ANGULAR MOMENTUM LOSS AND THE ORIGIN OF CATACLYSMIC BINARIES

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Abstract. A two-stage mechanism is proposed whereby detached dwarf systems like V471 Tau may evolve into cataclysmic binaries. The two stages are (1) angular momentum loss from the secondary due to braking by a stellar wind linked with magnetic fields, and (2) angular momentum gain by the secondary from the orbital motion, due to tidal friction. This combination may be able to remove angular momentum from short-period binaries on a timescale of $\sim 10^9$ yr.

The conventional theory of close binary evolution (e.g. Paczynski, 1971), in which both total mass and orbital angular momentum are conserved during mass exchange, has great difficulty in explaining the origin of the majority of cataclysmic binaries, i.e. those with periods of two to ten hours, although conventional theory may be able to explain such objects as the recurrent nova T CrB whose orbital period is 226 days (Kraft, 1958; Paczynski, 1965). This difficulty is partly because of the low angular momentum in a typical cataclysmic binary, although there is some overlap with the short period W UMa stars, but mainly because it is hard to see how a white dwarf of about one solar mass can have developed in such a close system even if the system was quite widely separated, and therefore with a very extreme mass ratio, at an earlier stage. The mechanism of Ostriker (1976) and Paczynski (1976) may cut through this difficulty by allowing a dwarf main sequence star to be engulfed in the atmosphere of a red giant, but the development of their theory so far does not yet give definitive answers to the questions

(a) will the dwarf main sequence star survive as a separate entity as it approaches close to the white dwarf core?

(b) if it does, and if the red giant envelope is blown off at this stage, will the main sequence remnant, after cooling to thermal equilibrium, be left semi-detached, as in cataclysmic binaries, or wholly detached, as in V471 Tau (Nelson and Young, 1976)?

Thus it is not clear that this mechanism, or any other, can produce cataclysmic binaries directly. It is less difficult to believe that this mechanism, or some other, can produce close but detached binaries such as V 471 Tau.

Let us consider the possibility of an evolutionary scheme:

two main sequence stars → Degenerate dwarf with close, but detached, Unevolved red Dwarf (DUD for short)
→ Cataclysmic Binary (CB).

If the white dwarf in the DUD stage is to be about one solar mass, then almost inevitably some angular momentum must be lost in the first evolutionary step, since such a massive white dwarf would require as a precursor a red giant or supergiant in a binary with a period of 100 to 1000 days. If furthermore the unevolved red dwarf in the DUD stage is later than mid-G some further angular momentum must be lost to start mass transfer in the CB stage, since nuclear evolution would be unreasonably slow. Some of the longer period cataclysmic binaries such as GK Per (16.43 h), AE Aqr (9.88 hr) and RU Peg

P. Eggleton et al. (eds.), Structure and Evolution of Close Binary Systems, 209–212.

https://doi.org/10.1017/S0074180900011979 Published online by Cambridge University Press

(8.90 h) may have started mass transfer through nuclear evolution, since the secondaries are all of later spectral type than main sequence stars of reasonable mass. These systems are extra evidence that at least some secondaries were detached for a period before mass transfer began. Presumably those secondaries which were fairly massive in the DUD stage can expand by nuclear evolution to the CB stage, while the less massive secondaries have to wait for sufficient angular momentum to be lost. This angular momentum loss might be due to gravitational radiation (Faulkner, 1971) but this mechanism, although just powerful enough to bring say V471 Tau to a CB stage in about 10^{10} yr, would not be adequate for systems starting from any longer period. I would like to suggest a mechanism that would work through a combination of two effects:

(1) braking of the secondary by a stellar wind coupled to a magnetic field;

(2) coupling of the secondary's rotation to the orbital rotation of the system through tidal friction.

The former mechanism is generally thought to be responsible for the slow rotation of main sequence stars later than mid-F, (Kraft, 1968); while the latter mechanism is responsible for the fact that main sequence components of binaries with periods less than about 4 days are always corotating with the binary (Zahn, 1966; Plavec, 1970). This two-stage process can drain angular momentum from the orbit via the secondary, provided that both stages can operate on a sufficiently rapid time scale. I infer that this time scale must be about 10^9 y, since secondaries which are massive enough to evolve significantly in about 10^9 yr seem to have done so.

Kraft (1967) showed that the rotation of main sequence stars of spectral type F in the Hyades, the Pleiades and the field is consistent with the assumption that braking of single stars occurs on a timescale of $\sim 10^9$ yr. Zahn (1966) estimated the braking effect of tidal friction, and showed that it could operate on timescales of $\sim 10^6$ yr or less in binaries with periods $\lesssim 10$ days. Both mechanisms are likely to be more efficient for stars with deeper convective envelopes, i.e. G or later. This is because stellar wind, which is a necessary part of single star braking, apparently requires a turbulent surface convection zone to heat the corona up to escape velocities; and because turbulent convection can provide a frictional, dissipative agent to make tidal friction effective. Thus it is possible that both mechanisms can work on a reasonable timescale in a binary consisting of a white dwarf and a red dwarf of type G or later, and with a period of less than a day or two. I imagine that the braking process is likely to be the slower, and therefore more critical, mechanism, and it might be that only in particularly favourable circumstances, such as unusually strong magnetic fields, is the combined process effective. However, the braking action may be speeded up if the presence of a close companion is able to enhance the stellar wind from the red dwarf significantly over what would be expected from a single star. If some or all of the following effects are observed, they may be evidence that the two-stage angular momentum loss mechanism is taking place in V471 Tau:

(a) slower rotation of the red dwarf than of the binary, because of braking – however this effect would be small if tidal friction works much faster than stellar wind torque;

(b) strong chromospheric activity and/or strong magnetic fields, which might be indicative of a stronger-than-average braking action;

(c) flickering of the white dwarf, due to accretion of a portion of the stellar wind – this might also serve to keep the white dwarf hotter than usual.

For main sequence stars of lower luminosity than G or early K the stellar wind may become too weak for adequate braking. However, when one gets down to M dwarfs one may be able to take advantage of the fact that some M dwarfs, the flare stars, have very active chromospheres and strong magnetic fields, at least intermittently; this may provide a good braking torque. It is tempting to speculate that the apparent division of CBs into two groups, with periods greater than ~3 h and less than ~2 h respectively (Warner, 1976), may reflect a division between steady, sufficiently strong, angular momentum loss from dwarfs down to say mid-K, and intermittent angular momentum loss from M dwarfs which happen to be flare stars. At any rate, since in CBs there should be a strong correlation between period and secondary mass, $M_2/M_\odot \sim 0.12P$ (h), if the secondary is a main sequence star which fills its Roche lobe, and since there is not much correlation between period and primary mass (Warner, 1976), I feel that the gap at ~2.5 h, if real, is more likely to reflect a property of the secondary than of the primary.

Schmidt *et al.* (1975) have recently discovered an object (PG 1413 + 01) which may be similar in character to V471 Tau. It is a white dwarf, apparently normal although possibly hot, which is eclipsed for ~13 min every 8.26 h. The white dwarf is ~17 mag, but during eclipse Schmidt *et al.* (1975) have not detected a signal down to ~22 mag in *B* or *V*. However, very weak signals at longer wavelength suggest that the eclipsing object may be a mid-M (or possibly late-M) dwarf; if it is, we must be extraordinarily close to the orbital plane. It is possible that this is a white dwarf/M dwarf DUD binary, which might evolve through intermittent angular momentum loss (due to flares) into something like WZ Sge. It is obviously extremely important to look for more DUD objects, at least like V471 Tau if not like PG 1413 + 01. They may be a very common kind of binary which is, however, extremely inconspicuous.

The author is indebted to Drs J. Faulkner, R. P. Kraft and R. E. Taam for helpful discussions, and to the Lick Observatory for its hospitality in the Spring of 1975. This work was supported in part by NSF grant GP-32337X.

References

Faulkner, J.: 1971, *Astrophys. J.* **175**, L99.
Kraft, R. P.: 1958, *Astrophys. J.* **127**, 625.
Kraft, R. P.: 1968, in Chiu, Warasila, and Remo (eds.), *Stellar Astronomy*, Gordon and Breach, p. 317.
Nelson, B. and Young, A.: 1976, this volume, p. 141.
Ostriker, J. P.: (unpublished).
Paczynski, B.: 1965, *Acta Astron.* **15**, 197.
Paczynski, B.: 1971, *Ann. Rev. Astron. Astrophys.* **9**, 183.
Paczynski, B.: 1976, this volume, p. 75.
Plavec, M.: 1970, in Slettebak (ed.), *Stellar Rotation*, D. Reidel Publ. Co., p. 133.
Schmidt, M., Green, R., and Richstone, D. O.: 1975, *Bull. Am. Astron. Soc.* 7, 462.
Warner, B.: 1976, this volume, p. 85.
Zahn, J.-P.: 1966, *Ann. Astrophys.* **29**, 313.

DISCUSSION

Pringle: It is not clear to me why you want your two 'DUD' systems to evolve into cataclysmic variables rather than that the 'DUD' systems and the cataclysmic variables should all evolve from the interactions described by Paczynski and Ostriker.

Eggleton: I don't particularly want them to be, but it seems to me that if a common envelope is rapidly blown off two cores, the cores will have to relax thermally, probably to sizes significally smaller than their Roche lobes: I would be a little surprised if one core usually left a secondary remnant which just filled its Roche lobe.

Flannery: Mass transfer driven by gravitational radiation can succeed in producing the sequence of dwarf novae in terms of evolution from long to short period. However stimulating mass transfer at a more rapid rate might in fact force the system to separate and never produce the shortest period systems, e.g. WZ Sge.

Eggleton: My tentative suggestion is that the short period systems might evolve, not from longer period semi-detached systems whose secondaries become progressively less massive, but from longer period detached systems whose secondaries have stayed at roughly the same low mass (cf. PG 1413 + 01) while losing angular momentum. Progressive evolution of a cataclysmic variable from a period of ~6 h to ~1 hr conflicts, at least superficially, with the apparent absence of systems with periods in the range 2 to 3 h.