PARTICLE MOTION IN MODELS OF CLOSE BINARIES

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Abstract. The characteristic features of particle motion in close binaries have been studied for sequences of evolutionary models with small or intermediate masses. The possible behaviour of the particle streams has been determined with regard to the change of systems with time as a result of mass-exchange between the two stellar components. A grid of values for the velocity and direction of ejection from the first Lagrangian point has been investigated. Among the various possibilities, impact of particles with one, or the other component, or orbits encircling the Main-Sequence star have been detailed. This latter possibility seems to lead to the formation of a disk-like structure around the Main-Sequence component. From the results obtained for semi-detached systems of both cases A and B of evolution it is found that the formation of disks is difficult in cases A, and in the early stages of the slow mass exchange in cases B.

Sommario. Sono state studiate le caratteristiche principali delle traiettorie in sequenze di modelli evolutivi di sistemi binari stretti di massa totale piccola e intermedia. E' stato messo in evidenza l'andamento generale delle traiettorie in connessione con la variazione temporale delle proprietà dei sistemi binari dovuta allo scambio di massa tra le componenti. La velocità e la direzione iniziali di eiezione dal primo punto lagrangiano sono state variate con sistematicità in un ampio intervallo di valori. Tra le varie possibilità sono state messe in luce sia l'impatto con l'una o l'altra delle componenti sia la formazione di orbite attorno alla componente di sequenza principale. Quest'ultima eventualità potrebbe condurre alla formazione di una struttura di disco. Dai risultati ottenuti con modelli evolutivi di sistemi semistaccati di casi A e B è emerso che la formazione di una struttura di disco sembra difficile nei casi A e nelle prime fasi dello scambio lento di massa nei casi B.

1. Introduction

In the attempt at a thorough comparison between observational data and evolutionary models of close binaries, the basic parameters (masses, luminosities, radii, etc.) and synthetic photometric properties have been obtained (e.g., Giannone and Giannuzzi, 1974; Giannone et al., 1975 and references quoted therein). However, the computed models and their photometric characteristics have usually been determined under some simplifying assumptions. Some observed features of close binaries are either not included in the models, or cannot be treated at all.

In order to incorporate in a complete scheme as many details as possible, we have studied the dynamics of gas streams in close binaries by means of the particle motion. This approach was shown to be not completely correct, since the problem of gas motion in close binaries must be treated according to a hydrodynamic scheme (Prendergast, 1960). However, the correct theory meets so severe difficulties with regard to the computational treatment (Prendergast and Taam, 1974; Sorensen et al., 1975) to be hardly applicable to an extensive project such as that we have in mind.
Even in our case, the computing time becomes rather large if a sufficient number of systems are investigated.

On the other hand, even with the limitations pointed above, the dynamical scheme was successful in showing the possibility of the formation of ring-like orbits about the more massive (i.e., Main-Sequence) component (e.g., Kruszewski, 1966) in a rough agreement with observations. Therefore, at least as a first approximation, it seemed worthwhile to investigate the behaviour of the particle motion along sequences of evolutionary models of semi-detached systems. In these binaries matter is transferred from the subgiant component to the Main-Sequence companion; it is assumed that matter is ejected from the first Lagrangian point. The acceleration mechanisms proposed in the literature are related to (i) thermal diffusion, (ii) difference between orbital and rotational velocities. The range of values adopted by us includes values corresponding to both items (i) and (ii).

In general, particles can impact on one, or the other component (either on the advancing, or the receding side), or can travel along orbits encircling the mass-gaining component. Rings around the whole system have not been fully considered. The results obtained have not to be taken too literally, especially when applied to individual observed binaries. However, they should give possible trend of jets and rings in close binaries at different evolutionary stages when examined in their whole context. A loss of mass and angular momentum may occur in binaries, though no univocal mechanism has been identified so far. The possibility of a reliable interpretation of the secular variation of the orbital period relies on some estimate of the mode and amount of the mass transferred between the components and lost from the system. From the trajectories of particles travelling from one component to the other, or leaving the system some evaluations are possible.

2. Method of Computation

In what follows the computational procedure used is briefly summarized together with the properties of the input models chosen to be representative of the semi-detached binaries with small or intermediate total masses. The scheme is that of the restricted three-body problem and is, therefore, well known.

We denote the mass-losing component as star 1 (original primary) and the other component as star 2 (original secondary). According to the Roche model for binaries, star 1 fills its critical lobe (that is, the part of the equipotential surface enclosing star 1 and passing through the first Lagrangian point $L_1$). Matter is supposed to be transferred from star 1 to star 2 through $L_1$. The study of the particle motion is confined to the orbital plane. This assumption is justified by both observational and theoretical reasons; matter streaming in the system should be mainly concentrated in that plane.

The equations of motion were integrated numerically by means of the Runge-Kutta method adapted so as to preserve fourth-order accuracy. Jacobi's integral was used to allow for an automatic choice of the integration step in order to maintain the accuracy