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EXTREME MASS RATIO INSPIRALS IN NUCLEAR STAR CLUSTERS

a post-Newtonian orbit-resolved approach

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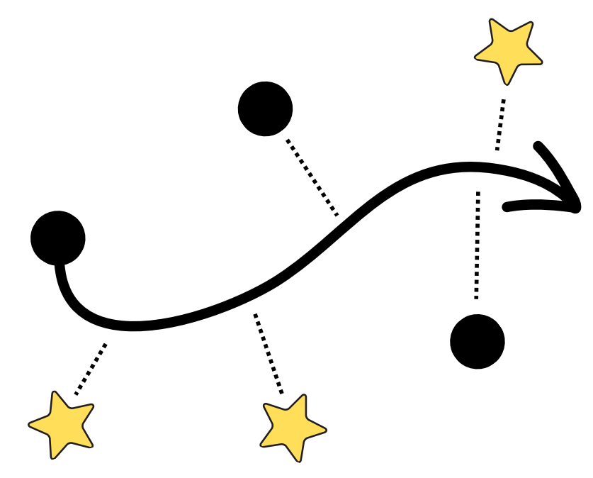
Introduction

- Extreme mass ratio inspirals (EMRIs) are **highly relativistic** binary systems consisting of a **massive black hole** (MBH) and a **compact object** which orbit each other on a tight and eccentric path, while avoiding a plunge.
- EMRIs emit **gravitational waves** (GWs) in the mHz frequency range, predominantly at pericentre, making them primary sources for the upcoming Laser Interferometer Space Antenna (**LISA**).
- In **nuclear star clusters**, MBHs are surrounded by many stars and compact objects. Here, **frequent two-body interactions** often scatter a compact object onto a very eccentric orbit, facilitating EMRI formation.

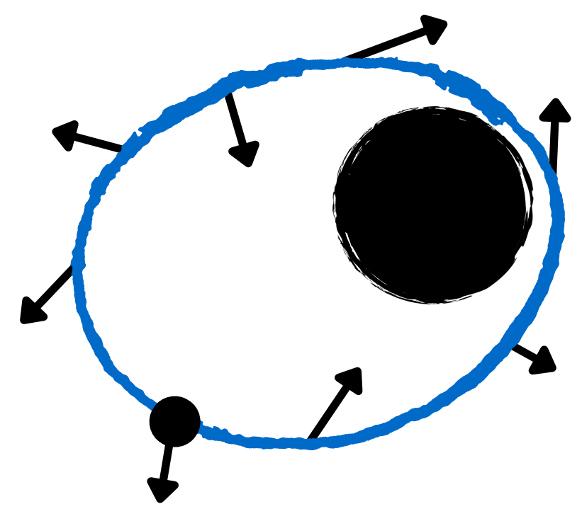
Simulations

- We simulate the formation of EMRIs in nuclear star clusters with a **few-body/Monte Carlo code**. We solve the equations of motion of the central MBH and of a stellar-mass black hole orbiting around it.
- We account for two-body interactions with surrounding bodies multiple times within an orbit. We call this approach "**orbit-resolved**", in opposition to the usual procedure of orbit-averaging interactions over an entire orbit. **This is the first time that such approximation has been lifted**.
- In particular, we accomplish this by **kicking the stellar-mass black hole** at the end of each time step of the system's evolution. These kicks are randomly drawn from an appropriate probability distribution such that each kick is representative of the total effect of two-body interactions that might have happened during a particular time step.
- We use **post-Newtonian** corrections and a **two-population model** for the nuclear star cluster, which accounts both for the presence of Sun-like stars and of stellar-mass black holes.

What happens:



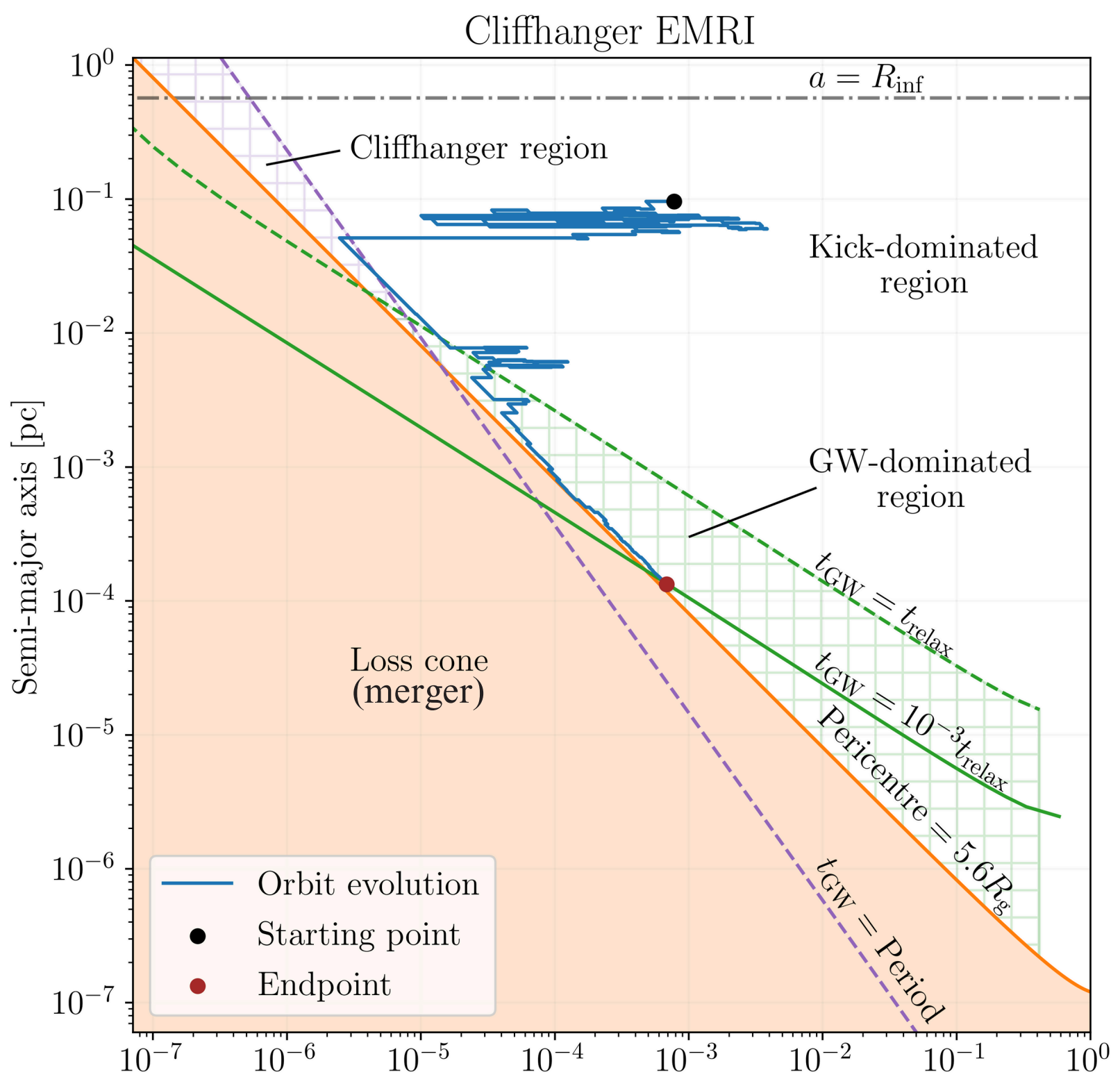
How we simulate it:



why?

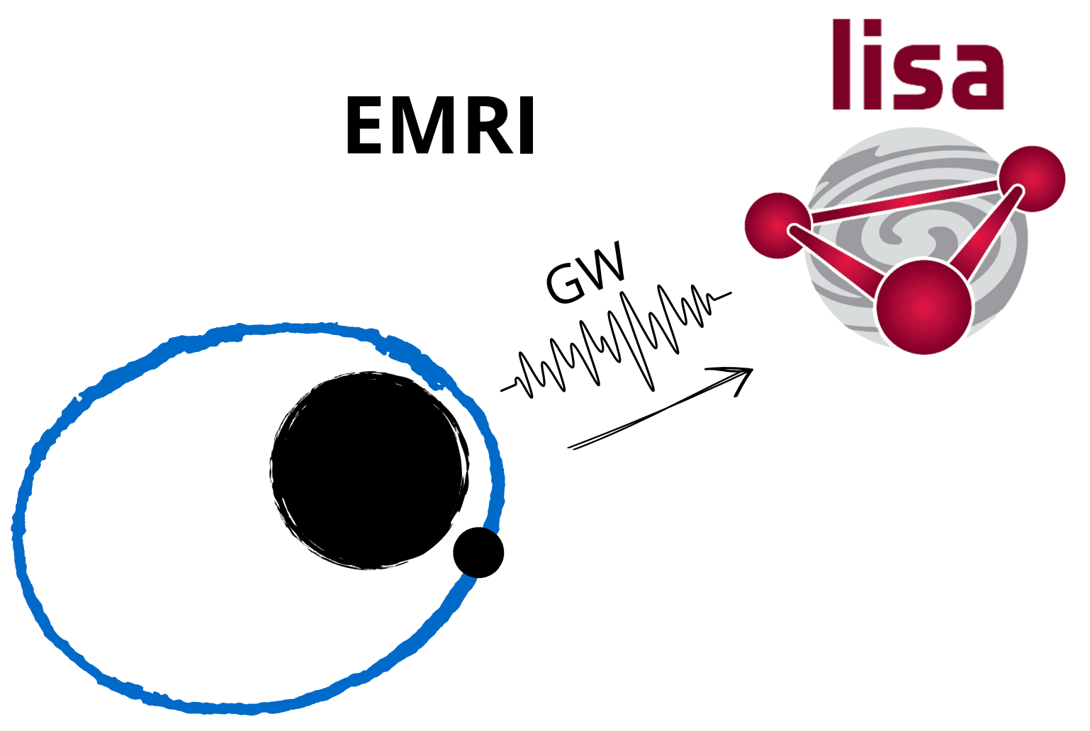
Cliffhanger EMRIs

- **Cliffhanger EMRIs are failed DPs**. They occur whenever a compact object gets into an almost radial orbit towards the MBH, but misses it. A **strong emission of GWs** follows, and the orbit jumps to a much smaller semi-major axis.
- They were first studied by Qunbar and Stone (2023).
- In this work **we explain why** cliffhanger EMRIs form around low-mass MBHs: the area of the "**cliffhanger region**" is inversely related to the mass of the MBH.



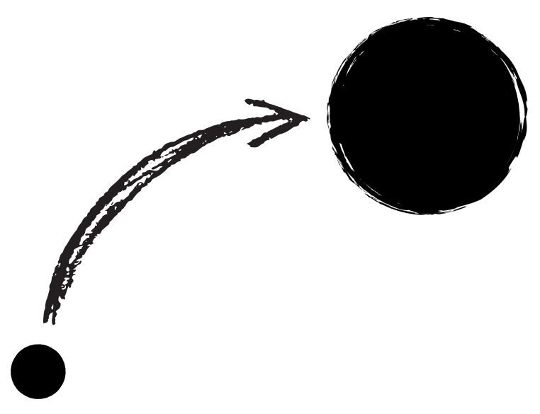
Inside the "cliffhanger region", the emission of GWs strongly modifies the orbit's shape in less than an orbital period

EMRI

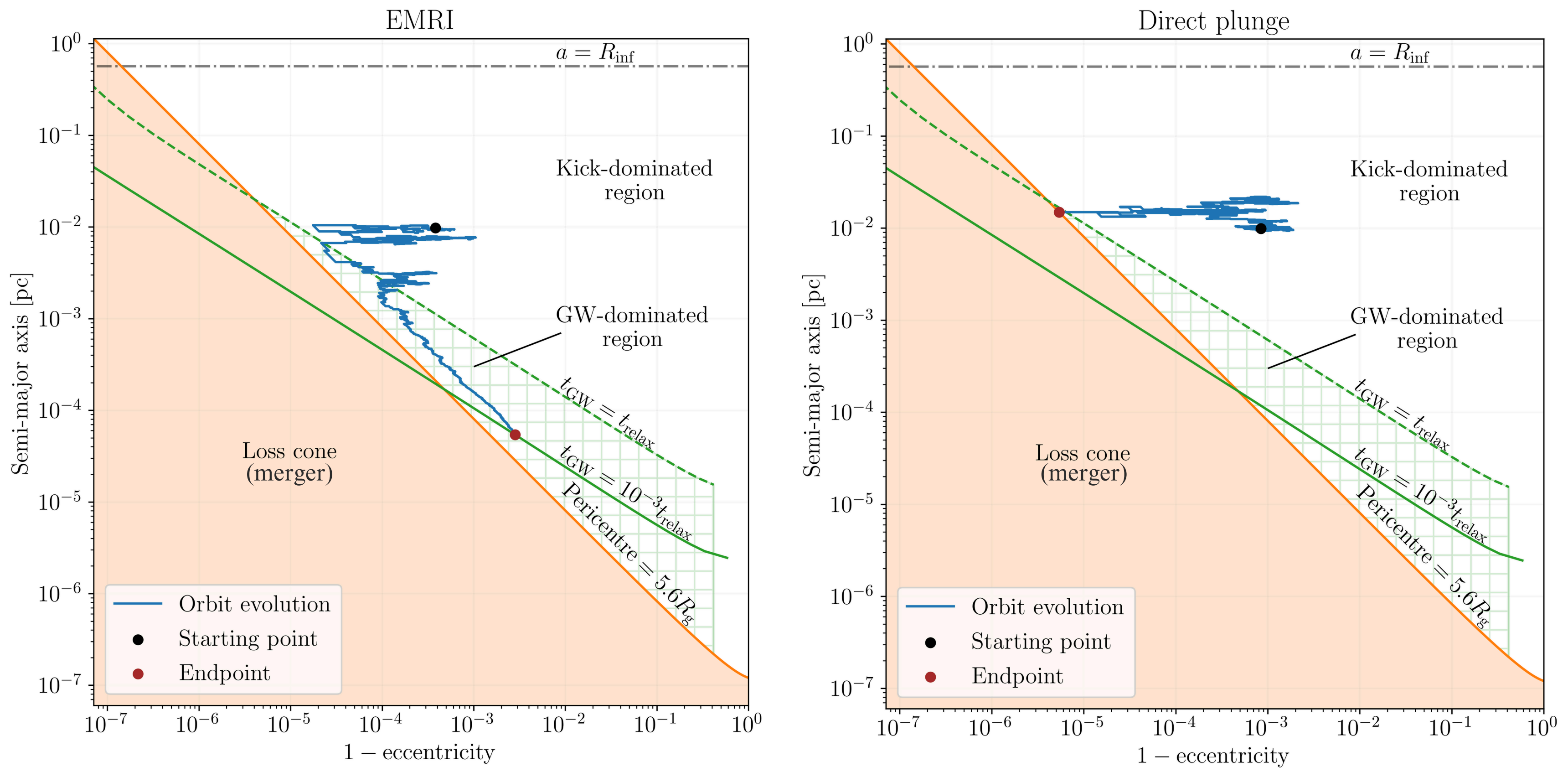


Due to the emission of GWs, the compact object slowly inspirals towards the MBH over thousands of orbits, until they eventually merge

Direct plunge (DP)



If the merger occurs after few orbits or in a head-on collision it is referred to as a direct plunge (DP). LISA should not be able to see DP

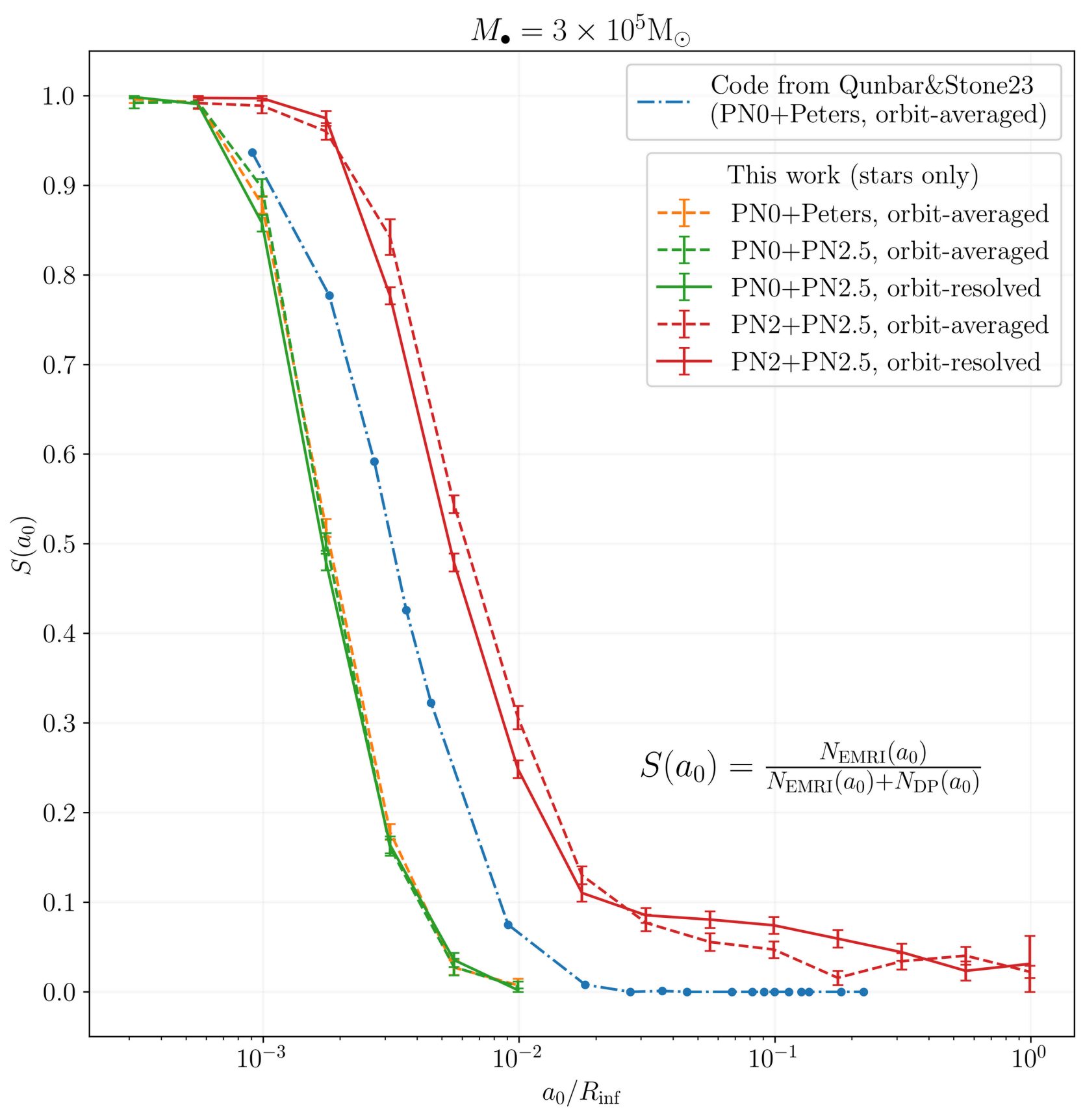


Two fundamental timescales describe the orbit evolution:

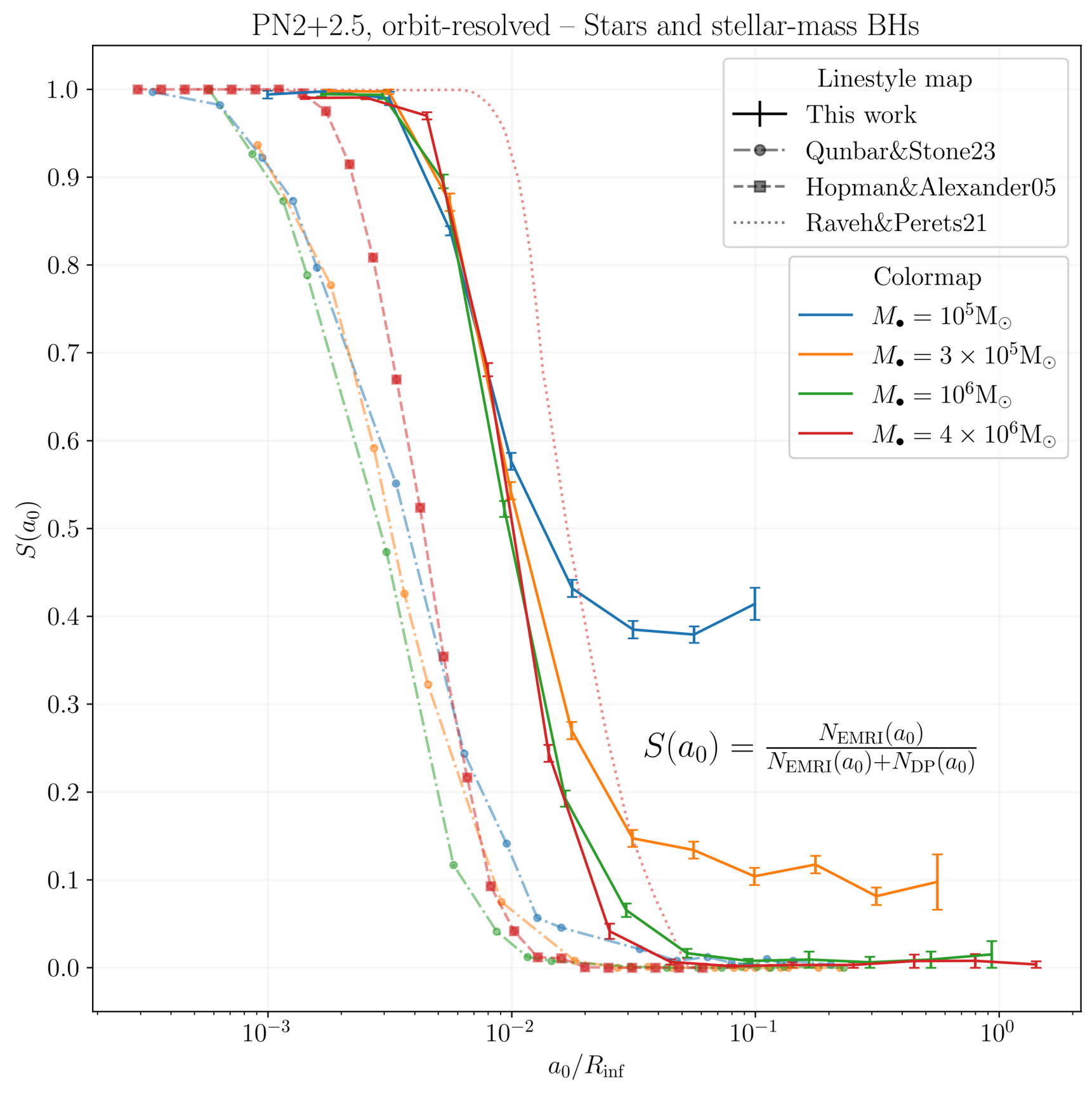
- t_{GW} is the time needed for **the emission of GWs** to significantly change the orbit
- t_{relax} is the time needed for **two-body interactions** to significantly change the orbit

Results

- We apply this model to the study of the **ratio of EMRIs to DPs forming as a function of the initial semi-major axis** of the orbit. It is currently believed that this ratio should always approach zero for large initial semi-major axes, where only DPs are expected to form.
- We find that this is not the case anymore when the central MBH is **smaller than 10^6 solar masses**.
- We also find that both the post-Newtonian treatment and the introduction of a population of stellar-mass black holes **significantly enhance the number of EMRIs that form from initially wide orbits**. Instead, the EMRI-to-DP ratio is only slightly influenced by the choice of averaging or not the effects of two-body relaxation.



Comparison between Newtonian (PN0) or post-Newtonian dynamics (PN2) and between orbit-averaged and orbit-resolved approaches. The PN2.5 term accounts for GW emission



Comparison between our model and results from the literature, for different MBH masses

Conclusions

- It is possible to form EMRIs even from initially wide orbits around low-mass MBHs (less than 10^6 solar masses) due to cliffhanger EMRIs.
- To avoid underestimating the occurrence of EMRIs, we have to use post-Newtonian corrections and a precise galactic nucleus model.
- The orbit-averaging approximation is reliable for estimating the EMRI-to-DP formation ratio.

These findings call for a reassessment of predicted LISA detection rates to account for cliffhanger EMRIs in the low-mass MBH regime.

ask me ANYTHING