Stream formation at the inner Lagrangian point in close binaries

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ASTROPHYSICS

STREAM FORMATION AT THE INNER LAGRANGIAN POINT IN CLOSE BINARIES

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Stream formation at the inner Lagrangian point was calculated for different types of binaries on the basis of non-stationary hydrodynamical equations, the "big-particle" code by Belotserkovskii and Davydov and the atmosphere model from Kurucz's grid. The types of binaries are W Ser stars, semi-detached binaries and W UMa stars. Our calculations show that physical conditions for the Roche lobe overflow are different for different binaries and a standard Roche lobe overflow regime does not occur for all the binaries. The stream size is $0.02 \text{ (U Gem)} - 0.1 \text{ (\beta Lyr)}$ in units of the orbit separation of the binary components. The degree of the Roche lobe overflow is such that atmosphere layers occur at the inner Lagrangian point with optical thickness equal to 100 for W UMa stars, 70 for W Ser stars, and less than 1 for the semi-detached binaries.

KEY WORDS Non-stationary numerical hydrodynamics, model atmosphere, stream formation, the inner Lagrangian point

We consider formation of a stream near the inner Lagrangian point ($L_1$) using methods of numerical hydrodynamics for the different close binaries. These binaries are $\beta$ Lyr, RY Sct and V367 Cyg (as examples of W Ser stars); AO Cas, XZ Cep, V448 Cyg, RY Gem, RY Per, CX Dra and TX UMa (as examples of semi-detached binaries); and W UMa, AW UMa and SW Lac (as examples of W UMa stars). The numerical code is based on the "big-particle" approach of Belotserkovskii and Davydov (1982); non-stationary hydrodynamic equations written in Euler form were used. The present calculations were performed in two planes: the orbital and perpendicular ones. Equations of motion are integrated until physical parameters of the stream settle to steady values. Thus, a stationary stream structure in the vicinity of $L_1$ is calculated. The initial stream structure is constructed using stellar atmosphere models from Kurucz's grid (Kurucz, 1979). Our calculations take into account the gravitational field of a binary, the centrifugal force of the orbital motion, synchronous rotation of the mass-losing star (the secondary). The calculations show that the Coriolis force does not change the stream radius in $L_1$, therefore this force is neglected in our calculations. The interaction between the moving gas and radiation was calculated in implicit way, a lower ratio of specific heats...
Parameters of the binaries investigated are given in Table 1 where $M_1$ is the mass of the secondary; $M_2$ is the mass of the mass gaining star (the primary); $T$ is the effective temperature of the secondary; $A$ is the orbital separation in units of the solar radius; $R_r$ is the average radius of the critical surface of the secondary; $P_0$ is the orbital period; $\dot{M}$ is the mass transfer rate through $L_1$ in units of the solar mass per year.

The degree of the Roche lobe overflow by the secondary and the stationary stream structure are determined by the following condition: mass transfer rate obtained from calculations must be equal to that obtained from observational data. Our calculations show that the stream radius is similar for the binaries of one type and is different for the different types of binaries.

The qualitative stream structure in the vicinity of $L_1$ is similar for all the investigated binaries. Density varies by a factor of three or four along the stream axis. Temperature distribution in the computational domain is isothermic if the effective temperature is less than 10,000–15,000 K. For higher effective temperature, the temperature changes by 10–20% with respect to that at $L_1$. Gas velocity at $L_1$
Figure 1  Density distribution in the direction perpendicular to the stream axis at the inner Lagrangian point for W Ser stars and AO Cas stars.

Figure 2  Density distribution in the direction perpendicular to the stream axis at the inner Lagrangian point for the semi-detached binaries (CX Dra, RY Gem, RY Per, TX UMa) and W UMa stars.
is equal to the local sound velocity in all the binaries. The stream radius is defined
by the following: the density variation in the direction perpendicular to the stream
axis must be equal to that in the initial atmosphere model chosen from Kurucz's
grid.

The result of calculations are somewhat unexpected in the case of W Ser stars
(Figure 1). In these binaries, the stream radius exceeds by more than 50% the
average radius of the secondary's Roche lobe. This apparently explains the physical
peculiarity of W Ser stars. The calculated stream radius for the semi-detached
binaries shows that these split into two groups: AO Cas, XZ Cep and V448 Cyg
have the stream radius equal to 0.05–0.07 (Figure 1). The remaining semi-detached
binaries have this radius equal to 0.02–0.04 (Figure 2). The stream radius for W
UMa stars is also considerable (about 0.04).

The degree of the Roche lobe overflow for the binaries investigated is the fol-
lowing: atmosphere layers with optical thickness 70–80 reside at $L_1$ in W Ser stars;
those with optical thickness 2/3 occur at $L_1$ in AO Cas, XZ Cep and V 448 Cyg;
they have optical thickness $10^{-1}$ in the other semi-detached binaries and 100 in W
UMa stars.

The main result of the present calculations is the following: the smaller orbital
separation in binaries the less stream radius in the vicinity of $L_1$.

References

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