Angular Momentum Changes Due to Direct Impact Accretion in a Simplified Binary System

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Abstract.
   We model a circular mass-transferring binary system to calculate the exchange of angular momentum between stellar spins and the orbit due to direct impact of the mass transfer stream onto the surface of the accretor. We simulate mass transfer by calculating the ballistic motion of a point mass ejected from the L_1 point of the donor star, conserving the total linear and angular momentum of the system, and treating the stars as uniform density spheres with main sequence radii determined by their masses. We show that, contrary to previous assumptions in the literature, direct impact does not always act as a sink of orbital angular momentum and may in fact increase it by facilitating the transfer of angular momentum from the spin of the donor to the orbit. Here, we show an example of the exchange of angular momentum, as well as a measure of the orbital angular momentum changes for a variety of binary star systems with main sequence components.

INTRODUCTION

In close binary systems, mass transfer is always accompanied by exchange of angular momentum. In cases where the mass transfer stream directly impacts the accretor, it is commonly assumed that any angular momentum carried by the mass is transferred entirely to the spin of the accretor, thereby removing it from the orbit [e.g. 1, 2, 3]. Furthermore, many of the same studies assume the angular momentum added to the accretor's spin is identical to the orbital angular momentum the transferred mass had at ejection from the donor, neglecting changes due to gravitational interaction with the binary.

   In order to assess the fate of these systems, accurate calculations of the angular momentum exchange are needed. For example, calculations of the systemic mass loss in Algol binaries depend strongly upon the rotation rate of the accretor [3], while the likelihood that double white dwarfs will be driven to coalesce requires knowledge of the orbital angular moment losses [2, 1]. In this paper, we briefly present our preliminary results showing a violation of these standard assumptions about orbital angular momentum transport in a simplified binary system.

CALCULATIONS

We consider a circular binary system consisting of two main sequence stars with masses M_D and M_A, radii $\mathscr{R}_D$ and $\mathscr{R}_A$ [4], and uniform rotation rates Ω_D and Ω_A, with the subscripts D and A corresponding to the donor and accretor, respectively. We let Ω_K be the Keplerian orbital angular velocity at the periastron of the orbit. We treat the stars as uniform density spheres with inertial constants $k_D = k_A = 2/5$, and choose the orbital separation a such that the volume equivalent radius of the effective Roche lobe [5] is equal to $\mathscr{R}_D$.

   To model the response of the system to mass loss, we eject a single particle of mass $M_P \ll M_D, M_A$ from the L_1 point of the donor star [5, 6] with a velocity equal to the vector sum of the orbital velocity at the L_1 point and the rotational velocity of the donor star at that point. The three-body system is then evolved via numerical integration of the Newtonian equations of motion until M_P impacts the surface of the accretor. During both accretion and ejection, the linear and angular momenta of the system are conserved. For details of the calculation, see Sepinsky et al. [7]. To model continuous mass transfer in the circular orbit, we assume that, for sufficiently small M_P, the specific angular momentum transferred by a single ejected particle is identical to that transferred by a continuous mass transfer stream which follows the same trajectory.
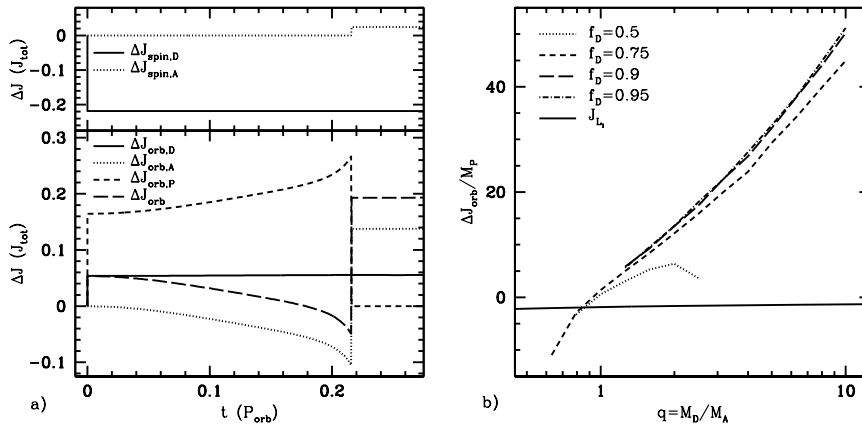
FIGURE 1. **a)** The change in the spin (*top*) and orbital (*bottom*) angular momenta between ejection and accretion of a single ballistic particle as a fraction of the total angular momentum for a system with $M_D = 10M_\odot$, $M_A = 1M_\odot$, and $\Omega_D = 0.9\Omega_K$. **b)** The change in the orbital angular momentum ($\Delta J_{\rm orb}$) of the binary orbit per unit accreted mass (M_P) for a system with $\Omega_A = \Omega_K$, $M_A = 1.0_\odot$, and $\Omega_D = f_D\Omega_K$. Note that we can see either an increase ($\Delta J_{\rm orb} > 0$) or a decrease ($\Delta J_{\rm orb} < 0$) in the orbital angular momentum of the system depending on the orbital parameters. For comparison, the solid line shows the change in orbital angular momentum assuming all of the ejected particle's initial orbital angular momentum is deposited into the spin of the accretor.

RESULTS & CONCLUSIONS

In Figure 1a, we show the change in the spin *(top)* and orbital *(bottom)* angular momenta for a binary system with the parameters given in the caption. Mass is ejected at $t = 0$, and accretes at $t = 0.216 P_{\rm orb}$ where rapid jumps in the momenta occur due to their conservation at the instantaneous inelastic ejection and accretion. In this case, nearly all the orbital angular momentum of the particle is transferred to the orbital angular momentum of the accretor, while only a small amount is transferred to its spin.

In Figure 1b we show the change in the orbital angular momentum per unit M_P for a large number of binary systems. We see that the orbital angular momentum of nearly all the tested systems increases due to direct impact accretion. During the ejection of M_P, conservation of momentum dictates a loss of spin angular momentum of the donor, increasing the orbital angular momentum of the particle. Upon accretion, a portion of this is added to the accretor's spin while the rest is added to the orbit. These results are characteristically different from those obtained by the standard assumption of decreasing the orbital angular momentum by the specific angular momentum of the particle at the L_1 point (J_{L_1}) and adding it entirely to the spin of the accretor. The solid line in Figure 1b shows the change in the orbital angular momentum following this perscription. This may have a large effect on the predictions of the survivability of any class of system which undergoes a direct impact mass transfer phase during the course of its evolution, e.g., double white dwarfs, Algol binaries, cataclysmic variables, etc.

In future work, we will explore this intriguing trend in more detail, applying the results to systems such as double white dwarfs where the change in orbital angular momentum is critical to assessing the stability of mass transfer.

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