

ORBITS OF BLACK HOLES IN GALACTIC TRIAXIAL POTENTIALS

Juan Barbosa

Jaime Forero
Advisor

Departamento de Física
Facultad de Ciencias
Universidad de los Andes

OVERVIEW

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2 METHODOLOGY

- Galactic setup
- Equation of motion

3 RESULTS

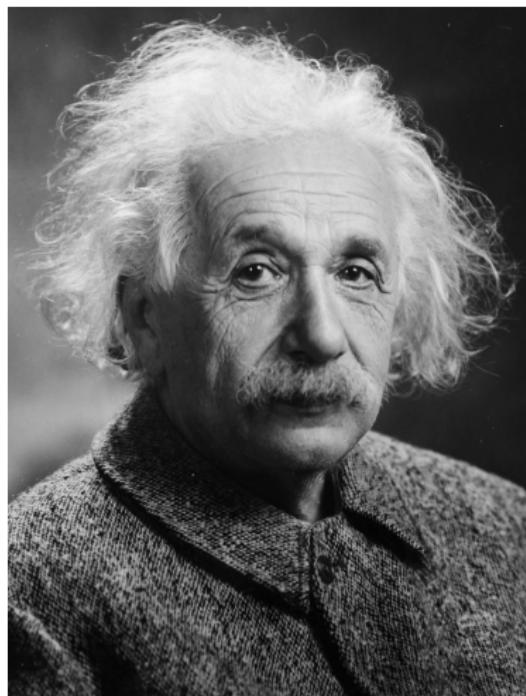
- Spherical potentials
- Triaxial potentials

4 CONCLUSIONS

5 REFERENCES

INTRODUCTION

INTRODUCTION



- Theory of General Relativity, 1916
- More than 100 years have passed since the publication of the theory
- Today there are gaps in the understanding and implications of Einstein's equations

INTRODUCTION

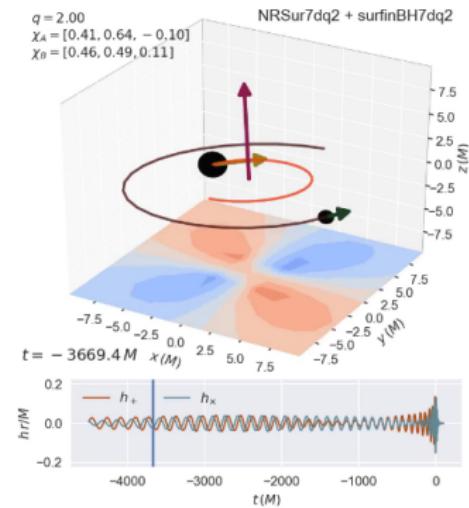


FIGURE: Binary black hole merger simulation

OBJECTIVES

Study the effect of different triaxial potentials, and initial velocities, on the times required by black holes to return to their initial position, after experiencing a recoil, as well as to quantify how chaotic its trajectory is

- Obtain probability distributions for the return properties of the black holes, based on the magnitude and direction of the initial velocity
- Study the chaotic behavior of orbits using Lyapunov exponents

└ METHODOLOGY

METHODOLOGY

GALACTIC SETUP

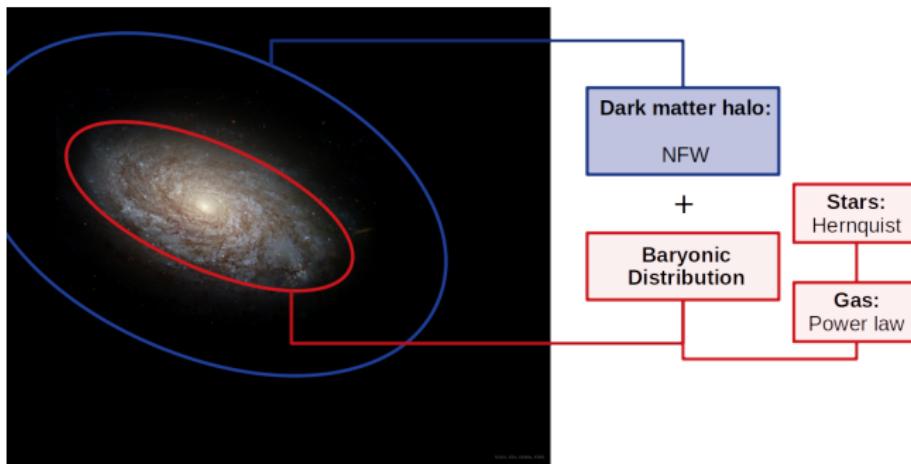


FIGURE: NGC4414 galaxy as seen by the Hubble telescope.

└ METHODOLOGY

 └ GALACTIC SETUP

MASS DISTRIBUTIONS

1 Dark matter (NWF):

$$\rho_{\text{DM}}(r) = \frac{\rho_0^{\text{DM}}}{\frac{r}{R_s} \left(1 + \frac{r}{R_s}\right)^2} \quad (1)$$

2 Stellar density (Hernquist):

$$\rho_s(r) = \frac{f_s f_b M_T \mathcal{R}_s}{2\pi r (r + \mathcal{R}_s)^3} \quad (2)$$

3 Gas density (Double power law):

$$\rho_{\text{gas}}(r) = \frac{\rho_0^{\text{gas}}}{\left(1 + \frac{r}{r_0}\right)^n} \quad (3)$$

└ METHODOLOGY

 └ EQUATION OF MOTION

EQUATION OF MOTION

Trajectories of the kicked black holes are obtained by numerically solving the equation of motion.

$$\ddot{\vec{x}} = -a_{\text{grav}}(\vec{x})\hat{x} + \left(a_{\text{DF}}(\vec{x}, \dot{\vec{x}}) - \dot{x} \frac{\dot{M}_\bullet(x, \dot{x})}{M_\bullet} \right) \dot{\hat{x}} \quad (4)$$

where M_\bullet is the black hole mass

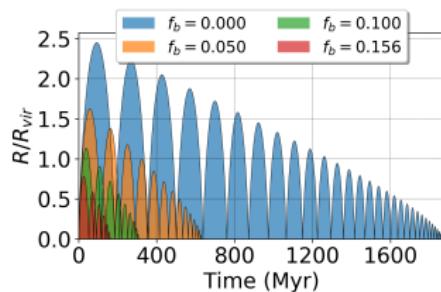
- Dark matter, stars and gaseous materials from the medium interact with the black hole adding a drag force
- The black hole accretes matter from the surroundings

RESULTS

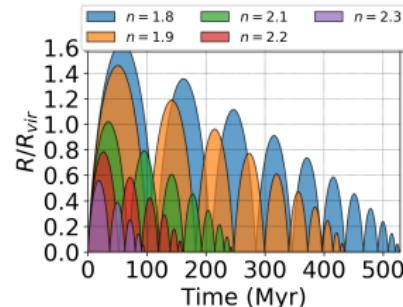
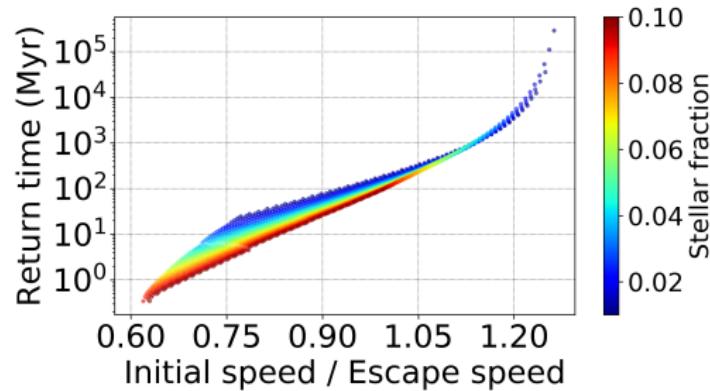
RESULTS

SPHERICAL POTENTIALS

SPHERICAL POTENTIALS



← Baryonic fraction
● Stellar fraction



← Power law exponent

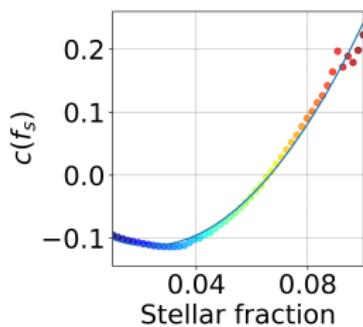
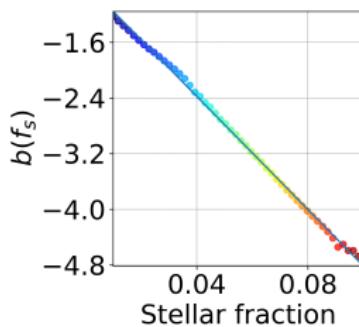
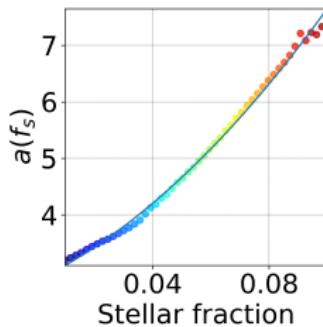
FIGURE: Return time for different initial speeds

└ RESULTS

└ SPHERICAL POTENTIALS

EFFECT OF THE STELLAR FRACTION

$$\log_{10}(T_{\text{return}}) = [a(f_s)v + b(f_s)] + \frac{c(f_s)}{v - 1.3} \quad (5)$$



$$a(f_s) = 232f_s^2 + 25f_s + 2.83 \quad (6)$$

$$b(f_s) = -40.7f_s - 0.75 \quad (7)$$

$$c(f_s) = 60f_s^2 - 2.8f_s - 0.080 \quad (8)$$

└ RESULTS

└ SPHERICAL POTENTIALS

EFFECT OF THE STELLAR FRACTION

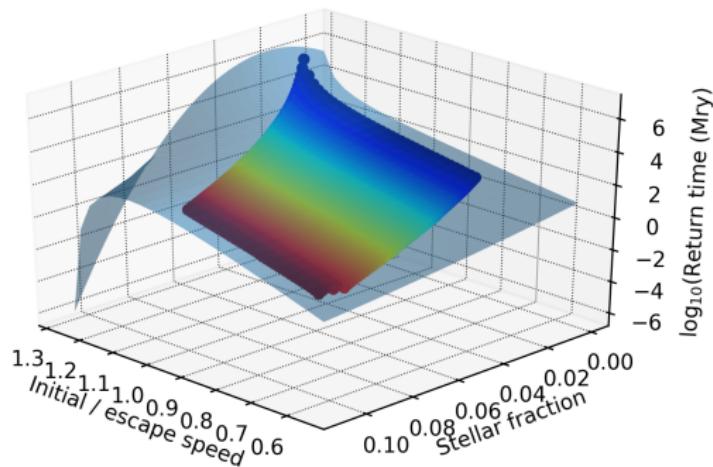
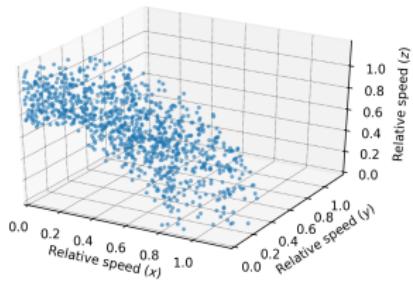


FIGURE: Generated surface with the proposed fitting curve

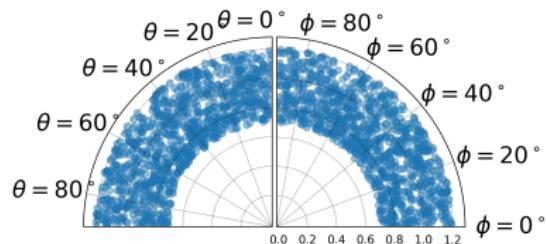
RESULTS

TRIAXIAL POTENTIALS

INITIAL CONDITIONS



(A) Cartesian



(B) Polar

FIGURE: Distributions of initial speeds for the triaxial lunches. θ describes the polar angle and ϕ the azimuth.

RESULTS

TRIAXIAL POTENTIALS

TRIAXIAL: INITIAL CONDITIONS

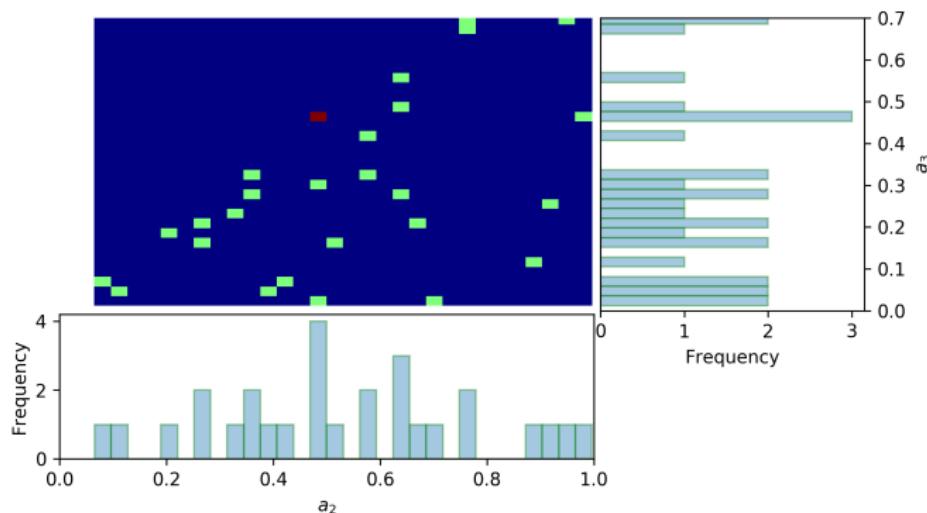


FIGURE: Distribution of the 28 pair of values for the y and z semiaxis.

└ RESULTS

 └ TRIAXIAL POTENTIALS

RESULTS

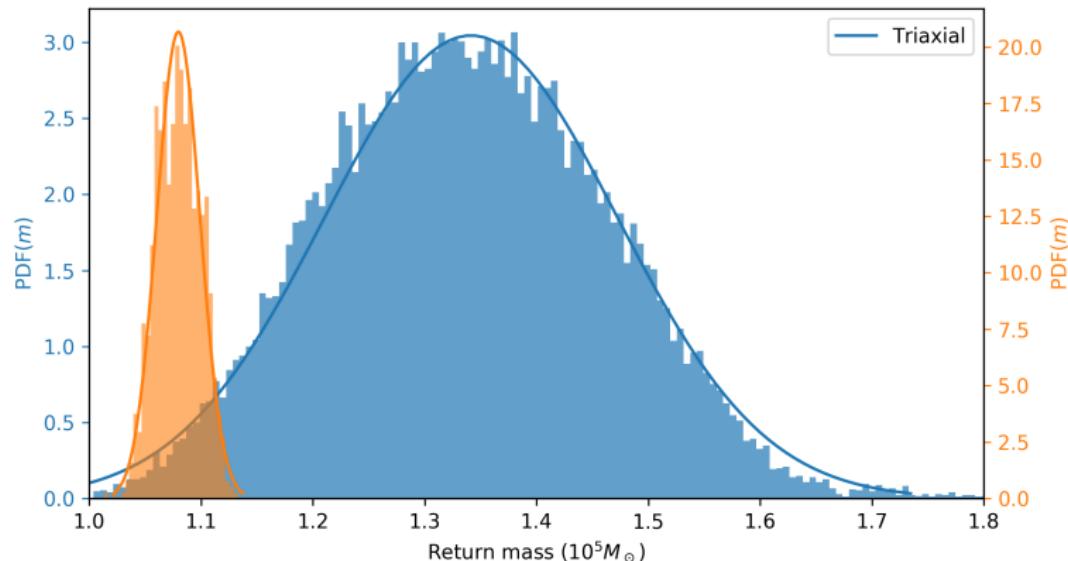


FIGURE: Mass distributions of the returned black holes

└ RESULTS

└ TRIAXIAL POTENTIALS

ULAS J1342+0928



FIGURE: ULAS J1342+0928 representation

- Most distant and oldest known SMBH
- $Z = 7.54$
- $M = 8 \times 10^8 M_{\odot}$

$$\begin{array}{c} Z = 7.54 \\ \downarrow \\ 692 \text{Myr} \\ \hline \Lambda - \text{CDM} \\ \hline Z = 20.00 \\ \downarrow \\ 180 \text{Myr} \\ 512 \text{Myr} \end{array}$$

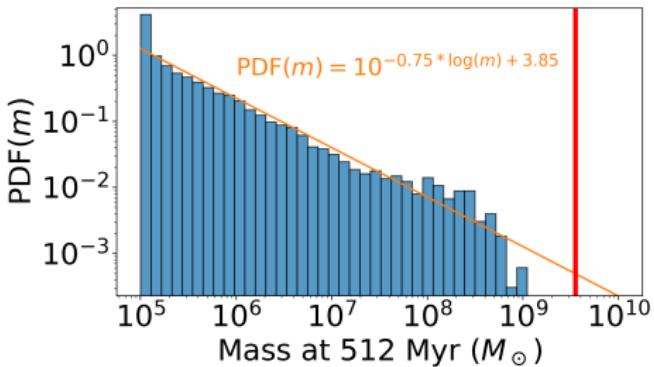


FIGURE: Mass distribution at 512 Myr

└ RESULTS

 └ TRIAXIAL POTENTIALS

RETURN TIMES

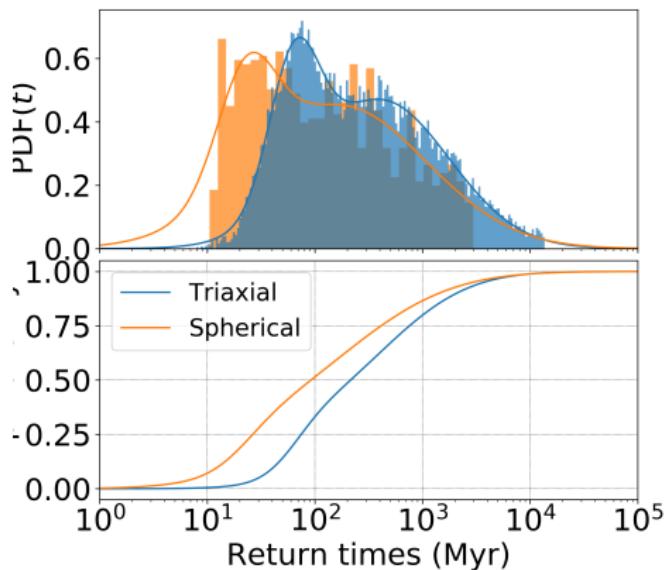


FIGURE: Return time distributions

RESULTS

└ TRIAXIAL POTENTIALS

RESULTS

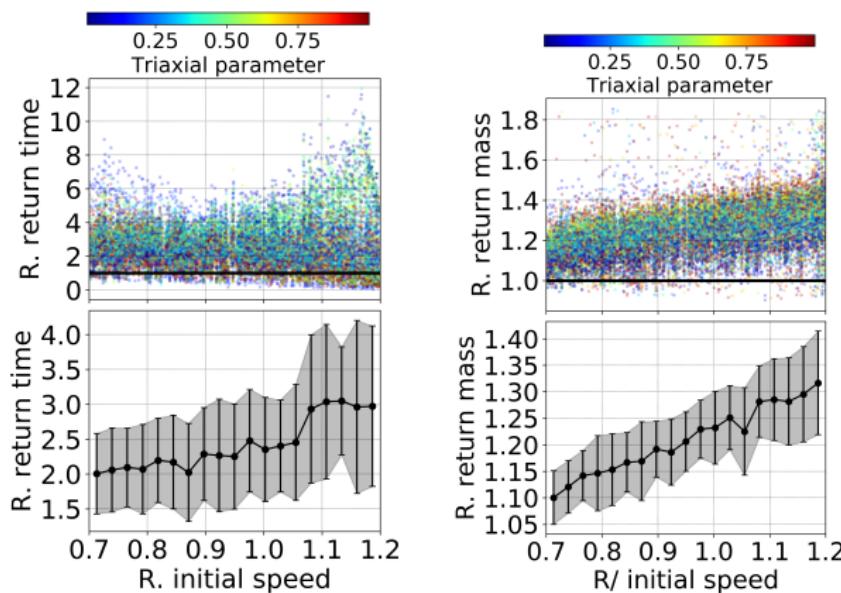


FIGURE: Distributions of the relative return properties.

└ RESULTS

└ TRIAXIAL POTENTIALS

RESULTS

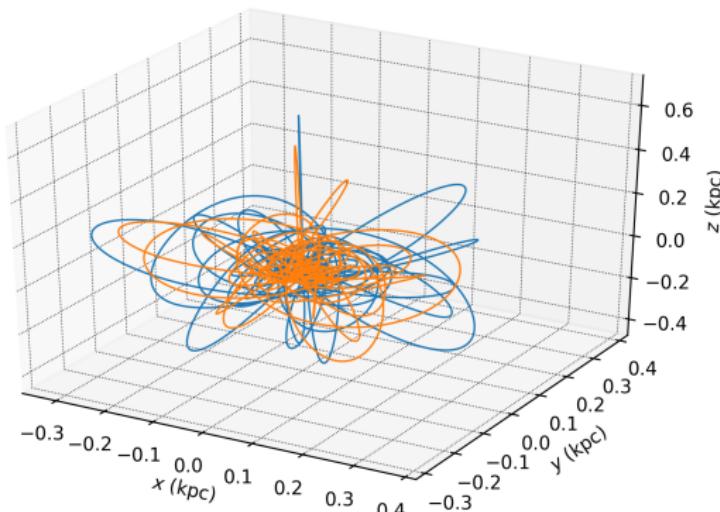
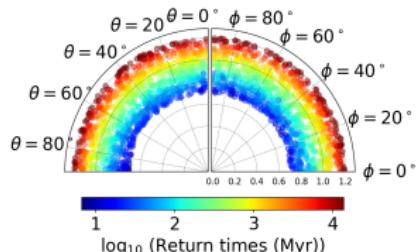


FIGURE: Orbits with a difference in the initial conditions of 1.9 %.

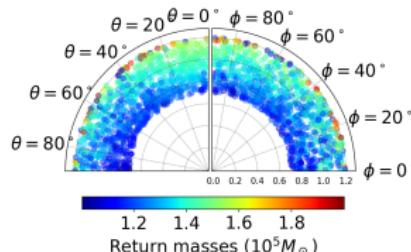
RESULTS

TRIAXIAL POTENTIALS

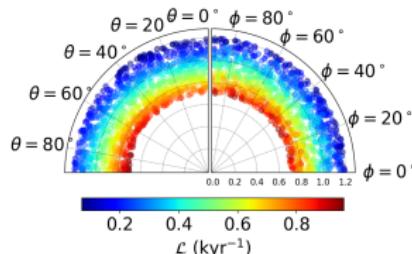
Spherical Galaxy



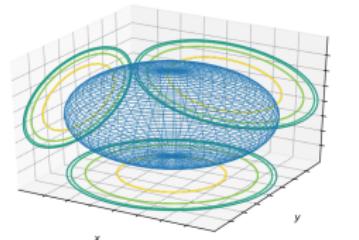
(A) Return times



(B) Return masses



(C) Lyapunov exponent



(D) Geometry

FIGURE: Distribution of the different properties for the galaxy with $a_1 = 1$, $a_2 = 9.6 \times 10^{-1}$, $a_3 = 7.0 \times 10^{-1}$.

RESULTS

TRIAXIAL POTENTIALS

DISC GALAXY

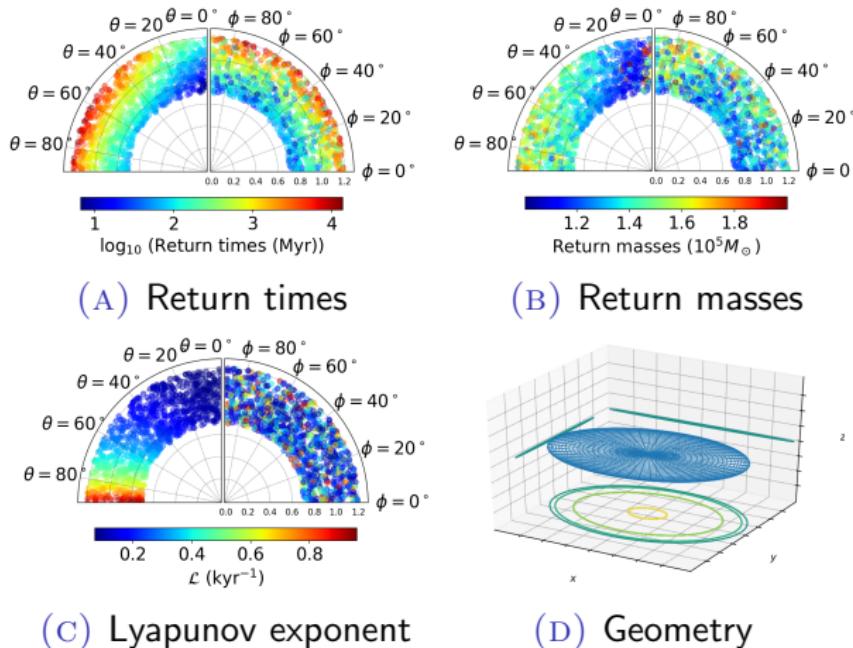


FIGURE: Distribution of the different properties for the galaxy with $a_1 = 1$, $a_2 = 6.9 \times 10^{-1}$, $a_3 = 1.2 \times 10^{-2}$.

RESULTS

TRIAXIAL POTENTIALS

BAR GALAXY

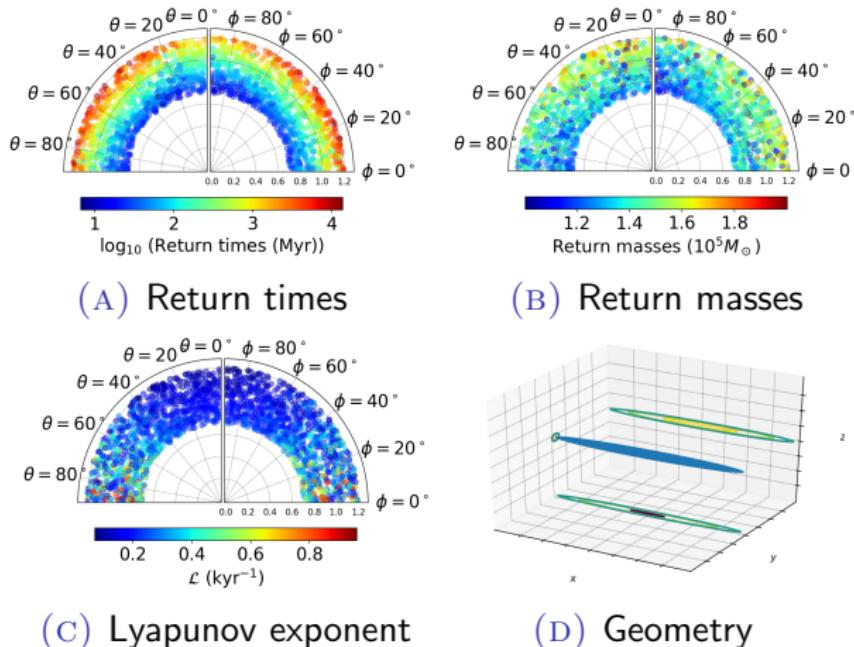


FIGURE: Distribution of the different properties for the galaxy with $a_1 = 1$, $a_2 = 6.6 \times 10^{-2}$, $a_3 = 6.1 \times 10^{-2}$.

└ CONCLUSIONS

CONCLUSIONS

CONCLUSIONS

- Including triaxiality in galaxies can shift the predictions from previous spherical studies
 - On average, return times for triaxial studies are 2.6 times longer than those expected in spherical galaxies
 - Masses, on the other hand, show an average increase of 24 %
- Person correlation between the return properties (time and mass) has been quantified at 0.63
- The probability of finding a black hole such as the ULAS J1342+0928 quasar in the simulations is 0.34 %
- The baryonic fraction of the galaxy, the power law exponent of the gas profile, and the amount of stars drastically alter the return properties of a black hole

CONCLUSIONS

- Lyapunov exponents show that there is a proportional dependency with the magnitude of the initial velocity
- More chaotic orbits are related with the highest potential axis (major semiaxis)

└ CONCLUSIONS

THANK YOU

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