THE MAY 1985 SUPEROUTBURST OF OY CARINAE:
I. STRUCTURE OF THE OUTER DISK FROM OPTICAL AND IR OBSERVATIONS

T. NAYLOR(1), J. BAILEY(2), F. M. BATESON(3), G. BERRIMAN(4), P. A. CHARLES(1), I. M. COULSON(5), A. R. HYLAND(6), K. REINSCH(7), B. WARNER(8), and P. A. WHITELOCK(5)
(1) Department of Astrophysics, Oxford, U.K.
(2) Anglo-Australian Observatory, Epping, Australia
(3) Astronomical Research Limited, Greerton, New Zealand
(4) Steward Observatory, University of Arizona, U.S.A.
(5) South African Astronomical Observatory, South Africa
(6) Mount Stromlo and Siding Spring Observatories, Australia
(7) Technische Universität Berlin, F.R.G.
(8) University ofCape Town, South Africa

ABSTRACT. We present optical and IR observations of the dwarf nova OY Car during the May 1985 superoutburst. From them we find that the superhump has a temperature of ~8000K and an area of order half the size of the red dwarf or accretion disk. We also compare the behaviour during two simultaneous optical/IR observations. Whilst the light curves in the two pass bands are similar during one observation, in the other observation they show marked differences that may be due to a cool region in the outer disk.

1. INTRODUCTION

OY Car is a member of the SU UMa sub-class of dwarf novae. A defining characteristic of the class is that during their "superoutbursts" an optical modulation, called the "superhump", of about 0.3 mag develops once the superoutburst is at or past its peak. OY Car displays a superhump with a period of about 93 minutes. Because the superhump period is slightly longer than the orbital period (91 minutes), the peak of the superhump gradually advances in orbital phase, systematically marching through the eclipses.

Figure 1 shows the magnitude of OY Car throughout the May 1985 superoutburst, as observed by the Variable Star Section of the Royal Astronomical Society of New Zealand. The times of optical photometry, EXOSAT and IUE observations are marked. In this paper we will discuss the photometry, the remaining data will be discussed in paper II.

2. THE SPECTRUM OF THE SUPERHUMP.

We have used the calibration of Lub and Pel (1977) to convert the observation #2 Walraven magnitudes into arbitrary flux units such that the ratio of the flux between any two bands is correct (see figure 2a). The flux is obviously greater before the eclipse than after it, though the asymmetry decreases with wavelength. The light after eclipse is

Paper presented at the IAU Colloquium No. 93 on 'Cataclysmic Variables. Recent Multi-Frequency Observations and Theoretical Developments', held at Dr. Remeis-Sternwarte Bamberg, F.R.G., 16–19 June, 1986.

Astrophysics and Space Science **130** (1987) 365–369.

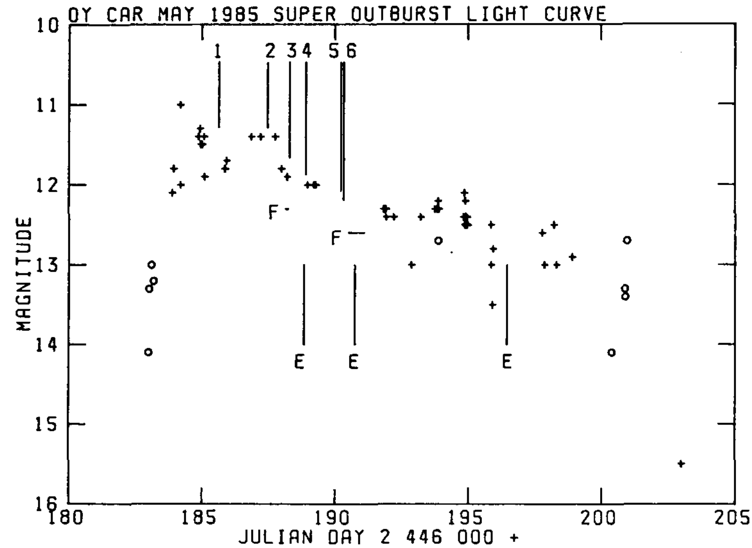

Figure 1. The light curve of OY Car during the May 1985 superoutburst. Crosses mark observations, circles upper limits. The times of optical photometry (numbers) and EXOSAT (E) observations are marked. The length of the IUE observations are shown by horizontal lines (F) that lie at the mean FES magnitude.

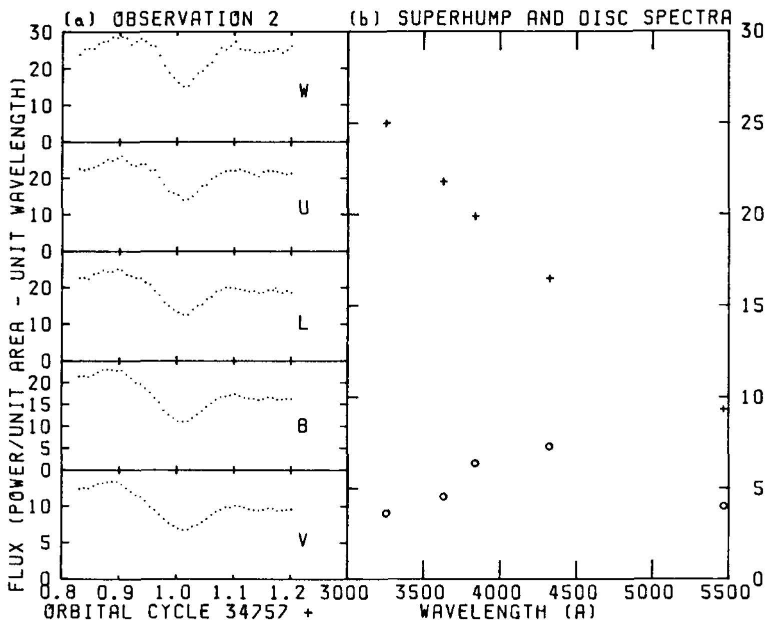

Figure 2. (a) The Walraven light curves of observation #2. (b) The derived spectral distribution for the disk (crosses) and superhump (circles).

https://doi.org/10.1017/S0252921100105093 Published online by Cambridge University Press

entirely due to the disk, and figure 2b shows this plotted as a function of wavelength. As the orbital phase of the superhump predicted from other observations is 0.87, we attribute the excess light before the eclipse to the superhump. This is also shown in figure 2b.

In the superhump spectrum the Balmer jump is clearly not in emission, in fact it shows evidence that it is in absorption, though there is no obvious rise afterwards. We conclude that the superhump is optically thick, and will now use this to estimate its area and temperature by black body arguments.

3. THE SUPERHUMP TEMPERATURE

Observation #6 allowed us to measure B and J band superhump fluxes, which yield a colour temperature of 9200 $\pm$ 1200 K, where the majority of the error is due to the uncertainty in judging the fluxes at superhump maximum and minimum. The corresponding area of the superhump when projected onto the plane of the sky is;

$$(11 \pm 3) \times 10^{19} \left(\frac{d}{100\mathrm{pc}}\right)^2 \mathrm{cm}^2 \qquad \ldots(1)$$

where d is the distance to OY Car in parsecs.

Observation #4 included low time resolution IR data that peaked at the time of superhump maximum calculated from the optical observations. Using the J and K flux in this peak we derive a temperature of 6200 + 700 K, and an area of $(11 \pm 3) \times 10^{19}$ cm^2 at 100 pc for the superhump.

Although the areas derived from observations 4 and 6 agree, the temperatures are significantly different. As the two temperatures are derived from the colour ratios of different pass bands we attribute the difference to temperature structure in the superhump, rather than to a temperature change between the two observations.

4. THE SUPERHUMP AREA AND LOCATION

Whitehurst, Bath and Charles (1984) have suggested that the superhump may lie on the red star. We can calculate the proportion of the red star's surface covered by such a superhump region.

We can find d in equation (1) in terms of the area of the red star when projected onto the sky using the Bailey relation, assuming only that the secondary is, in quiescence, a main sequence M star. We re-arrange the relationship thus;

$$d = \frac{R}{R_o} \times 10^{\left(\frac{K + 5 + S_k}{5}\right)} \qquad \ldots(2)$$

Where R is the radius of the red star. For K, the K band magnitude of the red star, and S_k we use the values of Berriman (1985) (13.9 to 14.9 and 4.1 to 5.1 respectively). We then find that;

$$25\% < \frac{\text{Projected area of superhump}}{\text{Projected area of red star}} < 125\%$$

Whitehurst et al (1984) make no predictions about the size of the superhump region, but our limits make it obvious that a large portion of one hemisphere of the red star must be involved.

In the elliptical disk (Vogt 1982) and intermediate polar (Warner 1985) models the superhump is due to a modulation in the flux from the bright spot. If this is an isotropically radiating bulge on the edge of the disk our data suggests the size of the bulge is of the same order as the size of the red component.

In order to find whether the superhump could lie in the plane of the disk we must first estimate the relative projected areas of disk and red star. We find this ratio is about 1.0, assuming (1) that the disk fills the Roche lobe and (2) the range of values for the inclination and mass ratio given in Cook (1985). So the superhump would cover between 25% and 125% of the disk area. It seems improbable that such a large area of the disk could modulate on a 10 minute timescale, when the viscous timescale of the entire disk is ~ 1 day.

In models where mass transfer modulates the luminosity of the stream impact region (i.e. the elliptical disk and mass transfer modulation of the hot spot models) there is no reason to assume that the stream impact region is a bulge, it may be a stream penetration region. In which case the emitting area derived in the plane of the disk corresponds to the size of the stream penetration zone.

5. THE INFRA-RED STRUCTURE

The IR data in observation #6 behaves much like the optical except that the eclipse is wider, as we expect if the outer regions of the disk are cooler than the inner regions. This contrasts sharply with observation #3 (see figure 3) which shows several strange features. The most striking is that whilst the optical flux is increasing from about phase 0.8, the IR continues to decline. After the eclipse the IR data follows the optical structure (such as "A" and "B") closely.

The IR eclipse is earlier and has a slowly rising flat bottom, whilst the optical eclipse is more nearly "V" shaped. The IR egress begins at the same time as the optical, but the ingress is complete before the optical ingress begins.

The simplest explanation of the pre-eclipse behaviour is that the hump changes temperature such that there is only a significant IR flux before the eclipse (say $\nless 0.5\times10^{-15}$ ergs/cm^2-sec-A). When combined with the B band flux the resulting colour temperature is $\ngtr$ 60 000 K. But this temperature must fall to ~10 000K in 20 minutes. We consider this explanation unlikely.

Instead we suggest that the superhump maintains its usual colours and that some other source of IR flux is fading before the eclipse. As this fall starts before phase 0.75 it cannot be an eclipse of the disk by the red star, and so we tentatively suggest an occultation of a cool region in the disk by the hot spot. An eclipse of the same region by the red star might be the cause of the eclipse distortion.

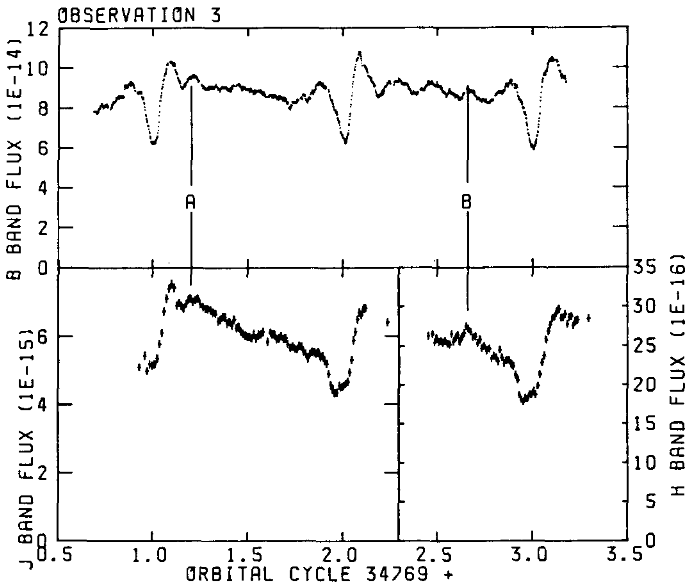

Figure 3. The optical and IR light curves of observation #3, fluxes are in ergs/cm^2-sec-A.

6. CONCLUSIONS

We have shown that the superhump is optically thick, has a temperature of about 8000K and covers an area of the order of half the red star or accretion disk. In addition we have found remarkable differences between the IR and optical behaviour and have concluded that this may be due to a cool region on one side of the outer disk.

More IR observations of superhumps are clearly required, and may well provide the evidence needed to construct a successful superhump model.

REFERENCES

Berriman, G. 1985. Mon. Not. R. astr. Soc. 210 223
Cook, M.C. 1985. Mon. Not. R. astr. Soc. 215 211.
Lub, J. and Pel, J.W. 1977. Astron. Astrophys. 54 137.
Vogt, N. 1982. Astrophys. J. 252 653.
Warner, B. 1985. Interacting Binaries pp 367-392. ed. Eggleton, P.P. and Pringle, J.E. D. Reidel, Dordrect, Holland.
Whitehurst, R., Bath, G.T. and Charles, P.A. 1984. Nature 309 768.