CONTACT BINARIES

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ASBTRACT. The most promising mechanism for the formation of contact binaries involves the orbital angular momentum loss (AML) and the resulting orbital decay of detached but close synchronized binaries. The efficiency of magnetic wind braking should abruptly decrease upon formation of a contact binary because of the transformation into a system of earlier spectral type and (possibly) of longer orbital period. The new primary of the contact system should have convective zone thinner than indicated by the surface temperature of the common envelope. The decrease in the coronal (X-rays and radio) activity of contact binaries, which is indeed observed, is used as an agrument that the AML efficiency in contact is relatively low and that the contact stage is considerably prolonged relative to adjacent stages. This small modification to the AML models is capable of explaining why many *different* contact binaries are observed in old systems like NGC188. The AML evolution is not the only mechanism leading to formation of contact binaries; some of them may have originated *via* Algol-like evolution. Thus, the observed contact binaries are probably a mixture of systems formed in different ways.

1. INTRODUCTION

The W UMa-type binaries need no introduction to participants at this meeting. Their short orbital periods make them prime targets for small telescopes, particularly as "easy" objects for photometric studies. This opinion about W UMa systems is not always profitable for their understanding because many papers have been prepared by first-time observers or students who were given "easy" term projects. This has resulted in too many incidental papers which obscure rather than enlighten the view. In addition, the pleasure of obtaining a really *curved* light curve with relatively little effort frequently eclipses the need of using a calibrated photometric system: Still quite common in papers are expressions such as: "...our light curve was obtained through the B and V filters which closely match..." (which usually means that everything was left in the instrumental system!). The spectroscopic observations of W UMa systems are more difficult and the situation here is a

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bit better but still frequent are orbital solutions based on less than 20 observations and with sine fits which neglect the *large* rotational effects of contact binaries.

However, my intention is not to complain about improper ways of obtaining and handling observations of W UMa systems but rather to address the questions of why we should study these systems and what do we know about their origin and evolution. Quite a few reviews have appeared relatively recently: The evolutionary state and activity of W UMa systems were described in the same volume by Mochnacki (1985) and by Ruciński (1985a); other reviews are by Smith (1984), Duerbeck (1984) and Ruciński (1985b). In this situation of the relative abundance of reviews, I decided to discuss here only some problems related to the formation and evolution of W UMa systems, assuming that the reader needs no detailed introduction to the field.

2. CONTACT NATURE OF W UMA SYSTEMS

It can hardly be argued that the W UMa systems are *not* in contact. This assertion results not only from solutions of light and radial-velocity curves but primarily from the mere fact that their components have identical temperatures and hence luminosities scaling as $L \propto R^2 (\propto M$ for Roche geometry) in spite of differing masses. We know that the W UMa systems avoid having equal components ($q = M_2/M_1 \neq 1$) and may, in fact, prefer small mass-ratios which are expected to be discriminated against by observational selection effects (Van't Veer 1978). Since the cores produce energy as $L \propto M^4$ (or steeper if the cores are evolved), it is an inevitable conclusion that very large amounts of energy must be transported through the optically thick "neck" between components. This picture must certainly be true for all systems which show EW-type light curves (i.e. with equal minima), irrespectively of orbital period. However, as noticed already by Lucy (1976), for $P > 0.4$ days, the EB-type systems (light curves with unequal minima) start to appear. Some of them may be semi-detached but some are in genuine contact but with strange surface-brightness distributions indicating the presence of bright spots in the neck area which can be modelled by unphysical values of the reflection albedo (Lucy and Wilson 1979; Kalužny 1983 and in press). The lesson given to us by the early-type system SV Cen may be instructive here. This system was once considered to be in unusually deep contact (Wilson and Starr 1976; Ruciński 1976); we know now that a strong and very hot light source, which is located somewhere between the components and results from the mass-transfer flow (Drechsel et al. 1982), mimics large distortion of components. We cannot exclude the possibility that at least in some "normal" EB-type binaries the mass-transfer and mass-accretion phenomena also produce systems which, perhaps similarly to SV Cen, *appear* to be in good physical but poor thermal contact.

The significance of the division at about 0.4 days is still not clear. It is interesting to note that contact binaries with the A-type light curves which, in fact, best conform to the contact model, also start appearing at roughly $P > 0.35 - 0.4$ days and that the range $0.22 < P < 0.35$ is almost exclusively populated by systems with W-type light curves.

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3. MODELS OF THE INTERNAL STRUCTURE

The two best-known models are both modifications of the "classic" model of Lucy (1968); we shall summarize their properties in turn.[1] The TRO (thermal-relaxation-oscillation) model was proposed by Flannery (1976) and by Lucy (1976) and was later more broadly explored by Robertson and Eggleton (1977). It is a direct extension of the original models of Lucy (1968) but now the matter - and not only the energy - is also permitted to be exchanged between components. When the total mass and angular momentum are preserved, such models reveal relaxation-type oscillations with alternate long-lasting contact phases and relatively short semi-detached phases. During the contact phase the mass-ratio decreases and the separation increases until disruption of contact; in the semi-detached phase the matter flows back until contact is re-established. The relative duration of both phases depends on the ratio of thermal time scales of both components. Since these time-scales depend on the masses roughly as $t \propto M^{-3}$, the relative durations of contact and semi-detached phases should scale as $t_{cont}/t_{sd} \propto q^{-3}$. Thus, for small mass-ratios, the semi-detached phase may be relatively brief.

The AML (angular-momentum-loss) model (Mochnacki 1981; Rahunen and Vilhu 1982) was proposed to explain the non-existence of semi-detached configurations of the TRO models, at least among short-period W UMa binaries. It also derives from the known strong magnetic activity of W UMa systems (to which we shall return later) and the presumed importance of the loss of angular momentum *via* the magnetized wind.[2]

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[1] We will not discuss the contact-discontinuity model (DSC) which is in fact an alternative to the original Lucy models (Shu et al. 1976; for a full list of later references, see Shu et al. 1980). Its main idea is that one can hide the cooler component inside the mantle extended over it by the hotter component. This model presented *no* explicit predictions as to the testable properties of contact binaries (except the by-product concerning the non-existence of the gravity darkening: Anderson and Shu 1977) but generated a hot debate which, from the present perspective, seems to have played an important rôle in visualizing the extreme complexity of the energy transfer between components. This hydrodynamic Pandora's Box is relatively little explored, except for a few pioneering efforts such as those by Robertson (1980) and Hazlehurst (1985). It should be noted that the DSC models may correctly describe contact binaries at *some* stages of evolution such as immediately after establishing contact in the TRO models. The concept of the DSC models also helped to recognise the over-constrained nature of the original models of Lucy (1968).

[2] Importance of the AML, especially at the very early stages of binary-star evolution, was pointed out much earlier by Okamoto and Sato (1970).

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In effect, this loss is used here to gently squeeze the systems and thus to prolong the contact phase of the TRO model to such a degree that the semi-detached phase never appears (or appears very rarely). The system drifts to smaller and smaller mass-ratios along contact branches of the TRO cycles. It is not clear what regulates the AML in such a way that it is strong *enough* to eliminate the semi-detached configuration yet not *too* strong to lead to a premature merger. It is an observed fact, however, that models constructed according to the precepts of the self-regulated AML explain the period - color relation very well. The expected time-scales of evolution *via* this mechanism are of the order of 5×10^8 years (Rahunen 1981) or may be even longer (Mochnacki 1981).

The TRO and AML models have explained many observational facts: the preference for marginal contact, the evolution towards small mass-ratios, and the shape of the period - color diagram. They have also given many leads where to look for possible observational tests. Particularly easily testable seemed to be the occurrence of the broken-contact phase and the correlation of period changes with the branch of the oscillation cycle. Only later on it was realized that the period changes are dominated by magnetic effects which have more in common with those observed in RS CVn systems (Kreiner 1977; Herczeg 1979; Hall and Kreiner 1980; Van Buren and Young 1985) than with real mass-transfer effects. As we already said, systems which appear to be in the semi-detached phase (or at least with poor thermal contact) do seem to exist: They start at about P = 0.35 days; there are few of them for $0.35 < P <$ 0.45 days but they become more frequent at longer periods. In none of the better studied cases (Kalužny 1983; Hilditch et al. 1984; King and Hilditch 1984; Mochnacki et al. 1985; further as yet unpublished studies by Kalužny and Hilditch et al.) can we be sure that these are really broken-contact exemplifications of the TRO models; they look more like evolved Algols which started with much longer periods and through mass-exchange, mass-ratio reversal and loss of angular momentum followed by further evolution of former secondaries approached configurations just bordering on contact (see Budding 1984, or the scenario suggested by Tapia and Whelan (1975) to explain the properties of ε Cr A). We should not, however, dismiss the possibility that these objects *are* related to the contact systems. In fact, if we consider what must happen to them, we come to the conclusion that these semi-detached objects may very well form contact binaries in the not too distant future. As is well known from the experience of calculating contact models (Lucy 1968, 1976; Moss and Whelan 1970; Hazlehurst 1970; Moss 1971), it is much easier to obtain stable contact binaries using *evolved* models, preferebly with quite differently evolved cores. Indeed, the further we depart from homology relations for both components, the easier it is to form a contact binary. But contact binaries consisting of *unevolved* Main Sequence components certainly also exist, as documented by their large mean densities and locations on the H-R diagrams of clusters (Mochnacki 1981, 1985). How to explain those systems? It seems that to solve that, we really must consider contact binaries in the broader perspective of the evolution of close but detached binaries under the influence of the angular momentum loss. This loss *must* operate in all cool, rapidly-rotating stars and may produce dramatic effects in close synchronized

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binaries. Before we do that in Sec. 5, we will have a look at the magnetic activity of W UMa systems.

4. ACTIVITY OF W UMA SYSTEMS

The W UMa systems are very active stars, fully confirming the well known correlation between activity on one hand and the rotational period and spectral type on the other hand. A single quantity, the inverse Rossby number τ/P (Noyes et al. 1984), combines the spectral type and period in one convenient parameter[3] which can be used to compare activity levels in single stars or even to predict rotation periods from the observed activity levels (Soderblom 1985). Apparently, it can also be used for synchronized binary stars, including W UMa systems (Vilhu 1984). But there are some important differences between contact binaries and all other stars and we will describe them shortly.

One of the indications of elevated activity, photometric spots, are know to exist on surfaces of W UMa systems. Such spots *may* exist in ordinary systems such as W UMa itself (Eaton et al. 1980) but they *must* exist in unusual ones such as TZ Boo (Hoffmann 1978; Ruciński 1985a), where there is no other way to explain weird changes in light curves on time scales of years (conversions from A- to W-type of light curve, etc.). It is difficult to quantize the spot coverage; it is much easier to do that for various non-thermal emissions of these stars. In terms of the chromospheric (Riciński 1985c) and transition-region (Vilhu and Ruciński 1983; Eaton 1983) emissions, the W UMa systems seem to be identical to those few single stars and detached-binary components which have equally short rotation periods and hence equally large τ/P (Vilhu 1984). In fact, strengths of these emissions increase very slowly with the increase of τ/P for these very active stars; this can be explained as resulting from the total saturation of stellar surfaces by small-scale active regions. But interesting things start to happen when we consider the coronal exissions: Both in X-rays (Cruddace and Dupree 1984; Vilhu 1984) and in the radio (Hughes and McLean 1984, 1985) the W UMa systems are definitely *less active* than are similar single stars or components of non-contact binaries. Apparently, *the W UMa systems are unable to generate and maintain large magnetic-loop structures which could retain coronal plasma.* What is the reason for that?

We can hypothesize an explanation for the lowered coronal activity of contact binaries by making an observation that sizes of magnetic loops tell us something about dimensions of interior regions where these loops are generated and then temporarily anchored. The largest coronal structures should have sizes of the order of the vertical extent of the whole convective zone. The important distinction for contact binaries

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[3] The quantity τ (which is a function of the spectral type) gives the convective turnover time in the deep layers of the convective envelope where the time scales for magnetic bouyancy losses are long; the rotational period P describes, to first order, the rotational velocity field which can amplify the magnetic field.

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is that their convective zones may be *thinner than indicated by their surface temperatures*. The reason for this is the following: the contact binaries must have lower surface temperatures than identical non-contact stars because of the large radiating area which is fed by the energy generated practically only in the more massive component (Mochnacki 1981). This component - except for the relatively shallow envelope which is shared with the less massive secondary - has the inner structure of an *earlier-type* star, i.e. of the star with much shallower convective zone. Thus, we hypothesize, that *deeply-rooted and large magnetic structures in contact binaries are expected to be weaker than in similar non-contact stars*; this would be in contrast to chromospheric and transition-region structures which penetrate to shallow layers and which should have normal strengths corresponding to the observed temperature of the common envelope.

Another factor which can make contact binaries different in their coronal activity is the internal rotation. Because of the strong distortion of these stars, incomparably much larger than even for the most-rapidly rotating single late-type stars, the turbulent convection may be split into very small eddies which would make the rotation more rigid than in less distorted stars. Since it is the differential rotation which is needed to generate magnetic fields and to pump the non-thermal energy into outer atmospheres by twisting the magnetic loops, the W UMa systems would be expected to be less active than similar, non-contact stars. The obvious questions would be then: why is this decrease in activity observed only for the coronal structures?

Whatever the reason of the relative weakness of coronae in W UMa systems, the observations *directly* tell us that their largest-scale magnetic structures are smaller and contain less plasma than in other similar but non-contact stars. Since the magnetic structures of coronal dimensions control also the flow of the stellar wind, we come to our hypothesis that *the efficiency of the angular-momentum-loss in W UMa systems may be lowered in comparison with non-contact stars of the same* τ/P. We shall expand this view in the next section over the broader background of the evolution of binary systems under influence of the angular-momentum-loss.

5. W UMA SYSTEMS AS END PRODUCTS OF BINARY STAR EVOLUTION

There is no question that the angular-momentum-loss (AML) must play an important rôle in the evolution of close binary systems consisting of late-type stars. Short time-scales of spin-orbit synchronisation for orbital periods below a few days (Zahn 1977; Scharlemann 1981a, 1981b; for large rotation rates: Campbell and Papaloizou 1983) mean that the angular momentum is effectively removed from the *orbital* angular momentum leading to the orbit decay in time scales of the rotational AML (Ruciński 1984). Even if short-period binaries consisting of late-type components are nor formed by the initial star formation process (Popova et al. 1982a, 1982b), they will be pushed into the domain of short periods by the ever-prevailing AML. But progressively shorter periods mean also progressively more efficient AML. Skumanich's (1972) famous

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law of the angular-velocity decay with age for single stars $\Omega \propto t^{-1/2}$ requires the efficiency of the AML process to scale as $dJ/dt \propto -\Omega^3$ (J is the angular momentum here). As noted by Soderblom (1985) this process has a high degree of self-regulation and there is no reason not to suppose that a similar situation exists in close binaries. But there is one important difference: as the orbit decays and the orbital period becomes progressively shorter, the AML evolution of a detached binary will rapidly *accelerate* because Ω *increases* with time (Ruciński 1982). Thus, in effect, this evolution is a mirror image of the changes of Ω in single stars where the rotation shows down and its changes decelerate with time. At some point components of a binary will come so close to each other that something unusual will happen to them: in a dynamical time-scale of about one orbital period something new will emerge - a contact binary.

The most coherent picture of the above process was presented by Vilhu (1982). He calculated the distribution functions of periods for close but detached binaries which evolve under the influence of the AML and concluded that the efficiency for very short rotation periods depends somewhat less steeply on Ω than for single, slowly-rotating stars. From statistics of binaries he found that the exponent α in the expressions for the AML efficiency $dJ/dt \propto -\Omega^{\alpha}$ is $\alpha \approx 1.5$. A similar exponent was derived from the statistics of bright binaries by Ruciński (1984). This flattening of the AML efficiency may have something to do with the saturation in the general level of activity for very large rotation rates.

The simple picture suggested by Vilhu has the attractive feature of explaining formation of contact binaries from stars at different evolutionary stages but with the important preference for *older and thus more evolved* stellar systems because - in their case - the AML has had more time to bring stars into contact. The advanced age of at least *some* contact binaries is indicated not only by their high numbers in *old* open clusters but also by their galactic distribution (Duerbeck 1984) and by a common tendency for positive metallicity indices δm_1 (Ruciński and Kalužny 1981; Ruciński 1983); contact binaries may also exist in the globular cluster M 55 (Irwin and Trimble 1984). But even this very promising scenario has some problems. The main problem is that the AML still continues in the contact stage and will destroy the binary system too quickly by converting it into an FK Com-type star (Webbink 1976; Bopp and Ruciński 1981; Bopp and Stencel 1981). The time scale estimated by Rahunen (1981) to be of the order of $\sim 5 \times 10^8$ years is short in comparison with ages of old open clusters (such as NGC 188 or M 67) where W UMa systems are particularly abundant. As noted already by Vilhu (1982), the AML scenario has difficulties explaining the existence of four contact systems in NGC 188 (where their density is a hundred times higher than in the galactic field) unless one postulates that large numbers of similar binaries with periods of $\sim$ 3.5 days were initially formed and then roughly simultaneously evolved into contact.[4]

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[4] There are no indications of recent star-formation bursts in this cluster as suggested by Van't Veer (1984).

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In fact, NGC 188 (Baliunas and Guinan 1985; Moss 1985) must contain even more contact binaries which are undetectable for randomly distributed aspect angles (Van't Veer 1982). Indeed, there are indications that there are more variables in the cluster at right magnitudes and colors (Baliunas and Guinan, private communication); some of them may be contact binaries. A similar problem is the existence of two *different* contact binaries in the visual binary ADS 9537 (BV Dra + BW Dra; Ruciński and Kałużny 1982; Batten and Wenxian Lu 1985). It is difficult to imagine reasons why both systems of this binary should be in the contact stage *unless this stage is relatively long-lived.* Summing up: even within the AML model we encounter the returning problem that there exist too many contact binaries.

As discussed in the previous Section, we have now direct observational indications that the coronal activity of W UMa systems - and presumably also the AML efficiency in them - is lower when compared with non-contact stars. We were even able to present plausible reasons why this should be so by arguing that the inner structure of the dominant primary component does not correspond to the observed effective temperature but rather to that of an earlier-type star with a much thinner convective envelope. Our main argument is that the AML efficiency should drop immediately upon formation of the contact binary from the detached system. As an example, let us consider a situation that a hypothetical equal-mass binary consisting of two G 2 V stars ($1.0M_\odot + 1.0M_\odot$) transforms into a contact binary (Fig. 1). Considerations of the thermal stability suggest that the new mass-ratio q_{cont} will tend to values progressively smaller and more different from unity on the thermal time-scale of the less-massive component (Flannery 1976; Lucy 1976). As shown by Williams and Roxburgh (1976), the tendency toward small mass-ratio develops already in the very short, dynamical time-scale of the system. If there has been no mass loss, the new contact system may have components of, say, $1.5M_\odot$ and $0.5M_\odot$. The "internal" spectral types would be then something like F 2 and M 0 but, of course, they have nothing to do with what we could observe: the effective temperature of the whole system should correspond to a late-F spectral type. (The resulting spectral type will depend on the surface area of the new system, i.e. on q_{cont} and on how much angular momentum has been lost in the violent transformation). For the situation of no loss of angular momentum, the new period will be *longer* than the original one by $(q_{det}/q_{cont})^3[(1 + q_{cont})/(1 + q_{det})]^6$; in our case ($q_{det} = 1$, $q_{cont} = 1/3$) by a factor of 2.4. But even if the process of transformation does not preserve the angular momentum and the period increases less than by the above factor (or possibly even shortens), more important is the change of the spectral type of the primary component. Now, instead of the rotational braking of *two* G 2-type stars, the braking is exerted by an equivalent of *one* F 2-type star; the less-massive component, even if it is very active "internally"[5], is of negligible importance for the over-all balance of the angular

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[5] Surface activity in all studied cases is surprisingly uniform over the whole common envelope; possibly, it is even the *more-massive* component which is more active but the evidence is only marginal.

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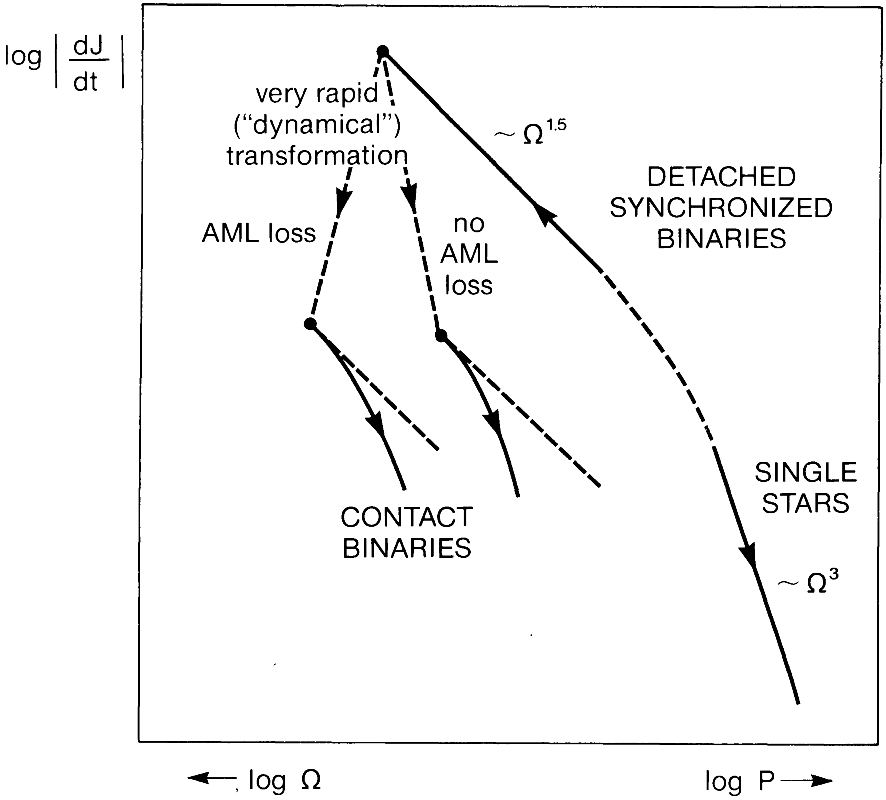

Figure 1. A detached synchronized binary loses its *orbital* angular momentum: its period shortens and AML efficiency increases until components come in contact. Then, after a relatively short interaction, a stable contact binary is formed. It has an earlier spectral type than the components of the original detached binary and its AML rate is therefore reduced. From this moment, the orbital period will slowly *lengthen* (because of evolution towards smaller mass-ratios) leading to progressively less efficient AML. An additional decrease in this efficiency (represented here by downward curving arrows) results from evolution towards earlier spectral types.

control the wind outflow.

It seems that the above small modification to the AML model which concerns the relative longevity of the contact stage very nicely explains many observational facts. However, we should not be too quick in assuming that *all* binaries become transformed into single stars through the AML pre-Main Sequence stage. Then, the AML process will produce any effects only if it acts for long enough. Most probably, only a narrow range of periods will be swept clean of detached binaries even in relatively old systems (for NGC 188 with $t \approx 10^{10}$ years (VandenBerg 1985) up to ~ 4 days); those with longer periods should

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momentum. The surface areas for the emission of the wind of the new contact system and of the original detached system are comparable so that the relative efficiencies of the wind braking should depend only on the rotational periods and spectral types. Using the inverse Rossby number as a guide, we estimate that the drop in coronal activity should be ~ 20 times. To arrive at this very approximate number we note that the change in τ/P for the transformation from G 2 to F 2 is by a factor ~ 50 but the activity is not linear in τ/P so the drop should be smaller; however, one star is lost from the AML budget compensating for this effect. We think that the AML efficiency should drop by a comparable factor, possibly retaining the same dependence on Ω as before establishment of contact. Thus, only the constant of proportionality in $dJ/dt \propto -\Omega^{1.5}$ would have to change. The subsequent evolution of the contact binary towards smaller mass-ratio will result in some *increase* of the orbital period (decrease of Ω); the spectral type will also become earlier. If we again use τ/P as a guide, we see that both effects should lead to a further decrease of $|dJ/dt|$; this is in accordance with the models of Rahunen (1981) which indicate that progressively less of the AML is needed to keep a system in marginal contact. This type of braking can extend up to relatively early spectral types, perhaps as early as ~A 7 where the convective dynamo still seems to operate (Schmitt et al. 1985).

It is not clear how the mechanism described in Figure 1 regulates itself so precisely that the W UMa systems always stay close to marginal contact. Therefore, much remains to be done to obtain a coherent picture of the whole process from general tendencies we have only enumerated here.

6. CONCLUSIONS

As a result of much observational and theoretical work, a picture of the contact binary formation and evolution starts to emerge. Apparently, these systems can be formed from detached binaries by a variety of processes with the common denominator being the loss of angular momentum. Thus, some of them may have been formed by the Algol-type evolution with a mass-ratio reversal; some of them may have evolved directly into contact from detached Main-Sequence binaries *via* the magnetic-wind braking. Therefore, the contact stage seems to be the *purgatory* for all close binaries which precedes the ultimate merging of components and disappearance in the sea of single stars. We think that the contact stage is relatively long-lived because the magnetic braking is less efficient at that time than in stages which precede and follow the contact configuration. This drop in efficiency results from two effects: at first, there is a jump to earlier spectral types and (probably) longer periods; later, there is the evolution in contact to smaller mass-ratios and even earlier spectral types. Both effects should lead to a drop in activity and to a less efficient wind braking. We see this drop only in the coronal radiation; the much cooler common convective envelope generates quite strong surface activity but this activity has no influence on the large-scale magnetic structures which survive intact.

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Possibly related to these considerations of the binary survival and contact binary formation are reasons why we do not observe cool contact binaries with spectral type later than ~K 5 and periods shorter than 0.22 days (Mochnacki 1985). This is not the only subject which has been left undiscussed here: One of the still remaining problems is the explanation of the W-type light curves (Ruciński 1985) but - almost certainly - this phenomenon is also related to the magnetic activity which is generally so important for contact binaries.

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DISCUSSION

Breger: What important observations would best be done with small telescopes?

Rucinski: Period changes and light curves, but be careful with instrumental effects.

Breger: How large are the period changes?

Rucinski: Quite large changes over small time intervals. One needs to be able to make intensive observations, when everything is happening, for a few weeks every 10 years. The rest of the time one needs to just monitor the object.

Peery: Is the ultraviolet activity (e.g. strong CIV) of these systems observed to be phase dependent?

Rucinski: No, it's phase independent. That is, the stars show active regions distributed evenly over the surface.

Peery: It's intriguing to know if this sort of activity in late-type stars always implies a companion?

Rucinski: These stars are normal as far as their chromospheric and transition regions are concerned. What is abnormal is their coronal and X-ray activity which is lower than normal.

Cottrell: Do you have any comment on the recent paper by Bruce Campbell about the coalescence of contact binaries producing the globular cluster CN, Na/Aℓ anomalies?

Rucinski: Violent events occur over one or two cycles when stars go from detached to contact systems. One would expect even more disturbance when stars go from contact to single stars.

Cameron: A useful intermediate step towards answering that question

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might be to look for such abundance anomalies in the FK Com stars, which may be the post-coalescence descendants of contact systems.

Barwig: In the case of differential rotation, would the Rossby relationship still work?

Rucinski: This is another way of explaining the underactivity of contact binaries. Contact systems can be considered to be rotating more like solid bodies than other stars. If you disturb the star, by contact with another, you create strong turbulence, and the convective elements break into smaller cells which leads to a more solid body rotator which has less differential rotation.

Plavec: What is the present opinion about the subsurface discontinuity proposed by Shu and Lubow?

Rucinski: In their model they have one hotter and one cooler star. The hotter star envelops the cooler one. This is potentially a stable configuration. However the problem is that there is a temperature gradient going both ways - increasing inwards and outwards which is an unstable situation. This short phase of contact may equate with the rapid period changes which I alluded to earlier.

Mochnacki: With the lower rate of braking needed for the systems to survive more than a few times 10^8 years, the braking is insufficient to maintain the Vilhu-Rahunen mechanism for suppressing the thermal relaxation cycles.

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