Hydrodynamical simulation of tidal disruption events from SMBH binaries

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Introduction

- Tidal disruption flares from SMBH binaries may be a useful tool to detect “hidden” binaries at sub-pc distances
  - Relevant to the detection of precursors of mergers
- Liu et al (2009) and Ricarte et al (2016) have explored the issue with test particle simulations —> Interruptions of fallback of debris
- Coughlin et al (2016) performed SPH simulations by analysing statistically a large ensemble of configurations
- Our approach is complementary to Coughlin et al (2016): explore a few number of cases to identify the dependence on system parameters and geometry
Relevant separation range

• Interesting regime is when binary separation is ~ mpc (e.g. Liu et al 2009, Ricarte et al 2016)

• We identify the range of separations for which a flare initially looks like a TDE, but then deviates from $t^{-5/3}$. **Need to identify binaries from shape of TDE lightcurve**

• We assume that a debris is perturbed by the secondary if its apocenter is comparable to the Roche lobe of the primary (Coughlin et al 2016)

  • For very close orbits, even the most tightly bound debris are perturbed —> Fallback never follows a TDE like curve

  • For wide orbits, there will always be some debris which is perturbed. We assume that a TDE will be considered a “normal” TDE if flare follows $t^{-5/3}$ down to luminosities equal to 1% of the peak, corresponding to ~2 years after disruption for a $10^6 M_{\text{sun}}$ BH.
Relevant separation

- We thus define two critical binary separations

\[ a_{BH,min} = \frac{0.6q^{2/3} + \ln(1 + q^{1/3})}{0.49q^{2/3}} R_\ast \left(\frac{M_1}{M_\ast}\right)^{2/3} \]

\[ a_{BH,max} = e^{-2/5} a_{BH,min} \]

We ran a number of simulations with different geometries for 9 combinations of mass ratio and separation.
Encounter geometry

- We only consider disruptions from the primary (more frequent, Coughlin et al 2016)
- Parabolic orbit, with penetration factor $\eta=1$
- Still, have three angles to specify
  - Inclination of stellar orbit to binary orbit, $\theta$
  - Angular position of the line of the nodes, $\Omega$.
  - Apsidal position of the pericenter, $\omega$. 
Numerical simulations

• We use the SPH code PHANTOM (Lodato & Price 2009, Price et al. 2016, Coughlin et al 2016)

• We adopt the Cullen & Dehnen (2010) switch to reduce artificial viscosity

• We model the SMBH as an external potential (but with an accretion radius, equal to $0.8R_p$ for the primary and to the ISCO for the secondary)

• We use $N=10^5$ particles (we have run a convergence test for a couple of simulations with $10^6$ particles and did not notice any difference)
In-plane encounters, $\theta=0$

- Movie shows projected density
- Here, we show the case with
  - $q=0.1$
  - $a=0.5$ mpc
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1 mpc
Fallback rates

- Theoretical predictions very well reproduced
- See periodicity, roughly corresponding to the binary period
- Exact time of first disturbance depends on $\Omega$
Perpendicular encounters, $\theta=\pi/2$, $q=0.1$, $a=0.5$ mpc
Perpendicular encounters, $\theta=\pi/2$, $q=0.1$, $a=0.5$ mpc
Fallback rates

- Very different behaviour:
  - Much less affected by binary
  - Smooth decrease in fallback rather than abrupt interruptions
  - Time of first interaction roughly consistent with theory (except for small $q$)
  - No dependence on $\Omega$
Intermediate cases

• Transition from one extreme case to the other

• Quasi periodic interruptions appear for inclinations smaller than ~ 60 degrees
Caveat: calculation of fallback rate

- In most other studies, fallback computed from sinks (e.g. Coughlin et al 2016)
- Here, we use the energy distribution of debris (a la Rees 1988)
- Sink method **con**: strongly depends on numerics (accretion radii, resolution)
- Energy method **con**: energy is not a conserved quantity in a binary system
- Our method essentially tracks how much the presence of the binary modifies the energy distribution of debris at the time at which they would be expected to return to pericentre
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The Papaloizou-Pringle instability in TDEs

Bonnerot et al 2016

$\beta = 5$
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Bonnerot et al 2016

$\beta = 5$
Significant accretion due to the PPI with equivalent $\alpha \sim 0.04$

May be the dominant transport mechanism before the MRI takes over
Conclusions

• TDEs from SMBH binaries

• Geometry of the encounter changes the type of interaction
  
  • In-plane: direct interaction between the stream and the binary causes interruptions and periodic (on the binary period) variability
  
  • Perpendicular: the overall modification of the potential modifies fallback in a less pronounced way, with smoother reduction of the fallback rate

• Tori formed in TDE are unstable to the PPI: might lead to significant transport before the MRI takes over