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Understanding the impact of binary mass transfer in the accretor's measurable parameters

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In the context of binary evolution, details of the effects of direct mass accretion on a star's observable properties remain largely uncertain. In this work, we aim to further our understanding on the underlying physics using a novel analytic model for binary mass transfer. We find that a star's spin-up is most effective when the binary is close to tidal locking.

With a simplified model, Packet (1981) was among the first to note that accreting just 10% of a star's initial mass should spin it up to its critical rotation rate. This would make most mass accretion products rapid rotators. These, however, have been observed to prefer low-density environments (Ferraro et al., 2023) where wider systems have a higher survival rate due to the lower frequency of strong dissociative dynamical interactions. We aim to address these results using a more complex model than is often assumed for accretion, so as to characterize the changes in the observational properties of an accreting star due to mass transfer in a binary system, as a function of the system's initial conditions.

Fixing the accretor at the origin, $L1$ traces an ellipse around it. In order to measure the effects of direct accretion through a stream, we make the following assumptions: (i) the effect of the donor's potential on an infalling parcel of mass is negligible beyond $L1$, (ii) a stream can be built by superposition of parcels, (iii) the radial component of the velocity at impact onto the accretor contributes to its thermal energy and (iv) its tangential component contributes to its rotational energy.

At $L1$, a parcel's velocity must be lower than the orbital motion in order to move in a tighter orbit and approach the accretor star. In order to guarantee a direct impact, eq. 1 must be satisfied.

$$|v_i| \leq \sqrt{\frac{2Gm_{acc}}{d_{L1} + d_{L1}^2/r_{acc}}} \tag{1}$$

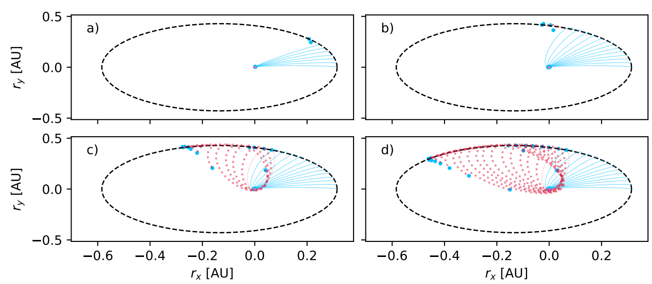

Figure 1. From a) to d), the system at times 20, 40, 60 & 80 days. In blue, the trajectory of a parcel that starts at $L1$ (dashed black line) and directly impacts the accretor (pink dot). In red, trajectories that fail to hit the star.

Here, m_{acc} and r_{acc} are the accretor's mass and radius and d_{L1} is the distance to $L1$. Knowing the donor's orbital velocity $v_{don,o}$, the opposing velocity is constrained by $v_i - v_{don,o} \leq |v_{ex}| \leq v_i + v_{don,o}$. This is measured at periapsis where the greater $v_{don,o}$ provides a wider range for v_{ex}. The maximum orbital separation is set so the donor's radius exceeds its Roche radius (Eggleton, 1983) at apoapsis.

A parcel is let go at each point of the $L1$ orbit and, from its initial velocity and velocity angle with respect to the radial direction, a new trajectory is defined (see fig. 1). This is repeated for different values of the extra velocity component v_{ex}, the semi-major axis a, and the eccentricity e while keeping the other two parameters and the mass ratio fixed. By analyzing the contribution from the tangential and radial components we find: (i) In all cases, the tangential component dominates through the whole range of values (i.e. spin up is favored), (ii) the contribution to spin peaks at $|v_{ex}| \sim |v_{don,o}|$ which suggests systems that are close to being tidally locked, and therefore have a higher v_{ex} than expected for a giant's rotation, are more effective at spinning up a star and, (iii) for the a and e samples, the total tangential component stays mostly constant, however, if we were to restrict v_{ex} to lower values (e.g. ≤ 10 km/s), systems with larger a where the $v_{don,o}$ is lower would be the most effective at spinning up stars.

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