NOTES ON THE INTERPRETATION OF OBSERVATIONS OF CIRCUMSTELLAR MATTER IN BINARY SYSTEMS

A. H. BATTEN
Dominion Astrophysical Observatory, Victoria B.C., Canada

Abstract. Problems of relating different observational indications of the presence of circumstellar matter in binary systems are discussed, with especial reference to the observed period changes in systems whose other properties are very similar. It is suggested that some fluctuations observed in the periods of close binary systems are apparent and not to be attributed to dynamical causes. The discussion includes some account of recent activity in U Cep, and the possible causes of spectroscopic changes in binary systems are examined.

Although the existence of circumstellar matter in close binary systems can be inferred from several different kinds of observation, a single consistent interpretation of them all cannot easily be made. Period changes and spectroscopic observations offer particular difficulties of interpretation, some of which are discussed in this paper.

When we infer changes in the orbital period of an eclipsing binary from accurate times of minimum light, we assume that those times are the same as the times of mid-eclipse and of the conjunctions of the two stars (unless the orbit has an appreciable eccentricity). Usually these assumptions are justified. Hall (1975) has shown that even the degree of asymmetry commonly found in the light curve of U Cep is insufficient to account for the deviations of normal points (averaged from several minima) from the mean parabola that best fits the apparently steady trend of residuals from the predictions of a constant period (Figure 1). This trend corresponds to a mean rate of increase of about 0.2 s yr^{-1} in the orbital period of approximately 2.5 days. Hall (1975) suggests, however, that the period increase is not steady, but consists of a series of increases (of different rates) interrupted by sharp decreases. The net effect is still an increase in period (which is needed to explain the observations) but Hall proposes nine or ten parabolic segments to represent the residuals, rather than one mean parabola on which are superimposed irregular fluctuations. He fits this proposal very neatly into the theory of period changes advanced earlier by Biermann and Hall (1973). His interpretation, however, depends strongly on the assumption described above. It omits the possibility that the light curve of U Cep may sometimes be very strongly distorted.

Bakos and Tremko (1973) observed an eclipse of U Cep in August 1969 from which they deduced a time of minimum 20 min later than predicted from the period and epoch found from eclipses observed only a few weeks before and after. Hall (1973) himself pointed out that a dynamical interpretation of this led to very improbable conclusions, and Bakos and Tremko (1974) checked their calculations in answer to his criticism. Their check revealed no mistakes, and unless some very improbable error in recording times (which cannot now be detected) was consistently made all night, there is no escape from the conclusion that a large delay in the observed time of minimum was produced by some cause that was not dynamical. The distortion of the light curve was more than usual on the night in question; totality lasted about ten minutes less than its normal duration. This may not seem enough to account for the twenty-minute delay, but if a light curve is appreciably distorted we cannot be sure exactly how great the distortion is. There is no

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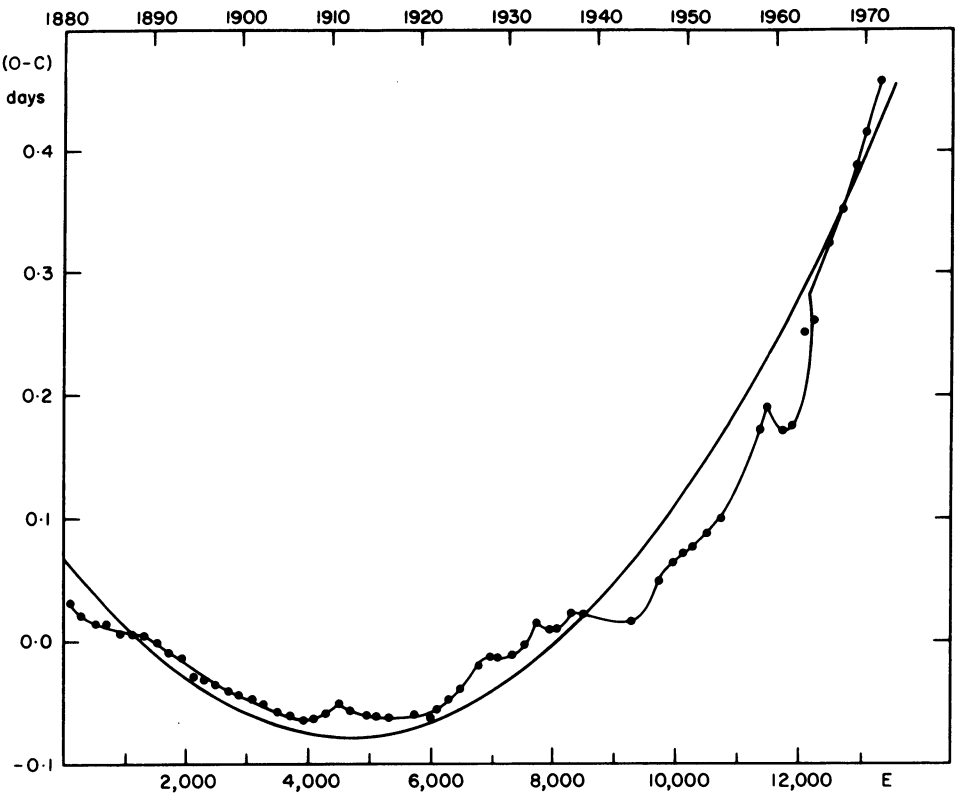

Fig. 1. Residuals of times of minimum of U Cep from a linear ephemeris. The smooth curve is the best-fitting single parabola; the other curves indicate the period changes proposed by Hall.

reason to suppose that the distortion is necessarily symmetrical about the time of mid-eclipse.

During the latter part of 1974 we observed an outburst of U Cep during which several people independently recorded very large distortions of the light curve. The best photometric coverage of the event was obtained by Olson (1976) although photometric anomalies were also reported by Batten *et al.* (1975) and Plavec and Polidan (1975). At times, the light curve resembled that of a partial eclipse. If the eclipses of October 1974 had been observed only visually, even this marked asymmetry might have escaped notice, but the time determined for minimum light would certainly have been different both from that of mid-eclipse and that of conjunction. Although the outburst observed in 1974 is unique in our experience similar ones have probably occurred many times before. Indeed the event of 1969 may have been one since the photometric disturbance was accompanied by the appearance of emission (Batten, 1969) as was also the case in 1974. Emission was seen in the spectrum again in 1972 (Naftilan, 1975) although we do not know if any photometric anomalies were observable then. Some of the departures of points in Figure 1 from the smooth parabola may indicate earlier outbursts of the type observed last year. If so, Hall's interpretation of the fine structure of this diagram is open to question. The fine structure may be very important for understanding what is going on in the system, but it is not necessarily entirely the result of dynamical causes.

Mass transfer within a binary system should lead to either a steady increase or a steady decrease in the period, depending on which way the mass flows, yet U Cep belongs to a very small group of systems in which anything like this is observed. The other two well established cases are β Lyr (period 12.9 days, increasing at about 18 seconds a year) and SV Cen (period about 1.7 days, decreasing by a variable amount around 3 s a year according to Irwin and Landolt, 1972). In other respects these three systems are very different, but this one exceptional property puts them in a class together. By contrast, systems that resemble U Cep quite closely in other respects differ from it in the behaviour of their periods. For example, RW Tau, with an orbital period not much longer than that of U Cep, contains very similar stars to those in the latter system, and also shows intermittent emission during primary eclipse of the same general characteristics as that observed in U Cep in 1974; yet there is no steady trend in the period. Instead, like most Algol-type systems, RW Tau undergoes abrupt irregular changes of period.

Another system that illustrates this difference is the much neglected one of S Cnc. Its period (9.5 days) is appreciably longer than that of U Cep, but the two systems resemble each other in being composed of a late B-type (or early A-type) primary star that appears to be close to the main sequence, and a G-type subgiant secondary. The secondary of U Cep certainly fills its Roche lobe (Batten, 1974) but we are uncertain about that of S Cnc. Hall (1974) regards it as one of three possibly genuine instances of an undersized subgiant. Its fractional radius (0.19) implies a mass ratio (primary: secondary) of 10:1 if it does fill its lobe. This is large for an Algol-type system, but not unknown. No emission has been seen at any of the few eclipses so far observed spectroscopically. No velocity curve has been published for this star, although Joy observed it and communicated approximate values of $K_1 = 50\,\mathrm{km\,s^{-1}}$ and $K_2 = 140\,\mathrm{km\,s^{-1}}$ to Kopal and Shapley (1956) who published them. If these values give the correct mass ratio the subgiant must be considerably undersize and the case for saying it is rests largely on them. Joy's observations have been published by Abt (1970) and are shown in Figure 2. The secondary spectrum was observed during primary eclipse, and Joy's value of K_2 is probably as good a one as can be determined. A glance at the primary velocity curve, however, shows something seriously wrong. Even if the large scatter of observations near the nodes is ignored, the velocity curve is 180° out of phase with the light curve (zero phase in Figure 2 corresponds to primary mid-eclipse). Joy's work on this system largely antedates Struve's discovery of the frequent distortion of velocity curves, and it is not surprising that Joy never published the observations himself. I have observed S Cnc at Victoria since 1972, using much higher dispersions (10, 15, and 30 $\mathrm{\AA\,mm^{-1}}$) than Joy could use. Velocities determined from these spectrograms are plotted in Figure 3. The amplitude is much smaller over most of the cycle, although the residual variation is in the same sense that Joy found. Spectrograms obtained near phases 0.8 and 0.9 (just the phases where the velocity curve of U Cep is most distorted) show very complex line profiles and double or even triple components of the hydrogen lines can be measured. One plate obtained near phase 0.5 shows a similar effect. A tracing of one of these plates is shown in Figure 4. Clearly Joy's value of K_1 cannot be used to determine the mass ratio of the system; the new observations are consistent with a much smaller value of K_1, and quite possibly the secondary component does

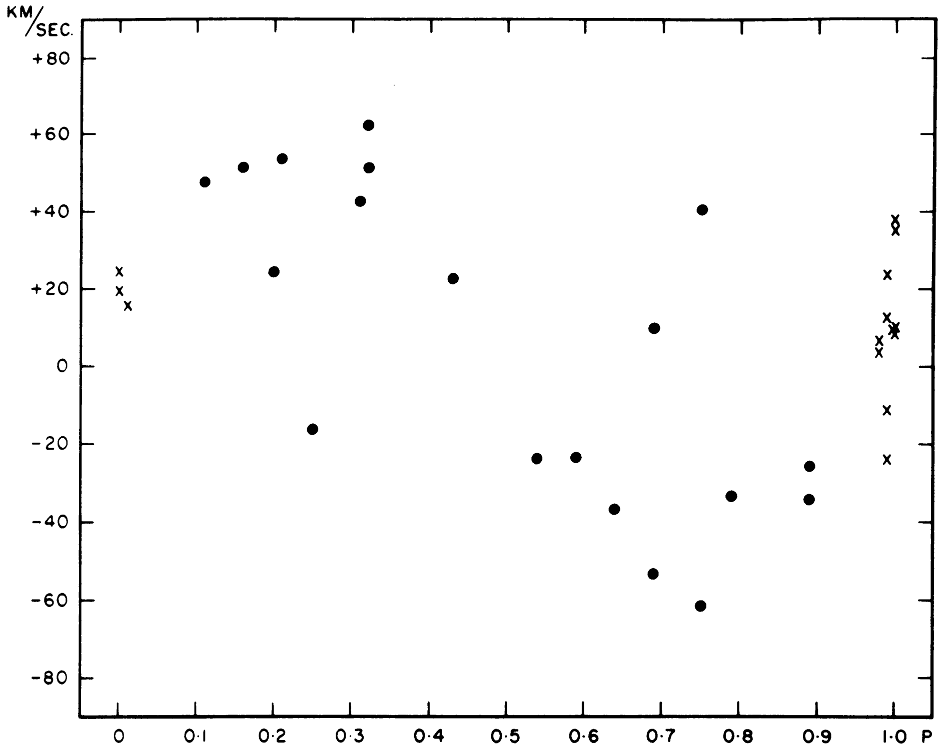

Fig. 2. Radial-velocity observations of S Cnc by Joy, plotted against orbital phase measured from primary mid-eclipse. Dots represent measures of the primary star and crosses of the secondary.

fill its Roche lobe. The doubling of the lines strengthens this possibility, for it probably indicates the presence of circumstellar matter.

Eclipses of S Cnc (discovered 1846) have been known and studied even longer than those of U Cep (discovered 1880). Plavec *et al.* (1961) collected all the material then available but found it "entirely inadequate for studies of period changes". Individual times of minima show a large scatter – partly because the period is long and the light changes during eclipse are slow, partly because many early determinations were based on quite crude visual estimates, but perhaps also partly because of the variable influence of circumstellar matter on the shape of the light curve. I have combined the individual minima into normal points, omitting some of the most deviant ones (one value of (O-C) is nearly half a period!), and have added the very few minima that have been observed since the work of Plavec *et al.* Figure 5 shows the result: again there appears to have been a single abrupt change around 1900. The period decreased by about 0.00002 days as is attested by the revised ephemeris used for some years past in the *Cracow Supplements* (Koziel, 1974). There is no sign of the kind of steady increase found for U Cep which ought to be detectable by now, if it exists, even when the greater length of the period of S Cnc is taken into account. Spectroscopically the two systems are very similar; the distortion of the velocity curve of S Cnc is even greater than that of U Cep and one would intuitively expect a

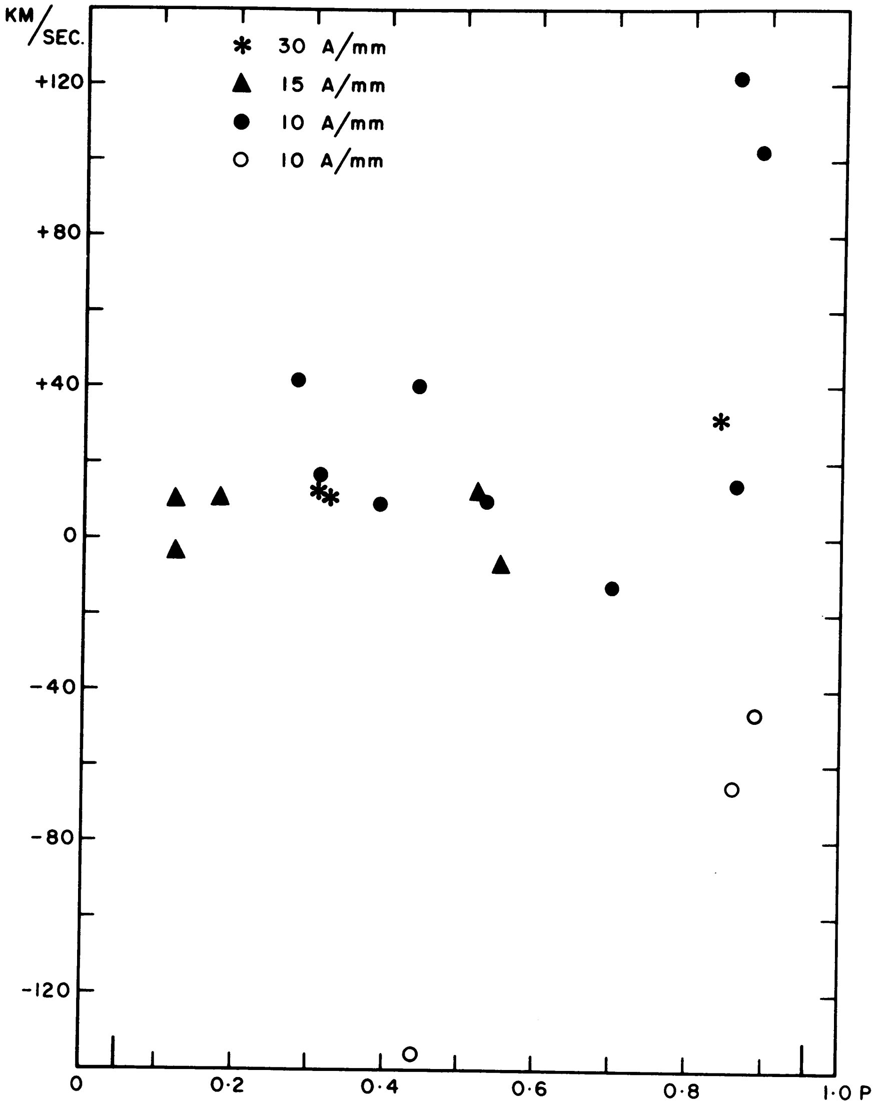

Fig. 3. Recent velocity measurements of S Cnc made at Victoria. Zero phase is again primary mid-eclipse. Open circles represent measures of subsidiary absorption features.

greater concentration of circumstellar matter in the former system. Analysis of the period changes does not bear out this expectation, but more times of minima are needed.

We may ask whether changes in the amount of emission or distortion of line profiles observed in a spectrum necessarily indicate changes in the amount of circumstellar matter in a system. Relatively small changes in excitation and ionization can have rather large effects on the observable spectrum of circumstellar matter. We might suppose that despite apparently large spectroscopic changes, a system could be in a nearly steady state and a

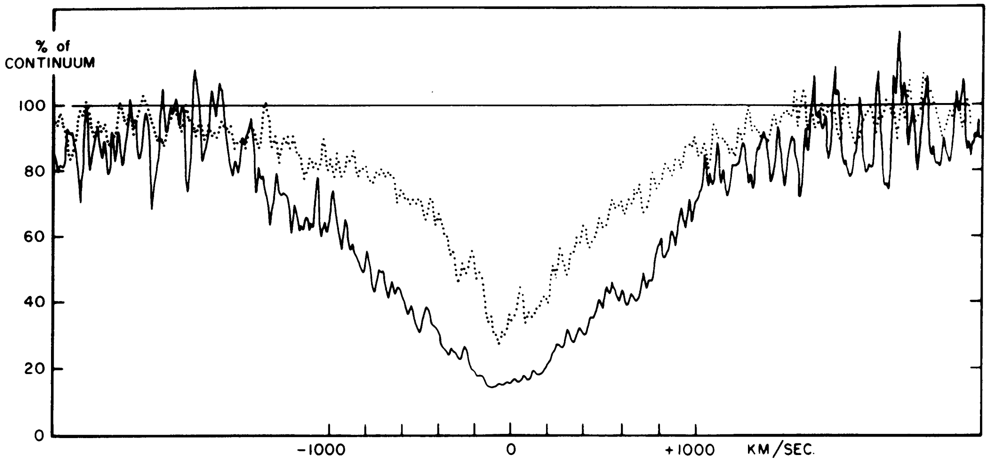

Fig. 4. Profiles of Hγ on two plates of S Cnc obtained at phase 0.86 in different cycles.

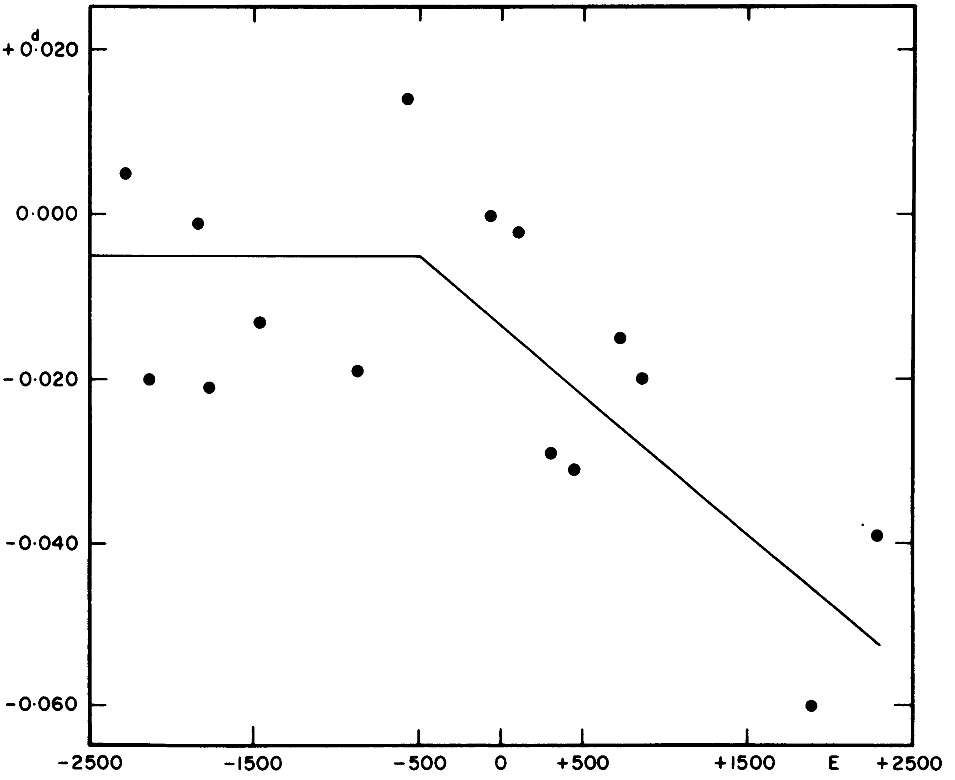

Fig. 5. Normal times of minima of S Cnc plotted on a linear ephemeris.

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relation would not necessarily be observed between the spectroscopic properties of a system and its period behaviour. I explored this idea in my recent study of U Cep (Batten, 1974), and found that one could reconcile the (then) constant distortion of the light curve with the variable distortion of the velocity curve. Unfortunately, a necessary consequence of this idea was that the primary star is surrounded by a permanent electron-scattering disk that should produce variable polarization of the starlight during primary eclipse. This prediction was speedily falsified by Coyne (1974), and the outburst observed last year has made the hypothesis still less plausible. During the outburst, the appearance and disappearance of emission did, to some extent, correlate with the distortions of the light curve, and we found clear evidence (Batten *et al.*, 1975) for the existence of an expanding envelope around the primary star that is not normally present. It seems probable, therefore, that the appearance and disappearance of emission lines in the spectrum of U Cep do signal changes in the amount of circumstellar matter rather than merely changes in its excitation. It is not clear whether this is a general rule. Batten and Sahade (1973) drew attention to changes in the emission intensity of Hα in the spectrum of β Lyr that take place in intervals of a few weeks. I have since found that the intensities of other strong emission lines in the spectrum of β Lyr correlate well with that of Hα and this confirms the reality of the changes. There is no difficulty about assigning such slow changes to variations in the amount of emitting matter, but Sanyal (1975) has found evidence for much more rapid changes that occur in a matter of minutes, and these virtually demand changes of excitation since the regions of space involved are probably relatively large. In any given system it may prove difficult to separate changes in emission intensities and profiles produced by these two causes, and yet it may be of considerable importance in our attempts to understand what is going on to be able to do so.

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DISCUSSION

Herczeg: It is very discouraging that no detailed investigation seems to be available about the possible influence of light-curve changes on the timing of minima although the effect itself is frequently mentioned; technical methods of handling asymmetric minima are also proposed. Looking into many O-C diagrams and a number of good photoelectric series of observations, however, I would not expect that more than a small part of the strange O-C curve of U Cep can be explained by light curve distortion. In the case of RZ Cas, showing another rather complicated O-C diagram, I actually tried to trace a possible influence of distorted minima on the time residuals but the result was negative.

Pringle: (1) You estimated the scatter in the O-C diagram of U Cep caused by asymmetry of the eclipse to be ±0.012 days. This estimate is much less than the size of the wiggles about the best fit parabola reported by Dr Hall. Would you not therefore agree that the times of eclipse observed for this system differ significantly from the times of eclipse that would be predicted if the rate of mass transfer were constant?

(2) You suggested that S Cnc has undergone a period change. Have you calculated the statistical significance of your result?

Batten: (1) My argument is not so much aimed to justify the idea of a steady period increase as to point out that not every detail in these diagrams should necessarily be interpreted dynamically – that is to say as an actual period change.

(2) No, but the most recent times of minima were determined photoelectrically and should not be subject to large accidental errors. There is not much doubt that the period did change but if it did not, my argument would not be seriously affected.

Wood: One brief comment – after receiving your letter, one of the Florida graduate students, Norman Markworth, begun extensive photoelectric observations of U Cep, especially in primary eclipse. He found changes in shape strikingly similar to those you have shown which strongly confirm your results.

Note Added in Proof. While this paper was in press, Weis (*Observatory* **96**, 9, 1976) has published essentially the same conclusions as those given on pp. 305–6 about the previously accepted values of K_1 and K_2 for S Cnc.