Stream Parameters in the Neighbourhood of the L_1 Point in W Serpentis-type Binaries

V.G. Karetnikov, E.V. Luthardt-Menchenkova, V.V. Nazarenko

Astronomical Observatory of the Odessa State University, Park Shevchenko, 270014 Odessa, Ukraine

The gas motion in close binary systems has been investigated by several authors using a hydrodynamic method (e.g. Prendergast & Taam 1974, Flannery 1975, Lubow & Shu 1975, 1976). All these researches have, besides important results, a common deficiency: in the analysis of the gas motion, the extent and velocity of the stream in the neighbourhood of the inner Lagrangian point L_1 was not calculated. They have been chosen on the basis of general assumptions (the same for all types of close binaries). A fundamental assumption was the small extent of the stream in the neighbourhood of L_1 perpendicular to the line connecting the centers of the stars. At the same time the extent and the velocity of the stream near L_1 exert a great influence on the further stream motion, on the formation of the circumstellar envelope and finally on the evolution of the close binary system. Therefore the first step in the investigation of the gas motion in a close binary must be the determination of the initial parameters of the stream in the neighbourhood of the point L_1.

A method of calculation of the parameters and the evolution of the stream near L_1 in binary systems was proposed by Nazarenko (1993). Using this method we calculated the physical conditions in the stream near point L_1 for three interacting binary systems of W Ser-type: β Lyr, V367 Cyg, and RY Sct. For β Lyr and V367 Cyg several versions of stream parameters were calculated, corresponding to different orbital elements obtained by different authors. For

Table 1. Main parameters of the investigated systems

N	Star	M_1 ($M_\odot$)	M_2 ($M_\odot$)	T_1 (K)	A ($R_\odot$)	P (days)	References
1	β Lyr	3.8	14.6	12000	61.0	12.914	Skul'ski (1975)
2	β Lyr	2.0	11.7	11000	55.0	12.914	Ziolkowski (1976)
3	V367 Cyg	2.3	3.6	12000	53.0	18.598	Menchenkova (1990)
4	V367 Cyg	2.5	4.4	8000	56.7	18.598	Pavlowski et al. (1992)
5	V367 Cyg	19	12	11600	93.0	18.598	Li & Leung (1987)
6	RY Sct	10	33	28000	75.0	11.125	Antokhina & Cherepashchuk (1988)

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Table 2. Stream parameters in the neighbourhood of point L_1

Star	N_L (cm^{-3})	T_L (K)	R_S	R_R	$\dot{M}$ ($M_\odot$/yr)	V_L (km/s)	References
β Lyr	$6.4 \cdot 10^{14}$	46000	0.15	0.22	$6.4 \cdot 10^{-6}$	29.5	Ziolkowski (1976)
β Lyr	$2.9 \cdot 10^{14}$	32200	0.10	0.25	$1.3 \cdot 10^{-6}$	23.7	Skul'ski (1975)
V367 Cyg	$5.2 \cdot 10^{14}$	51780	0.19	0.34	$1.8 \cdot 10^{-5}$	28.5	Menchenkova (1990)
V367 Cyg	$3.8 \cdot 10^{14}$	23040	0.14	0.33	$4.0 \cdot 10^{-6}$	19.3	Pavlowski et al.(1992)
V367 Cyg	$2.7 \cdot 10^{14}$	36300	0.10	0.42	$1.0 \cdot 10^{-6}$	25.0	Li&Leung (1987)
RY Sct	$1.4 \cdot 10^{15}$	69100	0.15	0.27	$1.0 \cdot 10^{-5}$	32.3	Antokhina & Cherepashchuk (1988)

RY Sct, only one variant was calculated, because the orbital elements, obtained for this system by different authors, have similar values. The main parameters of the investigated systems are collected in Table 1, together with the references. M_1 and T_1 are the mass and the temperature of the mass losing star, M_2 is the mass of the accreting star, A is the distance between the centres of the stars, P is the orbital period.

The main results of our calculations are collected in Table 2. N_L is the concentration of matter in the point L_1, T_L is the temperature and V_L is the stream velocity (along the line connecting the centres of the stars) in the point L_1. We calculated the mass exchange rate $\dot{M}$ through the point L_1 on the basis of the velocity V_L and the concentration of matter in the neigbourhood of the point L_1 (using the correlation between the concentration in the stream N and the distance from the stream axis and taking into consideration the axial symmetry of the stream near point L_1). R_S is the stream radius (assuming that at the edge of the stream the concentration of matter has decreased by three orders), R_R is the radius of Roche lobe of the mass losing star. R_S and R_R are given in units of the distance between the centres of the stars.

The analysis of the results permits the following conclusions:

1. The extent and the velocity of the stream in the neighbourhood of the point L_1 depend mainly on the degree of filling the Roche lobe by the mass losing star and on the conditions in its atmosphere.
2. The stream has an axial symmetry in the neighbourhood of the point L_1 (the symmetry axis coincides with the line connecting the centres of the stars). The stream radii in the investigated systems are very large (0.10...0.19). They are only two times less than the radii of the mass losing stars.
3. The stream velocity along the line connecting the centres of the stars in the neighbourhood of the point L_1 amounts 20...30 km/s and is equal to the sound velocity in this point. This result confirms the supposition by Lubow & Shu (1975) about the stream velocity in the point L_1. In perpendicular direction the stream is in hydrostatical equilibrium (its velocity does not exceed a few hundred m/s). It also agrees well with the earlier assumption of Prendergast & Taam (1974).

4. The stream radius and the mass transfer rate are in good correlation with the parameter F ($F = U_L/K$, where U_L is the total gravitational potential in the point L_1, K is the specific kinetic energy of the ideal gas in the atmosphere of the mass losing component in the point L_1). For small values of F the stream radius and the mass transfer rate are large. For large values of F the stream radius and the mass transfer rate are small. For the investigated systems the rate of mass transfer reaches 10^{-5} $M_\odot$/yr.
5. For V367 Cyg the stream radii calculated on the basis of the system parameters, obtained by the different authors, differ considerably. The maximum value of the stream radius and the rate of mass transfer were obtained by using the parameters of the system from Menchenkova (1990). The stream radius and the rate of mass transfer calculated on the basis of the parameters from Pavlowski et al. (1992) and Li & Leung (1987) are smaller. These small values are in contradiction to the observational data about the existence of circumstellar matter with developed structure in this system. Therefore we draw the conclusion, that for V367 Cyg the parameters obtained by Menchenkova (1990) are more realistic: $M_1 = 2.3$ $M_\odot$, $M_2 = 3.6$ $M_\odot$, $T_1 = 12000$ K, $A = 53$ $R_\odot$.
6. For β Lyr the maximum values of the stream radius and the rate of mass transfer obtained for the system parameters calculated by Ziolkowski (1976) are: $M_1 = 2.0$ $M_\odot$, $M_2 = 11.7$ $M_\odot$, $T_1 = 11000$ K, $A = 55$ $R_\odot$.
7. For RY Sct the stream radius calculated on the basis of the different variants of the system parameters are equal.

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