phases of the primary eclipse contact times (ϕ_{p1} , ϕ_{p2} , ϕ_{p3} , ϕ_{p4}), mid-ingress (ϕ_{pi}) and mid-egress (ϕ_{pe}). Phasing was performed using the quadratic ephemeris given in the text.

Date	Cycle	ϕ_{p1}	ϕ_{p2}	ϕ_{pi}	ϕ_{p3}	ϕ_{p4}	ϕ_{pe}
3	22230	-----	-----	-----	0.0208	0.0288	0.0244
3	22231	-0.0291	-0.0181	-0.0248	0.0210	0.0282	0.0236
4	22246	-0.0298	-0.0218	-0.0265	0.0198	0.0283	0.0250
5	22261	-0.0288	-0.0215	-0.0240	0.0224	0.0297	0.0256
5	22262	-0.0288	-0.0222	-0.0251	0.0217	0.0290	0.0254
6	22278	-0.0310	-0.0231	-0.0261	0.0215	0.0282	0.0245
7	22294	-0.0286	-0.0222	-0.0248	0.0228	0.0288	0.0250
9	22322	-0.0285	-0.0200	-0.0245	0.0208	0.0274	0.0245
10	22339	-0.0277	-0.0230	-0.0254	0.0244	0.0287	0.0259
11	22357	-0.0312	-0.0192	-0.0245	0.0206	0.0299	0.0260
13	22390	-0.0303	-0.0227	-0.0259	0.0214	0.0276	0.0245
14	22405	-0.0274	-0.0219	-0.0247	0.0224	0.0286	0.0251
15	22417	-0.0275	-0.0205	-0.0250	0.0223	0.0285	0.0254
16	22437	-0.0290	-0.0215	-0.0261	0.0220	0.0287	0.0252
17	22451	-0.0293	-0.0222	-0.0251	0.0224	0.0292	0.0251
18	22468	-0.0291	-0.0227	-0.0254	0.0219	0.0280	0.0250
18	22469	-0.0289	-0.0223	-0.0257	0.0212	0.0273	0.0242
19	22484	-0.0298	-0.0230	-0.0259	0.0213	0.0277	0.0245
21	22515	-0.0283	-0.0226	-0.0250	0.0231	0.0317	0.0264
24	22561	-0.0283	-0.0214	-0.0237	0.0214	0.0297	0.0264
24	22563	-0.0277	-0.0215	-0.0240	0.0221	0.0289	0.0258

Table 6. Mean and sample errors of the quantities listed in Table 5; 20 eclipses were available for calculating the ingress parameters, 21 eclipses were available for the egress parameters. Also listed are the mean values and samples errors of the various half widths and ingress/egress durations, whose definitions are given in the text.

Primary eclipse, Mean parameter values

1st Contact	-0.0290+0.0010
2nd Contact	-0.0217+0.0013
3rd Contact	0.0218+0.0010
4th Contact	0.0287+0.0010
Mid Ingress	-0.0251+0.0008
Mid Egress	0.0251+0.0007
$HWHI_1$	0.0251+0.0004
$HWHI_2$	0.0251+0.0010
HWFI	0.0288+0.0007
HWZI	0.0217+0.0010
Ingress duration	0.0073+0.0017
Egress duration	0.0069+0.0011

Half width at full primary intensity ($HWFI$)= $0.5 \times (\phi_{p4} - \phi_{p1})$

Half width at half primary intensity $HWHI_1$ = $0.5 \times (\phi_{pe} - \phi_{pi})$

$$HWHI_2 = 0.5 \times (HWZI + HWFI)$$

Ingress duration $d_i = \phi_{p2} - \phi_{p1}$

Egress duration $d_e = \phi_{p4} - \phi_{p3}$

The mean values and sample errors of these quantities are listed in Table 6. The two definitions of the half width at half intensity ($HWHI_1$ and $HWHI_2$) show no significant mean differences, but the sample error of $HWHI_1$ (based on times of mid-ingress and mid-egress) is smaller than that of $HWHI_2$. This is to be expected as mid-ingress and mid-egress occur where the intensity is

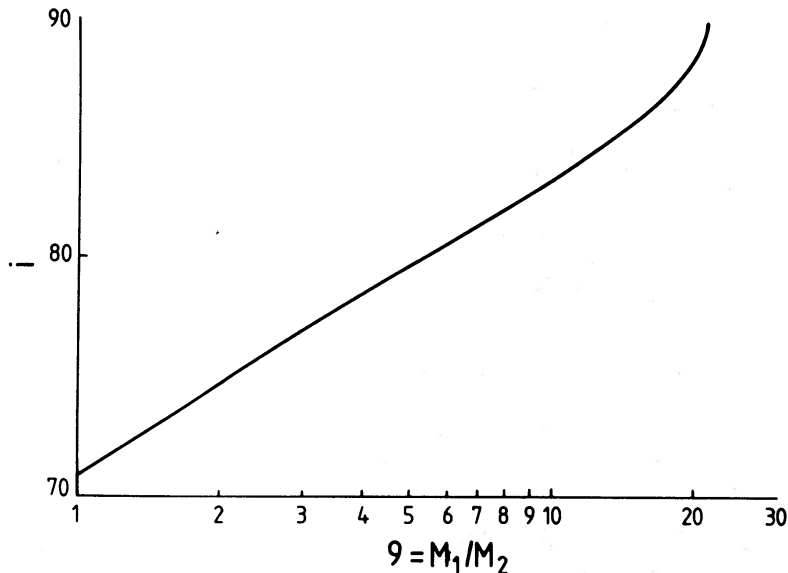


Figure 5. Mass ratio–inclination for OY Car for a primary eclipse half width at half intensity of 0.0251.

Table 7. Radii of spherical or disc-like emission regions which could produce the observed primary eclipse duration of 0.0288. The unit of distance is the orbital separation. Limb darkening has not been taken into account.

Mass ratio	Inclination	Radius	
		Disc	Sphere
1.0	70.75	.0161	.0086
2.0	74.71	.0189	.0108
3.0	76.93	.0202	.0123
4.0	78.47	.0209	.0135
5.0	79.64	.0214	.0145
6.0	80.59	.0217	.0154
7.0	81.40	.0219	.0161
8.0	82.10	.0221	.0168
9.0	82.73	.0222	.0172
10.0	83.31	.0223	.0181
11.0	83.84	.0224	.0186
12.0	84.34	.0225	.0191

changing rapidly, and so are insensitive to errors in the estimates of the mid-ingress, mid-egress intensity levels. No significant differences were found between the half widths obtained here and those obtained by [SH].

The half width at half intensity ($HWHI_1$) of the point-like primary eclipse determines inclination of OY Car as a function of the mass ratio (Bailey 1979) with errors ranging from $0^\circ.1$ to $0^\circ.6$ (mass ratio ranging from 1 to 15). This relation is shown in Fig. 5. This relation provides a loose upper limit of 21.1 for the mass ratio. The half width at full intensity, or alternately, the duration of ingress and egress, measures the size of the emission region responsible for the primary eclipse as a function of mass ratio [CW]. There is some dependence on shape and the computed radii, in units of orbital separation, are listed in Table 7 for a disc/ring shaped source (in the orbital plane) and a spherical source. The actual emission region is likely to be a combination of both extremes with the disc region being the innermost part of the accretion disc. The radii in Table 7, $[r(q)]$, are converted into physical quantities by the relation:

$$R_e = r(q)D \quad (3)$$

where D is the orbital separation given by

$$D = \left[\frac{P_{\text{orb}}}{2\pi} \right]^{2/3} [G(M_1 + M_2)]^{1/3}. \quad (4)$$

For OY Car, $P_{\text{orb}} = 0.06312$ day so:

$$R_e = 4.64 \times 10^{10} r(q)(1+q)^{1/3} (M_2/M_\odot)^{1/3} \text{ cm} \quad (5)$$

where

$$M_1 = qM_2.$$

Relation (5) is to be compared with the mass-radius relation for cold, non-rotating white dwarfs. A good analytic representation of the latter is

$$R_w = 7.795 \times 10^8 [(M_1/M_C)^{-2/3} - (M_1/M_C)^{2/3}]^{1/2} \text{ cm} \quad (6)$$

where $M_C = 1.44 M_\odot$ is the Chandrasekhar mass (Nauenberg 1972, [CW]).

Equation (6) specifies a unique curve in the mass-radius diagram (Fig. 6). Equation (5) specifies a range of curves in Fig. 6, parameterized by the secondary star mass M_2 , and dependent on the shape of the emission region. In Fig. 6 the M_2 has been set to $0.14 M_\odot$ and the solutions for a disc-like primary source and a spherical primary source have been plotted. Their intersections

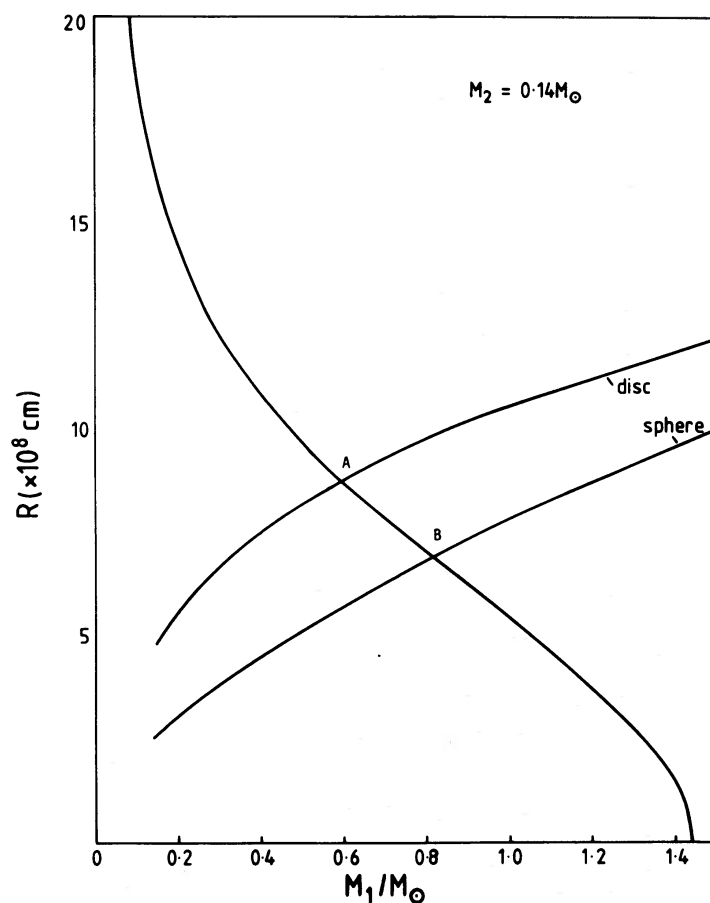


Figure 6. Radii of the central source, spherical or disc-like, as a function of primary mass, with the secondary mass set equal to $0.14 M_{\odot}$. Also shown is an analytic expression for the mass–radius relation of cold non-rotating white dwarfs. The points A and B denote the intersections of the white-dwarf mass–radius relation with the two former curves.

with equation (6) have been denoted points A and B respectively, with mass coordinates M_A and M_B . Values of M_A and M_B have been listed in Table 8 as a function of the secondary star mass. The one-sigma errors are propagated from the one-sigma sample errors of the *HWFI*.

Following the analysis given to [CW], the requirement that the size of a disc-like emission

Table 8. Mass coordinates and corresponding mass ratios of points A and B in Fig. 6, as a function of the secondary star mass, in units of solar mass. Typical 1σ errors propagated from the sample error of the primary eclipse duration are -0.10 and $+0.11 M_{\odot}$.

M	M	q	M	q
2	A	A	B	B
.04	.57	14.4	.63	15.7
.06	.58	9.6	.68	11.4
.08	.58	7.2	.73	9.1
.10	.58	5.8	.76	7.6
.12	.59	4.9	.79	6.6
.14	.59	4.2	.81	5.8
.16	.59	3.7	.83	5.2
.18	.60	3.3	.84	4.7
.20	.60	3.0	.86	4.3
.22	.60	2.7	.87	4.0
.24	.60	2.5	.88	3.7
.26	.61	2.3	.90	3.4
.28	.61	2.2	.91	3.2
.30	.61	2.0	.91	3.0

region be larger than a cold, non-rotating white dwarf produces a lower limit to the mass of the white dwarf (i.e. $M_1 > M_A$). From Table 8 this lower limit is $0.6 \pm 0.1 M_\odot$, and is insensitive to the actual mass of the secondary star. The mass coordinate of point B provides no limits on the mass of the white dwarf, but can be used to determine the nature of the emission region responsible for the primary eclipse. If $M_1 > M_B$ then the radius of the white dwarf in OY Car is smaller than the actual size of any spherical emission region which could account for the structure of the primary eclipse. This would indicate the existence of an optically bright disc-like region around the white dwarf in order to account for the eclipse duration. If the mass of the white dwarf lay between points M_A and M_B , then the radius of the white dwarf would be too large to account for the eclipse duration. White dwarf masses in this range are still acceptable if, however, the lower hemisphere of the white dwarf was obscured by the accretion disc. If this were so, then only the innermost region of such a disc must be luminous in order to produce the observed eclipse duration.

4 The hotspot eclipse

The hotspot in cataclysmic variables is produced by the impact of the gas stream on to the accretion disc. From the phasing of the hotspot eclipse and the use of Roche-lobe geometry, the size and location of the hotspot in the disc can be determined as a function of mass ratio [CW]. Constraints on the mass ratio are obtained by insisting that the gas stream passes through the hotspot in some manner. The stream trajectories are calculated using the prescription by Lubow & Shu (1975), and are valid for the case of a non-magnetic system with a synchronized secondary. The synchronization requirement may be relaxed as work on the rotation of Roche-lobe-filling low-mass stars by Cambell & Papaloizou (1983) suggests that the rotation of the outer layers of the secondary may be synchronized with the orbital period even when the rotation of the core of the secondary is mildly asynchronous. The lack of any long-lived coherent pulsations in the light curves of OY Car (Vogt *et al.* 1981; Vogt 1983, [SH], and the data presented here) argues for a weak magnetic field in OY Car.

The critical phases of the hotspot eclipse are given in Table 9. These phases were measured in the same manner as those for the primary eclipse. Each phase determines a boundary in the

Table 9. Hotspot eclipse contact phases (ϕ_{h1} , ϕ_{h2} , ϕ_{h3} , ϕ_{h4}) and phases of mid-ingress (ϕ_{hi}) and mid-egress (ϕ_{he}), calculated from the quadratic ephemeris in the text.

Date	Cycle	ϕ_{h1}	ϕ_{h2}	ϕ_{hi}	ϕ_{h3}	ϕ_{h4}	ϕ_{he}
3	22230	-----	-----	-----	0.0696	0.0805	0.0725
3	22231	-0.0004	0.0210	0.0038	0.0700	0.0855	0.0778
4	22246	-0.0104	0.0147	0.0036	0.0729	0.0782	0.0758
5	22261	-0.0019	0.0097	0.0024	0.0734	0.0797	0.0764
5	22262	-0.0057	0.0085	0.0016	0.0653	0.0796	0.0752
6	22277	-----	-----	-----	0.0691	0.0806	0.0764
6	22278	-0.0111	0.0118	0.0001	0.0698	0.0798	0.0751
7	22294	-0.0029	0.0160	0.0035	0.0641	0.0817	0.0722
9	22322	-0.0059	0.0130	-0.0007	0.0709	0.0859	0.0777
10	22339	-0.0113	0.0044	0.0013	0.0686	0.0837	0.0761
11	22357	-0.0046	0.0113	0.0020	0.0679	0.0820	0.0768
13	22390	-0.0024	0.0077	0.0015	0.0726	0.0794	0.0757
14	22405	-0.0027	0.0105	0.0018	0.0680	0.0815	0.0751
15	22417	-0.0052	0.0126	0.0018	0.0737	0.0808	0.0774
16	22437	-0.0027	0.0096	0.0011	0.0713	0.0787	0.0765
17	22451	-0.0101	0.0110	-0.0008	0.0699	0.0879	0.0789
18	22468	-0.0063	0.0058	-0.0009	0.0728	0.0828	0.0778
18	22469	-0.0055	0.0067	-0.0017	0.0762	0.0903	0.0815
19	22484	-0.0063	0.0112	0.0000	0.0727	0.0789	0.0768
21	22515	-0.0226	0.0088	-0.0045	0.0706	0.0812	0.0771
24	22561	-0.0046	0.0087	0.0009	0.0617	0.0790	0.0682
24	22563	-0.0080	0.0147	0.0006	0.0715	0.0843	0.0767

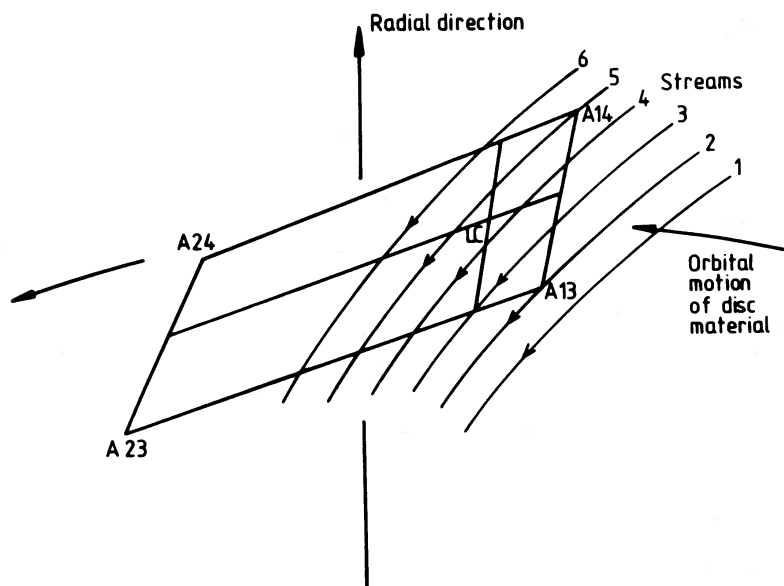


Figure 7. Schemating diagram showing the typical orientation of the hotspot box envelopes for mass ratios in excess of 3. The numbered curves denote the possible manners in which the core of the gas stream can intersect the hotspot envelope.

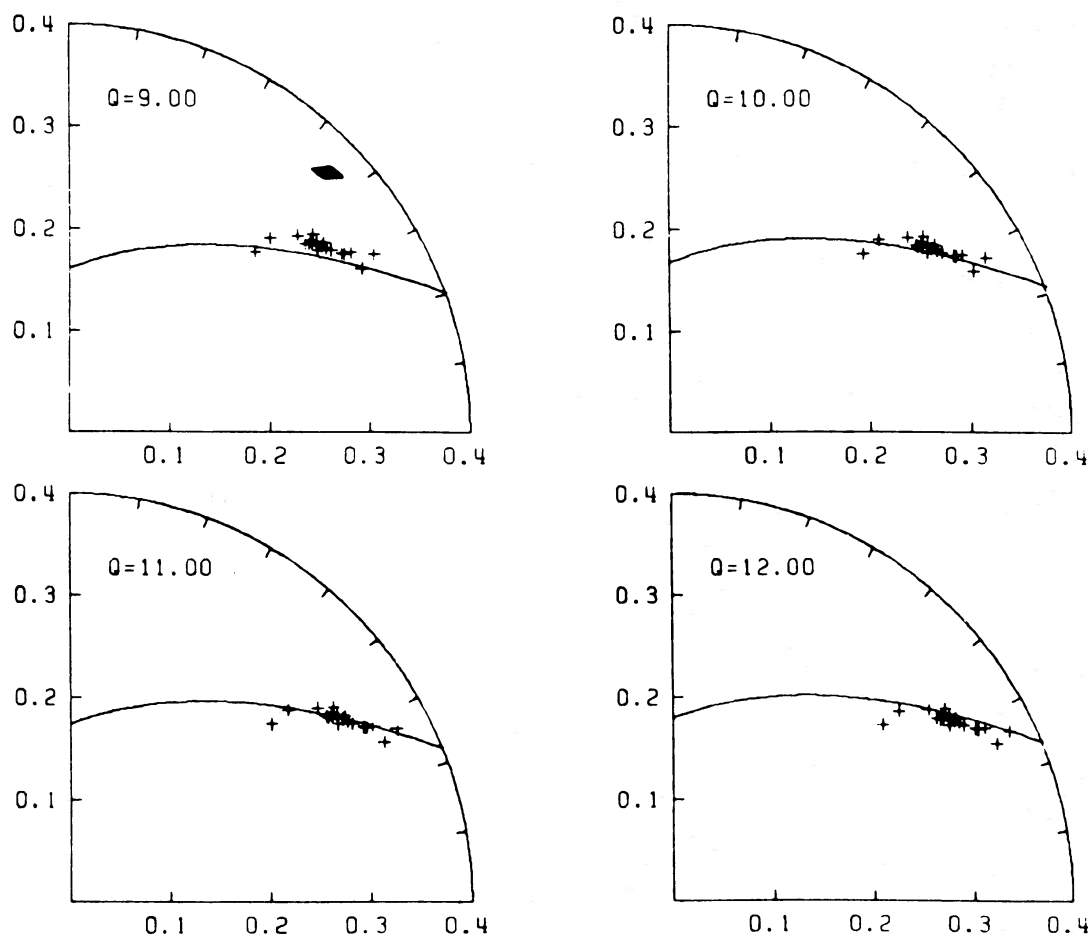


Figure 8. Positions of the hotspot light centres in the accretion disc for mass ratios 9, 10, 11, and 12. The horizontal axes lies along the line joining the two stars, and is marked off into units of orbital separation. The continuous curves show the theoretical paths of the gas stream. The small diamond in the $q=9$ figure demonstrates the typical range of variation expected if the measured times of mid-ingress and mid-egress were in error by 0.0010 in phase (~ 6 s).

orbital plane dividing eclipsed and non-eclipsed regions of the plane. The shape of the boundary depends solely on the orbital phase and on the mass ratio. The intersections of the boundaries associated with the four eclipse contacts defines a box-like envelope which must contain the hotspot. It is assumed that the thickness of the hotspot can be neglected. The intersection of the boundaries corresponding to mid-ingress and mid-egress determines the position of the 'light centre' of the hotspot. The typical orientation of the box envelopes for mass ratios greater than 3 is shown in Fig. 7, along with some representations of the trajectory of the core of the gas stream. The corners of the envelope are denoted by the symbol A_{IJ} , with polar coordinates r_{IJ} and θ_{IJ} , where I is the ingress contact, J the egress contact corresponding to the contact boundaries defining the intersection. The light centre is denoted by the symbol LC. Following the analysis for

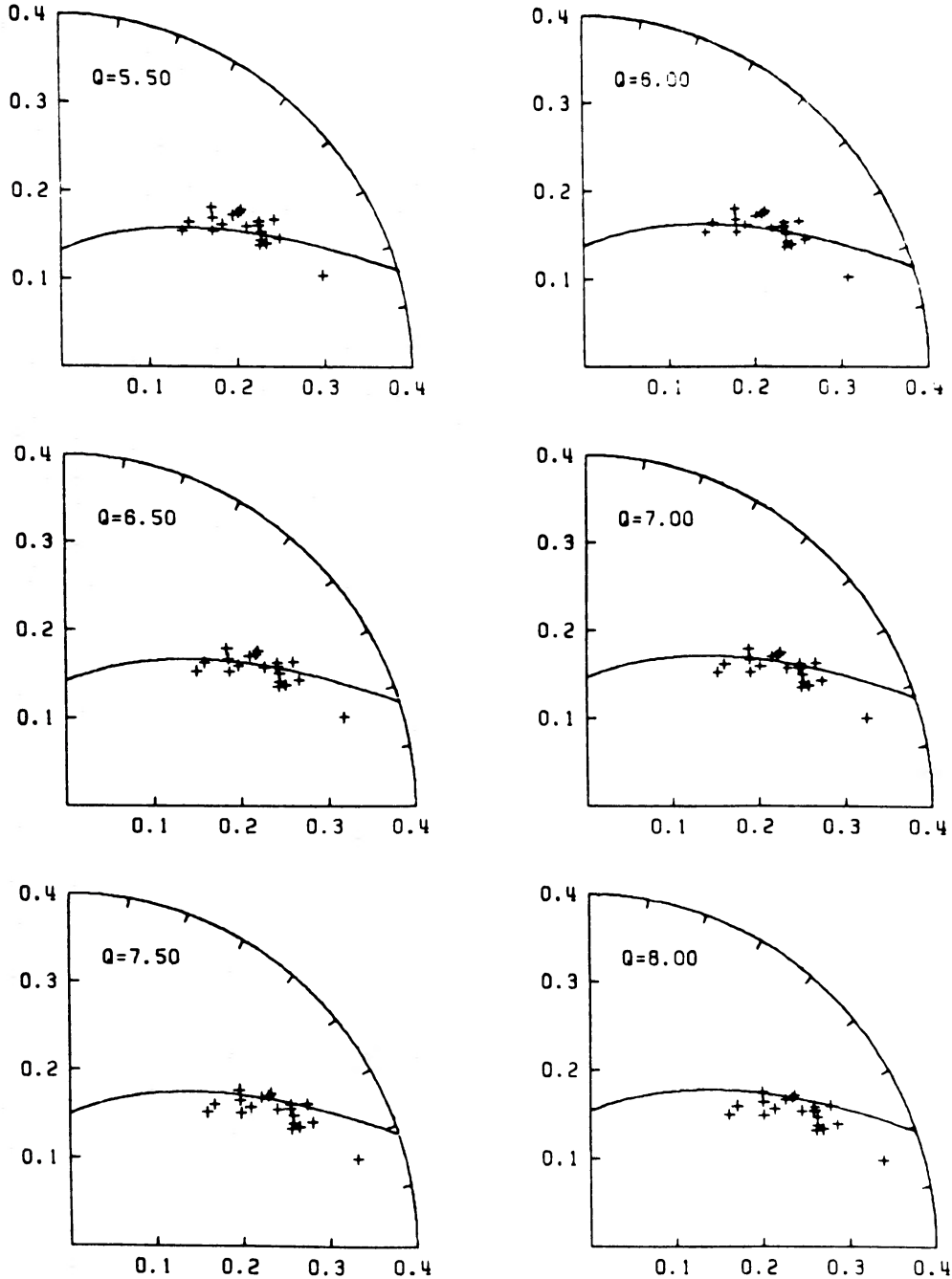


Figure 9. Locations of the points A_{13} for mass ratios 5.5 to 8.

Z Cha by [CW], acceptable mass ratios are obtained if the stream trajectory passes between the points A_{13} and LC (curves 2 to 4 in Fig. 7). Fig. 8 shows the locations of the light centres of all the usable hotspot eclipses for mass ratios 9, 10, 11 and 12. The small diamond near the top of the $q=9$ diagram shows the typical range of variation of the positions of the light centres caused by an uncertainty of ± 0.001 in the phases of mid-ingress and mid-egress (equivalent almost two integration times). In most cases, particularly those eclipses with ingresses and egresses undistorted by flickering, the measurement error is about half this value. The size and shape of the diamond shows that the distribution of the light centre positions, whose coordinates are highly correlated (coefficient -0.93) along a direction nearly parallel to the stream trajectory, cannot be due to measurement error alone. A light centre will reject a mass ratio if it lies in the region defined by the gas stream and the horizontal axis. About 50 per cent of the light centres reject a mass ratio of 11 whilst all but one reject a mass ratio of 12. The latter mass ratio is therefore taken as an upper limit.

The locations of the points A_{13} are shown in Fig. 9 for mass ratios 5.5 to 8.0. The effect of measurement errors are again of order that shown by the diamond shape in Fig. 8. A point will reject a mass ratio if it lies outside the region defined by the gas stream and the horizontal axis. These points clearly show a greater scatter perpendicular to the path of the stream than do the light centres. The scatter of the light centres is due to intrinsic changes in the position of the light centre, systematic errors caused by intrinsic flickering and measurement error of the phases of mid-ingress and mid-egress. In the case of the corner points A_{13} , intrinsic variation in the dimensions of the hotspot is an additional mechanism for increasing the scatter of the points. The effect of measurement error and changes in the position of the light centre would be to produce a scatter similar to that seen in Fig. 8. Intrinsic changes in the dimensions of the hotspot and flickering can, however, increase the scatter perpendicular to the path of the stream. A large hotspot would accept smaller mass-ratios than a small hotspot. Flickering can distort the shape of the eclipse near the times of contact, whilst having a minor effect during times of rapid intensity changes. From Fig. 9 it is found that over 50 per cent of the points accept a mass ratio of 6.5 and almost all accept a mass ratio of 8.0. Similar results occur when one restricts the data to hotspot eclipses with the best-defined and sharpest egresses (cycles 22246, 22261, 22262, 22278, 22390, 22417, 22437 and 22484). Because of the increased scatter due to the size of the hotspot, the mass

Table 10. Polar coordinates of the hotspot light centres in the accretion disc for mass ratios 7, 9 and 11.

Date	Cycle	$q=7$		$q=9$		$q=11$	
		R	θ	R	θ	R	θ
		LC	LC	LC	LC	LC	LC
3	22231	.299	42.3	.312	38.8	.324	36.0
4	22246	.287	44.0	.299	40.4	.311	37.6
5	22261	.293	41.6	.306	38.1	.319	35.3
5	22262	.288	41.2	.302	37.7	.314	35.0
6	22278	.291	39.3	.306	35.8	.319	33.1
7	22294	.267	47.3	.277	43.7	.287	40.8
9	22322	.308	36.3	.324	32.9	.339	30.4
10	22339	.294	40.1	.308	36.7	.321	33.9
11	22357	.296	40.7	.310	37.2	.323	34.5
13	22390	.291	40.9	.305	37.4	.317	34.7
14	22405	.287	41.8	.300	38.2	.313	35.5
15	22417	.300	39.8	.315	36.3	.328	33.7
16	22437	.296	39.5	.311	36.1	.325	33.4
17	22451	.315	35.5	.332	32.2	.347	29.7
18	22468	.310	35.9	.326	32.6	.341	30.0
18	22469	.332	33.1	.351	29.9	.367	27.5
19	22484	.301	37.9	.317	34.5	.331	31.8
21	22515	.314	32.1	.334	28.9	.350	26.5
24	22561	.246	47.4	.256	43.8	.266	40.9
24	22563	.299	38.7	.314	35.3	.328	32.6

Table 11. Angular separation between the shock front and light centre ($\delta\theta$), angular width of the hotspot ($\Delta\theta$), radial width (Δr), maximum radial width ($\Delta r_{\max}$), and minimum radial width of the hotspot ($\Delta r_{\min}$), for a mass ratio of 9. Negative values of the minimum radial width indicates inward post-shock flow of material.

Date	Cycle	$\delta\theta$	$\Delta\theta$	Δr	$\Delta r_{\max}$	$\Delta r_{\min}$
3	22231	4.4	24.1	.088	.111	.065
4	22246	16.7	30.5	.031	.095	-.029
5	22261	5.8	16.5	.039	.067	.012
5	22262	7.0	24.7	.087	.121	.053
6	22278	12.4	30.3	.059	.119	-.002
7	22294	8.9	28.5	.100	.120	.080
9	22322	5.4	23.2	.089	.130	.048
10	22339	13.5	19.6	.093	.143	.043
11	22357	6.6	23.8	.085	.119	.052
13	22390	5.3	15.0	.043	.070	.016
14	22405	5.1	20.7	.083	.110	.057
15	22417	8.1	22.0	.043	.084	.002
16	22437	3.7	18.7	.047	.075	.018
17	22451	8.6	25.8	.104	.158	.051
18	22468	5.5	15.3	.062	.098	.026
18	22469	3.9	13.5	.083	.117	.048
19	22484	6.6	23.4	.038	.081	-.005
21	22515	14.0	34.8	.060	.164	-.044
24	22561	9.3	26.1	.104	.127	.082
24	22563	9.8	26.7	.074	.124	.024

ratio at which 50 per cent accept and 50 per cent reject is used to define the lower limit. With the present data this lower limit is ~ 6.5 . It should be noted that the gas stream should have a semi-width of ~ 0.02 (Lubow & Shu 1975) which would make the points A₁₃ unlikely to lie near the core of the stream. If this was taken into effect, it would increase the lower limit. From the mass ratio inclination relation of $i \sim 81-84^\circ$.

The locations of the light centres of all the eclipses have been listed in Table 10 for mass ratios 7, 9 and 11. Table 11 lists, for a mass ratio of 9, the angular separation between the first contact boundary and the light centre, defined by:

$$\delta\theta = \theta_{\text{LC}} - 0.5 \times (\theta_{13} + \theta_{14})$$

the angular width of the hotspot:

$$\Delta\theta = 0.5 \times (\theta_{23} + \theta_{24} - \theta_{13} - \theta_{14})$$

the mean radial width of the hotspot:

$$\Delta r = 0.5 \times (r_{14} + r_{24} - r_{13} - r_{23})$$

and the maximum and minimum possible radial widths of the hotspot:

$$\Delta r_{\max} = \max(r_{14} - r_{23}, r_{24} - r_{13})$$

$$\Delta r_{\min} = \min(r_{14} - r_{23}, r_{24} - r_{13})$$

Negative values of $\Delta r_{\min}$ indicate that the post-shock flow of material in the hotspot must have an inwardly directed velocity component. These quantities show little dependence on the mass ratio when the latter is large.

Using a mass ratio of 9 for OY Car, the mean radial distance of the hotspot from the white dwarf is ~ 0.31 , with sample error ~ 0.02 . As this is equivalent to the radius of the quiescent accretion disc in OY Car, it is clear that OY Car is yet another cataclysmic variable whose disc radius is significantly larger than that predicted from non-viscous models (radius $\sim 0.20-0.23$, Lubow & Shu). Several of these systems have been listed in Sulkänen, Brasure & Patterson

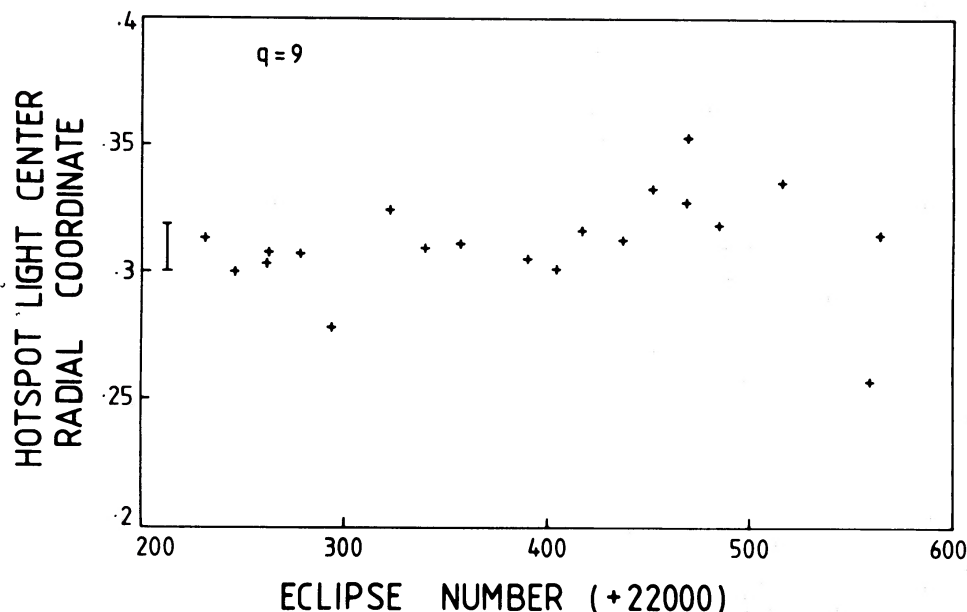


Figure 10. Radial coordinate of the hotspot light centre against the eclipse cycle number. The vertical bar indicates the error introduced if the measured times of hotspot mid-ingress and mid-egress were in error by ± 6 s. There appears to be systematic increase in the radial coordinates for cycles 22417 to 22515 (March 1983 15 to 21) which is larger than the vertical bar.

(1981). The disc radius varies over a range of radii (relative to the orbital separation) which is similar to that found for Z Cha ($r \sim 0.31\text{--}0.37$ ($q=6$), [CW], but the angular coordinate of the hotspot light centre ($32\text{--}40^\circ$) is significantly larger than that found for Z Cha ($22\text{--}31^\circ$). This is due to the larger mass ratio required for OY Car, as the discs in both systems have the same dimensions relative to the orbital separation. The radial and angular widths of the hotspots in OY Car and Z Cha are found to vary over similar ranges, but the angular separation between the shock front (first contact boundary) and the light centre is significantly larger for OY Car ($8 \pm 4^\circ$ as

Table 12. Values of the intensity changes during hotspot ingress and egress, normalized to the average of the intensity jumps during the primary ingress and egress. Also listed is the ratio of the intensity jumps during hotspot ingress and egress.

Date	Cycle	$\frac{H(\text{ingress})}{\text{primary}}$	$\frac{H(\text{egress})}{\text{primary}}$	$\frac{H(\text{egress})}{H(\text{ingress})}$
3	22231	.79	.37	.47
4	22246	.58	.38	.66
5	22261	.65	.42	.65
5	22262	.64	.32	.50
6	22278	.68	.36	.53
7	22294	.87	.50	.58
9	22322	.82	.31	.38
10	22339	.82	.47	.58
11	22357	.61	.47	.76
13	22390	.54	.39	.72
14	22405	.74	.29	.39
15	22417	.93	.44	.47
16	22437	.73	.34	.47
17	22451	.64	.24	.38
18	22468	.51	.22	.44
18	22469	.62	.28	.45
19	22484	.57	.18	.31
21	22515	.90	.37	.41
24	22561	.67	.37	.54
24	22563	.80	.30	.38

opposed to $4.4 \pm 2.5^\circ$). As in Z Cha, the hotspot is elongated along the rim of the disc and the light centre is displaced towards the shock front. This reflects the cooling of the hotspot material as it flows away from the impact region.

The angular separation of the light centre from the first contact boundary and the angular width of the hotspot are significantly correlated with each other (coefficient 0.71), but show no significant correlations with the radial or angular coordinates of the light centre. The correlation between the two angular widths is to be expected as both are primarily determined by the structure of the hotspot ingress. The radial width of the hotspot also shows little correlation with the light centre coordinates. There is some weak evidence for possible systematic variations in the light centre coordinates over a time-scale of several days. Fig. 10 shows the radial coordinate of the light centre plotted against cycle number, with the vertical bar showing the effect of a 6-s error in the measured times of hotspot mid-ingress and mid-egress. The radial coordinate shows a tendency to be larger for cycles 22451 to 22515, although there is considerable cycle-to-cycle variation. This variability could be due changes in the radius of the accretion disc, or to changes in the gas densities of the stream and/or disc, which would affect the penetration depth of the stream into the disc. The short-term position changes are mostly likely due to the latter explanation. One may expect some anti-correlation between the luminosity of the hotspot and the position of its light centre, particularly if the variations were solely due to changes in the accretion disc radius. Table 12 lists the intensity changes during hotspot ingress and egress, normalized to the mean intensity change during the ingress and egress of the primary eclipse, and the ratio of the intensity changes during the hotspot egress and ingress. The white-light intensity changes are subject to atmospheric and instrumental effects which would not have been fully taken into account by correcting the first-order extinction using the *U*-band extinction coefficient. The intensity ratios should be relatively free of any such effects. The normalized hotspot ingress intensity change showed no correlation with the radial coordinate of the hotspot light centre, although it showed, as one might expect, a weak correlation with the normalized egress intensity change (coefficient 0.45). The latter, and the ratio of hotspot egress intensity change to ingress intensity change, both showed weak anti-correlations with the radial coordinate of the light centre (coefficients -0.45 and -0.41 respectively).

5 Discussion

Table 7 lists the critical primary masses (and mass ratios) depicted by points A and B in Fig. 6 as a function of the secondary mass M_2 . If the primary mass M_1 is greater than M_B , then the observed primary eclipse duration is longer than could be attained by a white dwarf. If $M_A < M_1 < M_B$ then the observed eclipse duration would be too short unless the lower hemisphere of the white dwarf was obscured from view by an optically thick accretion disc, non-luminous except close to the white dwarf. Primary masses below M_A are not allowed in any circumstances.

The theoretical low-mass main-sequence star mass–radius relation, when applied to secondaries filling their Roche lobes, enables one to predict the secondary mass solely as a function of the orbital period (Warner 1976). The Grossman, Hays & Graboske (1974) models lead to a secondary mass of $\sim 0.14 M_\odot$ (Vogt *et al.* 1981; Bailey & Ward 1981). At this mass, $M_A \sim 0.59 M_\odot$ and $M_B \sim 0.81 M_\odot$, with errors $\pm 0.10 M_\odot$. Alternatively $q_A \sim 3.5\text{--}5.1$ and $q_B \sim 5.1\text{--}6.6$. The former mass ratio range is below the range 6.5 to 12 obtained from the hotspot eclipse, and the range for q_B just overlaps at the lower end, indicating that the white dwarf could not produce the observed primary eclipse. With such a secondary mass it would be necessary therefore, for the white dwarf to be surrounded by luminous ring of radius 0.022 ± 0.005 . Higher values of the secondary mass do not affect this conclusion.

Secondary star masses below $0.14 M_\odot$ allow for the possibility of the white dwarf alone being

responsible for the primary eclipse, or for the possibility of a white dwarf whose lower hemisphere is obscured by an optically thick disc which is luminous at its inner edge. The lower mass ratio limit q_A becomes greater than that found from the hotspot eclipse (6.5) for secondary masses below $0.09 M_\odot$, and a secondary star mass less than $\sim 0.04 M_\odot$ can be ruled out on the grounds that q_A is greater than all mass ratios acceptable to the hotspot eclipse.

The lower limit to the mass of the white dwarf ($M_A \sim 0.6 \pm 0.1 M_\odot$) immediately rules out the solutions obtained by Bailey & Ward (1981), and Ritter (1980). Vogt *et al.* (1981) used a combination of eclipse data, an emission line radial velocity amplitude of 100 km s^{-1} , and theoretical mass–radius relations for the primary and secondary stars to determine a primary mass range of $0.95 \pm 0.15 M_\odot$, a secondary mass range $0.14 \pm 0.05 M_\odot$, and an inclination range of $77\text{--}81^\circ$. Consistency with the results obtained here are attained in the upper range of their primary masses, and their lower range of their secondary masses. Their inclination range is below that obtained here ($81\text{--}84^\circ$), but their determination of the location of the hotspot (radius vector $\sim 0.325\text{--}0.329$, position angle $\sim 29\text{--}37^\circ$) is comparable with the present work (Table 10). Their determination of the size of the hotspot ($0.013\text{--}0.025$) is significantly smaller than the typical dimensions found here (radial width $\sim 0.049\text{--}0.095$, transverse width $\sim 0.141\text{--}0.209$). Their observation that the angular coordinate of the hotspot is more variable than its radial coordinate is not supported, as in the present work it is found that the radial and angular coordinates of the hotspot light centre are highly correlated, and vary so as to move the light centre on a path roughly parallel to the gas stream. Vogt *et al.* however, had little information on the egress of the hotspot, which may explain these discrepancies. The results of detailed eclipse analysis (above and in [CW]) show that measurement of the egress of the hotspot is critical for the determination of its radial properties.

[SH] have computed a variety of mass solutions for various values of the white-dwarf radial velocity amplitude and emission line widths at zero intensity. The latter parameter is used to determine an upper limit to the size of the white dwarf, (as used in Bailey & Ward 1981). Best agreement with their results and the range of mass ratios found here is attained for their solutions which employ mass–radius relation for the stellar components (note, such relations were not used to determine the mass ratio in this paper), and a radial velocity amplitude of 85 km s^{-1} . A similar agreement is found with the results of Berriman's analysis, who also used a combination of eclipse data radial velocity data, and stellar mass–radius relations. The conclusion by [SH] that little or no continuum emission arises close to the white dwarf cannot be reconciled with their estimate of the secondary mass ($\sim 0.15 M_\odot$). Such a secondary mass, coupled with the mass ratio range found in this paper (6.5–12), implies white dwarfs which are too small to account for the observed primary eclipse duration. A hot optically thick ring surrounding the white dwarf would be required, which if sufficiently hot, could account for the lack of line emission from this region.

6 Conclusions

An analysis of the eclipse structure of OY Car has shown that:

- (i) OY Car becomes highly reddened during primary and hotspot ingress, and returns to near pre-eclipse colours during primary egress. The colours at minimum indicate that the flux in the *U* and *B* bandpasses at this phase originates from an optically thin emitting region of the cataclysmic variable.
- (ii) The mass ratio lies between 6.5 and 12, with corresponding binary inclinations of 81.0 and 84.3° .
- (iii) The mass of the white dwarf must be greater than $0.6 \pm 0.1 M_\odot$.
- (iv) A secondary mass of $0.14 M_\odot$, suggested from theoretical mass–radius relations and from observations ([SH], Berriman, 1984a, b), implies white-dwarf masses in the range $0.91\text{--}1.68 M_\odot$,

the upper limit being in excess of the Chandrasekhar mass ($\sim 1.44 M_{\odot}$). Such white dwarfs are too small to account for the observed eclipse duration, indicating the presence of luminous rings around the white dwarfs.

(v) If the mass of the secondary is smaller than $0.14 M_{\odot}$, then the white dwarf alone can account for the primary eclipse, or allows for the case of a white dwarf surrounded by an optically thick disc.

(vi) The hotspot varies in position along a path roughly parallel with the gas stream trajectory. These variations indicate either a variable accretion disc radius or density variations in the outerparts of the accretion disc and the gas stream. In all observations the accretion disc radius is larger than can be attained from zero viscosity models (Lubow & Shu 1975).

(vii) The hotspot is elongated along the rim of the disc and does not radiate uniformly. The luminosity distribution is consistent with that expected from the cooling post-shocked material as it flowing away from the shock front.

(viii) The binary period of OY Car is decreasing on an evolution time-scale of $\sim 2 \times 10^7$ yr. This cannot be explained by conservative mass exchange. Mass loss from the system, a third body, or long-term angular momentum transfer between the accretion disc and the binary system may be involved.

(ix) More studies are required to: (a) Remove the uncertainty in the nature of the central source by obtaining accurate observational limits on the mass of the secondary star. Unambiguous observational limits on the mass of the white dwarf, and/or more observations of hotspot eclipses with very rapid egresses would be of use in this regard. (b) Investigate the long-term variability of the structure and position of the hotspot light centre, and so see if there is any dependence on the time elapsed from a previous outburst, or time to the next outburst. (c) Further improve the eclipse ephemeris, which can be used to investigate the processes by which angular momentum is transferred to or from the binary orbit.

Acknowledgments

I gratefully acknowledge CTIO for the allocation of observing time and travel support. Part of this research was carried out whilst a member of the department of physics, University of Illinois, Urbana, Illinois 61801, USA, and was supported by NSF grant PHY80-25605 and NASA grant 7653. I am grateful to Drs G. Berriman and K. Horne for their useful comments, and also Drs M. G. Watson, C. Page, and R. Willingale for their help in enabling the data presented in this paper to be analysed with the University of Leicester, X-ray astronomy group, data reduction package DGS.

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