THE RELATION OF ALGOLS AND W SERPENTIS STARS

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ABSTRACT. Evidence on the issues of whether the W Serpentis stars are a coherent class, and how they may interface with the Algol systems, is reviewed, with emphasis on the idea that they are semi-detached systems in the latter part of the rapid phase of mass transfer, with optically and geometrically thick disks of transferred gas around the (now) more massive star. We are interested in what will be seen when the gas clears away, and mainly examine the idea that it will be an Algol-type system. More particularly, consideration is given to centrifugally limited accretion as a mechanism to build up a substantial disk, and the presumed evolutionary sequence is from a W Ser to a rapidly rotating Algol to a normal Algol system. Systems such as V367 Cyg and RW Tau fit into this scheme only with difficulty. Because it is extremely difficult to measure the rotation of some W Ser (mass) primaries, it is natural to look at the rotation statistics of Algols to test this idea. The badly behaved light curves and spectroscopy of some Algols (eg. U Cep, RZ Sct) may be attributable to the double contact condition, and the ramifications of this possibility are discussed. If so, the rotation statistics of Algols should show two spikes, corresponding to the two special conditions into which a system should be driven by tidal braking and centrifugally limited spin-up. Present rotation statistics do show these spikes. Algols should flip between these states fairly quickly, depending on the mass transfer rate. Thus, to the extent that the meager statistics can be accepted as meaningful, the new (fourth) morphological type of close binary (double contact) has attained demonstrable reality. The rotation statistics are presented in terms of a particular rotation parameter, R, which is zero for synchronism and unity for the centrifugal limit. Future work should develop rotation statistics to see if the rotational lobe-filling (R=1) spike persists. It should also look into whether W Ser primaries are on the hydrogen burning main sequence, or in general what they are. We also need more light curves of W Ser type systems, high resolution line profiles for the (mass) primaries (with particular attention to the W Ser-Algol transition cases), and spectroscopy of low inclination W Serpentis systems, such as KX And.

1. Introduction

The class of close binaries known as the W Serpentis stars is defined at present in terms of purely observational criteria (Plavec, 1980), in contrast with

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some other classes whose definitions involve some evolutionary or morphological theoretical ideas (such as lobe filling, etc.). Essentially W Sers have been discovered by their strong ultraviolet emission line radiation, most of which probably comes from gas outside the system, filling a volume much larger than the binary. Thus, if today one were forced to identify one theoretical notion common to all W Ser stars, it would be that of recent large scale mass loss. There are, to be sure, other theoretical ideas, but it is unclear whether they apply to some, all, or none of the W Sers, and they are being promoted by only a few persons.

Naturally it would be satisfying to find an agreed-upon central theme of the W Ser phenomenon, much as we now have for W UMa or Algol binaries, but it is not clear that all W Sers are even the "same kind of animal", and it could well be that they are not. Observationally important characteristics of some or most W Sers include large secular period changes (probably due to currently active mass transfer or mass loss or both), various kinds of spectroscopic and photometric evidence for very substantial disks around the more massive components, strange light curves which repeat poorly, and prominent optical emission lines, some of which originate within the binary system proper. A prevalent view would be that most of the W Sers are in the latter part of the rapid phase of mass transfer (RPMT) and still have disks of transferred gas around the (now) more massive star. In due course, the mass transfer will cease, the disks will clear away, and we shall have a ???? type object as a residue. What is that ???? object? If it should be a main sequence star, the product would be called an Algol system, while if it is a helium star or white dwarf we would have one of quite a variety of possibilities. The main thrust of this review is toward the Algol outcome, but again one should not be surprised if the known W Sers represent several possible outcomes. While the results we examine on rotational statistics pertain specifically to Algols, the underlying idea of the role of centrifugally limited disk accretion (see below) applies as well to helium star residues. It should also be kept in mind that only for the main sequence star case would we be dealing with the first epoch of mass transfer -- naturally a helium star residue corresponds to a later epoch of mass transfer.

An important common physical characteristic of most W Ser systems is the presence of large amounts of circumstellar gas around the high mass component. How are we to understand the presence of this gas? It is easy to say that large scale mass transfer obviously provides such matter, so where is the mystery? However, even in the rapid phase, there is not so much mass flow as to produce the observed amounts of matter on a few times the dynamical time scale, so some mechanism must inhibit the accretion process. Indeed, the bulk of the material must not be quickly accreted, or it would be in a more highly flattened distribution than we see (Wilson, 1974) in Beta Lyrae. Here we focus on the idea (Wilson, 1979) that the inhibiting mechanism is rotation, so that we have centrifugally limited accretion. The temporal sequence would then be from a W Ser to a semi-detached system with a fast rotating primary to a semi-detached system with a slowly rotating primary, after allowing tidal damping to act. For the first epoch of mass transfer, the intermediate stage would be a rapidly rotating Algol system (viz. Wilson, Van Hamme, and Pettera, 1985), while for the second epoch it could be a (perhaps hard to detect) semi-detached binary with a rapidly rotating helium star. Ideally, one would like to investigate the rotational statistics of both kinds of objects, but at present that is only feasible for the Algols.

Before we look at Algol rotation statistics, we should check the absolute masses and angular momenta of W Ser and Algol systems to be sure there is no contradiction. Since the hypothesis is that W Sers become Algols, losing some mass and angular momentum in the process, we should find the masses and angular momenta of W Sers to be roughly the same, or on average somewhat greater, than those of Algols. If those quantities were smaller for W Sers than for Algols, or if they were enormously larger, the idea would lose attractiveness. Figures 1 and 2 show mass and angular momentum data, mostly taken from Giuricin, Mardirossian, and Mezzetti (1983), with a few W Ser stars added. The graphs are compatible with W Sers becoming Algols, in that the W Ser masses and angular momenta are statistically somewhat larger than those of Algols, but with considerable overlap.

Having passed that preliminary test, the idea of W Sers becoming Algols will now be tested against rotation statistics. Here we face major observational problems, first among which is a "can't win" situation, which fortunately is only an "almost can't win" situation. Its essence is that in a fully developed W Ser system, centrifugally limited rotation cannot be validated because the accreting star cannot be seen within the circumstellar matter. The star can be seen if the circumstellar matter goes away, but then it is not a W Ser system, and it rather quickly becomes tidally braked to slow rotation. So the interesting case is not observable and the observable case is not interesting. However, the mass transfer rate should be a critical parameter, so there may be a few systems on the W Ser - Algol borderline which have transfer rates just sufficient to maintain centrifugally limited rotation. Overall features of the expected distribution of Algol rotations will be discussed in the next section.

2. Why Rotation?

A few Algol systems are particularly erratic in regard to their light curves, spectra, and period change behavior, for no glaringly obvious reason. The best example is U Cephei, which Dobias and Plavec (1985) have compared with the relatively well behaved system of U Sge, contrasting their dissimilarity in activity. Is there some hidden parameter which has a critical value in U Cep, causing activity to be switched on? An obvious candidate is (primary star) rotation, which has the following intriguing features:

a. It has a well-defined critical value — that for which the surface matter just becomes centrifugally unbound (this happens on the line of centers of the two stars).

b. Fast rotation can efficiently be produced by the mass transfer process (Packet, 1981). In fact, there seems to be no escaping fast rotation for a binary in the RPMT.

c. Rotation can account, at least qualitatively, for the several kinds of strange behavior of U Cep-like systems.

d. U Cep and a few somewhat similar Algols are known to be fast rotators.

e. Centrifugally limited accretion provides a natural mechanism for inhibiting accretion and accounting for W Ser stars (Plavec 1970; Wilson, 1979).

Perhaps this idea can be tested by means of the rotation statistics of Algols. What should be expected? Notice that we are dealing with two very efficient mechanisms for changing rotation. There is tidal braking for slowing rotation and the even more efficient accretion process for speeding up rotation. Thus we

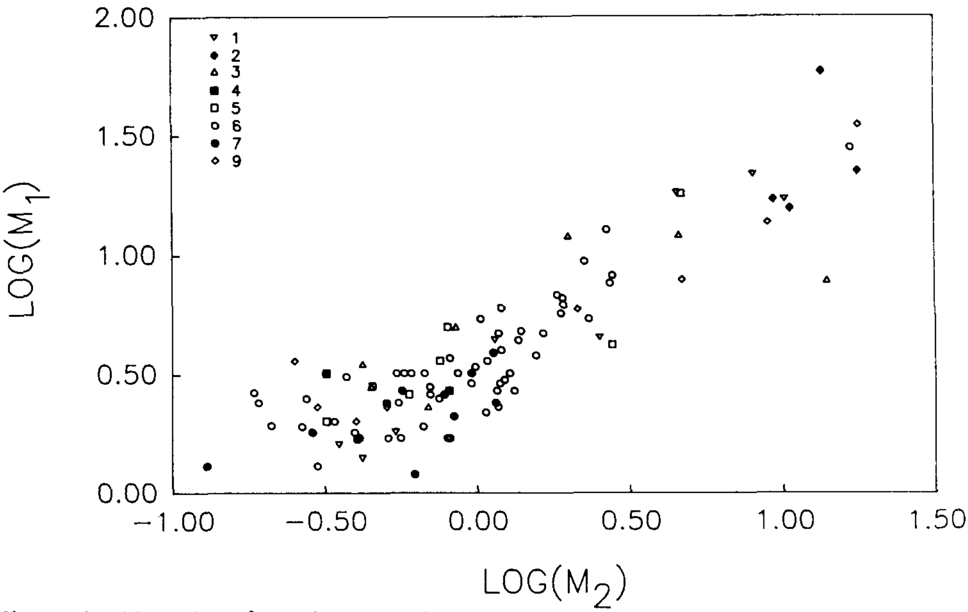

Figure 1. Mass data for primary and secondary components of close binaries. Key to legend: 1= detached; 2= early type overcontact; 3= W Ser; 4= "Weak" W Ser; 5= rapidly rotating Algol; 6= normal Algol; 7= short period Algol; 8= possibly an Algol; 9= difficult to classify.

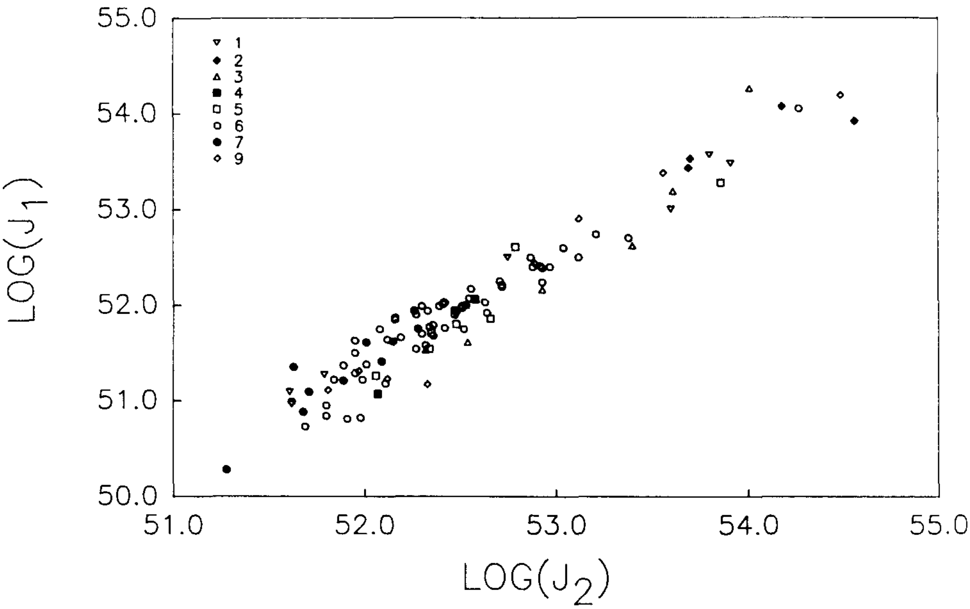

Figure 2. Angular momenta of primary and secondary components of close binaries (cgs units). Legend is the same as for Figure 1.

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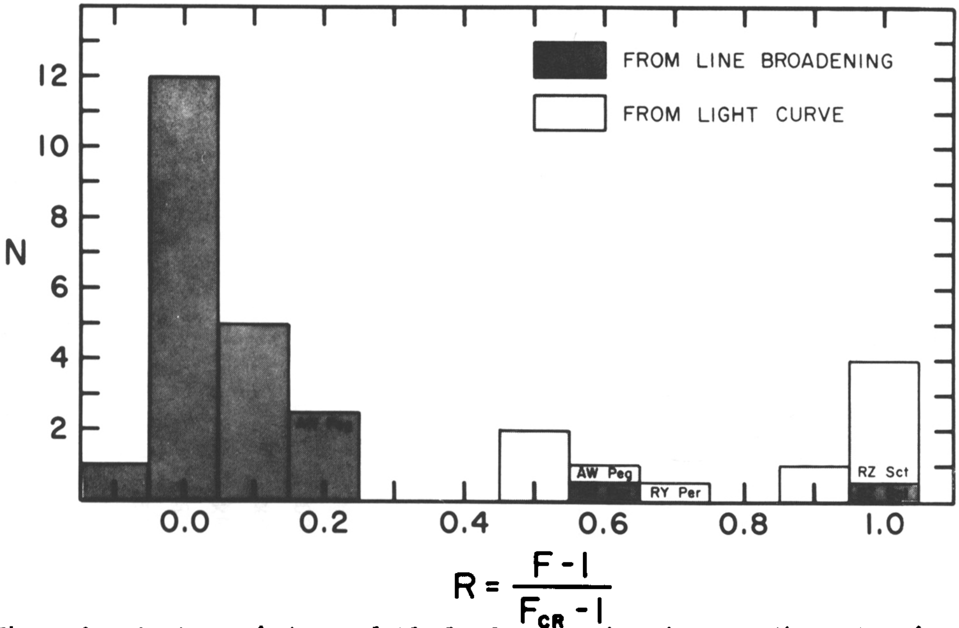

Figure 3. Numbers of observed Algol primaries at various rotation rates, from synchronism (R=0) to the centrifugal limit (R=1). R is defined in the text. The one star at negative R is an error, and should be added to the R=0 bin.

expect the rotation of an Algol primary star to flip rather quickly between two extremes — synchronous rotation and centrifugally limited rotation, depending on whether "significant" mass transfer occurs. A frequency plot of a suitable rotation parameter should show a large spike around synchronism and a smaller spike around the centrifugal limit, with not many systems in between. A good rotation parameter is $R=(F-1)/(F_{cr}-1)$, because it runs to definite numerical values at both synchronism (R=0) and at the centrifugal limit (R=1). F itself has a definite, system-independent value at synchronism but not at the centrifugal limit, while F/F_{cr} is definite at the centrifugal limit, but not at synchronism. Working with R, we can meaningfully plot all systems in one figure.

It is useful to think in terms of the double contact condition (Wilson, 1979) at the upper limit of rotation, partly because the idea of double contact associates a specific physical condition with the expected spike in the N(R) distribution, and also because it provides a natural completion to the set of morphological types of close binaries, following the long known detached, semi-detached, and overcontact cases. In a double contact binary, a fast rotating accreting component fills its limiting "rotational" lobe, for which effective gravity goes to zero at one surface point, while the other star also fills its limiting lobe (normally in synchronous rotation). The topology of the star-disk interface may be understood in terms of equipotential surfaces (Wilson, 1981), so as to provide a logical separation between star and disk. Ideas on the structural make-up of such disks (including quantitative models) have even been offered (Wilson, 1982), and the results have a fair degree of internal consistency. In principle, the double contact idea could apply either with a normal main sequence accreting star, or with a more evolved star (e.g. a helium star), but here we think mainly in terms of a star of normal

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Table 1
Rotation Statistics of Algols

Binary	Sp_1	Period	q_{sp}	q_{ptm}	$\frac{m_1}{m_\odot}$	$\frac{m_2}{m_\odot}$	$F1_{sp}$	$F1_{ptm}$	($V_e \sin i$) (km/sec)	a (cm)	R_{1}/a	$R_1/R_\odot$	F_{cr}	R	$V_e \sin i$ or F References
SW Cyg	A2	$4^{d}.57$	—	0.37	—	—	—	11.7	(306)[e]	9.7×10^{11}	0.151	2.4	11.7	1.00	WM
AW Peg	A4	$10^{d}.6$	—	0.17	2.0	0.34	14.6	36	85	1.88×10^{12}	0.054	1.5	59	0.23[b]	WM, KOY, L
AQ Peg[a]	A2	$5^{d}.54$	0.23	0.34	—	—	—	14.1	—	———	0.135	—	14.1	1.00	WM
U Sge	B7.5	$3^{d}.38$	0.33	0.40	5.3	2.1	1.3	—	80	1.29×10^{12}	0.217	4.0	7.3	0.05	O
RY Per	B3	$6^{d}.86$	—	0.30	6.7	2.0	9.2	10.8	(307)	2.18×10^{12}	0.126	4.2	15.9	0.55[c]	VW1, L
RW Per	B9.6	$13^{d}.20$	0.15	0.15	2.7	0.4	—	28.8	(321)	2.38×10^{12}	0.087	3.0	29.2	0.99	WP
RW Mon	B9	$1^{d}.91$	—	0.37	3.0	1.1	—	5.0	(266)	7.22×10^{11}	0.194	2.0	8.6	0.53	VW2
RZ Sct	B2	$15^{d}.19$	—	0.28	13.7	3.8	6.7	6.7	250	4.66×10^{12}	0.221	10.9	6.7	1.00[d]	WVP
U Cep	B7	$2^{d}.49$	0.67	0.64	4.2	2.8	—	5.8	310	1.04×10^{12}	.187	2.7	8.0	0.69	RM
β Per	B8	$2^{d}.87$	0.22	—	3.6	0.80	1.06	—	52	9.7×10^{11}	0.22	2.9	7.7	0.01	R
RW Tau	B8	$2^{d}.77$	—	0.23	2.6	0.59	2.23	—	94	8.5×10^{11}	0.189	2.24	9.2	0.15	O
RY Gem	A2	$9^{d}.30$	0.17	0.18	2.2	0.39	—	12.9	(178)	1.79×10^{12}	0.093	2.39	26.1	0.47	VW2
TX UMa	B8	$3^{d}.07$	—	0.31	3.2	1.0	1.74	—	64	1.00×10^{12}	0.16	2.3	11.2	0.07	O
R CMa	F1	$1^{d}.14$	—	0.17	1.13	0.19	1.55	—	98	3.5×10^{11}	0.30	1.5	4.5	0.16	KOY
S Equ	B8	$3^{d}.44$	—	0.12	2.9	0.35	1.4	—	55	9.9×10^{11}	0.20	2.7	9.0	0.05	O

Rotation Statistics of Algols

Binary	Sp_1	Period	q_{sp}	q_{ptm}	$\frac{m_1}{m_\odot}$	$\frac{m_2}{m_\odot}$	$F1_{sp}$	$F1_{ptm}$	$(V_e \sin i)_{sp}$	a(cm.)	$R_{1/a}$	$R_{1/R_\odot}$	F_{cr}	R	Refs.
RS Vul	B5	$4^d.48$	---	0.11	5.1	0.6	1.4	---	62	1.42×10^{12}	0.20	4.0	9.0	0.05	O
IM Aur	B7	$1^d.25$	---	0.34	2.2	0.7	1.30	---	133	4.84×10^{11}	0.37	2.6	2.9	0.16	O
λ Tau	B2	$3^d.96$	0.26	---	6.5	1.7	1.27	---	101	1.48×10^{12}	0.30	6.4	4.3	0.08	O
RZ Cas	A2	$1^d.19$	---	0.35	1.9	0.7	1.2	---	74	4.5×10^{11}	0.24	1.5	6.2	0.04	O
U Cr B	B6	$3^d.45$	---	0.24	5.4	1.3	1.15	---	50	1.26×10^{12}	0.17	3.0	10.3	0.02	O
TV Cas	B9	$1^d.82$	---	0.60	1.5	0.9	1.14	---	78	5.9×10^{11}	0.30	2.5	3.7	0.05	O
TW Dra	A5	$2^d.80$	---	0.42	2.0	0.9	1.11	---	50	8.3×10^{11}	0.21	2.5	7.6	0.02	L
XX Cep	A8	$2^d.34$	---	0.16	1.6	0.26	1.09	---	47	6.4×10^{11}	0.22	2.0	7.9	0.01	L
V 505 Sgr	A2	$1^d.18$	---	0.42			1.09	---	118	5.7×10^{11}	0.31	2.5	3.8	0.03	L
Z Vul	B4	$2^d.45$	---	0.45	5.3	2.4	1.05	---	100	1.05×10^{12}	0.31	4.6	3.7	0.02	O
Y Psc	A3	$3^d.77$	---	0.25	1.9	0.5	1.01	---	37	9.5×10^{11}	0.20	2.7	8.6	0.00	L
AI Dra	A1	$1^d.19$	---	0.46	2.4	1.1	0.90	---	79	5.0×10^{11}	0.30	2.2	3.9	-0.03	O, KOY
δ Lib	A0	$2^d.33$	---	0.44	2.8	1.2	0.82	---	61	8.2×10^{11}	0.29	3.5	4.2	-0.06	O
AS Eri	A3	$2^d.66$	---	0.11	2.0	0.22	1.5	---	45	7.3×10^{11}	0.15	1.6	13.4	0.04	L

a. Absolute masses too uncertain to list.
b. Listed value is from line broadening. Light curve value is 0.60.
c. Listed value is from line broadening. Light curve value is 0.66.
d. Line broadening and light curve values are the same.
e. Velocities in parentheses are estimated from the photometric F.

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composition.

Figure 3 shows the frequency distribution of our rotation parameter R, extracted from several spectroscopic (i.e. line broadening) and photometric (light curve) papers. The numerical data are given in Table 1. A discussion of why the low-R end is dominated by line broadening cases and the high-R end by light curve cases can be found in Wilson (1989). The graph shows the expected spikes around synchronism and double contact, but does include a few binaries at in-between states of rotation. Of course, several kinds of strong observational selection effects must be present, and these are presently impossible to evaluate. For example, someone measuring rotation probably will actively select known or suspected fast rotators so as to have an interesting result. On the other hand, some stars with ultra-fast rotation may have their photospheric lines so rotationally broadened as to be unmeasurable, at least by ordinary methods, and the profiles of the photospheric lines may be difficult to separate from those of circumstellar gas. In general, fast rotators tend to have poorly behaved spectroscopy and photometry, thus discouraging persons from making observations.

Among the systems of Table 1, U Cep and RZ Sct stand out in regard to having especially strangely behaved light curves and spectroscopy. One could speculate that they are indeed double contact systems and that it is the double contact condition, rather than only fast rotation, which is responsible. Systems such as RY Per and RW Mon are in rapid rotation, but have much more consistent and ordinary observational properties, which might be attributed to their not being double contact systems. SW Cyg and AQ Peg will be interesting to discuss in this regard when more observed light and velocity observations have been made.

3. Strategy for Future Work

It seems clear from the foregoing that two ideas which need to be tested are:

1) That centrifugal inhibition of accretion is responsible for the extensive circumstellar gas found around the higher mass components of W Ser systems, essentially independently of what kind of stars those objects are, and
2) that some, most, or even all of those more massive stars are on the ordinary hydrogen burning main sequence, so that the systems later become Algols.

It should be kept in mind that these are separate issues. What can be done observationally on the two items? Ideally one would like to find some means to observe the accreting objects directly, both to establish their general nature (e.g. hydrogen main sequence star, helium main sequence star, black hole, ????), and to measure their rotation. At present that prospect seems elusive for the more extreme W Sers, although for some "weak" W Sers (Plavec's term) such as V356 Sgr it can certainly be done. A second strategy is to concentrate on the Algols, where we see the mass-primaries, and to look into their rotation statistics for the features discussed in Section 2. If we find the expected spike around the centrifugal limit of the N(R) diagram, then the double contact condition will be established as a stage through which Algols evolve, and it would be natural to assume that with somewhat larger mass transfer rates, a W Ser-like situation will be inevitable. As discussed in Section 2, the statistics now in hand (Figure 1) do show that spike, but it is somewhat early to regard that finding as definite.

In order to calculate R (Table 1), one must first estimate F(critical), the F value for rotational lobe filling. Physically we imagine spinning up the star until it is contacted by the lobe. Although the star would change its volume by some small percentage, this effect is neglected in Table 1, where constant volume is assumed. In fact, no attempt was made to make a rigorous constant volume calculation. Instead it was estimated that, at lobe filling, the x-coordinate of the balance point on the line of centers is typically about 1.16 times the mean (equivalent sphere) radius. Values of F(critical) were then interpolated from a table of that x-coordinate vs. F and q (mass ratio) for each binary. A computer program could be written to do this calculation more accurately, but the above procedure seems adequate for now.

What is needed in future work, in order to clarify our ideas? First, light curves for some W Sers and related binaries either do not exist at all, or are insufficiently well covered to allow even a rough photometric analysis. For example, there is very little on KU Cyg, KX And, and AU Mon, while several other systems have only one light curve, so that it is unknown whether the light curve is constant over time. An observational program to improve this situation is being carried out by J. B. Rafert and N.L. Markworth (Wilson, Rafert, and Markworth, 1987). Such work needs to be encouraged and to be supplemented by that of other observers where possible. Spectroscopically we need high resolution observations of photospheric line profiles for the more massive accreting components, to check on their rotation. Naturally, this kind of observation is made extremely difficult by circumstellar disks, but perhaps some systems will yield interesting results. In regard to modeling, attention needs to be directed toward the transition cases. To give an example, a sequence (from weak to strong) might be U Cep -- V356 Sgr -- SX Cas. Except on the extreme "weak W Ser" end of such a sequence, the photometric model definitely needs to incorporate an optically and geometrically thick disk. For example, none of the efforts to model SX Cas light curves without a disk can be considered at all successful. However we are still at the rough stage of disk modeling, and it is too early to be overly refined about the figures and surface brightnesses of the disks. The main point is that one cannot omit a disk entirely from the model and expect to make progress.

Can something important be learned from low inclination W Sers? Here one should be able to see the central region of the disk, but will lose the eclipse "handle" on system properties. Binaries such as KX And (Plavec, 1986) should therefore be particularly interesting spectroscopically.

4. Present Puzzles and Outlook

It would be assuring if there were no serious observational evidence against the essential notions that W Sers in general become RRA's, which become normal Algols, and that centrifugally limited rotation is the phenomenon which regulates the transitions. However there are puzzling items which do not seem to fit in with the idea that all W Sers are in the same evolutionary stage, and that very fast rotation is the one essential key to the whole phenomenon. For example, if we accept Plavec's (1980) operational definition of a W Ser system, V367 Cygni belongs to the class, but V367 Cyg appears to be an early type overcontact (radiative common envelope) binary, not a sub-giant accurately filling its Roche lobe, with mass transfer onto a main sequence primary (K.C. Leung, unpublished). However this may not be a serious problem — perhaps V367 Cyg just

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represents an earlier stage in the "standard" mass transfer episode. Possibly it could be placed in an evolutionary sequence with other hot contact systems, such as SV Cen and V701 Sco, which one would assign even an earlier place in the sequence. A highly relevant problem in this regard is that of identifying the mechanism for mass loss from the system, and we may not be too far from being able to specify (observationally) approximately where large scale mass transfer begins within the RPMT. Finally, it should be noted that fitting experiments with a disk model (R.E. Wilson, unpublished) suggest that V367 Cyg may indeed be semi-detached rather than overcontact.

RW Tauri is an interesting case, because it violates the "rule" that emission line activity goes with very fast rotation. As determined from line broadening (Olson, 1984) the primary's rotation is only about twice synchronous, while the centrifugal limit should be around 9 times synchronous. Of course, RW Tau has a long history of intermittent detection of emission lines in totality, and it is among the small minority of systems to show such activity in the survey by Kaitchuck, Honeycutt, and Schlegel (1985). Since emission lines in totality have been used with apparent good success lately as predictors of fast rotation (Wilson, 1989; Van Hamme and Wilson, 1989), one must ask why they appear in RW Tau, a relatively slow rotator. Is RW Tau really rotating faster than the line profile results suggest? Probably not, as a recent light curve analysis (Van Hamme and Wilson, 1989) also gives slow rotation. Is the seemingly strong connection between fast rotation and emission lines an illusory finding, perhaps based on small number statistics? This must be kept in mind as a possibility until the statistics are more numerous. Is there some unsuspected idiosyncrasy of RW Tau which causes its aberrant behavior? Again, this must simply be kept for now as a possibility. One could speculate, for example, that systems like RW Tau and U Sge rotate slowly despite a relatively large mass flow because the primaries are much less evolved than that, for example, in RZ Sct, so that the density of the envelope is relatively large and the added angular momentum is thereby too small (compared to the existing angular momentum of the outermost layers) to have much effect. Implicit in this notion is the idea that observed fast rotation in Algol primaries is not much more than a surface phenomenon. Clearly, present observations do not much limit speculations of this kind.

In terms of critical periods (Plavec, 1968), the observed W Sers all would be case B systems (lobe overflow begins in the shell hydrogen burning phase), while many common Algols must be case A (overflow begins in the core hydrogen burning phase). An uncertainty enters the critical period argument because the post mass transfer periods are not the same as the pre mass transfer periods. They are longer for conservative mass transfer and might be shorter for non-conservative transfer. Anyway, one would expect that the particular W Sers that we see are not the progenitors of those case A Algols, and we need to ask where those progenitors are. Perhaps there are W Ser - like progenitors of the case A Algols, but the phase is extremely short-lived, or for some reason not easily identified (not observationally spectacular).

Paczynski (1967, 1971), Plavec (1968), and Kippenhahn (1969) all have discussed the idea that W Sers (actually the name did not then exist) lead to Wolf-Rayet binaries, as a natural consequence of the eventual uncovering of the helium core of the mass losing star. After 20 years, there seems to be no critical observational input to that question, but it remains as one of the more interesting questions of the W Sers. At some point it will be necessary to ask where the circumstellar gas (which gives the characteristic Wolf-Rayet emission lines)

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originates and why it persists, rather than simply being accreted.

We are now at a stage in which new light cast on the W Ser problem by a new kind of penetrating observation would be particularly welcome. The W Sers are difficult to probe observationally, and there are not very many of them. It is enjoyable to decode a puzzle from meager information, but now we have a plausible solution and, while we must remember that more than one explanation may be needed to cover the whole class, most of us seem ready to peek at the answer.

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DISCUSSION

Livio drew attention to the fact that the system AW Peg appears twice in Wilson's Figure 3, with rather different values of R determined from line-broadening and from the light-curve. He also asked why most values of R close to unity had been determined from the light-curve, while those close to zero had been determined from line-broadening. Wilson promised to answer the latter question in his second paper (p.235). There are, at present, only three systems for which rotational velocities can be determined by both methods. Of these, two show the methods to agree quite well; AW Peg is the exception. Since eclipses of AW Peg are partial and neither light-curve nor velocity-curve is well-defined, perhaps the disagreement is not important.

Olson asked if tidal dissipation in the predominantly radiative envelope of the gainer is large enough to resynchronize rotation within the evolutionary time. Smak interjected that the effectiveness of tidal synchronization is strongly dependent on the dimensions of the star relative to its Roche lobe. Wilson replied that he had addressed this problem in a paper given at the 1985 Beijing colloquium, just published. He found it convenient to consider the rate at which rotation decayed, rather than absolute times, and it looked as if tidal synchronization could be effective but the viscosity is still uncertain. Walker expressed misgivings about the ease with which synchronous rotation was often assumed and asked about the determination of rotational velocities from light-curves. Wilson replied that this, too, would be dealt with in his second paper.

Polidan expressed surprise that V356 Sgr had not been included in Figure 3. Spectroscopic and photometric observations showed the primary to be rotating at critical (near break-up) speed. He had discussed this in his own paper (p.85). Polidan had used unpublished model atmospheres by Collins and Sinneborne in his analysis of the system. From these models, two predictions could be made: the spectral type of the rotating star will not match the mass (V356 Sgr has a B3-4V star of $12m_{\odot}$) and the flux distribution shortward of the peak intensity will not match that found from studies at longer wavelengths (this effect is also seen in V356 Sgr). These two effects, therefore, provide other ways of determining if a star is rotating at critical velocity, but observations from space are needed. Wilson replied that had the result been available to him, he would certainly have used it.

Hilditch emphasized that light-curves can give a wide range of solutions unless constrained by a spectroscopic value of the mass-ratio. Wilson said that this varied from system to system. If eclipses are complete and no third light is present, the mass-ratio can be well determined photometrically. Van Hamme suggested that the spectroscopic mass-ratios of many of the systems analyzed were themselves poorly determined. Andersen remarked that in their light-curve solutions made of W Ser stars, near-critical rotation had been adopted as the most natural assumption, but the changes produced by allowing F to vary from 1 to 50 were far smaller than those produced by the disk, so they could not constrain rotation even though they knew the mass-ratio. He asked about the sources of masses given for W Ser stars in Wilson's Figure 1.

The reply was that most of the Algols came from the catalogue by G. Giuricin, F. Mardirossian and M. Mezzetti (Astrophys. J. Supp. **52**, 35, 1983), although he had made some additions and deletions. The masses of W Ser stars had come from a variety of sources. Andersen reported that the few values of W Ser masses given by Giuricin et al. that he had been able to check were in error by a large factor.

Chambliss asked if RW Per, for which a velocity of 30 times the synchronous rate had been quoted was in fact rotating at more than the critical break-up value. He also commented on the high rotational velocity ascribed to RW Mon, which, he believed, showed less prominent emission lines in its spectrum than did RW Tauri in its. Wilson replied that the primary in RW Per is close to, but not at its limit of stability. Since emission features in the spectra of both RW Mon and RW Tau are transient, it is difficult to be sure which are the stronger.