BLUE STRAGGLERS AS A MERGING PRODUCT OF LOW-MASSIVE MAIN SEQUENCE BINARIES WITH DETACHED COMPONENTS

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ABSTRACT. In the framework of magnetic braking formalism the evolutionary chain describing the sequential evolutionary transitions of the low-massive detached close binaries into "*short – periodic*" *RS CVn*-type systems and then into *W UMa*-class contact stars with the final stage of the single objects of Blue Stragglers-type was reconstructed. This problem was solved with the use of extensive observation materials. The relations of statistics and lifetimes obtained for systems participating in evolutionary chain serve as an evidence for genetic relationship of given objects.

Keywords: close binaries, *W UMa*-type, magnetic braking, Blue Stragglers.

1. Introduction

The possibility of the formation of late spectral class contact systems known as *W UMa*-type stars from the detached binaries with low masses and belonging to the Main Sequence (MS) was proposed in the early sixties last century.

The timescale of this evolutionary transition is determined by Angular Momentum Loss (AML) process due to magnetic braking of the donor star. The law of deceleration of the spin rotation with the age for solar-like single stars found by Scumanich in 1972 (Skumanich, 1972) and written as $V_{rot} \sim \alpha/t^{1/2}$ serves as an empirical basis for this evolutionary scenario and quantitative estimation of the efficiency of the Magnetic Stellar Wind (MSW). As an evidence for MSW in the contact systems one may point out to:

- coronal activity recorded in X-rays, near and far IR- and *Radio*-ranges;
- presence of the *dark spots* in the photosphere;
- strong *chromospheric emission*;
- sudden *jumps* of the orbital period.

The magnetic braking process in the binaries in contrast to single stars leads to orbital AML as a result of the tidal interaction between the components. Magnetic braking is produced by the interaction of the stellar wind emanating from the star with the surface magnetic field. It tends to keep the spin rotation of the donor synchronous to its orbital revolving. Using the simple formulas for orbital and spin angular momenta:

$$J_{orb} = M_1 \cdot M_2 \cdot (M_1 + M_2)^{-1/2} \cdot A^{1/2} \cdot G^{1/2} \quad (1)$$

$$J_{spin} = (M_1 \cdot {R_1}^2 + M_2 \cdot {R_2}^2) \cdot V_{rot}/R \quad (2)$$

and following the synchronization condition $\frac{J_{spin}}{dt} = \frac{J_{orb}}{dt}$ one can express the time having the sense of the timescale of AML in the binary:

$$\tau = 3 \cdot 10^6 \cdot A^5 \cdot R^{-4} \cdot M_1 \cdot (M_1 + M_2)^{-2}. \quad (3)$$

It is a well-known expression for estimation of the orbital AML for binary system which was first derived by Iben and Tutukov in 1983 (Iben & Tutukov, 1984). Returning to the question of magnetic braking one should note that an extensive convective envelope and radiative core are necessary structural elements for effective MSW. It means that the mass range has to be rigorously determined within the limits $0.3 \div 1.5 M_\odot$.

The study of the merging process in such low-massive Detached Main Sequence (DMS) close binaries in the timescale of the orbital AML due to magnetic braking allows to explain the origin of the single objects of Blue Stragglers-type (BS) populating the stellar clusters older than $2 \cdot 10^9$ yrs (Stryker, 1993).

So, on the basis of extensive observation data taken from the (Svechnikov & Kuznetsova, 1990) the evolutionary relationship of the close binaries of considered classes was revealed and presented in the form of evolutionary chain $DMS \Rightarrow$*short-period* $RS\ CVn \Rightarrow W\ UMa \Rightarrow BS$.

2. $M_1 - A$ diagram and precursors of BS-objects

The $M_1 - A$ diagram occupies the central place when studying the evolution of low-massive close binaries. Namely in this diagram the deficiency of the short-periodic DMS with $M_1 \leq 5M_\odot$ and $A \leq 10R_\odot$ was first noticed by Svechnikov (Svechnikov, 1969). This domain was named as "*forbidden triangle*" and explained by Tutukov (Popova et al., 1982a) via accretion regime of the close binary formation.

Fig.1 presents in $M_1 - A$ diagram the distribution of the close binaries of DMS, pre-contact, $W\ UMa$ and Contact systems of Early spectral class (CE) types taken from catalogue (Svechnikov & Kuznetsova, 1990). Lets try to identify in this plane the domain occupied by the "precursors" of the contact systems under the assumption that MSW is driving force for the components approaching.

Mentioned above accretion regime of the close binaries formation imposes restrictions on the star sizes and semi-major axis. Thus the minimum possible value of the semi-major axis at the fixed primary mass separating the detached binary zone from contact one may be written in the next form:

$$A_{min}/R_\odot \sim 6 \cdot (M_1/M_\odot)^{1/3} \quad (4)$$

It is a low boundary of the sought domain found from considerations that the radii of newly formed stars have not to be less than $3R_\odot$ otherwise they merge at the Hayashi stage (Popova et al., 1982a).

Also it is well known that the evolution of low-massive binaries is described by orbital AML timescale which is much more shorter than nuclear timescale. At the same time if masses of both components are less than $1.5M_\odot$ such binary will expend its orbital angular moment two times as intensive. Therefore from the relation connecting the lifetime of the primary component within MS-band and characteristic time of orbital AML we found the upper boundary of the "*feeding zone*" for contact systems submitting to power dependence:

$$A_{min}/R_\odot \sim 7.67 \cdot (M_1/M_\odot)^{0.42} \quad (5)$$

It should be noted that binaries with $M_1 > 1.5M_\odot$ also might be "parents" for contact systems. But in this case the satellites have to be responsible for magnetic braking and their masses ought be less than $1.5M_\odot$. Then from the equalization of satellite timescale of spin AML to the nuclear timescale of the primary component one can derive the law of the right boundary:

$$A_{min}/R_\odot \sim 11.58 \cdot (M_1/M_\odot)^{-0.58} \quad (6)$$

The left boundary is obtained for reasons of restriction of the contactization timescale by Galaxy age adopted as 15 Gyrs and may be presented in linear form:

$$A_{min}/R_\odot \sim 7.25 \cdot M_1/M_\odot \quad (7)$$

The intersection of these four boundaries forms the *trapezium*-like domain occupied by detached binaries, which may evolve into contact one (see Fig.1).

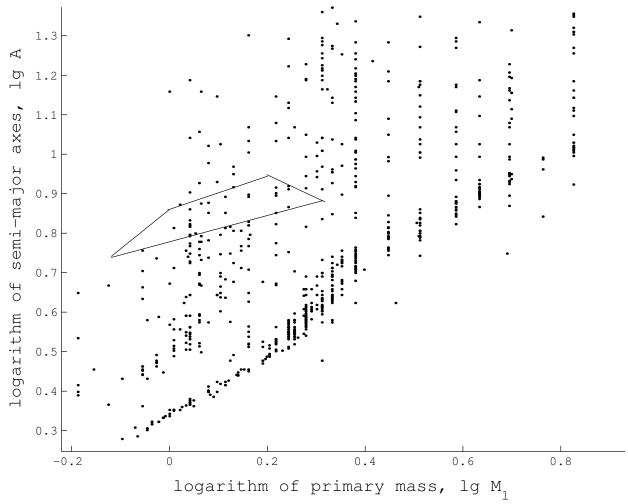

Figure 1: Distribution of the close binaries taken from (Svechnikov & Kuznetsova, 1990) in $M_1 - A$ diagram.

Concerning the possible mechanisms of the filling the "*forbidden triangle*" zone one may emphasize the following:

1. satellite magnetic braking;
2. *Algol*-mechanism for far evolved systems;
3. disintegration of the multiple and mainly triple systems when they collide.

3. Testing $DMS \Rightarrow W\ UMa \Rightarrow BS$ scenario

If it were adopted that all single stars of BS-type in old globular clusters are the product of merging contact systems due to MSW one might theoretically estimate their formation frequency. For that one may use the birth-rate function (Popova et al., 1982b) of the close binaries in the entire Galaxy reconstituted on the basis of observational data of Sun neighborhood:

$$d\nu^3 = 0.2 \cdot d(lgA/R_\odot) \cdot (M_1/M_\odot)^{-2.5} \cdot d(M_1/M_\odot) \cdot dq. \quad (8)$$

Supposing all potential parents of BS-stars are enclosed into *trapezium*-like area and setting $q \sim 1$, $\Delta\ lgA/R_\odot \sim 0.1$ and $\Delta M_1 \sim 0.75 \div 2M_\odot$ one may found that BS-objects are formed at a frequency ~ 0.01 per year. Knowledge of mean age of BS (2.5 Gyrs) allows to determine their average number $N_{BS} \sim 25 \cdot 10^6$.

Nevertheless it would be more suitable to evaluate not the absolute BS number but the weighted over the Horizontal Branch (HB) stars number. Since indicated systems have fixed lifetime ($\sim 10^8$ yrs) and BS age is a function of mass the ratio of last to the first may be considered as a measure of their formation frequencies. So to form the typical HB-star with $1M_\odot$ the satellite is to be within $10^3 \div 10^6 R_\odot$. Then their ν_{HB} and N_{HB} in our Galaxy may be estimated as ~ 0.6 per year and $\sim 60 \cdot 10^6$ respectively.

Thus the sought ratio of these numbers N_{BS}/N_{HB} is evaluated as ~ 0.4 that is very close to observed estimate equal to 0.3 (De Angeli & Piotto G., *astro-ph/0303292*). It is evident that observed value of N_{BS}/N_{HB} is well reproduced by magnetic braking process in AML timescale under all residual uncertainty of input parameters.

The more massive DMS-stars with $M_1 \sim 3M_\odot$ have not MSW and may revolve with top velosities. This fact in the absence of other braking mechanisms of the rotation may leads to formation of the deccretion disks and to beginnings of the planetary systems.

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