TRANSIENT DISKS AND MASS TRANSFER IN U CEPHEI*

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Conspicuous, variable photometric contamination was observed during primary eclipses of the totally eclipsing Algol-like system U Cep from late-1974 to late-1977. Excess light was particularly prominent between second and third contacts, and originated mainly in optically thick accretion disks surrounding the B-type hot component. Observations of such disks were obtained with uvby (I) photometry during 10 eclipses, using the 1.0 M and 0.4 M reflectors at Prairie and Kitt Peak National Observatories. Figure 1 shows ultraviolet observations between internal contacts for active (October, 1975) and quiescent eclipses. The light excess over quiescent levels was converted to flux distributions L_λ^c relative to the quiescent visual flux of the G-star.

Some light variation was present even at mid-eclipse. This light declined in brightness during October, 1975, and its spectral distribution was that of the G-type cool component. Most of the extra light evident closer to internal contacts came from accretion disks. Ingress disk light was always stronger than egress light, and varied significantly on a time scale as short as 10 days. It is possible that the brightness variations of the outer hemisphere of the G-star were related to the erratic mass flows that produced the accretion disks.

Incremental fluxes $\Delta L_\lambda^c(\phi_1,\phi_2)$ between orbital phases ϕ_1 and ϕ_2, being independent of G-star variations from eclipse to eclipse, were used to describe the disk light. Phases 0.995, 0.990, 0.985, and 0.9815 ($\approx$ second contact), and egress counterparts, were convenient in calculating ΔL_λ^c. Similar progressive changes in flux distribution with phase were noted in 16 ingress/egress disks. Light from disk edges showed Balmer jumps in emission, and was characteristic of near-10,000 K plasma of finite optical thickness. Most disk radiation was truly optically thick; the Balmer jump, in absorption, grew slightly but consistently stronger moving in phase away from the disk "limb". A satisfactory model (Figure 2) explains this radiation as near-limb emergent intensity from a slight extended stellar atmosphere. That is,

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ΔL^{c}_{λ}(calc) $\sim I_{\lambda}(o,\mu)$ ΔA(disk), where ΔA(disk) is the radiating cross section. Four parameters enter these models: T(disk), log g, μ, and A(disk). Disk properties were fairly consistent on all nights. T(disk) was usually between 12000 and 13000 K; log g, as expected, was lower than that of the B-star; μ was $\approx$ 0.05 to 0.2, implying near-grazing light emergence. H/R(B), disk semi-thickness normal to the orbital plane and relative to the B-star radius, varied from 0.2 to 0.6. Outer disk radii were (1.3 to 1.5) R(B). Thus, at peak disk size, U Cep resembled peculiar close binaries such as W Ser and RX Cas, recently discussed by Plavec and Koch (1979).

Such geometrically thick disks were not in hydrostatic equilibrium since the sound travel time from disk center to top was about three times the orbital period of a typical disk particle. To be optically thick at all observed wavelengths, minimum required disk masses were $\approx 2 \times 10^{-10}$ solar masses. An order-of-magnitude estimate of the rate of mass transfer follows by assuming that much of the transferred mass went into the disk, and that accretion from the disk supplied the disk luminosity. If the disk was continuous around the outer hemisphere of the B-star, and had mean properties of the disk segments seen at ingress or egress phases, the luminosity increase with disk was $\Delta L \approx$ (0.1 to 0.6) L(B), where L(B) is the normal B-star luminosity. Since most of the orbital kinetic energy is unavailable for accretional heating because of the rapid B-star rotation, let L(B) $\Delta L \approx [0.3\ G\ M(B)/R(B)]\dot{M}$, where M(B) is the B-star mass and $\dot{M}$ the mass accretion rate. This gives $\dot{M} \approx (1 \text{ to } 6) \times 10^{-6}$ solar masses yr^{-1}. Significant disk light was present from late-1974 to late-1977 about 0.3 of the time, suggesting a mean transfer rate $\approx (0.3 \text{ to } 2) \times 10^{-6}$ solar masses yr^{-1}. The period was essentially constant in this same interval (Crawford and Olson 1979). It therefore seems likely that this time of active disk formation and collapse was one of normal or below-normal mass transfer. A large period decrease, implying loss of orbital angular momentum occurred in 1972 (Hall and Keel 1977). If the historical period trend of U Cep is to continue, a significant period increase must occur in the near future.

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References

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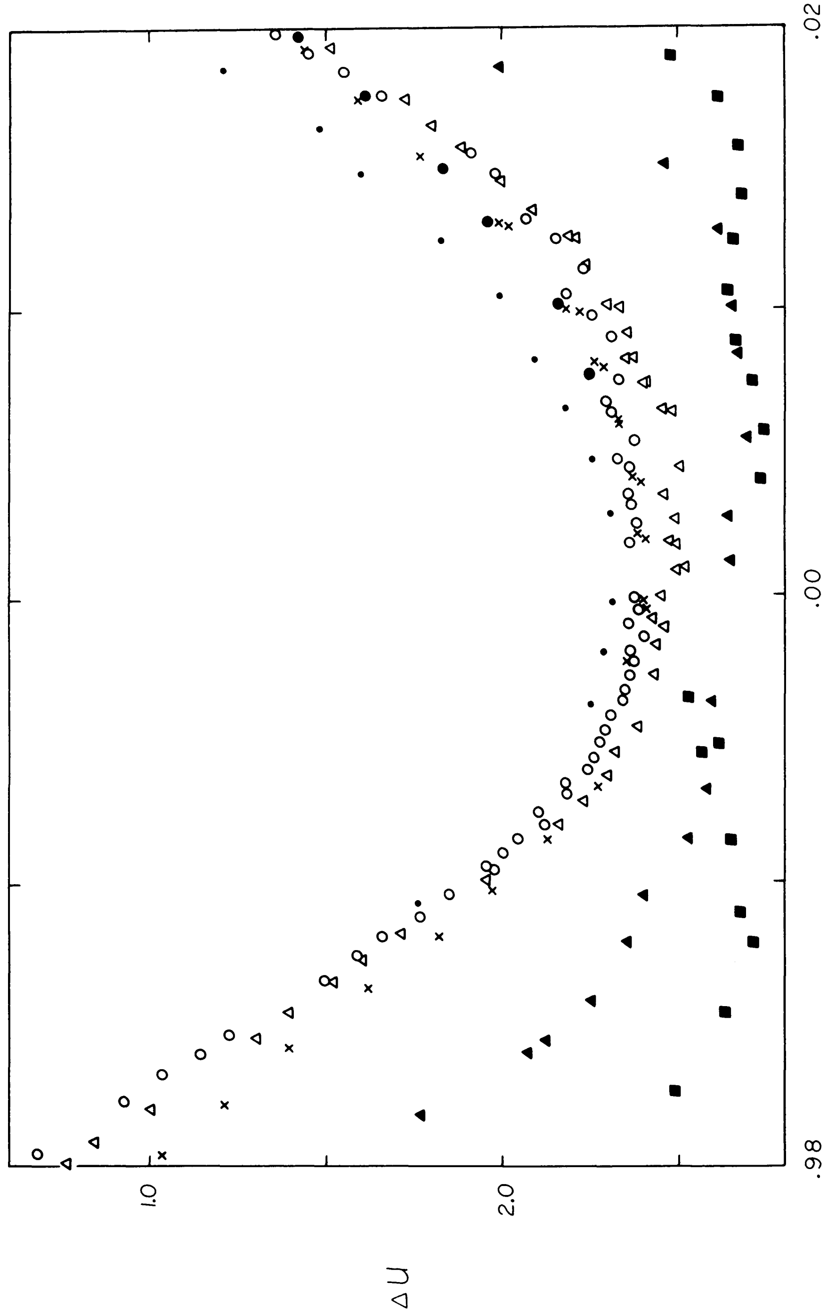

Fig. 1. - Ultraviolet observations of U Cep near mid-primary eclipse. Small filled circles, UT 1975 October 6; crosses, October 11; large filled circles, October 16; open circles, October 26; open triangles, October 31; filled triangles, November 20, filled squares, 1975 December 20.

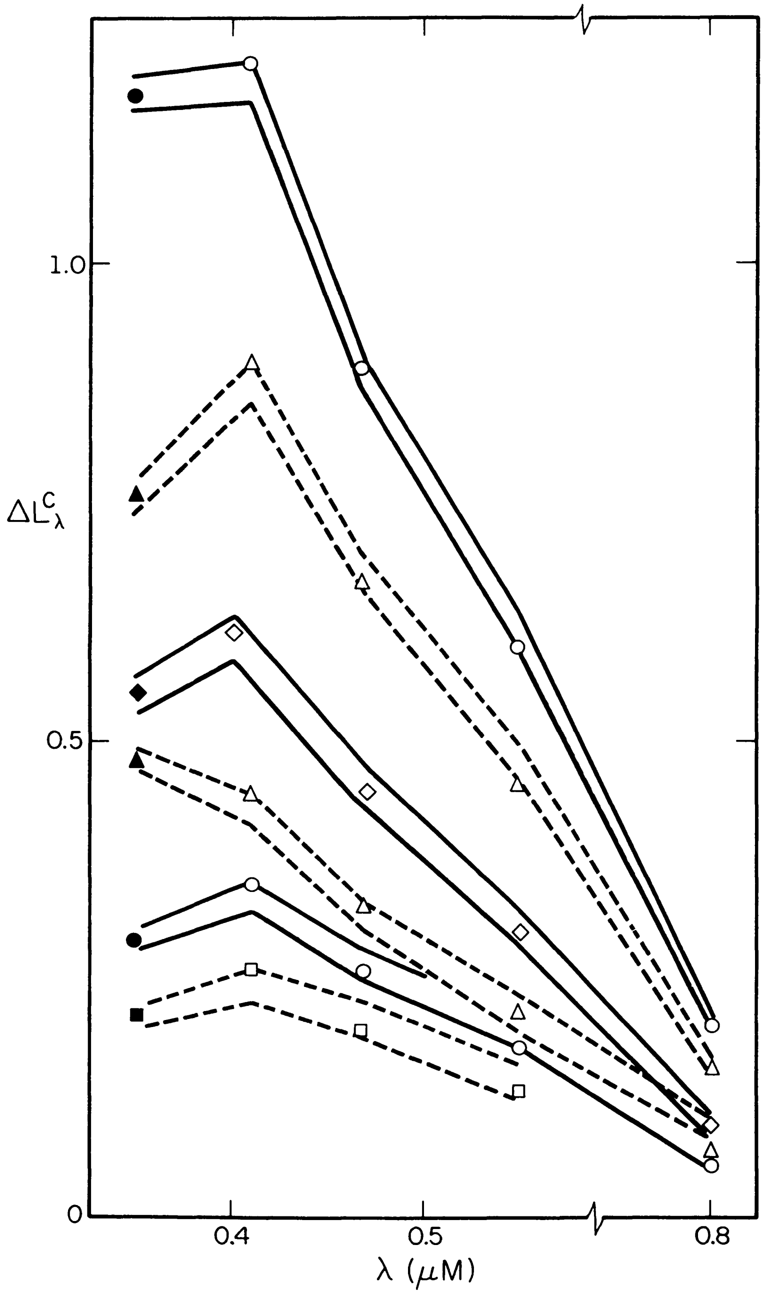

Fig. 2. - Flux distributions from various portions of ingress and egress disks. Solid and broken lines show observations with estimated errors. Symbols are model calculations, and represent (L to R) u, v, b, y, and I wavelengths.

COMMENTS FOLLOWING OLSON

Zuiderwijk: Do you have an estimate of the total mass in this disk-like structure? If so, can you build it, or destroy it, on the timescales you observe?

Olson: Minimum disk masses, estimated by supplying enough mass to produce optically thick disks, $\sim 2 \times 10^{-10}$ solar masses. Rapid disk collapse is not via viscosity effects. Disk particles may simply carry insufficient angular momentum to complete orbits around the B-star. Therefore, mass accretion from the disk may supply the disk luminosity.

Kondo: The CIV ($\lambda\lambda$1548 and 1550) and SiIV ($\lambda\lambda$1393 and 1402) resonance lines showed variations at different phases of U Cep. This may be related to the presence or absence of the hot or cool spots.

Olson: Yes.

Smak: A comment and a question: It would seem to me that the nearly identical values of O-C you obtain from "distorted" light curves may indicate that the source of this distortion is the hot spot. And how did you determine the moments of minima when distortions were present?

Olson:
The disk light asymmetry and extra light from the hot spot both contribute to delays in apparent times of minima. Distorted light curves also may show light losses on egress branches, which also contribute to the delays. Kwee-van Woerden method was used to determine t(min), but only undisturbed eclipses were used to determine the true "undisturbed ephemeris"(see Crawford and Olson, P.A.S.P. in press).

Hall: Concerning the brightness changes you ascribe to the cooler star and the brightness changes you ascribe to the hotter star and its temporary disk, were they related in any way? For example, were they coincident in time or did the first precede the second?

Olson: In both the fall 1974 and fall 1975 series of distorted eclipses, peak brightness of the outer hemisphere of the G-star preceded disk maxima by many orbital cycles. G-star brightness fell monotonically during each fall. There is a suggestion that brightening of the G-star precedes mass-transfer bursts that produce transient disks.

Smak (after Hall): As a follow up to Doug Hall's question: Did you get any IR observations for the secondary eclipse?

Olson: I have some observations of secondary eclipse in late October, 1975, but no detailed time sequence that might show progressive changes in the G-star.