Perseus in Sicily: From Black Hole to Cluster Outskirts
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The role of stellar rotation in Tidal Disruption Events

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Abstract. Tidal Disruption Events (TDEs) are highly variable high energy phenomena originating from Galactic Nuclei (Komossa & Bade 1999). TDEs are thus powerful tools to study quiescent Galactic Nuclei given their extreme brightness (several times super-Eddington) and the possibility of being seen in non-AGN galaxies. A TDE is the violent disruption of a star passing by a Super Massive Black Hole (SMBH); after the disruption, roughly half of the star mass gains enough energy to escape from the Black Hole, while the other half is bound to the Hole, falls back and eventually accretes onto it. Early works, (Rees 1988), pointed out a $t^{-5/3}$ behaviour for the light curves of this event and since then such a time dependency became the signature of these events. Strong deviations are however introduced when one considers the internal stellar structure or if one considers partial disruptions. One feature that has never been taken into account is the effect of stellar rotation in the resulting fallback rate, which is the aim of the present work. Firstly, we will show analytical estimates of the impact of stellar rotation on the TDE and we will then present a set of Smoothed Particle Hydrodynamic simulations of the tidal disruption of rotating stars, performed in order to test these analytical estimates.

Keywords. galaxies: nuclei, hydrodynamics, black hole physics

1. Analytical estimates

A Tidal Disruption Event occurs when a star gets so close to a SMBH that the BH tides overcame its self-gravity. After the disruption half of the debris are launched into highly eccentric bound orbits around the SMBH. TDEs are characterized by the mass return rate to the pericentre that is proportional to the event light curve. This quantity is determined by three parameters (in the simplest model): the mass return rate peak, the characteristic time and the time dependency. In our work we focused on understanding how stellar rotation would change these parameters with respect to the non rotating case. Analytically we followed the calculations in Rees (1988) assuming that the star is a rigidly rotating sphere with spin perpendicular to the orbital plane and with uniform density. That is because tidal forces induce a rotation to the star up to its break up velocity along an axis parallel to the orbital angular momentum.

We obtained an analytical relation that links the mass return rate peak of a TDE to the stellar rotation: we found that a TDE can be brightened or dimmed or even completely turned off depending on whether the stellar rotation is prograde or retrograde with respect to the tidal induced one. We show such analytical relation in Fig. 1 (solid curve). To better study this configuration and to investigate other stellar and orbital spin alignment, we performed numerical simulation.

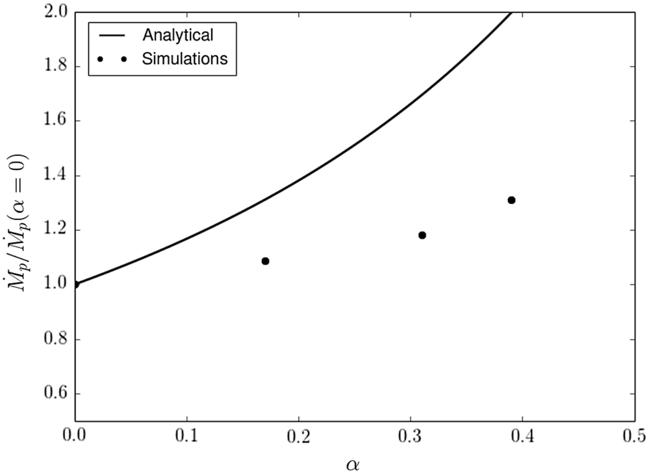

Figure 1. Mass return rate peak as a function of stellar rotation: analytical estimate and simulation outputs.

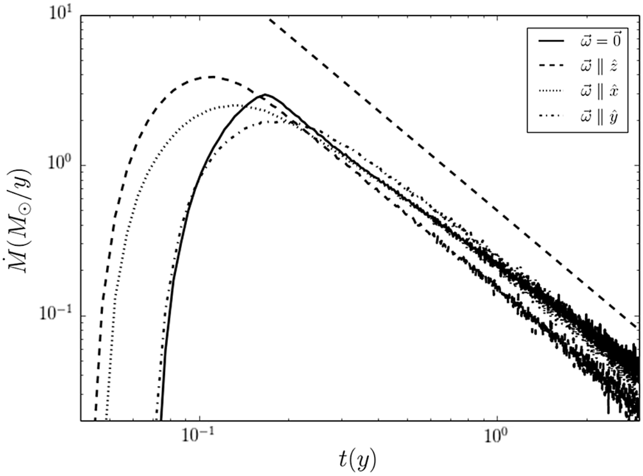

Figure 2. Mass return rate as a function of stellar spin orientation: the straight dashed line above every other curve is the $t^{-5/3}$ behaviour predicted.

2. Numerical set up

Our numerical simulations were performed with Smoothed Particle Hydrodynamic code PHANTOM (Price *et al.* 2017). Firstly, we set up a rotating star: we started from a polytropic sphere with polytropic index $\gamma = 5/3$ and we let the star relax in an empty space. Once relaxed we imposed a rigid rotation with magnitude $\alpha = \omega/\omega_b$ (where $\omega_b = \sqrt{2GM_\star/R_\star^2}$ is the break up angular velocity of the star) and then let the rotating star relax once more. Once the star is relaxed we check that the rotation is still rigid and then set the star on a parabolic orbit around a black hole of $10^6\ M_\odot$ with pericentre equal to the tidal radius (the distance at which tidal forces equal stellar self-gravity).

3. Results

Varying α, but keeping the star rotation prograde, we indeed observed brighter and shorter TDEs, however the enhancement is not as high as predicted analytically, this is probably due to the stellar polytropic structure (Fig. 1).

Varying stellar spin orientation with respect to the orbital plane we observed a distorted behaviour for TDEs light curves compared to the non rotating case (Fig. 2), however in both this and the scenario presented above the time dependency of $t^{-5/3}$ is reached asymptotically.

Very interesting is the case of a star rotating in retrograde way with respect to the orbital motion. In this case the simulations show that the debris are ripped off the star but stay bound to it and eventually fall back, forming a disc and getting accreted. Preliminary results indicate that this new kind of event will be shorter than a TDE (roughly some tens of days), but very bright: several times super-Eddington onto the star. It is also interesting to notice that the star (that initially was on a parabolic orbit) is bound to the black hole after the flyby and the tidal forces manage to completely reverse the spin of the star. We can thus predict that roughly one hundred years after the bright and short peak due to the material acrreting onto the star a normal TDE will take place.

References

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