Stellar Capture Rates in Galactic Nuclei Containing a Supermassive Binary Black Hole

Shashank Dattathri [1] **Arun Mangalam** [2]

[1]Indian Institute of Science, Bangalore, India
[2]Indian Institute of Astrophysics, Bangalore, India

Introduction

The study of galaxies whose central black hole has negligible or no surrounding disks (called deaed quasars or inactive galaxies) is an observational challenge. The tidal disruption of stars provides the mass for accretion by the black hole leading to emission and thus is a promising phenomenon to observe the inactive nuclei. Tidal disruption events (TDEs) can manifest themselves as a luminosity flare at the center of a galaxy for a few years, and the gas released from the disrupted star can be a source of power for quasars and AGN [1]. Some nuclei have binary black holes with star cluster around one or both of these systems.

In this work, we study the stellar capture rates in galactic nuclei containing an unequal mass binary black hole. Our study consists of a hierarchical system of a primary black hole, a secondary black hole, and a star in a stellar cusp surrounding the primary. *We study the orbital dynamics around the binary black hole, calculate the flux of stars into the loss cone of the binary, and make predications for the capture rates over time.*

Loss Cone Dynamics

The condition for tidal disruption is that the tidal force of the black hole is greater than the star's self-gravity. For a star of mass m_* and radius r_* orbiting a SMBH of mass M, the tidal radius is given by [2]:

$$r_t = \left(\eta^2 \frac{M}{m_*}\right)^{1/3} r_* \,.$$

An orbit with a periapsis of r_t has angular momentum equal to $L_{lc} = \sqrt{2r_t^2(E - \Phi(r_t))} \approx \sqrt{2GMr_t}$ [3]. Orbits with $L \leq L_{lc}$ are called loss cone orbits, and the set of all loss cone orbits is called the loss cone.

Orbital Dynamics

The primary BH-secondary BH-star system constitutes a hierarchical three-body system. The presence of the secondary black hole induces oscillations in the angular momentum of the star which are very similar to the Lidov-Kozai mechanism. The timescale of these oscillations is given by [4]:

$$\tau_{LK} = \frac{\sqrt{M_1}}{\sqrt{G}M_2}\frac{a_2^3}{a^{3/2}}(1-e_2^2)^{3/2} \,.$$

The Lidov-Kozai oscillations are disturbed by the competing mechanisms of stellar cusp precession and general relativity. Apsidal precession due to the stellar cusp leads to precession of the orbital pericenter which is retrograde in nature, while general relativity effects cause precession which is prograde in nature. The timescales of these competing mechanisms are [5]:

$$\tau_{SP} \sim \sqrt{\frac{a^3}{G^3 M_1 M_*(a)(1-e^2)}} \qquad \tau_{GR} \sim \frac{a^{5/2}(1-e^2)c^2}{(GM)^{3/2}} \,.$$

The total precession rate is given by [6]:

$$\dot{\omega}_{tot} = \dot{\omega}_{SP} + \dot{\omega}_{LK} + \dot{\omega}_{GR} \,.$$

Based on the timescales of the mechanisms involved, the angular momentum oscillations can be suppressed by the competing mechanisms.

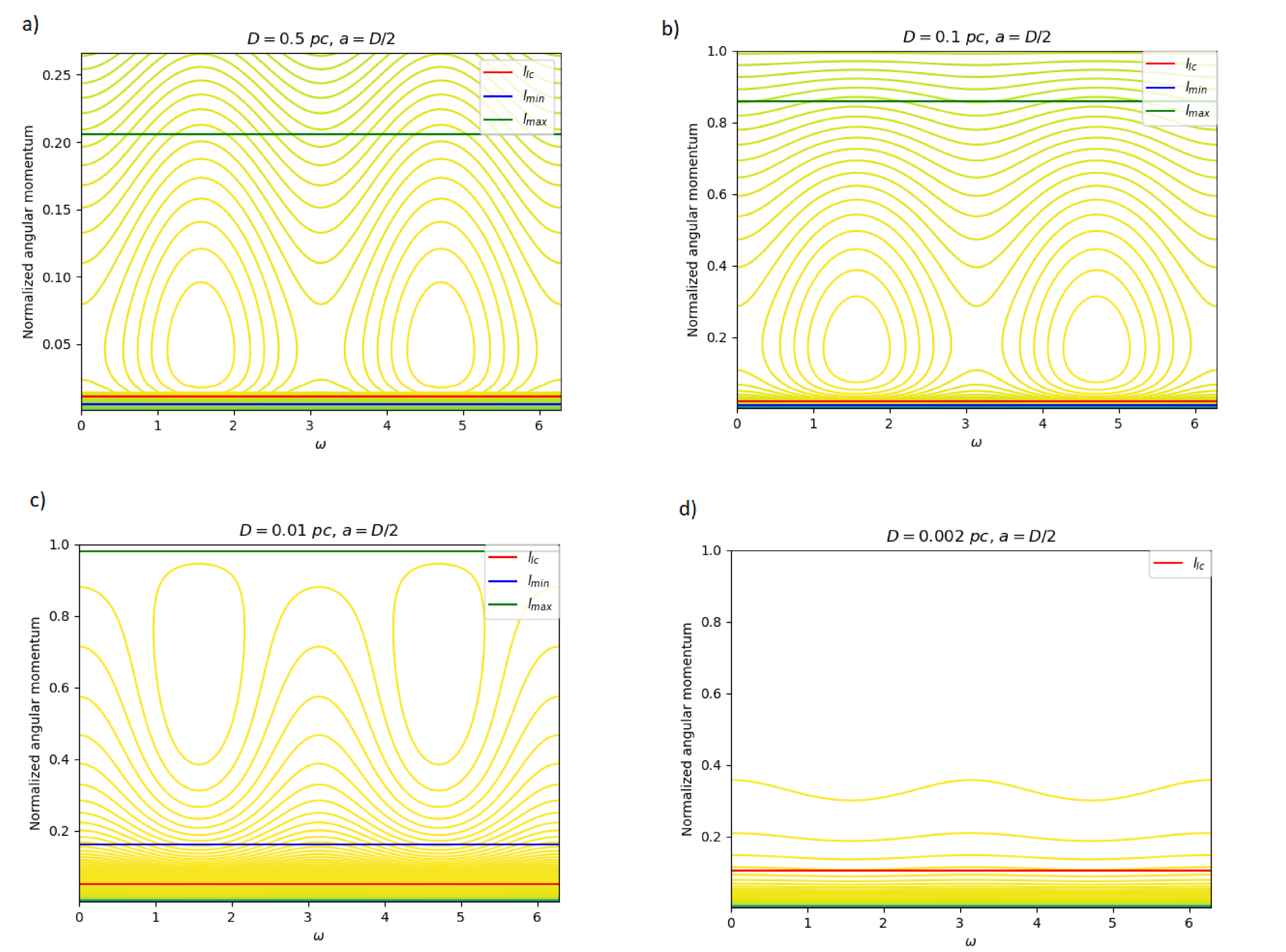

Fig. 1: a) The angular momentum oscillations are suppressed by apsidal precession. b) The Lidov-Kozai mechanism dominates and strong oscillations are observed. c) The oscillations are suppressed by general relativity. d) The oscillations are completely destroyed due to strong GR precession.

Results: Capture Rates

The binary itself is evolving. At early times, the secondary BH inspirals to the center due to dynamical friction, and at later times the binary hardens due to gravitational three-body slingshot mechanisms [7]. As the binary separation and the number of stars enclosed within the binary changes, the various timescales involved evolve. The strength of the angular momentum oscillations determine the flux of stars into the loss cone of the SMBH.

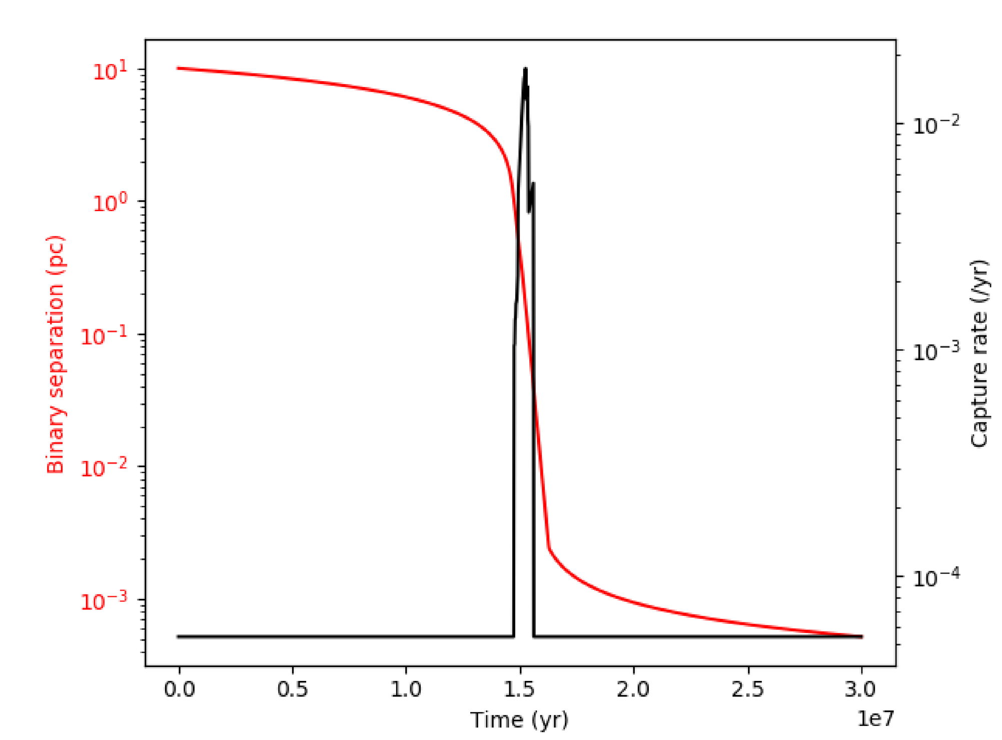

Fig. 2: Binary separation and capture rate into the primary black hole as a function of time.

- *The peak capture rate $\dot{N}_p$ is 2-3 orders of magnitude higher than the typical capture rate of nuclei containing a single SMBH [8].*
- The enhanced capture rate phase begins when the binary separation reaches $\sim 1pc$.
- The enhanced phase ends when the binary separation reaches $\sim 0.1pc$.
- The duration of the enhanced phase is of the order of $\sim 10^5 - 10^6$ yr.
- These results are consistent with the the results of several others works, who analyze the problem from the point of view of N-body simulations [9] [6] [10].

Results: Observational Consequences

- Since the TDE rates in nuclei containing a binary black hole are much higher than the rates in those containing a single black hole, the TDE rates of a galaxy can be a powerful method to confirm the presence of a binary black hole [11].
- From an observational point of view, an integral over the cosmic volume is to be performed, in order to calculate the number of TDEs which will be observable from Earth, and the fraction of the TDEs which originate in SMBHBs. The probability of a multiple-TDE galaxy hosting a SMBHB is to be calculated.
- *Our novel semi-analytic model will provide more accurate predictions for binary merger rates and as a consequence better estimates for TDE rates.*

References

[1] J. Frank and M.J. Rees. In: *MNRAS* 176 (1976), pp. 633–647.
[2] J. Magorrain and S. Tremaine. In: *MNRAS* 309 (1999), pp. 447–460.
[3] T. Mageshwaran and A. Mangalam. In: *ApJ* 814 (2015), 141:161.
[4] P.B. Ivanov, A.G. Polnarev, and P. Saha. In: *MNRAS* 358 (2005), pp. 1361–1378.
[5] D Merritt. *Dynamics and Evolution of Galactic Nuclei.* Princeton: Princeton University Press, 2013.
[6] N. Bode and C. Wegg. In: *MNRAS* 438 (2013), 573:589.
[7] M. Milosavljevic and D. Merritt. In: *ApJ* 596 (2003), pp. 860–878.
[8] S. Dattathri and A. Mangalam. In Preparation.
[9] Xian Chen, F.K. Liu, and John Magorrian. In: *ApJ* 729 (2011), 13:28.
[10] S. Li et al. In: *ApJ* 883 (2019), p. 132.
[11] S. Thorp, E. Chadwick, and A. Sesana. In: *MNRAS* 488 (2019), 4042:4060.