THE ACCRETION DISK IN DQ HER

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DQ Her is one of the best studied Cataclysmic Variables. It is a classical nova which erupted in 1934 (Nova Herculis). Its optical lightcurve does not repeat accurately from one binary cycle to the next, but usually looks roughly like it does in Fig. 1. The small hump and

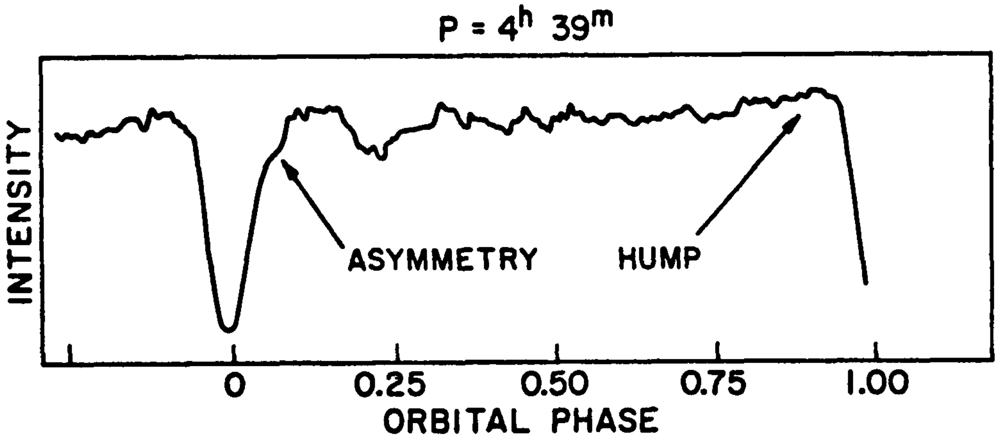

Fig. 1 Typical optical lightcurve of DQ Her, showing 90% deep eclipse, irregular flickering, and the eclipse asymmetry and hump.

small eclipse-asymmetry are probably both caused by the hot spot at the outer rim of the disk. The eclipse depth of ∿90% argues for an inclination angle near 90°.

DQ Her shows rapid oscillations with a 71 sec period. These are low amplitude sinusoidal variations which (in this system) remain coherent over many years. The quality factor for the underlying clock of about 10^{12} strongly suggests that we are dealing with the rotation of a solid body here, presumably the white dwarf. The phase of the oscillations undergoes a regular variation with the binary motion, and the most spectacular part of this is the large phase shift during eclipse, shown in Fig. 2 (Patterson et al. 1978). At eclipse ingress ($\phi \sim 0.91$) the oscillations begin to come earlier and earlier, until at mideclipse they jump from 90° early to approximately 90° late, after which they gradually return back to the phase they had originally. During the eclipse, the amplitude of the oscillations decreases as shown in Fig. 3. The slight asymmetry in both curves (Figs. 2 and 3) is usually attributed to the presence of the hot spot at the disk rim.

The oscillating light probably does not come directly from the white dwarf, but is reflected off the disk. This is strongly suggested

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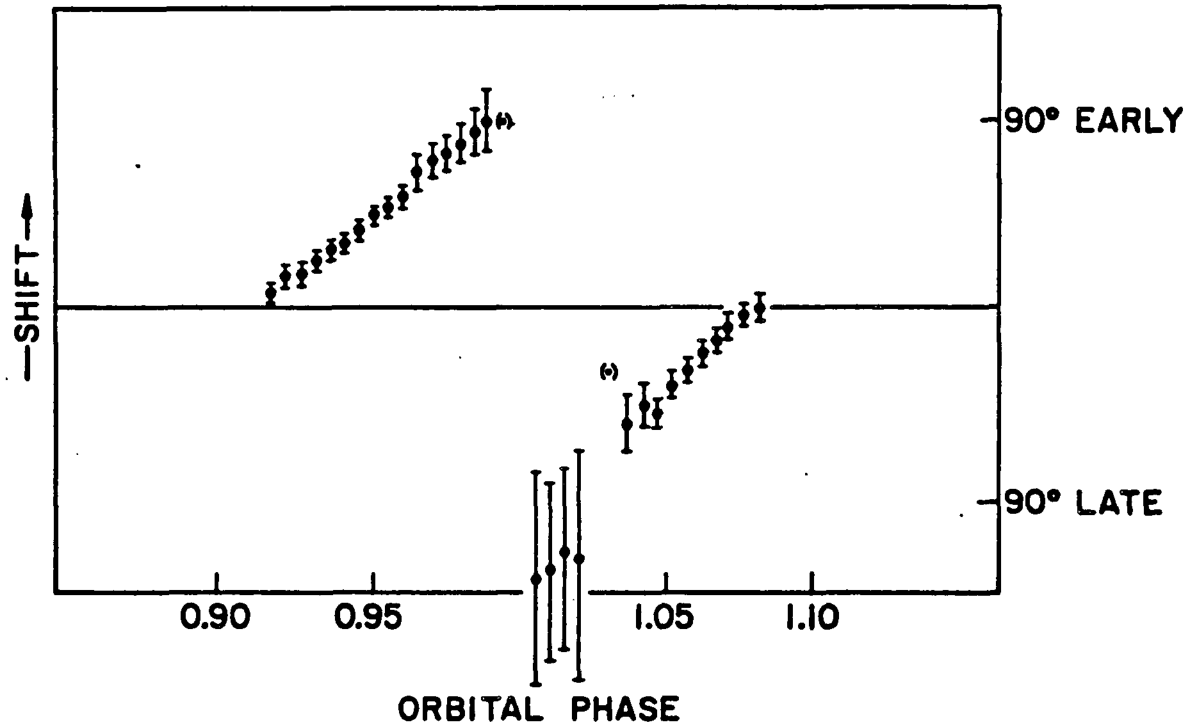

Fig. 2 Phase shift in the 71 sec oscillations as a function of orbital phase (data from Patterson et al. 1978).

by the fact that the duration of the phase-shift roughly equals the duration of the eclipse itself. It is further supported by the "wavelength dependent phase shift" of Chanan, Nelson, and Margon (1978). Adopting this idea, one can explain the shifts roughly as indicated in Fig. 4. Before eclipse, the maximum of the oscillation occurs when the illuminating rotating beam, emitted by some spot on or near the white dwarf surface, points in the direction of the backside of the disk, i.e. away from the observer (Rees, 1974; Herbst et al. 1974). This direction then changes when the eclipse progresses, as the sequence of snapshots in Fig. 4 illustrates.

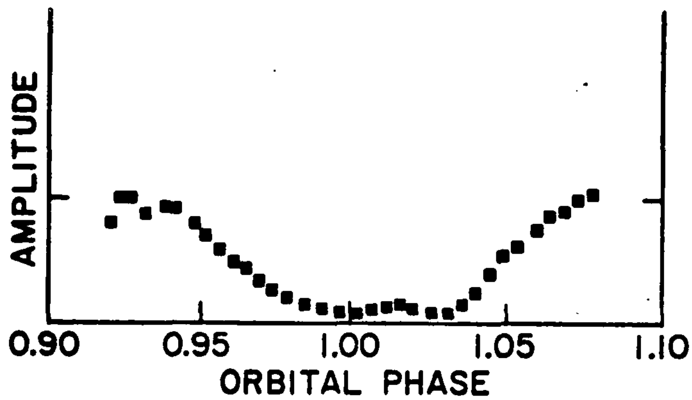

Fig. 3 Amplitude of the oscillations as a function of orbital phase (data from Patterson et al. 1978).

To make the explanation of the phase shifts somewhat more quantitative, I used the numerical model sketched in Fig. 5. A 0.6 $M_{\odot}$ Roche lobe filling star is accompanied by a 1 $M_{\odot}$ white dwarf which lies at the center of a slightly concave "standard accretion disk" (Shakura and Sunyaev, 1973) with a halfthickness proportional to $r^{9/8}$. The outer edge of the disk is fixed at 86% of the primary's Roche lobe, in accordance with estimates for its tidal cut-off radius (Papaloizou and Pringle, 1978). A spot on

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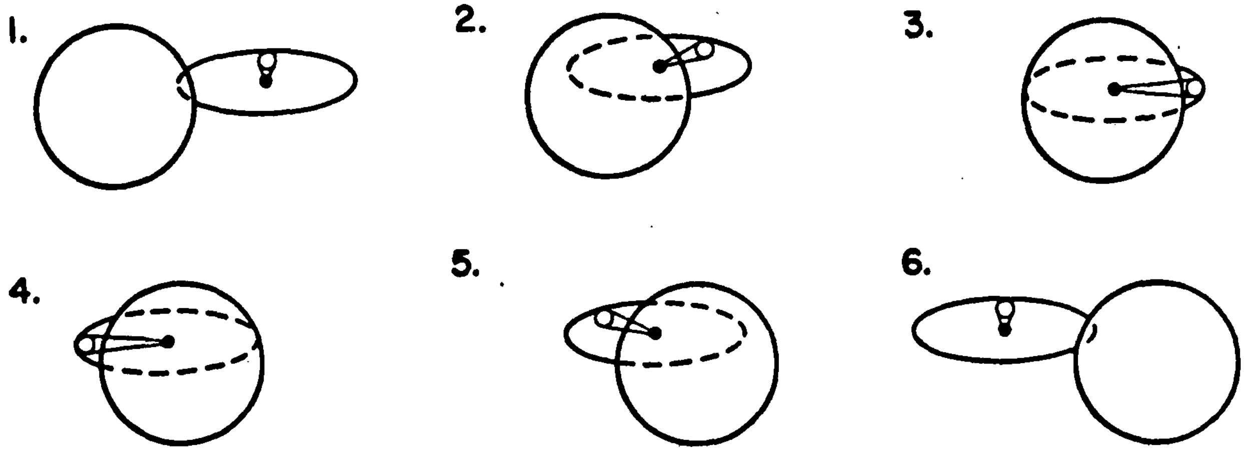

Fig. 4 Series of snapshots of the DQ Her system during eclipse. The illuminating beam which originates on or near the white dwarf surface is shown in the position where the oscillation goes through a maximum. It is drawn as a narrow beam for clarity, but is in reality probably quite wide.

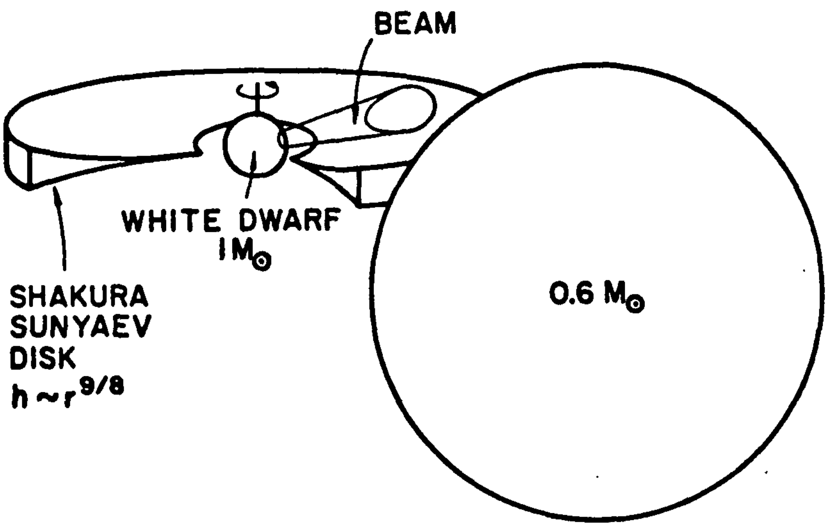

Fig. 5 Schematic view of the DQ Her binary system with white dwarf, disk, and companion star. The illuminating beam originates in the model from a small region on the surface of the rotating white dwarf, e.g. a magnetic pole.

the surface of the rotating white dwarf emits a cosθ-shaped beam, which reflects off the surface of the concave disk. Details of the model are given in Petterson (1979).

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The oscillating part of the reflected light seen by an observer at inclination angle i is then numerically computed, and the amplitude and phase of its fundamental and second harmonic determined as a function of orbital phase of the binary system. Figure 6 and Figure 7 show the phase shift and amplitude of the fundamental for different values of i,

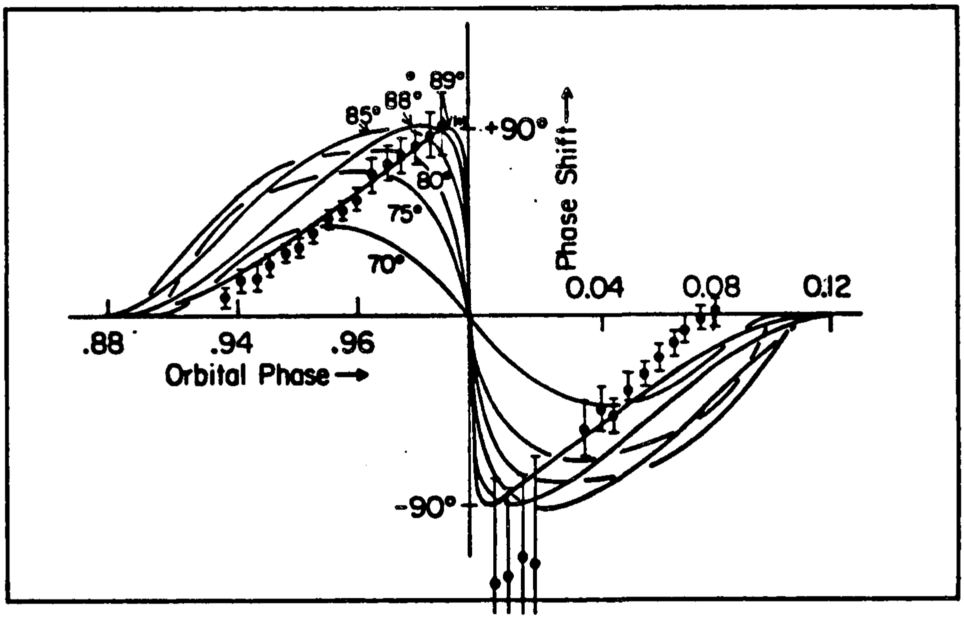

Fig. 6 Model curves of the phase shift for different inclination angles i, compared to observations. Curves are labeled by their inclination angle.

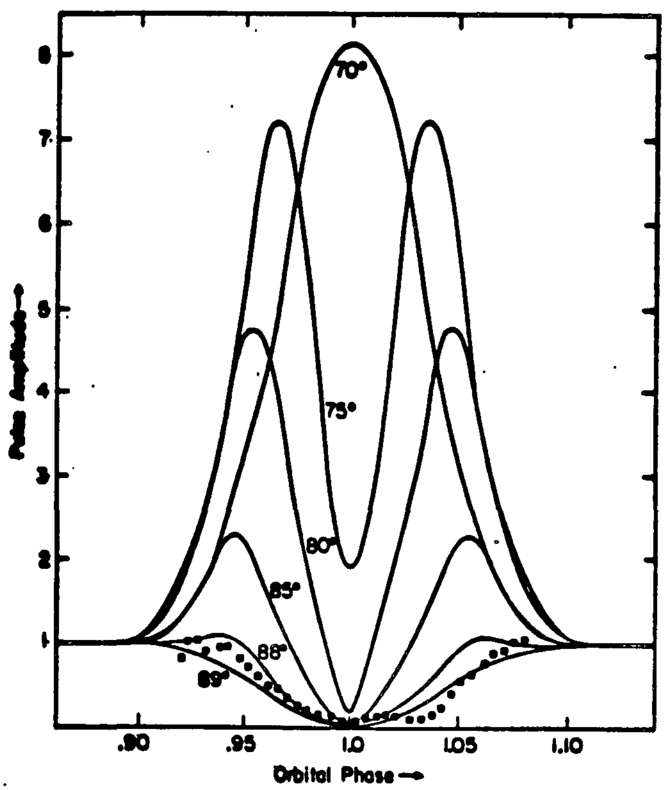

Fig. 7 Model curves of the oscillation amplitude for different inclination angles i, compared to observations.

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during a range of orbital phases near eclipse. Comparison with the observations indicate a good agreement for inclination angles 88°-89°, i.e. very close to the binary plane. The small asymmetry in the observed curves cannot be matched by the model-curves, because the hot spot is not included in the model (Chester 1979, and Alpar 1979 propose disks which incorporate a hot spot).

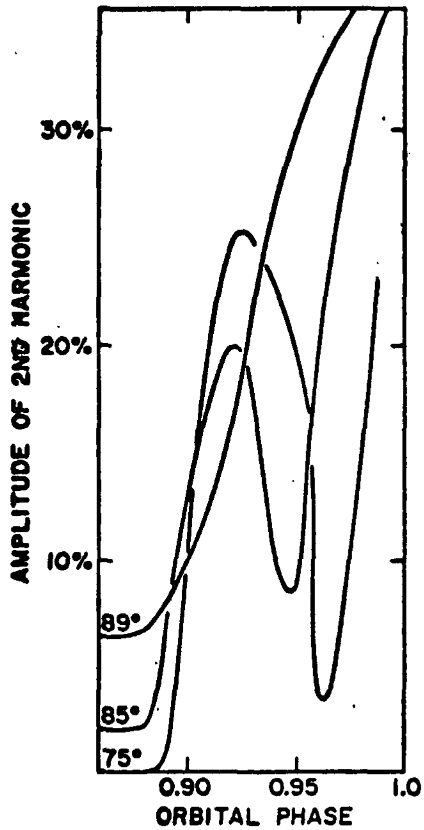

Fig. 8 Amplitude of second harmonic (expressed in % of the fundamental) as a function of orbital phase, for three different inclination angles.

The amplitude of the second harmonic (in % of the amplitude of the fundamental) is plotted in Fig. 8 as a function of orbital phase for three different inclination angles. The value of 5%, observed outside of eclipse (Kiplinger and Nather 1975), fits a model curve of ∿88°. During eclipse the amplitude of the second harmonic dramatically increases for all values of i in the model. It would be interesting to look for this effect in the observations.

The good agreement between observations and model at angles i ≃ 88°-89° suggests that we observe DQ Her so close to the orbital plane, that the disk rim (in the "standard" disk model it is about 2° thick) obscures the entire front half of the disk surface, including the white dwarf itself. Thus, it should perhaps be no surprise that no X-rays are observed from this system. However, the determination of the inclination angle may not be quite as accurate as the fit in Fig. 6 suggests. The disk may have a thicker outer rim than it does in the standard model, and that probably would allow inclination angles a few degrees further away from the binary plane.

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