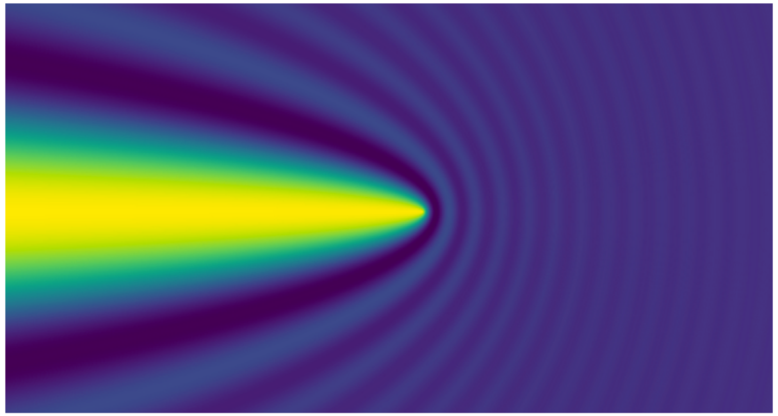
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ
UNIVERSITY OF PATRAS

Dark Matter Tension: The impact of dynamical friction due to fuzzy dark matter on satellites with logarithmic potentials



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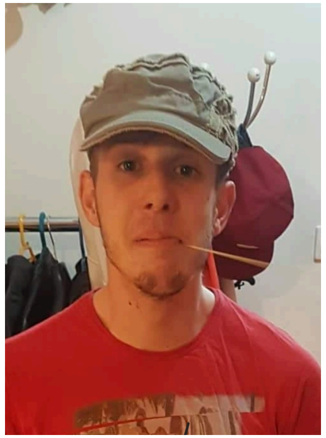
Outline

- Fuzzy Dark Matter.
- Dynamical Friction.
- Numerical Scheme.
- Non-spherically symmetric systems
- Implications and Results.



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Fuzzy Dark Matter (FDM)

- An alternative model to CDM, considering an ultralight scalar particle, with mass $m \sim 10^{-22}\mathrm{eV}$, and a de Broglie wavelength of $\lambda_{dB} = \frac{h}{mv_{rel}} \sim 1\ \mathrm{kpc}$. Motivated by the cuspy-core problem (i.e. Hu et al. 2000, Hui et al. 2017).
- Studies of various phenomena related to FDM: structure formation, satellites, dynamical heating due to friction (Church et al. 2019).

Madelung Formalism

Quantum Hydrodynamics: The wavefunction is written in terms of a density function and a phase whose gradient is proportional to the velocity (Madelung 1926):

$$\psi = \sqrt{\rho} e^{i\theta},$$
$$\mathbf{u} = \frac{\hbar}{m} \nabla\theta \,.$$

The wavefunction is the solution of Schrödinger’s equation:

$$i\hbar \frac{\partial\psi}{\partial t} = \left(\frac{\hbar^2}{2m} \nabla^2 + mU \right) \psi,$$

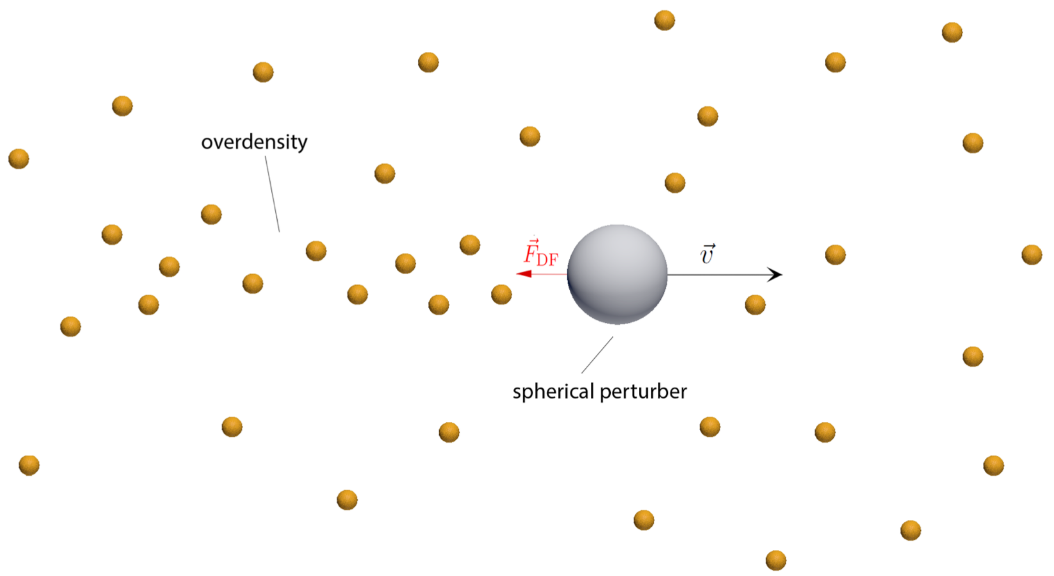
The potential is given by Poisson equation:

$$\nabla^2 U = 4\pi G\rho.$$

Dynamical Friction

The motion of a large body within a sea of smaller bodies creates an overdensity trailing the larger body which decelerates the larger one (Chandrasekhar 1943). .

What is the impact of dynamical friction from a Fuzzy Dark Matter distribution? How does it depend on the potential?



$$F_{DF} = \bar{\rho} \int dV \frac{\rho - \bar{\rho}}{\bar{\rho}} \frac{\boldsymbol{u}}{u} \cdot \nabla U, \qquad F_{ref} = 4\pi\bar{\rho}\left(\frac{GM}{u}\right)^2.$$

$$C_{rel} = \frac{F_{DF}}{F_{rel}}.$$

Numerical Scheme

We consider a fixed potential, a ”satellite”, traveling through a FDM distribution.

We assume that the potential remains unchanged. We impose an initial condition of constant FDM density and uniform velocity:

$$\psi = \rho_0 e^{iM_Q z}$$

and integrate in time Schrödinger’s equation.

We apply period boundary conditions and integrate up for one domain crossing time.

Typical domain size: $(50\pi)^3$,
spectral decomposition $N = 256$

We apply the kick-drift-kick technique, a leap-frog, symplectic-type integrator (Mocz et al. 2017, Lancaster et al. 2020).

$$\psi \leftarrow \exp\left[-i\frac{\Delta t}{2}\frac{m}{\hbar}U\right]\psi,$$

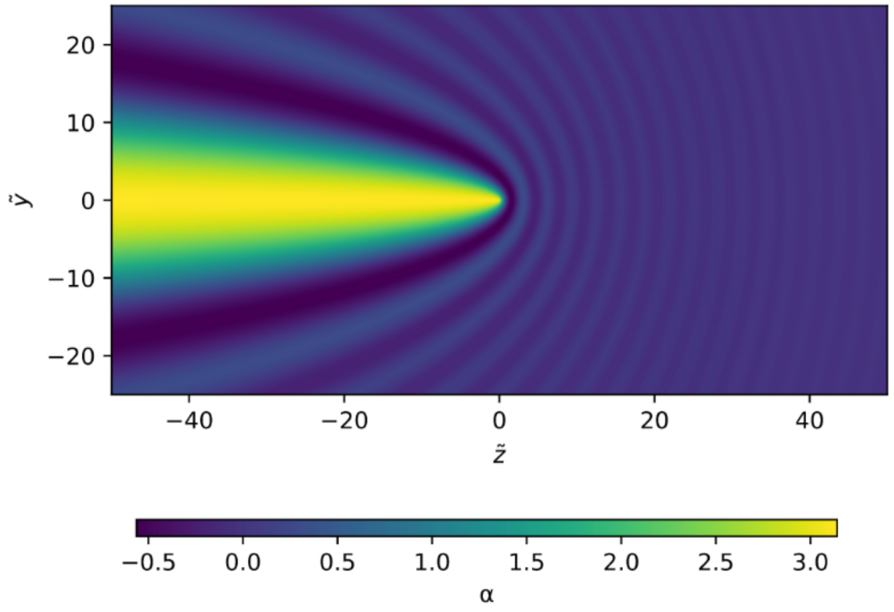
$$\psi \leftarrow \mathrm{ifft}\left\{\exp\left(-ik^2\Delta t\frac{\hbar}{2m}\right)\mathrm{fft}\left[\psi\right]\right\},$$

$$\psi \leftarrow \exp\left[-i\frac{\Delta t}{2}\frac{m}{\hbar}U\right]\psi,$$

Potentials

We have studied families of different potentials: spherically symmetric Plummer and logarithmic potentials.

Analytical solution for a point mass (Lancaster et al. 2020).



$$U = -\frac{GM}{\sqrt{r^2 + R_c^2}}$$

$$U = \frac{v_c^2}{2} \ln\left(R^2 + \frac{y^2}{b_y^2} + R_c^2\right)$$

$$U = \frac{v_c^2}{2} \ln\left(R^2 + \frac{z^2}{b_z^2} + R_c^2\right)$$

$$\frac{1}{\sqrt{2}} < b_{y,z} < 1.08$$

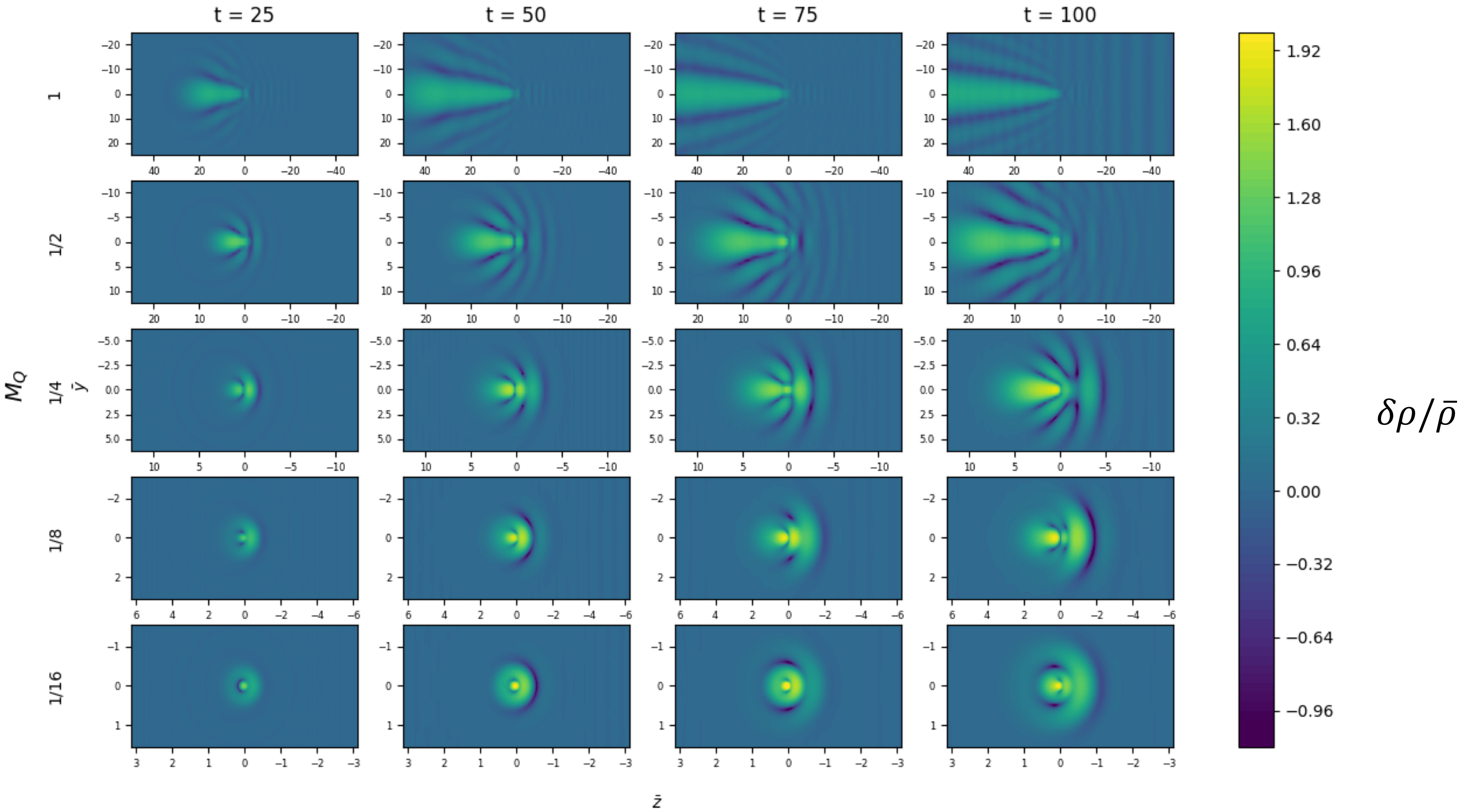
$M_Q = 0.5$, Plummer

Video1

$M_Q = 0.0625$, Plummer

Video2

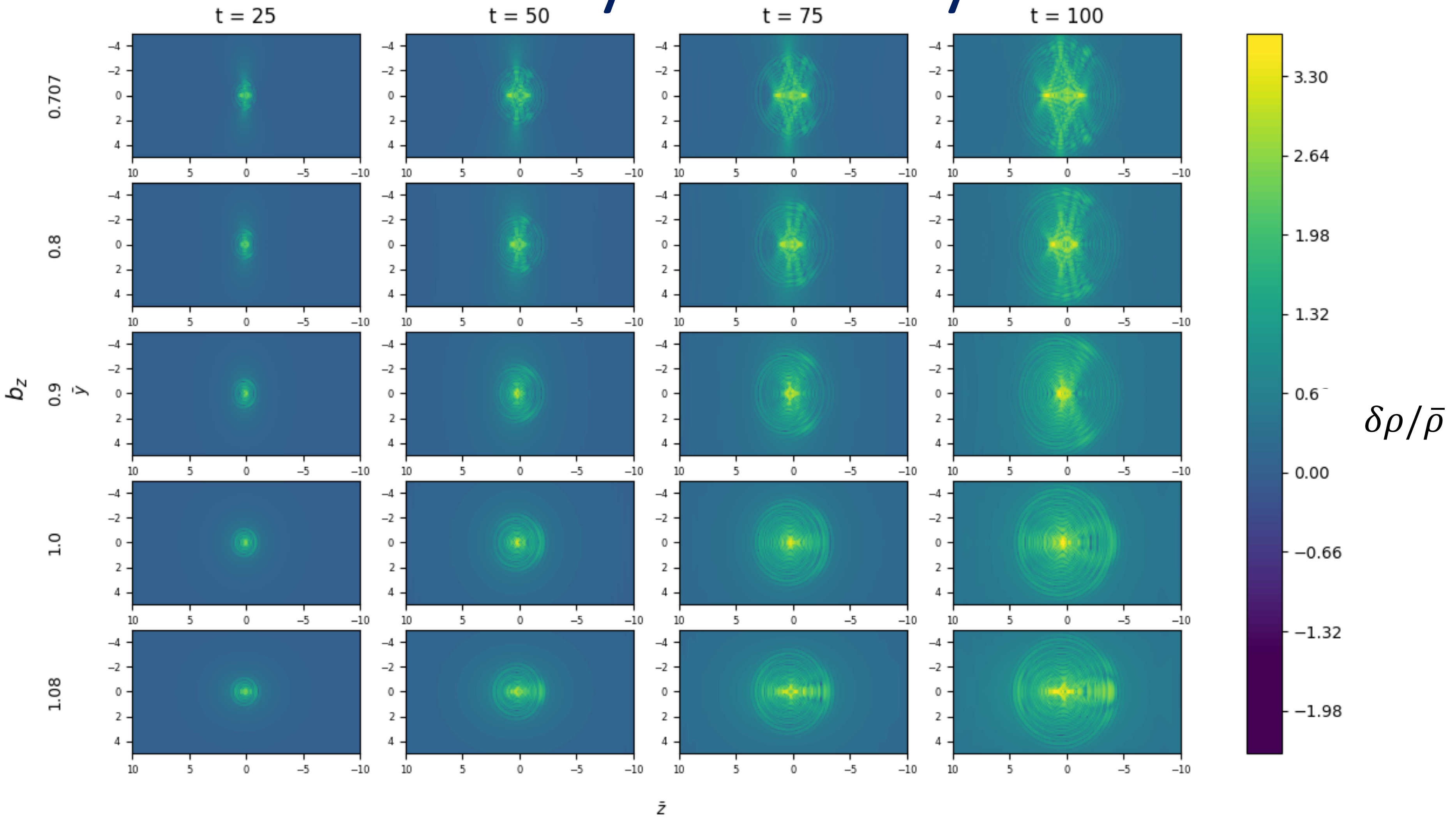
Plummer Potential



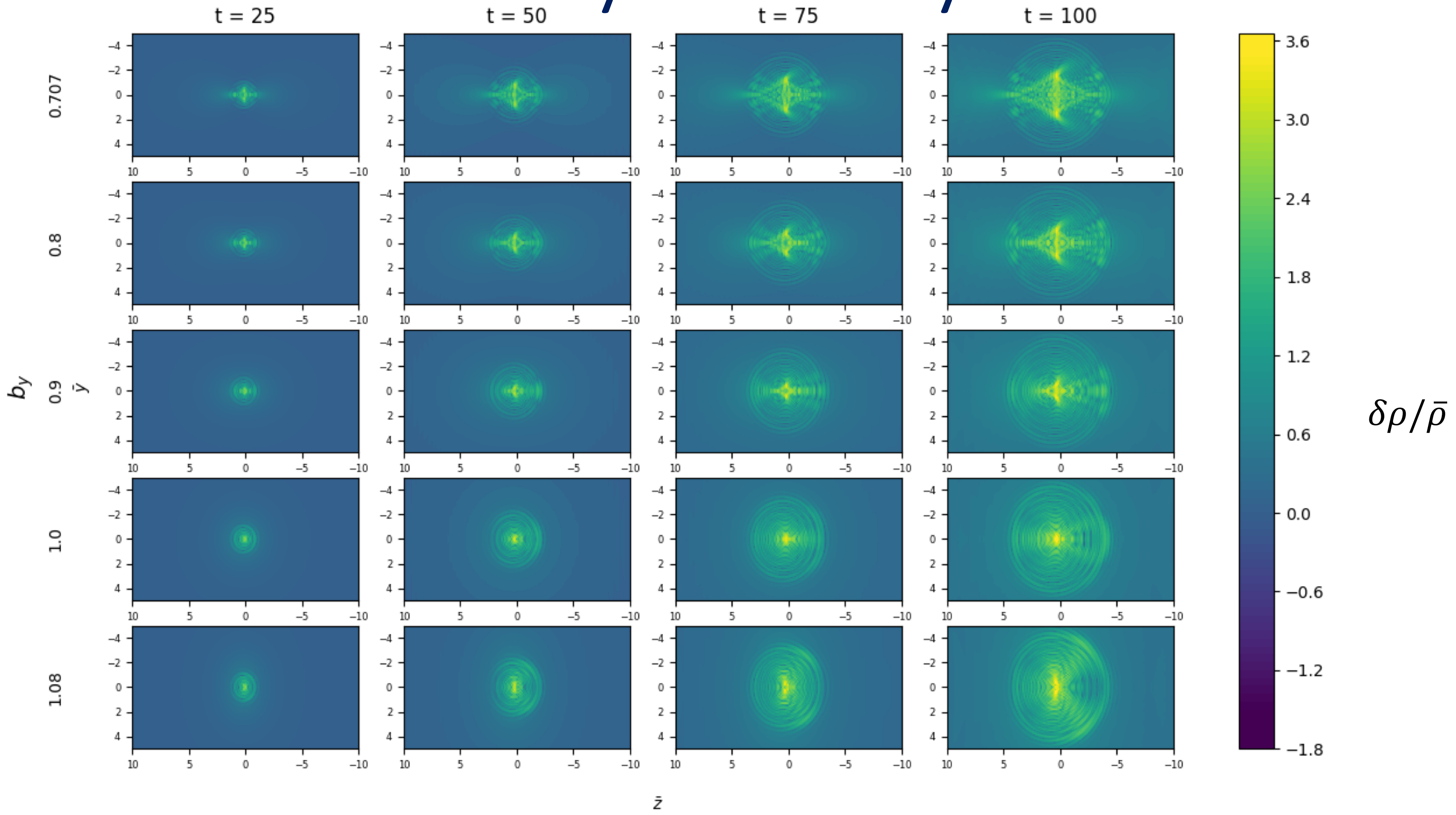
$M_Q = 0.1, \mathrm{b_z} = 0.8$, Logarthmic – (prolate)

Video3

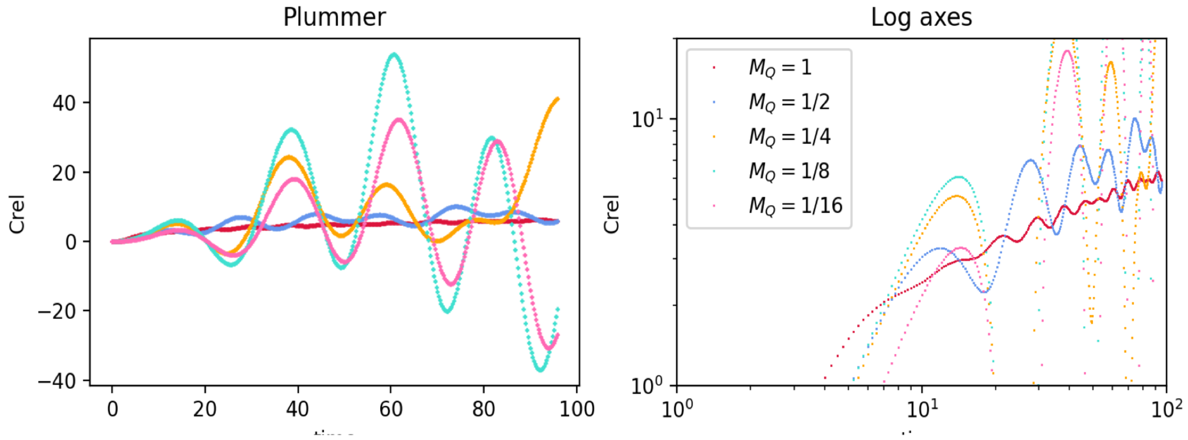
Logarithmic: motion parallel to axis of symmetry

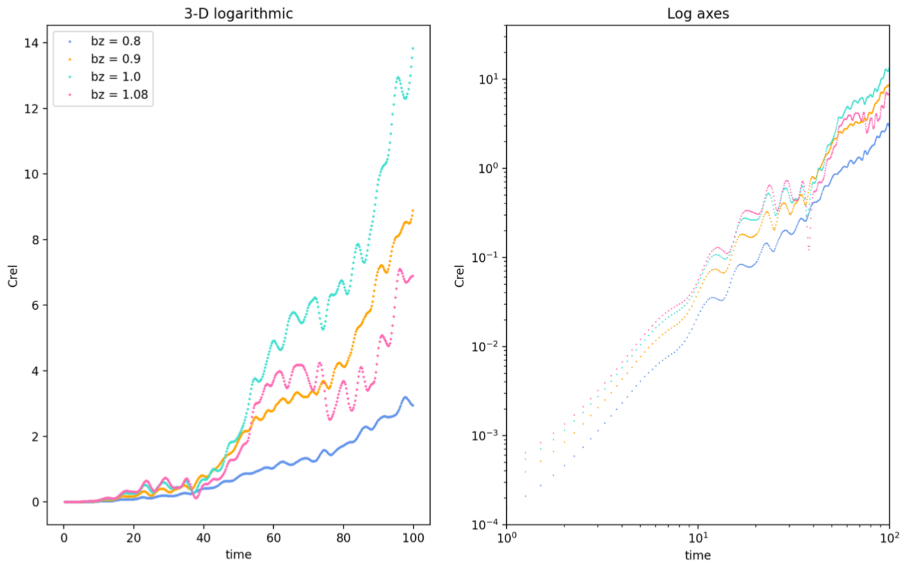


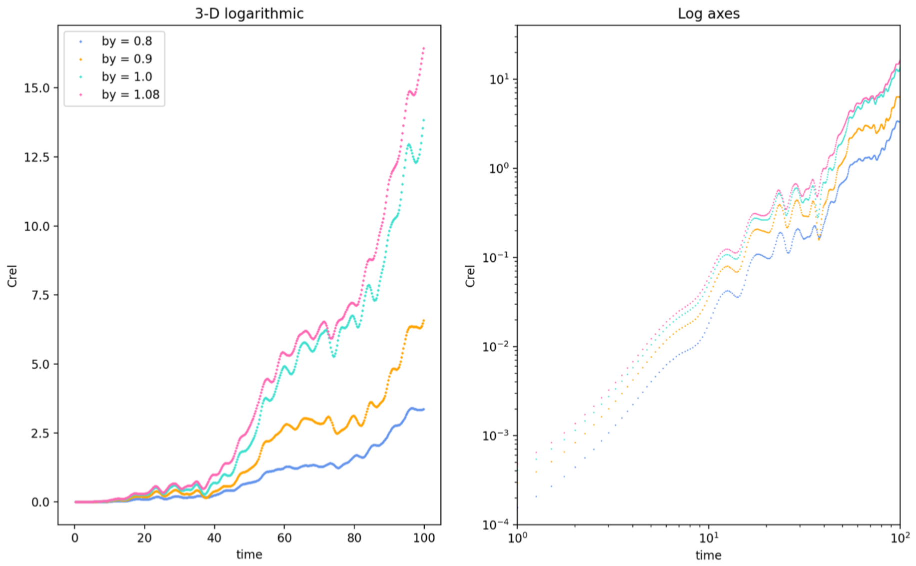
Logarithmic: motion normal to axis of symmetry



Dynamical Friction Coefficient







Implications

The dynamical friction characteristic time is given by the expression:

$$\tau_{DF} = \frac{v_{\rm rel}^3}{4\pi\bar{\rho}G^2 M C_{\rm rel}} \sim t_H$$

Name	Type	M ($10^9 M_\odot$)	u ($km\ s^{-1}$)	M_Q
NGC 2217	SBa	≥ 140	1622	≤ 0.05
NGC 1512	SB(r)ab	200	833	0.02
M95	SBb	50	778	0.07
M109	SBb	200	1046	0.02
NGC 3953	SBbc	14	1052	0.33
M58	SBc	300	1517	0.02
M108	SBcd	125	697	0.02
NGC 2903	SBd	49	556	0.05
NGC 55	SBm	46	129	0.01
NGC 1300	SBm	65	1573	0.11

For $v_{rel} \sim 10^3$km/s, $\bar{\rho} \sim 10^6 M_\odot\ \mathrm{kpc}^{-3}$, $\mathrm{M} \sim 10^{11} M_\odot$ $\mathrm{C_{rel}} \sim 10$

Conclusions

- Dynamical friction due to FDM has distinct characteristics affecting both the moving satellite and the FDM condensate itself.
- The impact of FDM may change by a factor of a few – up to one order of magnitude- depending on the geometry of the source, even if the other characteristics are the same.
- Identical systems moving parallel or normal to their symmetry axis experience different dynamical frictions.
- Dynamical friction can become a gravitational slingshot for appropriate combinations of masses and velocities – net effect is decelerating, though.
- Creation of complex structures: waves, vortices.
- Future prospects:
  - More realistic calculation: self-consistent treatment of the deformation of the potential of the satellite.
  - Use more non-uniform FDM environments.
  - Consider larger samples of satellites and provide timescales.

Thank you!