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1) Stream-disc accretion shocks

It is now well established, following the classic work of Smak, Warner and Nather, that discs in dwarf novae possess an anisotropic radiation pattern responsible for the hump, or shoulder, that occurs prior to eclipse in the quiescent state, and, in systems with suitable inclination such as Υ Gem, responsible also for the primary eclipse itself. In systems with higher inclination such as Z Cha, the primary eclipse is composed of both this anisotropic disc component and the inner-disc/white-dwarf primary component.

In the quiescent state the anisotropic component generates a radiation pattern and an eclipse profile which place it in the region where the mass transfer stream impacts the disc edge, while radiating away from the white dwarf in the form of a spot of dimension $\approx 10^9$ cm. This component is commonly called the "hot-spot", though it is now clear that it is not hot compared to the inner disc region. It is hotter than disc regions at different azimuth, but the same radius, but cooler than regions further in and is, relatively speaking, optically bright. It is probably better termed a "bright-spot" as some authors have previously indicated.

It is normally assumed that this quiescent bright-spot results from shock-heating of the stream/disc gas at the point of impact of the stream with the disc. However, in situations in which deep penetration of the stream is occurring it is not at all clear that such a spot will be formed. It is well established that during eruption the phase of maximum hump light is not stable. It may undergo somewhat irregular phase variations (humps), or behave as a periodic wave with a period longer than the quiescent hump period by a few percent (superhumps) (Vogt 1974, Warner 1975). We describe here two independent mechanisms which could account for these two phenomena.

2) Humps and peapod diagrams

In circumstances in which the main anisotropic component is generated by the disc, two extreme disc/stream shock heating patterns can be distinguished. These depend on the density of the stream and of the outer disc regions. In one case the stream hits a higher density disc with negligible penetration and formation of a standard bright-spot. In the second case the disc hits the stream as the stream penetrates the disc, a shock-heated "wall" is produced at the point where low density disc material impacts the stream, and some fraction of stream material is stripped into the disc.

The sort of conditions we envisage here are illustrated in Fig.1.

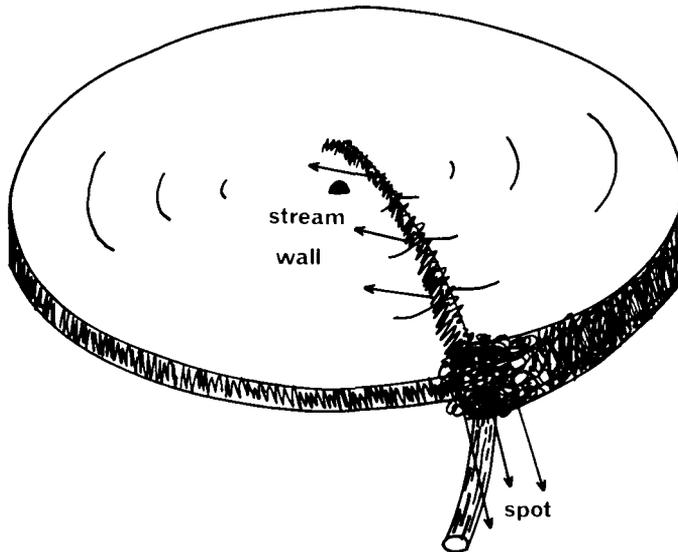


Fig.1

At its most extreme this stream-stripping process can be envisaged as producing a wall, tilted at an angle, ψ above and below the disc plane (we assume below a tilt angle of 45°) and radiating in the direction indicated in Fig.1. In practice the wall will not be a stable feature, and downstream disc emission will doubtless be significant. Nonetheless we anticipate that the radiation pattern will tend towards this extreme case in circumstances of deep stream penetration.

In order to study the anisotropic pattern generated by stream/disc impact we plot the anisotropic component generated by these two processes as a function of phase in a polar diagram. In Fig.2 we show the radiation generated by a quiescent state alpha beta disc ($\alpha = 1.5$, $\beta = 0.1$) in which the bright-spot component dominates. Within region (2) we plot the total anisotropic radiation component above the disc on a logarithmic scale, relative to the isotropic disc component. In region (1) we plot the anisotropic component alone. The continuous line is the visual luminosity, and the thin broken line the bolometric luminosity.

The thick dotted line shows the polar distribution of anisotropic radiation from Z Cha during the second orbit on Dec 1972 (Warner 1974). It is evident that all the characteristics of the radiation pattern are represented by the standard bright-spot model in this "peapod" diagram (peripheral excess anisotropy polar diagram). The diagram also suggests that stream penetration and wall radiation may be responsible for a small degree of excess flux at phases 0.25 to 0.50 with respect to the spot.

At outburst in Z Cha it is well established that the hump may move in binary phase to an apparent position almost opposite the spot. In Fig.3 we show the radiation pattern produced by an outburst in Z Cha during the second orbit on Jan 8 1973 (Warner 1974). We compare this with the radiation pattern generated by deep stream penetration. The movement of the hump is clearly reflected by a shocked wall model. In practice we find that such a wall always produces excess flux between phase ≈ 0.25 and ≈ 0.50 with respect to the spot, with small changes in phase in response to increased penetration. However, with increased penetration and disc evolution the contribution of the wall relative to the spot can change significantly. During the decline of the same outburst in Z Cha the hump pattern returned to a standard spot pattern, but with some excess flux in the region 0.50 to 0.75 in phase. Clearly the division of anisotropy effects into a bright-spot and a penetration wall is an over-simplification. We consider the general principles outlined here incorporate the fundamental features of stream/disc penetration and provide a basis for further discussion of anisotropy effects resulting from stream/disc impact.

Superhumps

Superhumps have probably led to more sleepless nights than any other phenomena so far discovered in cataclysmic variables. The increase of hump period by a few percent commonly found in SU UMa super maxima outbursts has proved resistant to any acceptable explanation when closely examined. We point out that Warner's (1975) original suggestion that the superhumps are due to anisotropic radiation from a non-synchronously rotating red component is still not excluded observationally, and we present here both observational and theoretical arguments in support of such a model.

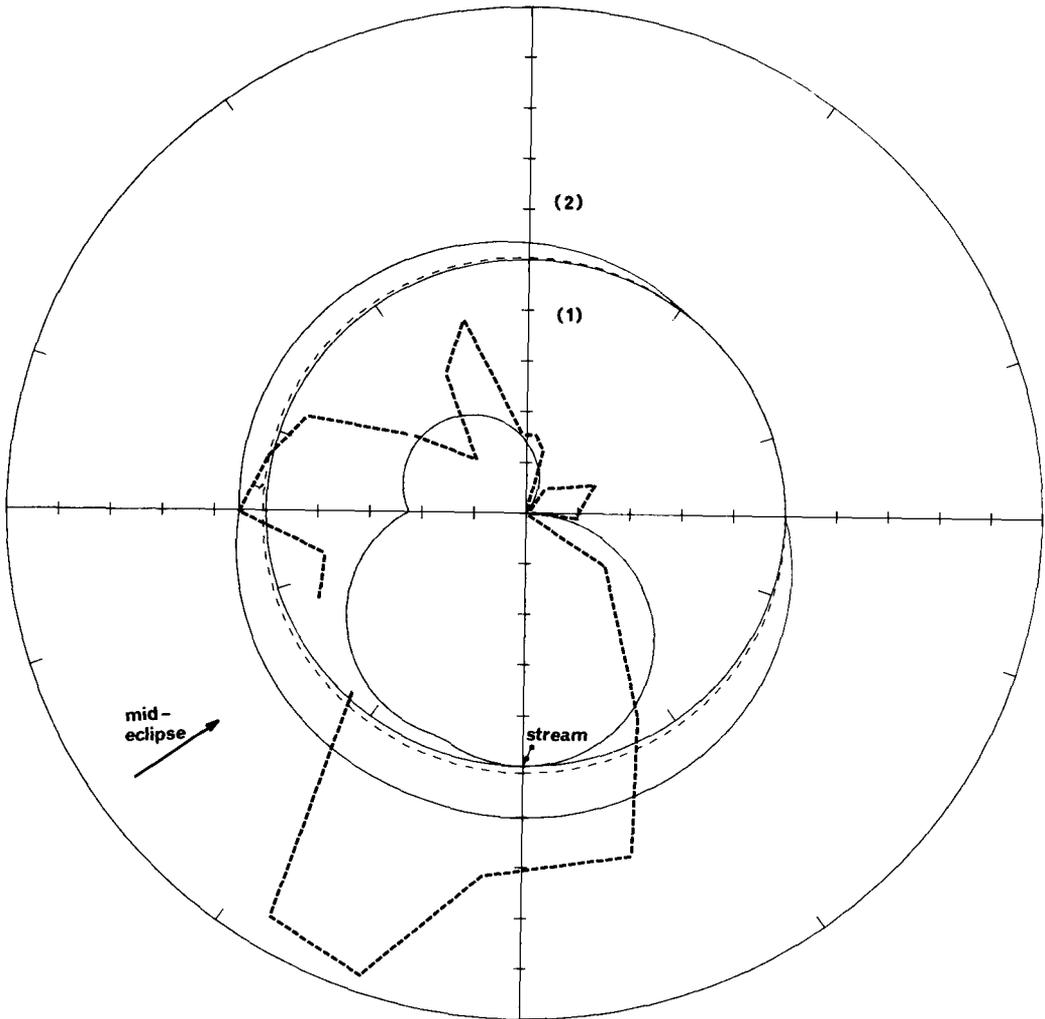


Fig.2 Distribution of anisotropic radiation with binary phase in the quiescent state (peapod diagram). In region (1) the anisotropic component only is shown, in region (2) the total relative to the background isotropic component. The model has $\beta = 0.1$ (thin line) and is compared with the observed hump distribution of Z Cha (thick dotted line) on Dec 7 1972.

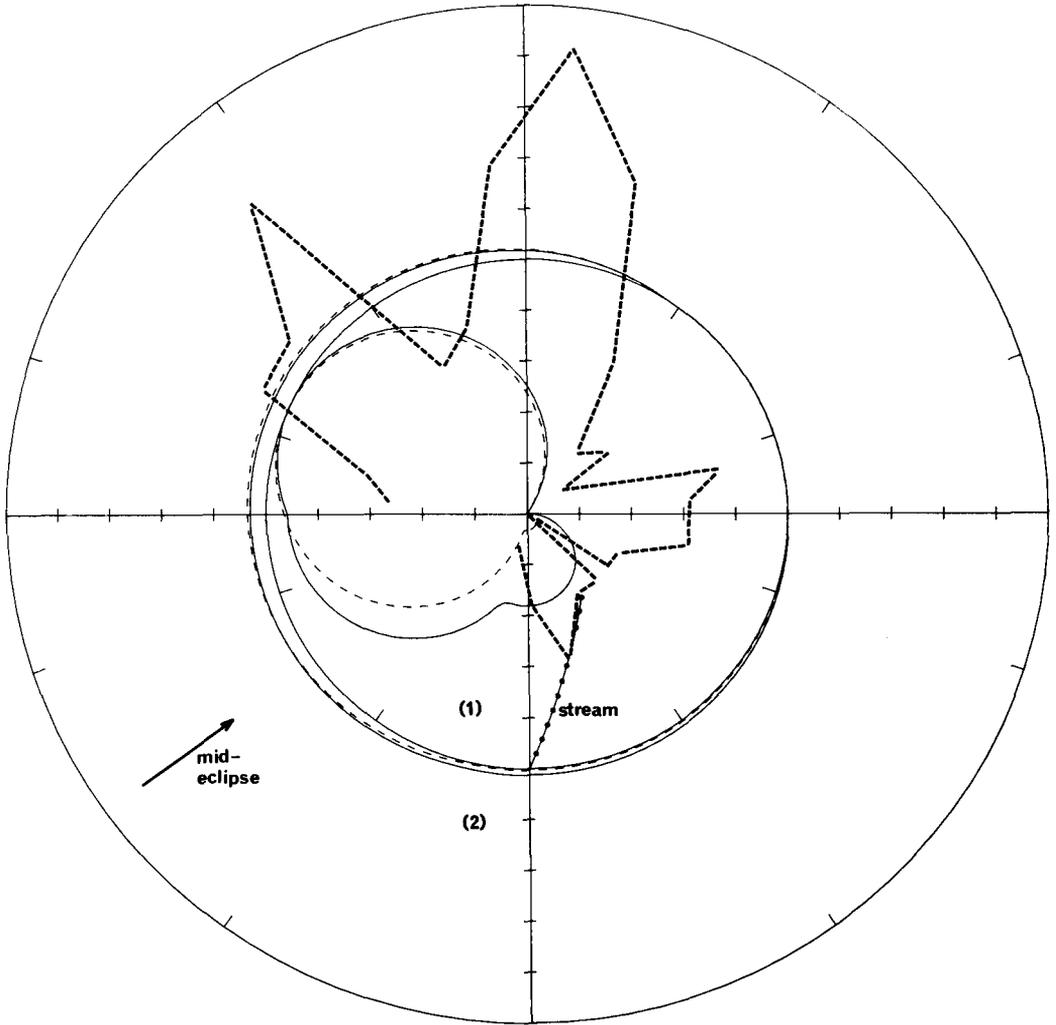


Fig.3 Peapod diagram in the outburst state. The model exhibits deep stream penetration and radiation from the wall now dominates. The distribution in phase is similar to that seen at outburst in Z Cha on Jan 8 1973 (thick dotted line).

In VW Hydr1 the quiescent hump period is well established to be stable with $P = .07427107 (\pm 5)$ day (Vogt 1974, Warner 1975, Bailey 1976). At supermaxima the typical quoted superhump period is $P = .074676$ day. If we interpret the quiescent period as the orbital period, then the superhump period corresponds to a beat period of 2.2 day, which would be produced by nonsynchronous rotation of an asymmetric radiation component with a backward rotation period of 2.2 day in the rotating frame of the binary. Evidently a slowly rotating red component with a large scale asymmetric radiation pattern due to a surface "bright-feature" radiating sufficient luminosity in the optical would produce the effect observed.

We argue here that the shortest period cataclysmic systems (i.e. the SU UMA systems exhibiting supermaxima) contain slowly rotating red components, which have lost angular momentum through previous evolutionary mass transfer and have yet to achieve synchronism through tidal dissipation. Normal outbursts are produced by a discrete local dynamical instability in the neighbourhood of the inner Lagrangian point (Bath 1975, Papaloizou and Bath 1975). Supermaxima outbursts are produced by continued dynamical mass transfer as material slides past the inner Lagrangian point through non-synchronism. The superhumps result from asymmetry in the radiation field on the surface of the red component through variation in the strength of the instability around the equator and variations with longitude in the subsequent thermal relaxation time.

It is a notable feature of many supermaxima outbursts that they show structure, or repetitive mini-maxima following the rise. In VW Hydr1 we find that all four supermaxima outbursts published by Bateson (1974) show evidence for modulation with a period 2.0-2.5 day. The average of all four light curves is shown in Fig.4, with the outbursts aligned to rise simultaneously. There is clear evidence for periodic modulation at about the beat period. Cross-correlating the data shows the signal disappears when shifts of an odd number of days are introduced. Could this be evidence that the red component is transferring mass into the accretion disc at a variable rate as the superhump region on the red component is brought past the inner Lagrangian point? It is certainly the case that the superhump becomes more isotropic and is progressively smeared out as the outburst progresses, in the same way as the 2.2 day modulation of the overall superoutburst dies away.

A decisive test which would locate the asymmetric radiating region on the red component (or possibly outside the system) is the depth of the primary eclipse. We predict that the depth of the primary eclipse below the background should be constant, that is, the bottom of the primary eclipse rise simultaneously with the march of the superhump through it (apart from any independent variations in disc luminosity which may occur). We do not anticipate deep secondary eclipses, since the primary eclipsing object is only a thin, flat, bright strip.

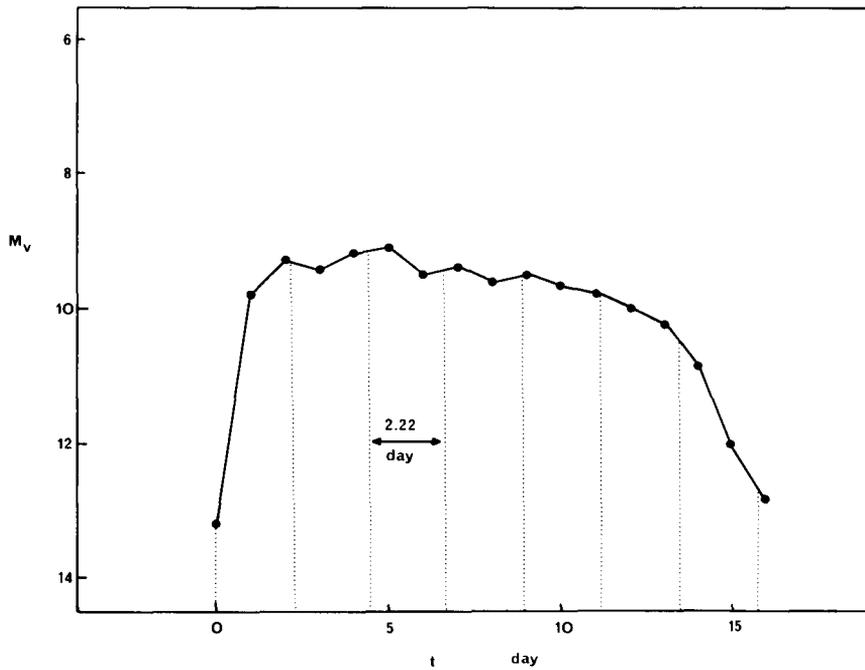


Fig.4 Average outburst light curve of four successive supermaxima outbursts of VW Hydri. Each individual superoutburst shows evidence of a 2.0-2.5 day oscillation, as does this average light curve.

References

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DISCUSSION FOLLOWING G. BATH'S TALK

ROBINSON: If your model is right one might expect a correlation between the amplitude of the hump and the inclination of the orbit, do you know of any such correlation?

BATH: No, I don't, I haven't thought about that.

RITTER: If this model is right, your bright spot on the secondary star must be bright indeed, because the overall luminosity of the system is very large and we know that in these systems we cannot see the secondary in quiescence in the visible region, so if you now create a spot which you can see in visible light, when the system is at least one hundred times brighter than in quiescence, you must have a fantastically hot region on the surface and so, you could immediately predict something about the colour behavior of your superoutbursts, so have you looked into that?

BATH: No, I have not looked into this. Let me just say about the luminosity of the hump or the superhump. Whatever model you propose for the superhump, it has to have that luminosity, that is the first point. The second point is that in the spherical models of mass transfer instabilities, I found that the luminosity did increase by a factor of the order of a hundred, over the whole surface of the star and the question is how much of this is covered.

WARNER: You are concentrating on VW Hyi here, if the mechanism applies, in say, OY Car, than you would expect deep secondary eclipses, secondary minima, which are not observed during a supermaximum of OY Car. So, the absence of deep secondary minima during superoutbursts, I think, excludes the secondary as the source of the extra luminosity.

MATTEI: I will study some more supermaxima light curves to see if there is a real structure, but I want to ask how do you explain the appearance of superhumps two or three days later than the start of the supermaximum, according to the model? Why don't they appear right away?

BATH: I don't know.