CLOSE BINARY SYSTEMS ON LATE EVOLUTIONARY STAGES

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ABSTRACT. Observational and theoretical progress in investigations of close binary stars allow to understand the nature and evolution of many types of close binary systems containing peculiar components: Wolf-Rayet stars, white dwarfs neutron stars and black holes. Catalogue of evolved close binary systems of stars after first mass exchanges has been published by our group in 1989. Second edition of this catalogue is now in preparation and will be published in 1995 by Gordon & Breach.

Key words: Stars: Binaries, Catalogs.

Let us consider modern evolutionary scenario for high mass close binary systems (HMCBS) developed in the pioneer works by Paczyński (1973), Tutukov & Yungelson (1973), Van den Heuvel (1976), Kornilov & Lipunov (1983).

Many of theoretical predictions made by this scenario have been confirmed by the observations. There are also some new observational data which stimulate further development of the theory.

Well known scheme of the evolution of the stars in high mass ($m_1+m_2 > 30M_\odot$) close binary system can be presented as follow: $OB_1 + OB_2 \rightarrow WR_1 + OB_2' \rightarrow$ explosion as a supernova of WR_1 star + $OB_2' \rightarrow$ relativistic object $(C) + OB_2' \rightarrow C + WR_2$ (or single Thorne - Zytkow object) $\rightarrow C+$ explosion as a supernova of WR_2 star $\rightarrow$ two relativistic objects.

For the majority of HMCBS ($\approx 90\%$), according to Yungelson & Massevich (1982), primary, more massive components will fill their Roche Lobe & begin transfer matter to their companions not before they have terminated core-hydrogen burning (so-called "Case B" evolution according to Kippenhahn & Weigert (1967)). In such a case the primary more massive star OB_1 will transfer practically all of its hydrogen envelope to its companion and only its helium core will be left after the transfer. This helium core, according to Paczyński (1973) can be identified with Wolf-Rayet (WR) star.

On the first stage HMCBS consists of two main sequence stars OB_1 (more massive) and OB_2. For further considerations we need some information about the initial mass ratio $q = m_1/m_2$ for the components. If q is close to unity it seems rather probable that the conservative mass exchange occurs in the binary system because the times of thermal relaxation for both stars are close to each other. For the values of q which are quite different from the unity conservative mass exchange in the binary system seems to have low probability, and mass loss and angular momentum loss from the system occurs. According to statistical investigations (see e.g. Svechnikov 1969), the value of q in average is close to unity (also there is different point of view by Iben & Tutukov 1984). Here we will consider the conservative case of evolution of HMCBS.

Let us consider the case of q close to unity. The time of nuclear evolution of the star on the core hydrogen burning stage (e.g. Yungelson & Massevich 1982)

$$\lg \frac{t}{1\ \mathrm{year}} = 9.9 - 3.8 \lg \frac{M}{M_\odot} + \lg^2 \frac{M}{M_\odot} \quad (1)$$

and for the value of mass of the star $M \approx 30M_\odot$ is equal to $\approx 3 \cdot 10^6$ years. More massive star OB_1 in HMCBS will evolve more rapidly and fills its Roche Lobe. Let us suppose that this filling corresponds to the "case B" of evolution. The first mass exchange begin in the binary system. The star OB_1 will transfer its mass through inner Lagrangian point onto the OB_2 star. This matter is accreted by the OB_2 star because the times of thermal relaxation for both stars in the system are comparable ($q \approx 1$). Process of the first mass exchange is very rapid (corresponding time scale is thermal but not nuclear), because, in particular, separation a between the components of the system in the conservative case of mass exchange is decreasing according to the formula:

$$a = \frac{\text{const}}{m_1^2 m_2^2} \qquad (2)$$

Under the condition of $m_1 + m_2 = const$ the minimum of the value of a is reached when $m_1 = m_2$. Therefore the value of a is decreasing when more massive star OB_1 transfers its mass onto less massive star OB_2 which stimulates the process of mass exchange in close binary system. The duration of the first mass exchange (in the case of Ledoux criterion) is

$$t_k \approx \frac{10^{6.3}}{(m_1/m_\odot)^2} \text{ years.} \qquad (3)$$

The primary component OB_1 for the time $\approx 10^4$ years will lose up to 70-90% of its hydrogen envelope, which will be accreted by OB_2 star. The OB_2' companion is formed in the HMCBS as a result of such primary mass exchange.

All the close binary systems after first mass exchange are called as evolved close binary systems.

Observational appearances of all known types of evolved close binary systems (high mass and low mass) are summarized in our Catalogue of close binary stars on late evolutionary stages (Aslanov et al. 1989).

The Catalogue contains the parameters of a wide number of close binary systems (CBS) at late evolutionary stages. The general list of the stars chosen for the Catalogue is given in the Introduction. Description of main evolutionary stages of CBS is given in Chapter 1. Chapter 2 contains the parameters of massive CBS: W Ser type stars; WR+OB systems, containing of a WR star and a massive star of early spectral class; CBS including an OB star and presumably a relativistic object (so called X-ray quiet binaries). Massive CBS at X-ray stage are given also in section 4. These are transient X-ray sources (CBS containing a Be star and a neutron star), and stationary X-ray binaries (CBS containing a massive OB star and a neutron star or black hole). The parameters of CBS containing of WR star and presumably a relativistic object are compiled in section 5.

Chapter 3 is dedicated to low-mass CBS containing a relativistic object coupled with a "normal" star. These are low mass transient X-ray sources, stationary X-ray sources in the Galactic bulge and Sco X-1 type stars, and X-ray bursters. The list of bursters in globular clusters is given too.

The wide class of cataclysmic variables (CV) and related object is divided in Chapter 4 into subclasses according to their physical parameters (specifically by their magnetic fields). Precataclysmic variables are described in section 1. Novae, recurrent novae, dwarf novae systems with determined or assumed orbital periods are collected in Table 13, and double white dwarfs in Table 14 (section 2).

The symbiotic stars with determined or assumed orbital periods are compiled in section 3.

DQ Her stars (intermediate polars) and AM Her stars (polars) are collected in section 4.

The parameters of radiopulsars - the members of binary systems are given in Chapter 5.

Second Edition of this Catalogue is now in preparation in our group and will be published in 1995 by Gordon & Breach.

It should be stressed that up to now reliable determinations of masses for 10 pulsars in binary systems have been carried out (6 in X-ray binaries and 4 in binary radiopulsars). For all 10 pulsars the value of mass is less than $3M_\odot$ - theoretical upper limit predicted for the mass of neutron star by Einstein General Relativity. On the other hand, there are 5 reliable estimates of the masses of black hole candidates in X-ray binary systems (Cyg X-1, LMC X-3, A 0620-00, V404 Cyg, XN Mus). For all these massive ($m_x > 5M_\odot$) compact X-ray sources pulsar phenomenon was not detected. Therefore X-ray sources in binary systems are different from each other not only by masses but also by their observational appearances, in accordance with Einstein General Relativity. This fact is very significant and has a great importance for the testing of Einstein General Relativity in strong gravitational fields.

All these facts demonstrate a big progress which has been achieved up to now after pioneer works made by V.P.Tsessevich in the investigation of close binary systems.

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UBVRI POLARIMETRY OF CLOSE BINARY SYSTEM V448 Cyg

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ABSTRACT. Analysis of the polarimetric measurements of the eclipsing binary system V448 Cyg in wide UBVRI filters has shown the presence of the following components of the polarization: a) interstellar; b) constant intrinsic polarization with a flat spectrum; c) phase-dependent contribution, the amplitude of which decreases with wavelength. Constant component is possibly caused by an extended disk-like optically thin refracting envelope; the variable one may be caused by relatively dense condensations near the Lagrangian points in a binary. By analyzing the Fourier harmonics, the inclination angle is found to be $i = 82°$. The orbital plane of the system is inclined in respect to the Galaxy plane at an angle 70°. Mass of the extended envelope is estimated to be $1.5 \cdot 10^{-8}\ M_\odot$ with a mass loss rate $8.6 \cdot 10^{-7}\ M_\odot$/yr.

Key words: Stars: binaries: close, eclipsing; circumstellar matter; polarization.