ON THE EXISTENCE OF DOUBLE-CONTACT BINARIES

R. E. Wilson and L. W. Twigg
Department of Astronomy
University of Florida
Gainesville, Florida 32611

We present observational evidence relevant to the existence of binaries of the morphological type proposed by Wilson (1979), called double-contact binaries. Consider normal evolution with Roche lobe overflow, in the rapid phase of mass exchange. It is well known that such mass-exchange spins-up the accreting star (most of whose mass is transferred material by the end of the rapid phase). Many examples are known (Table 1, for example) of Algol-types with fast-spinning primaries (original secondaries). Suppose the accreting star has been spun-up so much that it cannot accept further high-angular momentum material. It will then be filling its limiting rotational lobe (but not its Roche lobe). The secondary (original primary) will still be filling its Roche lobe. The overall result is that both stars fill their limiting lobes accurately, but are not in contact with one another. Since it is common to speak of "the contact component" of a semi-detached system - meaning the one in contact with its limiting lobe - it seems natural to call members of the new morphological type "double-contact" systems. Of course, there must be a repository for the mass lost by the Roche lobe filling and rotational lobe filling components. This would naturally be the circumstellar disks around the primary components of such systems as β Lyr and V356 Sgr (Wilson and Caldwell, 1978). The end of the double-contact phase would occur when the rate of transfer of rotational angular momentum back into the orbit, by tidal braking, begins to exceed the rate of transfer of angular momentum the opposite way by mass exchange.

Table 1 summarizes information on a number of possible double-contact systems we have investigated so far. One should direct attention toward Algol-types with rapidly rotating primaries. Here we have used the rotational disturbance (Rossiter effect) to estimate the ratio, F, of rotation rate to the synchronous rotation rate. Figures 1 to 7 show fits to the rotational eclipse disturbance for 6 binaries. Figure 8 is an example of a light curve fit. Column 5 of Table 1 gives quantitative estimates of F for U Cephei, RZ Scuti, AQ Peg, SW Cygni, U Sagittae, and RY Persei. By analysing light curves of the same binaries,

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we have estimated also the percent of the rotational lobe which the primary fills and the percent of the Roche lobe which it fills. If the former number is about 100%, we have a strong candidate for a double-contact binary. As the table shows, U Cep is the only strong candidate at present, but others may emerge when allowance is made for several effects which reduce the apparent rotational disturbance. All of the binaries listed in Table 1 show peculiarities, such as variable emission lines near eclipse and shoulder distortions in the light curves.

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Table 1

Summary of Results

Name	P(days)	M_2/M_1	SP_1	$\frac{V}{V_{syn.}}$	% Lobe Filled	% Lobe If Syn.	V_{eq} (km/sec)
U Cep	2.49	0.644	B7 V	10	100	32	380
RZ Sct	15.19	0.209	B2 II	10	61	19	268
U Sge	3.38	0.371	B8.5 V	5-6	72	37	260-312
AQ Peg	5.55	0.390	A2e	9	70	22	158
RY Per	6.86	0.260	B3 V	9	48	19	198
SW Cyg	4.57	0.301	A2e	5	46	23	125

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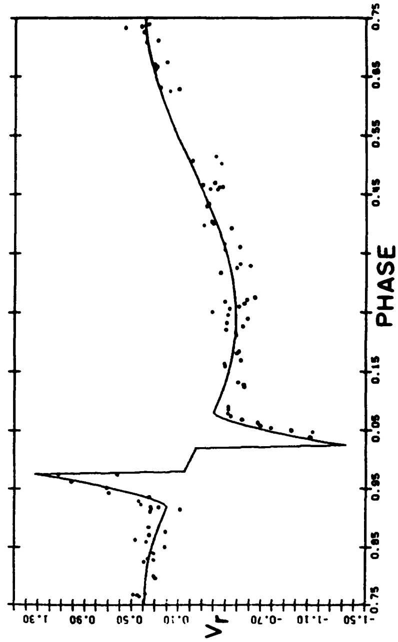

Figure 1. Observed and theoretical radial velocity curves for U Cep.

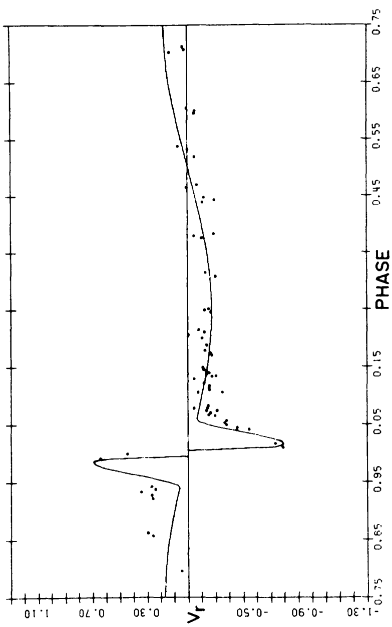

Figure 2. Radial velocity curves for RZ Sct (Hansen and McNamara observations).

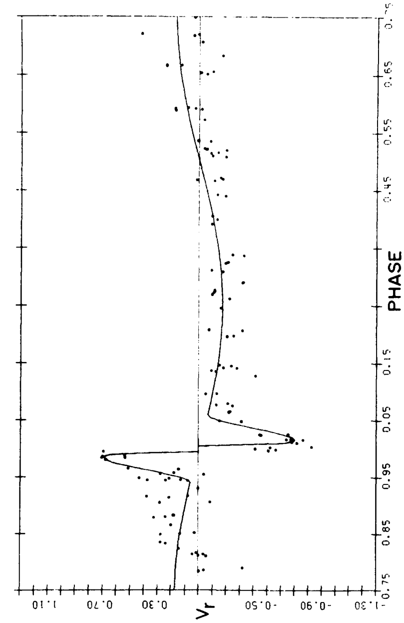

Figure 3. Radial velocity curves for RZ Sct (Neubauer and Struve observations).

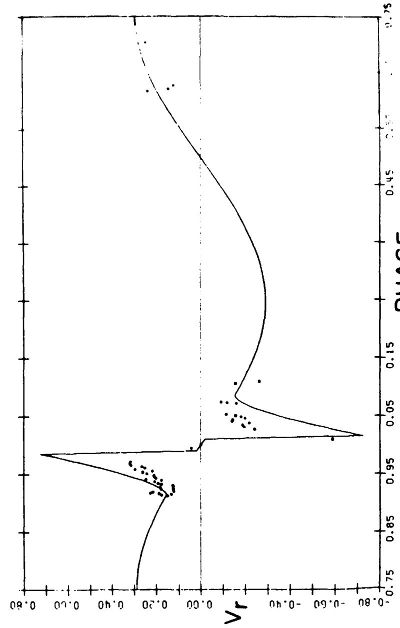

Figure 4. Radial velocity curves for U Sge.

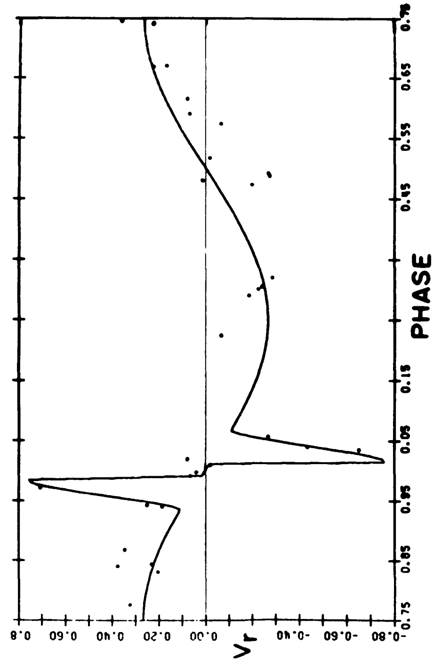

Figure 5. Radial velocity curves for AQ Peg.

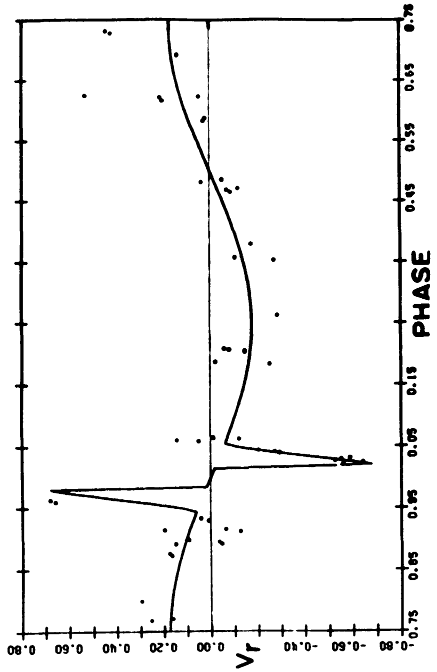

Figure 6. Radial velocity curves for RY Per.

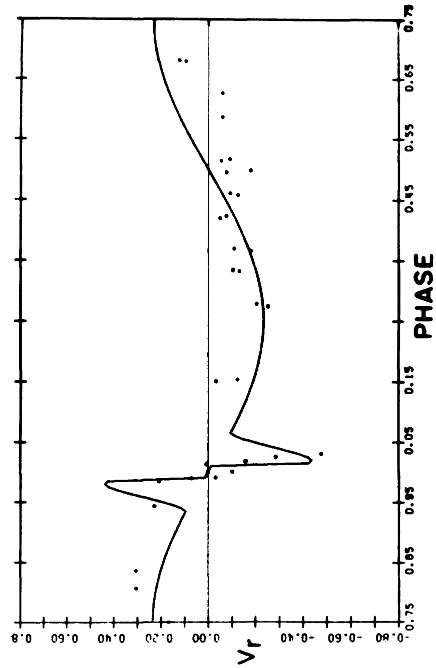

Figure 7. Radial velocity curves for SW Cyg.

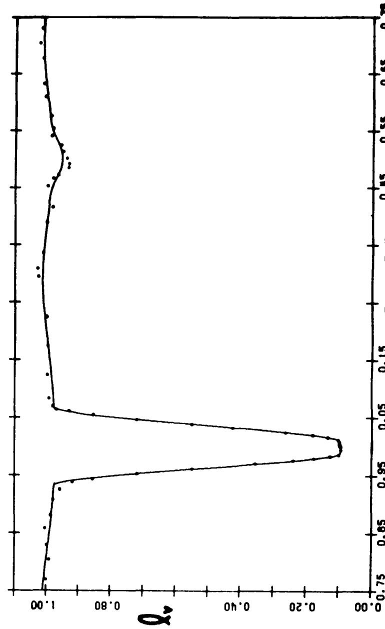

Figure 8. V light curve of SW Cyg and differential corrections solution curve.

COMMENTS FOLLOWING WILSON AND TWIGG

Smak: I am worrying about very serious systematical errors which are likely to affect your basic conclusion. It is rather obvious that the velocity of rotation can be obtained quite accurately from the Rossiter effect. They have to be compared with theoretical predictions involving several uncertain parameters, which come from the radial velocity and light curves. As for the radial velocities, all the systems you mentioned have been single-line objects, with radial velocity curves severely distorted by the presence of emission and absorption component (most dramatic examples being RZ Sct and U Sge); we could see, in many cases, how poor was the fit of your theoretical curves to the observed points outside of eclipse. To summarize, the K_1 values are very uncertain. As for the light curves, you need them to determine the radii and--indirectly--the mass-ratio. Again, these light curves are known to contain severe distortions due to disks, etc. and yet you are adding extra free parameters appropriate for a rapidly rotating star (flattening, gravity darkening). The basic quantity that enters your comparison is $GM_1/R_1 \sim \frac{K_1^2}{r_1}(1 + \frac{M_1}{M_2})\frac{M_1}{M_2}$ and one can see how sensitive it is to the uncertainties in k_1, r_1, and $g = g(r_2)$.

Wilson: I should emphasize that the photometric solutions were done from good photoelectric light curves for most of the systems. They were done by differential corrections, with the cooler star constrained to fill the Roche lobe. The geometry is rather well determined. We proceed tentatively with the figure of the hot star correctly computed from the rotation rate derived from the rotational disturbance. Thus there are not very many free parameters at all. I do not believe the masses could be wrong enough to undermine the overall result, which is that there do exist Algols (with spectroscopically visible hot components) which are fairly close to the double-contact configuration. By inference, the slightly faster rotating (and spectroscopically invisible) actual double-contact systems are likely to exist also.

Kuzma: You might run into trouble using the Rossiter effect to obtain rotational velocities. Gravity darkening and limb darkening lead to non concentric isophotal lines. This is also strongly dependent on the wavelength used. This can introduce a large ambiguity into the radial velocity obtained.

Wilson: These effects are all accounted for rather rigorously in our computations. The only possibly significant effect we do not treat is the variation of line strength over the surface.

Polidan: Later in this session I will discuss two non-eclipsing semi-detached systems that support your suggestion that there is a limit to the accretion rate for a rapidly rotating star. In these systems the "mass accreting" star is very rapidly rotating. Both stars display UV

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resonance line profiles indicative of strong stellar winds. It appears that the majority of the material being lost by the secondary is not accreted by the rotating star, rather it is ejected from the binary.

Pringle: I wish to dispel the idea that the accreting star can spin so fast that it cannot accrete any more mass from an accretion disc. An accretion disc is very efficient at redistributing angular momentum and can enable the star to accrete without problem.

Wilson: It seems to me that the time scale for tidal braking of the outer stellar envelope could be sufficiently long to allow a thick disk to be built up. As I understand the present situation, the amount of dissipation in such an envelope is at least somewhat controversial.

Rucinski: The shape of the component at "rotational contact" depends on the distribution of angular momentum versus radius; what sort of a distribution do you assume in your calculations?

Wilson: We assume uniform rotation (constant angular velocity). However differential rotation should affect the figure significantly only if the core rotates faster than the envelope. Here the core would rotate slower than the envelope, if anything.

Collins: If you actually believe that the star is rotating at near critical velocity then you must use great care in producing the line profile. For instance, the use of the Stoeckley-Mihalas atmosphere is inappropriate for velocities corresponding to a $W > 0.5$. These problems can perhaps be best demonstrated by noting that the radius which results from the light curve analysis cannot be unambiguously associated with any radius on the star. Since in the case of critical rotation whose radius varies by 50%, this is not a negligible problem.

Wilson: Since we compute the rotational and tidal distortion (and gravity darkening, etc.) in detail, there is not just one radius which characterizes the photometric solution. I agree that the refinement you propose could be significant, but it could hardly change our basic conclusions.

Hall: The question of the reliability of Wilson's absolute dimensions can be checked by seeing if they have the cooler star filling its Roche lobe and also have the hotter star obeying the mass luminosity relation. Such a test was used in Acta Astronomica 24, 215 to check absolute dimensions of many such systems, which have incomplete or unreliable radial velocity curve amplitudes.

Wilson: The solutions were done with the cooler star constrained to fill its Roche lobe. I maintain that the solution radii are less uncertain than is the mass-luminosity relation.