# EVOLUTIONARY PROCESSES IN CLOSE BINARY STARS

*(Letter to the Editor)*

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**Abstract.** The evolutionary processes of close binary stars have been examined. It is found that there is a strong deficit of binaries evolving in Case $A$ in the whole mass range. Probably the binary stars having binary separation corresponding to Case $A$ evolution cannot form.

## 1. Introduction

Kippenhahn and Weigert (1967) and Lauterborn (1968) introduced the, still used, terms Case $A$, Case $B$, and Case $C$, respectively, for the different types of evolution in binary stars. The criteria on which this term is based are the evolutionary stages of the massive primary in which it filled its Roche-lobe. If the massive primary of a binary fills its Roche-lobe during central hydrogen burning, the evolution is termed as Case $A$, while if Roche-lobe filling occurs during the shell hydrogen burning or during the central helium burning, the evolution is, respectively, termed as Case $B$ or Case $C$. These types of evolution are of basic interest for the theoretical investigations pertaining to the complete evolution of binary stars. The type of evolution that occurs for a binary with given masses of systemic components depends only on the initial separation of the components. If the initial separation is smaller than a certain critical value $A_{AB}$, the system will evolve in Case $A$ and if the initial separation is larger than another critical value $A_{BC}$, the system will evolve in Case $C$ while if initial separation lies between $A_{AB}$ and $A_{BC}$, the system will evolve in Case $B$.

The types of evolution that occur in well-known Algols have been studied by several investigators expressing various opinions. Ziolkowski (1968) suggested that the systems having a systemic mass greater than $5 M_\odot$ evolve in Case $A$ and those of less than $5 M_\odot$ follow Case $B$ while Hall (1975) interpreted U Cep and U Sge and similar Algols are as Case $B$ remnants. Further, Ziolkowski (1976) and Kreiner and Ziolkowski (1978) have calculated the initial periods of 18 Algol-type binaries having systemic mass greater than $5 M_\odot$ on the assumption of the conservation of total mass and total orbital angular momentum of the system and have concluded that ten systems are evolving in Case $A$ and other eight systems follow Case $B$. Mezzetti *et al.* (1980) have compared various theoretical models of mass loss and mass transfer against the observed properties of 55 Algol systems and have concluded that Case $A$ is pre-dominant if $M_{\text{total}} > 10 M_\odot$ and Case $B$ pre-dominant if $M_{\text{total}} < 6 M_\odot$, whilst in the intermediate range Case $A$ or

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TABLE I

The critical periods $P_{AB}$ and $P_{BC}$ for binary stars; $q = M_1/M_2$

| $M_1/M_\odot$ | $P_{AB}$ in days | | | | | $P_{BC}$ in days | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $q = 1.0$ | $q = 1.5$ | $q = 2.0$ | $q = 2.5$ | $q = 3.0$ | $q = 1.0$ | $q = 1.5$ | $q = 2.0$ | $q = 2.5$ | $q = 3.0$ |
| 1 | 0.415 | 0.398 | 0.385 | 0.373 | 0.364 | 3.300 | 3.165 | 3.056 | 2.965 | 2.888 |
| 2 | 0.685 | 0.661 | 0.638 | 0.619 | 0.603 | 15.162 | 14.542 | 14.042 | 13.625 | 13.270 |
| 3 | 0.926 | 0.888 | 0.878 | 0.832 | 0.811 | 36.995 | 35.484 | 34.264 | 33.247 | 32.380 |
| 4 | 1.143 | 1.096 | 1.058 | 1.027 | 1.000 | 69.664 | 66.818 | 64.521 | 62.606 | 60.974 |
| 5 | 1.345 | 1.290 | 1.246 | 1.209 | 1.177 | 113.818 | 109.168 | 105.415 | 102.286 | 99.620 |
| 6 | 1.537 | 1.474 | 1.423 | 1.381 | 1.345 | 169.985 | 163.040 | 157.436 | 152.762 | 148.781 |
| 7 | 1.720 | 1.649 | 1.593 | 1.545 | 1.505 | 238.613 | 228.864 | 220.997 | 214.436 | 208.848 |
| 8 | 1.896 | 1.818 | 1.756 | 1.703 | 1.659 | 320.093 | 307.014 | 296.461 | 287.660 | 280.164 |
| 9 | 2.065 | 1.981 | 1.913 | 1.856 | 1.808 | 414.774 | 397.827 | 384.153 | 372.748 | 363.034 |
| 10 | 2.231 | 2.140 | 2.066 | 2.005 | 1.953 | 522.912 | 501.604 | 484.262 | 469.983 | 457.735 |

Case $B$ seemed to be possible. Here, we have examined the possibilities that the different types of binary evolution occur in general.

## 2. Data and Procedure

In order to investigate the processes of binary evolution it is necessary to know the initial distribution of and correlation between the systemic masses and their periods (semi-major axes of their orbits). For this, we have computed the critical periods $P_{AB}$ and $P_{BC}$ and their critical separations $A_{AB}$ and $A_{BC}$ for several binary stars having various initial masses. The methods for computing these values are the same as given by Plavec (1968). Our computed values of critical periods for fifty binary stars are given in Table I for comparison with the observed periods of binaries.

Further, we have also examined the distributions of the double line spectroscopic binaries in the bilogarithmic plots of $M_1$ vs $A$ (Figure 1) with respect to our computed critical separations $A_{AB}$ and $A_{BC}$. By selecting the double line spectroscopic binaries, we have restricted ourselves to the systems where $M_2/M_1 \sim 1$ because the initial mass ratio of the Main-Sequence progenitors of binaries is close to unity (Lucy and Ricco, 1979; Garmany *et al.*, 1980; or Van 't Veer, 1981).

In Figure 1, the crosses mark pairs with $M_v > 7^m$, dots represent brighter pairs. The data presented in Figure 1, are taken from the compilation of Popova *et al.* (1982). In

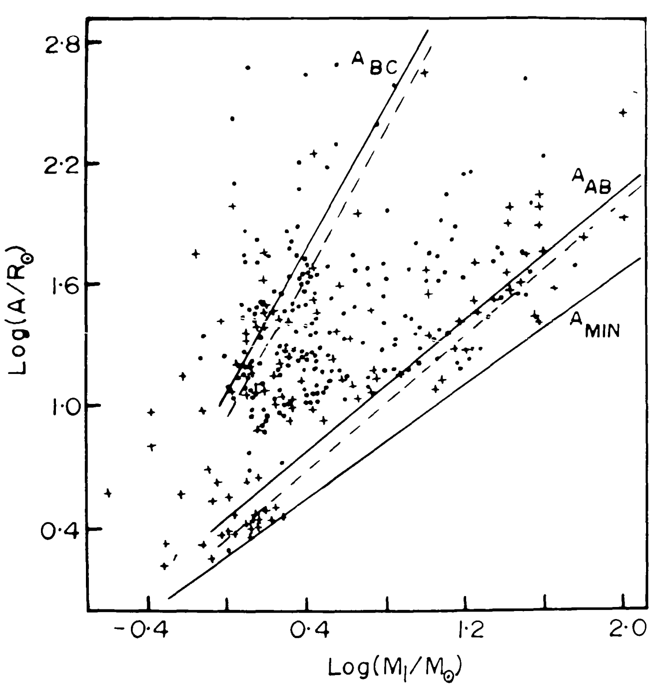


Fig. 1. The distributions of the primary component of double line spectroscopic binaries in the mass-semi-major axis plane. Crosses mark pairs with $M_v > 7^m$ while dots represent brighter pairs. The thick and dashed lines denote the critical separations $A_{AB}$ and $A_{BC}$, respectively, for $M_1/M_2 = 1$ and 3. The line $A_{min}$ represents the minimum possible separation of the binary components.

their compilation masses of the components with known $\sin i$ were obtained by the usual technique; when $\sin i$ was not known, masses were estimated from the spectra.

## 3. Inferrence

It can be seen from Table I that Case $B$ evolution occurs over an enormous range of binary periods while Case $A$ occurs only for a very narrow range. It means that the formation of systems corresponding to Case $A$ evolution is either rare or does not happen at all. From the survey of published data $M_1$, $M_2$, and $P$ of detached Main-Sequence unevolved eclipsing binaries (e.g., Popper, 1980), we have found no systems having an orbital period less than their critical orbital period $P_{AB}$.

An inspection of Figure 1 reveals that the systems positioned above the line $A_{BC}$ are evolving in Case $C$ while those below the line $A_{AB}$ are evolving in Case $A$ and the systems positioned between the lines $A_{AB}$ and $A_{BC}$ evolve in Case $B$. Figure 1 also reveals that, statistically speaking, nearly 20% binaries lie above the line $A_{BC}$ and 70% binaries lie between the lines $A_{AB}$ and $A_{BC}$ while only 10% lie below the line $A_{AB}$. In our opinion, several systems fall beneath the line $A_{AB}$ because of errors in determining $M_1$ from the spectrum, uncertainty as to the actual mass ratio of the components, or, perhaps, unreliability of the observational data. It is well known that in the binary stars having massive components of spectral types $O$ and $B$, the rotational velocities are so large that the central intensities of all the lines are low for reliable measurement and have damping wings causing the profiles of the component lines to overlap significantly (e.g., Leckrone, 1971). Taking into account the observational selection due to their radial velocities and the luminosities of systemic components and the errors in determining $M_1$ from the spectrum, we could derive at the conclusion that the specific density (i.e., the number of pairs per unit interval $\log M_1$) of the systems lying below the line $A_{AB}$ is negligible compared to the systems lying above the line $A_{AB}$ in the whole mass range.

From an examination of the data of the low mass binaries lying below the line $A_{AB}$, it can be seen that most of these binaries are evolved systems. These stars below the line $A_{AB}$ appear to be close pairs due to intensive loss of orbital angular momentum. Indeed, in the zone $M_1 \leq 1.5 M_\odot$, there are stars with high chromospheric activity (RS CVn type stars) for which X-ray observations reveal strong stellar wind, spots, and magnetic fields (Hall, 1976). It is well known that a magnetic stellar wind can be an effective mechanism of orbital angular momentum loss in close binary systems (e.g., Kraicheva *et al.*, 1981). Thus, from Figure 1, we can state that, practically, all binaries with systemic mass $< 20 M_\odot$ evolve either in Case $B$ or in Case $C$. This is in agreement with the finding of Popova *et al.* (1982) that close binary stars with $A < 10 R_\odot$ cannot form.

Regarding the systems having systemic mass $> 20 M_\odot$, Figure 1 reveals that very few systems may evolve in Case $A$, though not so frequently as expected from the comparison with theoretical evolutionary life-times. Perhaps they can also not form because in Figure 1, four more massive hotter eclipsing binaries (HD 288 854, HD 217 312, HD 100 213, and HD 35 921) of the systems lying below the line $A_{AB}$ with well determined masses (Popper, 1980), are all contact systems and have mass ratios differing much more from unity than can be expected from the small differences in the luminosities.

Thus, our results undoubtedly indicate a strong deficit of binaries originating from Case *A* in the whole mass range. Probably binaries with binary separation corresponding to Case *A* evolution cannot form. This view is consistent with Hall's finding that U Cep, U Sge, and similar Algols are Case *B* remnants (Hall, 1975).

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