strong. niels bohr institute

KØBENHAVNS UNIVERSITET

Danmarks Grundforskningsfond Danish National Research Foundation

VILLUM FONDEN

erc European Research Council Established by the European Commission

ETERNAL BINARIES

PRD 107 (2023)12 arXiv:2304.02039

26th Capra meeting @ Copenhagen

JAIME REDONDO-YUSTE

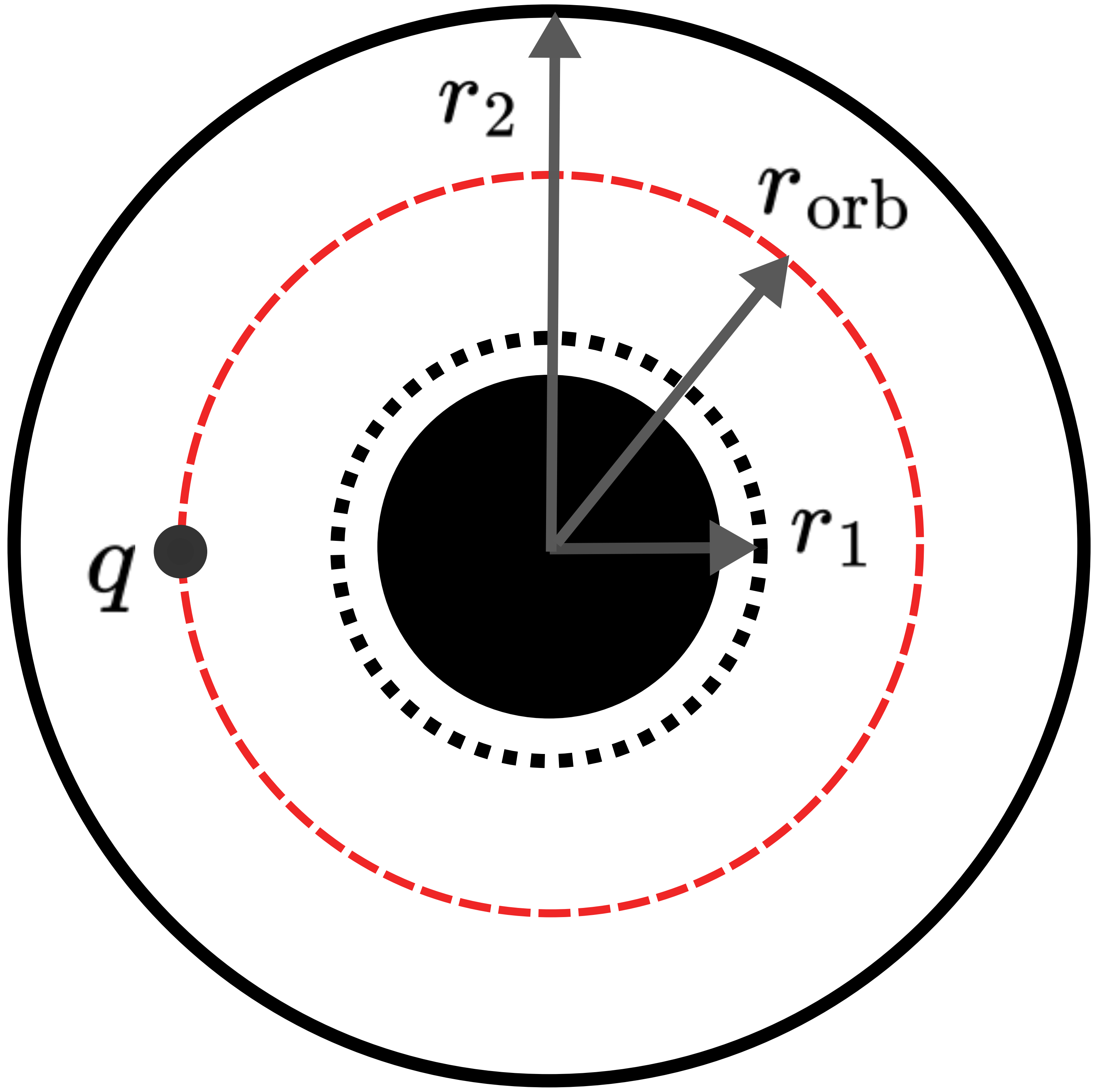
In collaboration with

V. Cardoso

C. Macedo

M. van de Meent

(Scalar) EMRI IN A BOX



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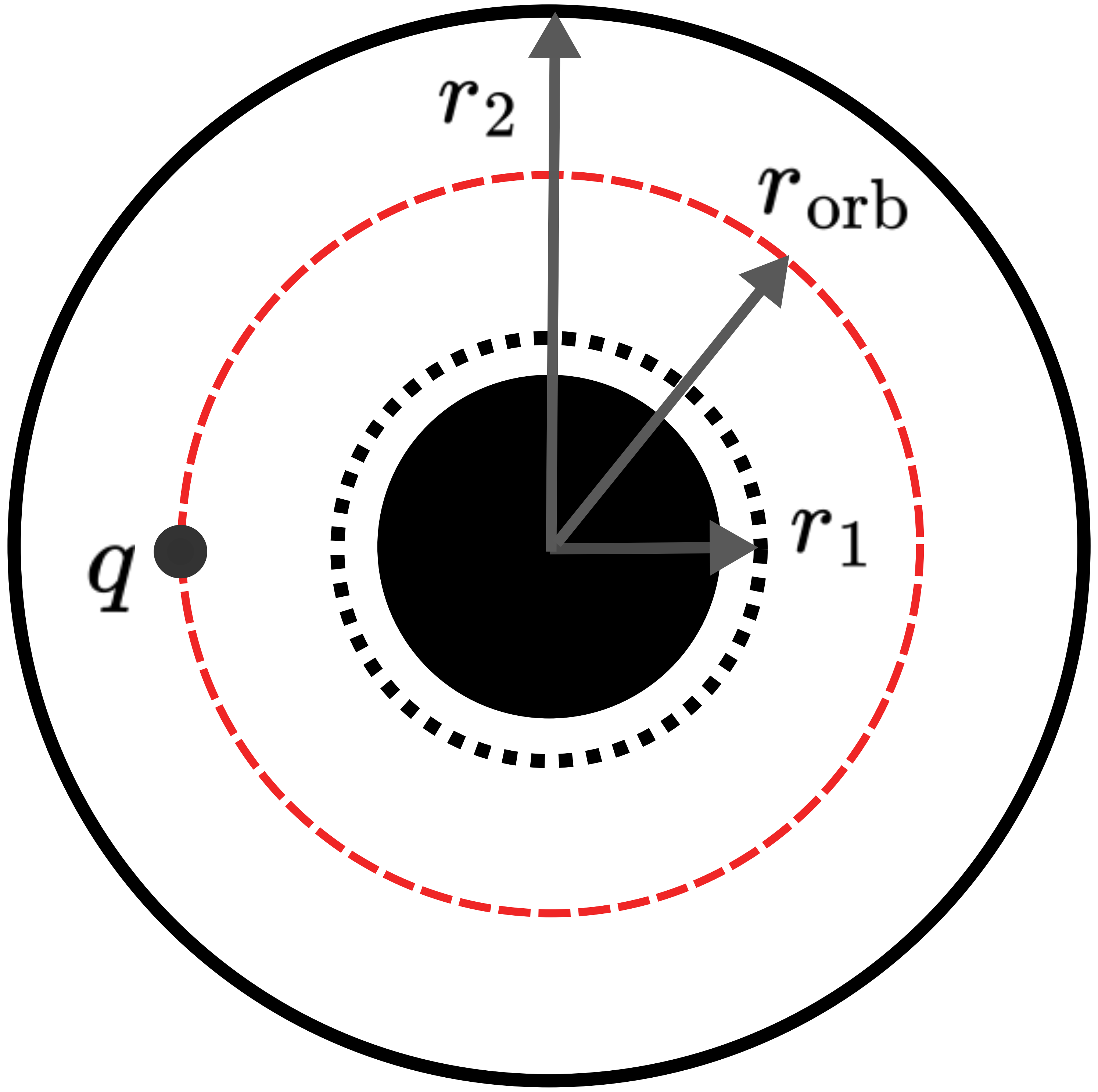

? Dynamics governed by the conservative self-force

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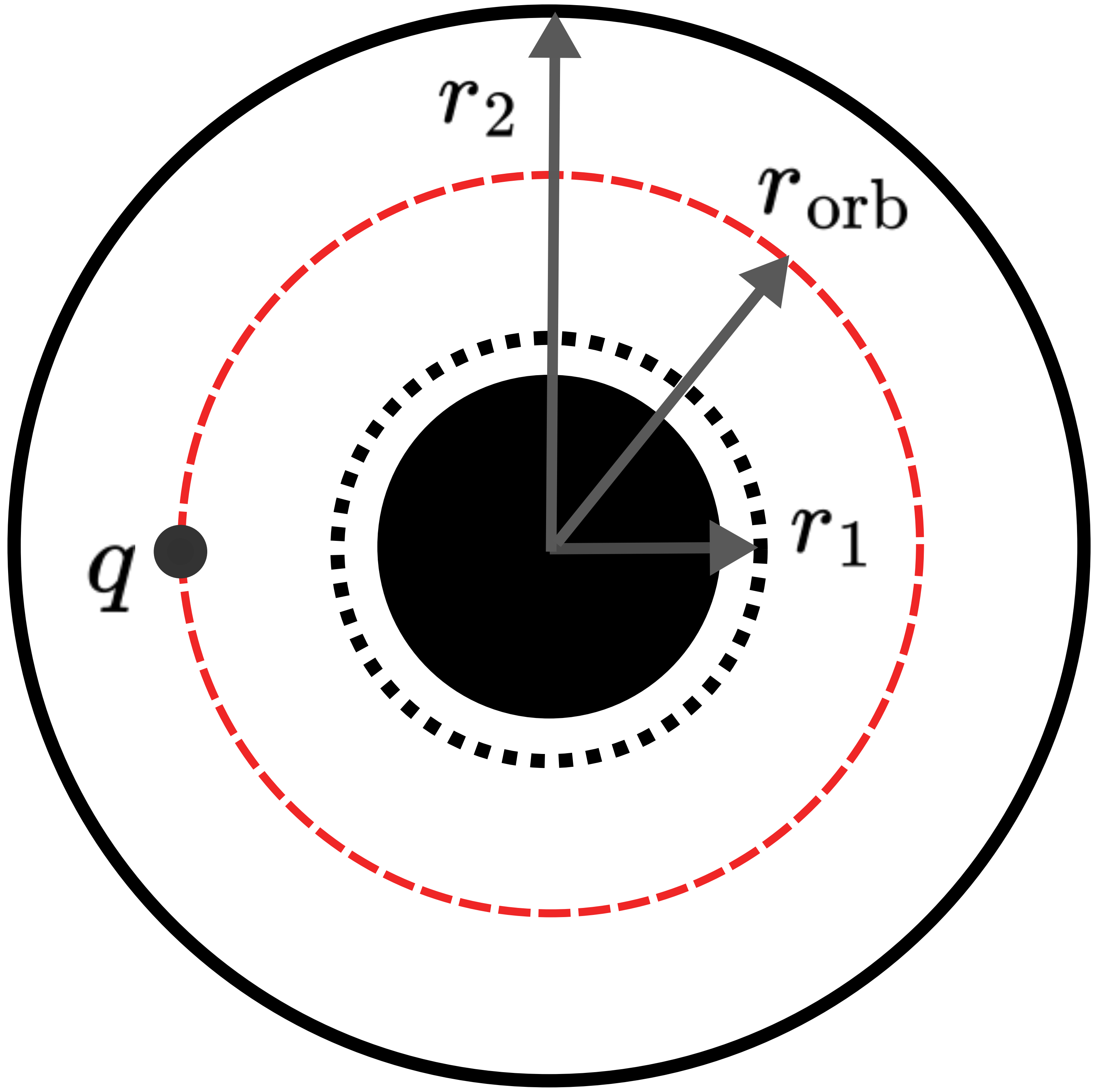

❓ Dynamics governed by the conservative self-force

❓ No dissipation: are the orbits eternal?

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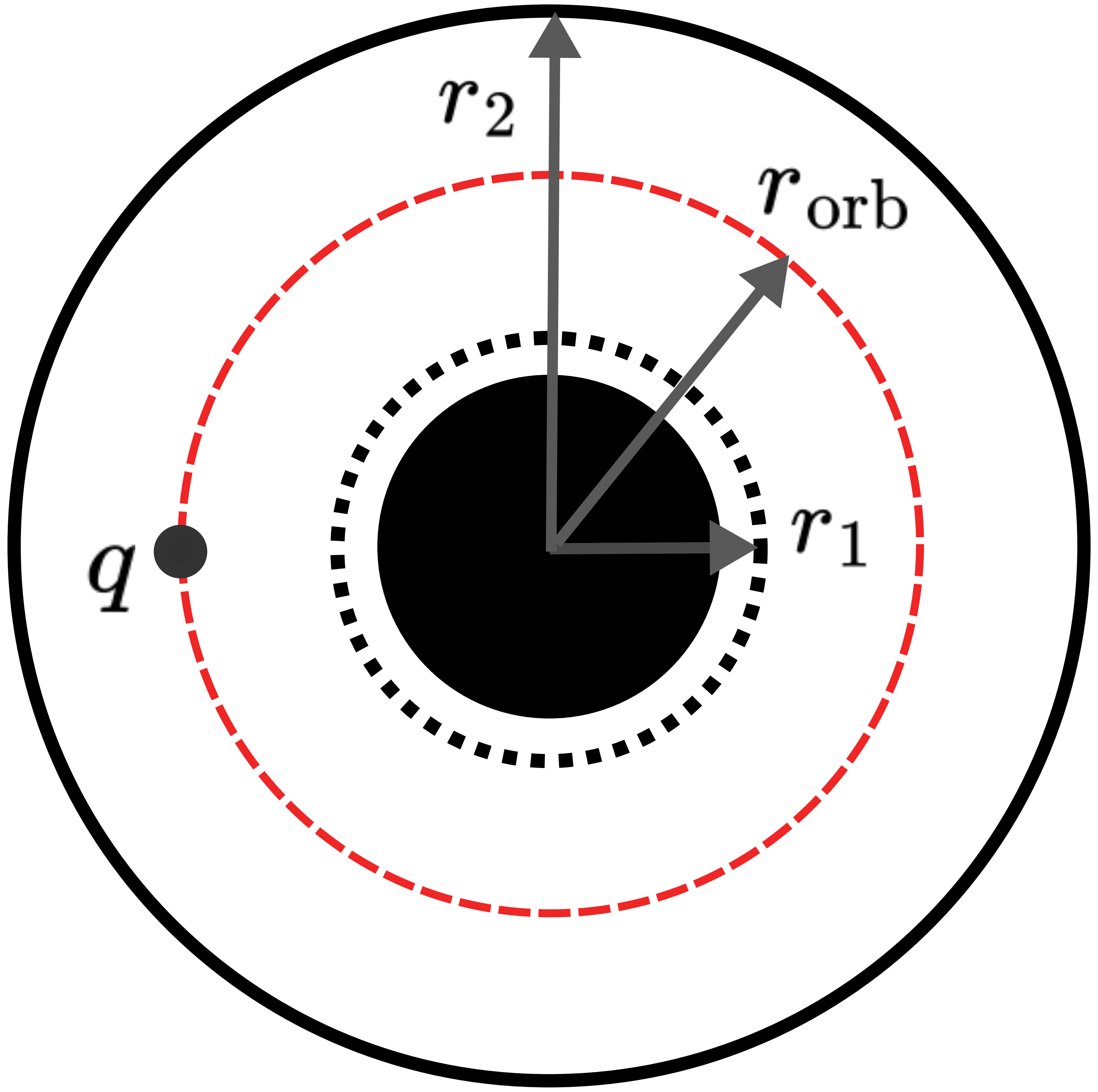

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? No dissipation: are the orbits eternal?

? Normal mode frequencies are real: what happens when $\omega_{\ell mn} = m\Omega$?

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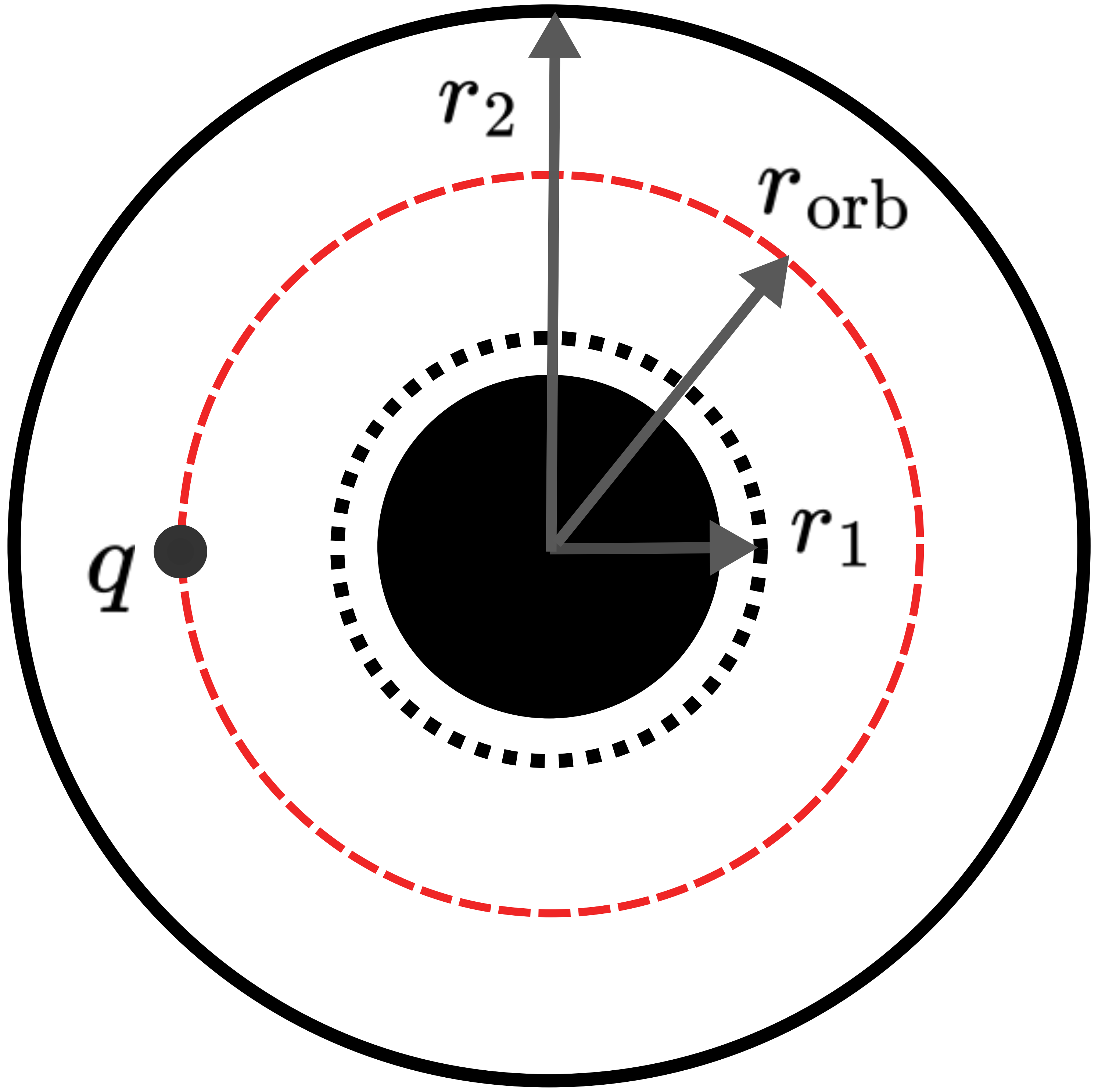

Dynamics governed by the conservative self-force

No dissipation: are the orbits eternal?

Normal mode frequencies are real: what happens when $\omega_{\ell mn} = m\Omega$?

Initial data does not leave the system

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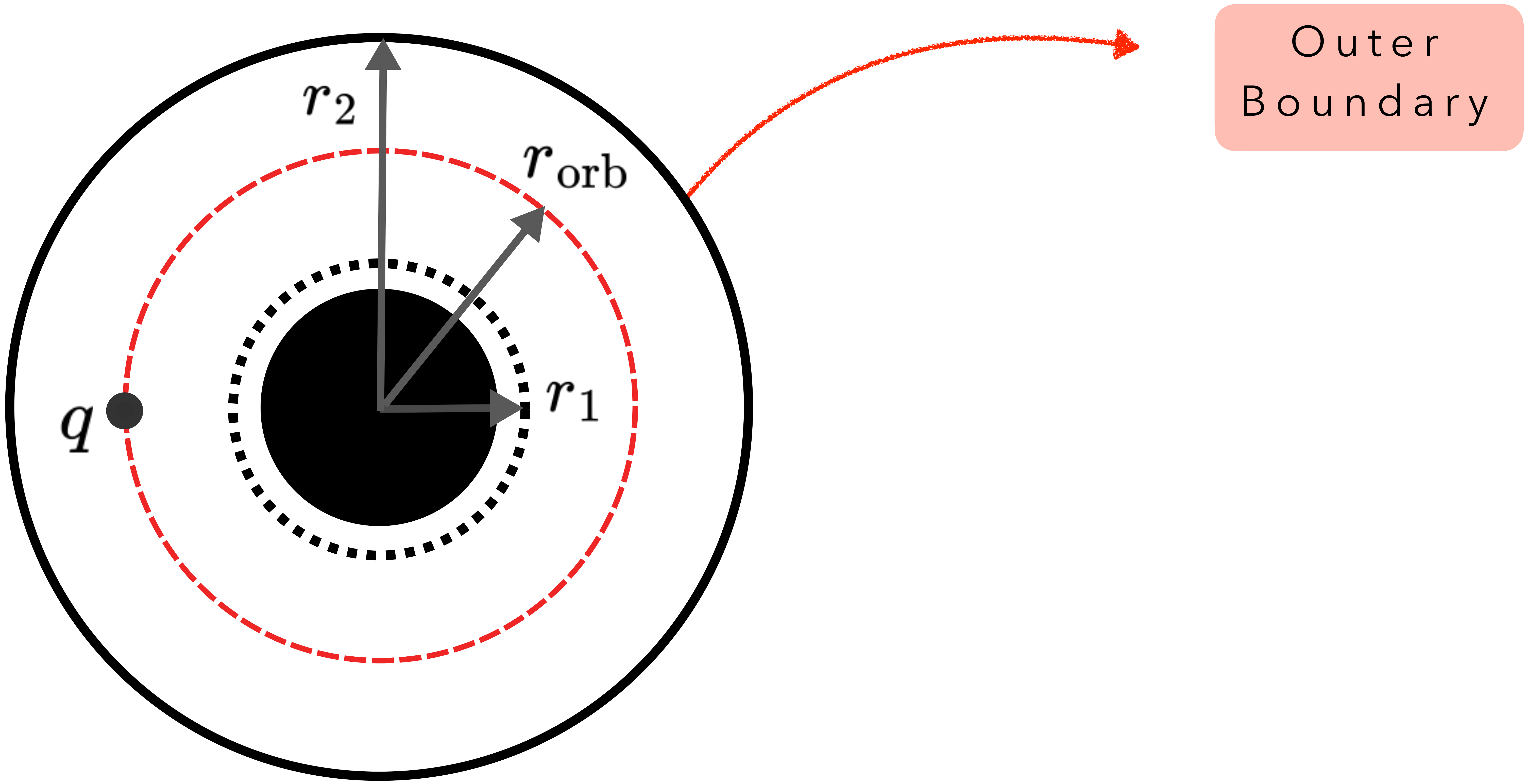

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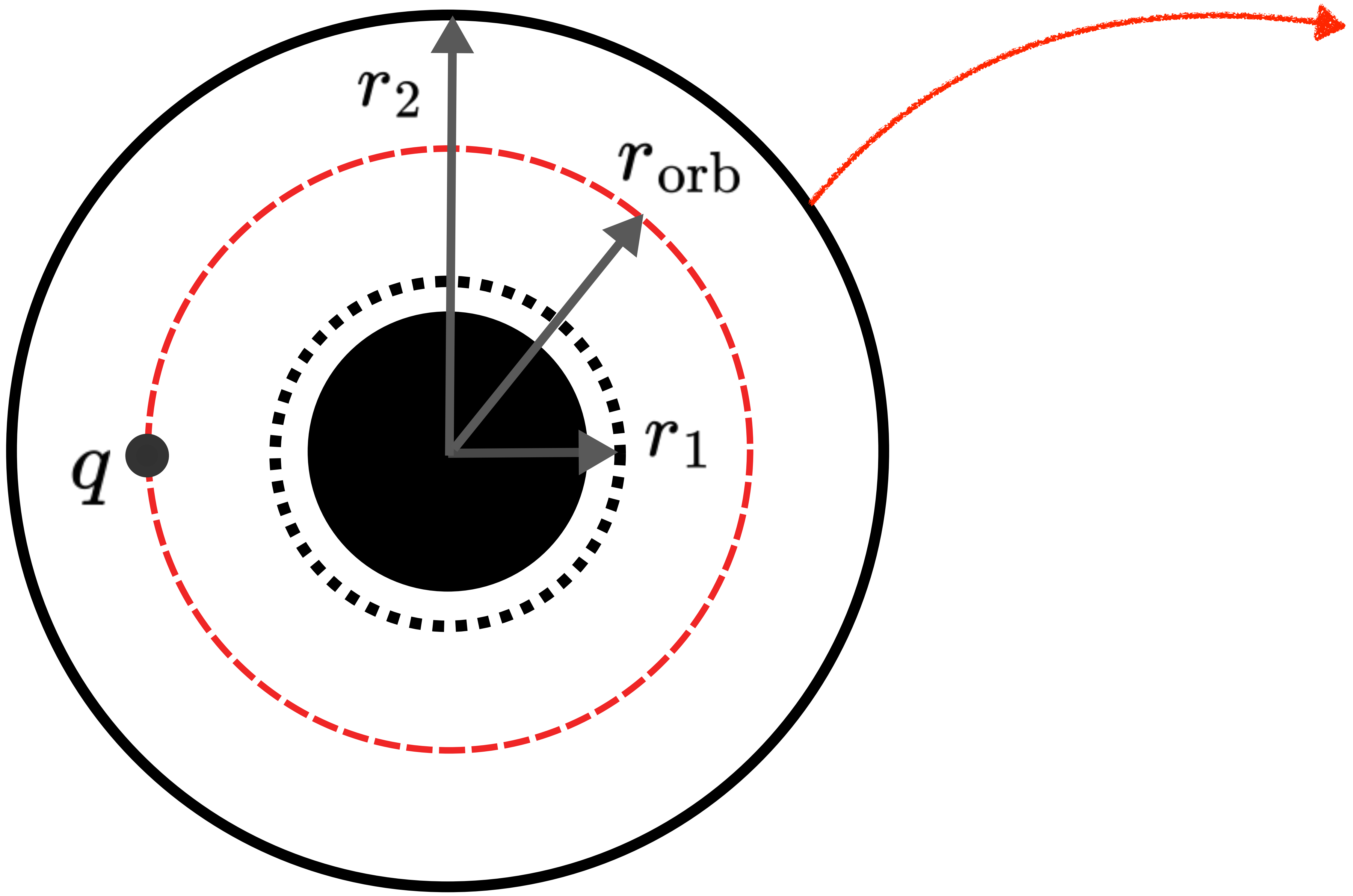

Outer Boundary

- AdS
- Fuzzy Dark Matter

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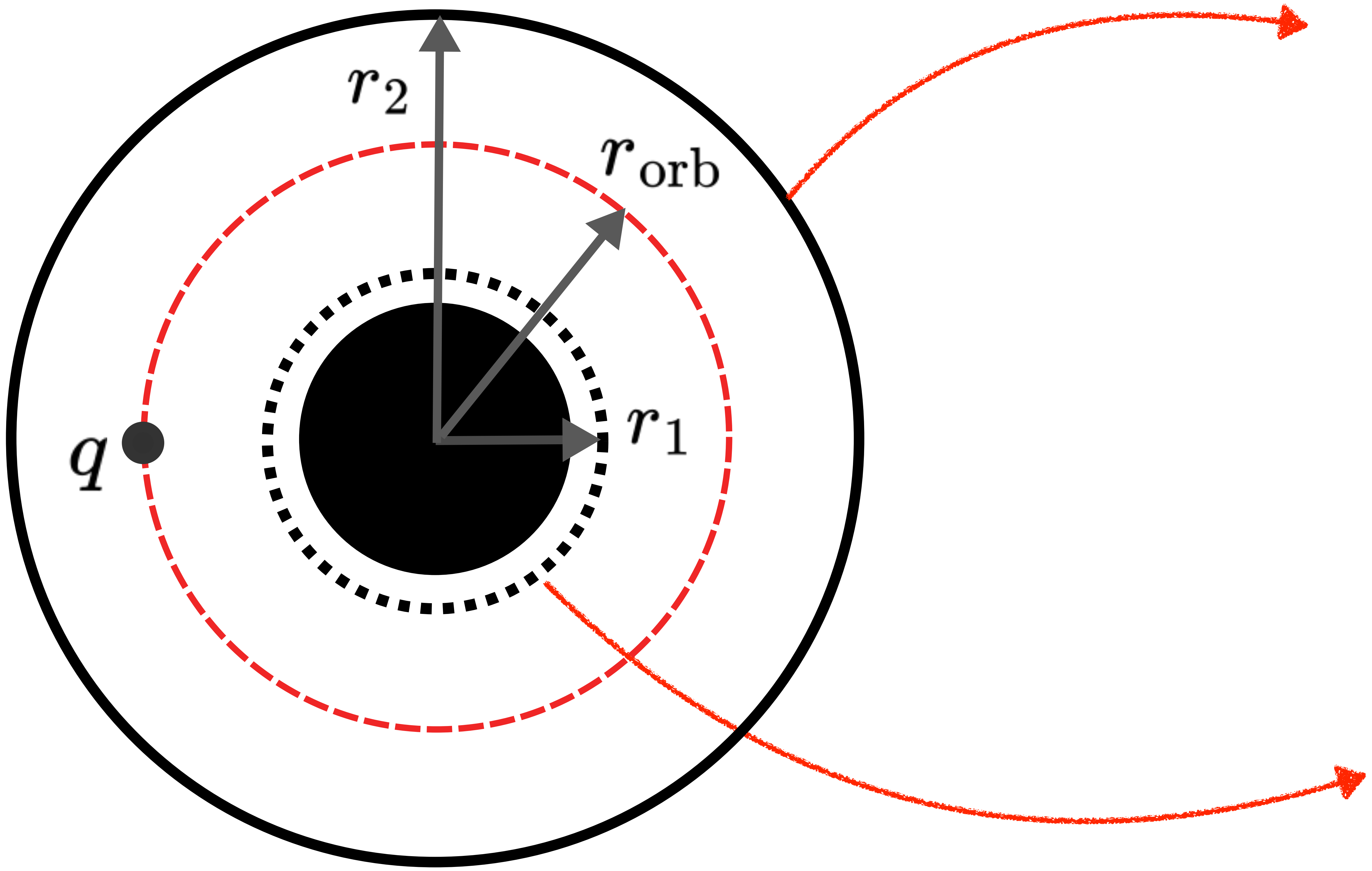

Outer Boundary

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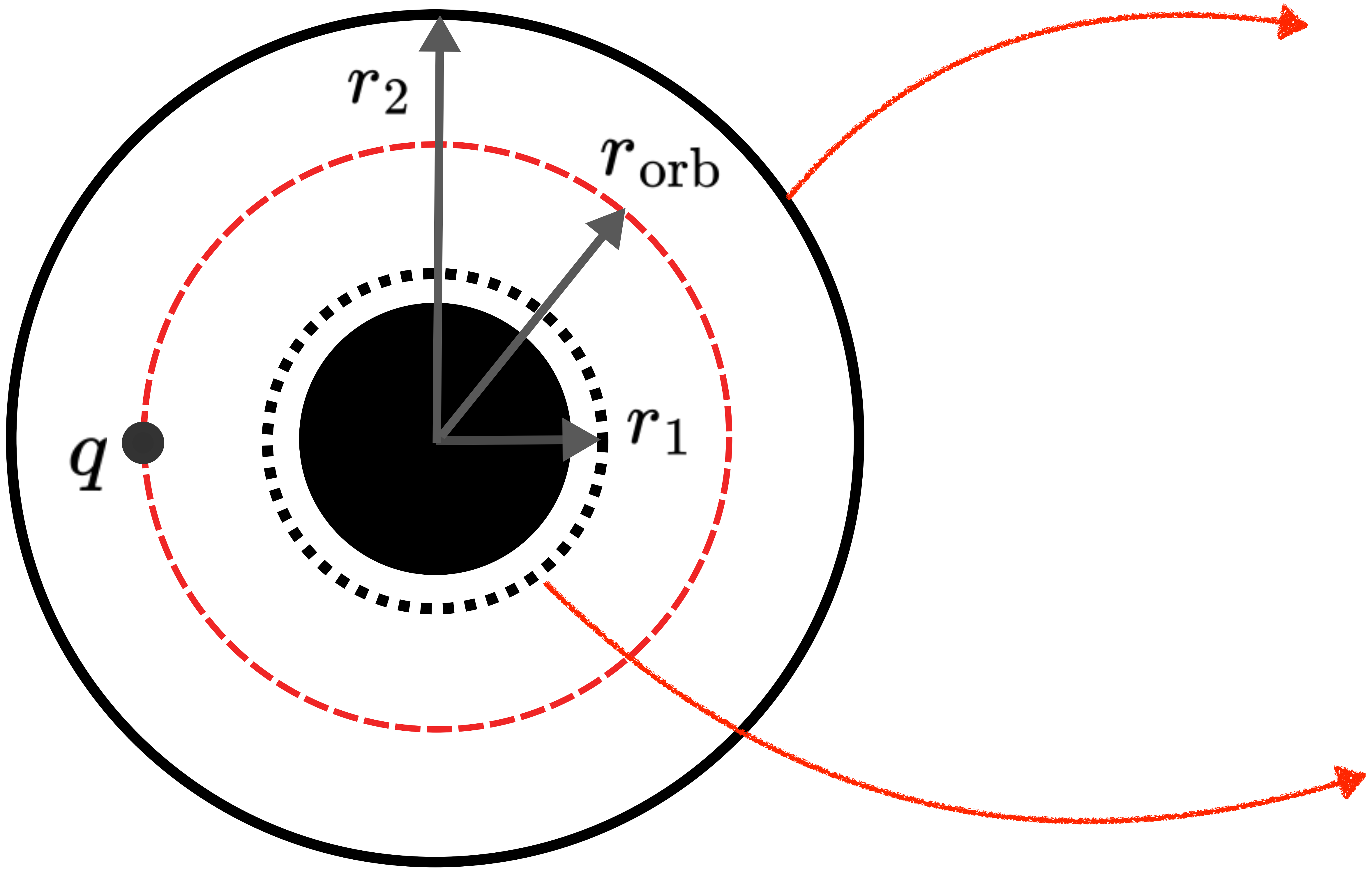
Inner Boundary

(Scalar) EMRI IN A BOX



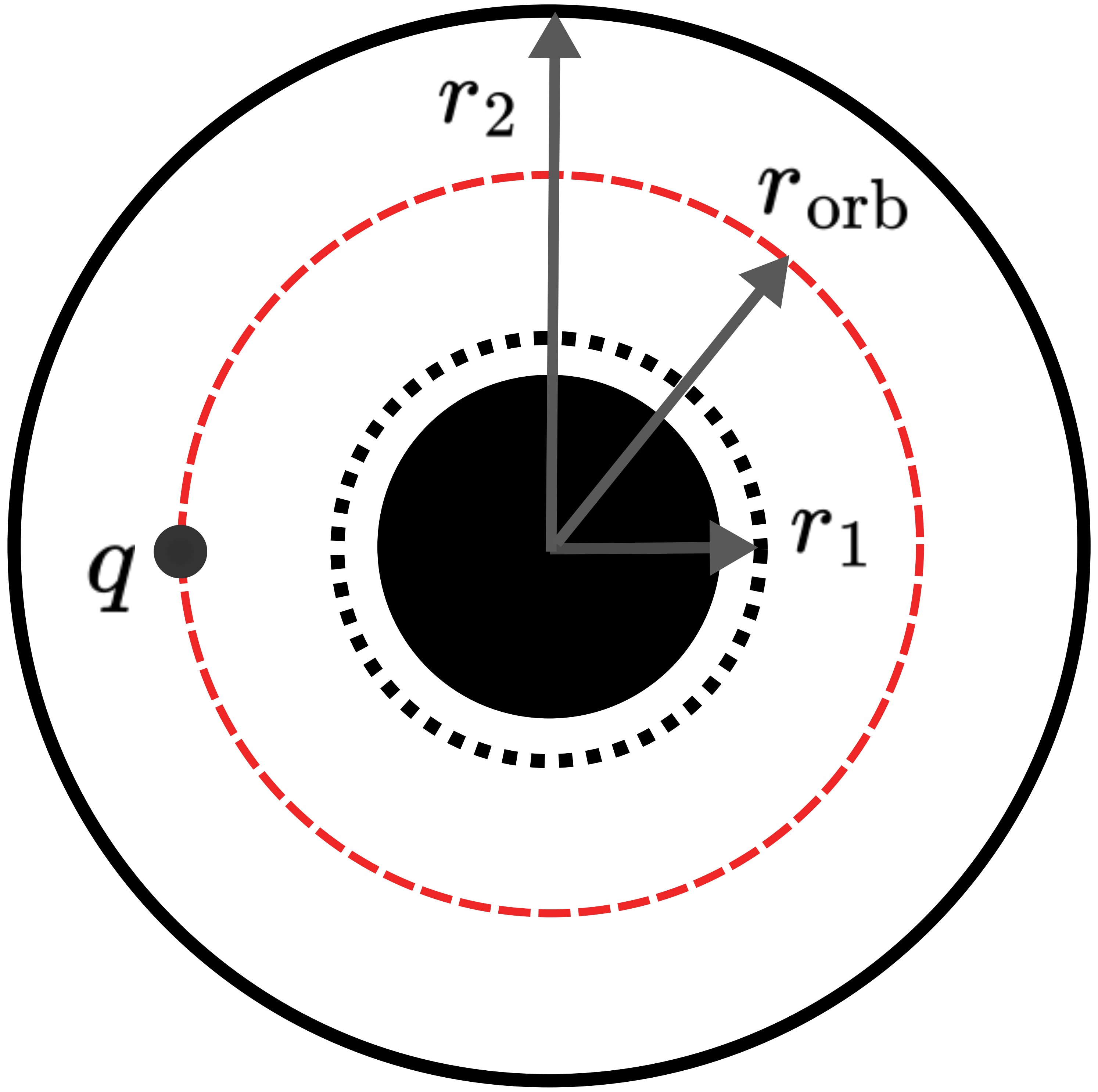
Outer Boundary

- AdS
- Fuzzy Dark Matter

Inner Boundary

- Compact stars
- Exotic compact objects

(Scalar) EMRI IN A BOX



EMRI → $m \ll M$

Charge → $q/m \ll 1$

Orbit → $r_{\rm orb} \in [r_{\rm ISCO}, r_2]$

Cavity → $R = r_2 - r_1$

RESULTS

✓ Dissipative scalar self-force vanishes*

* Depends on the initial conditions!

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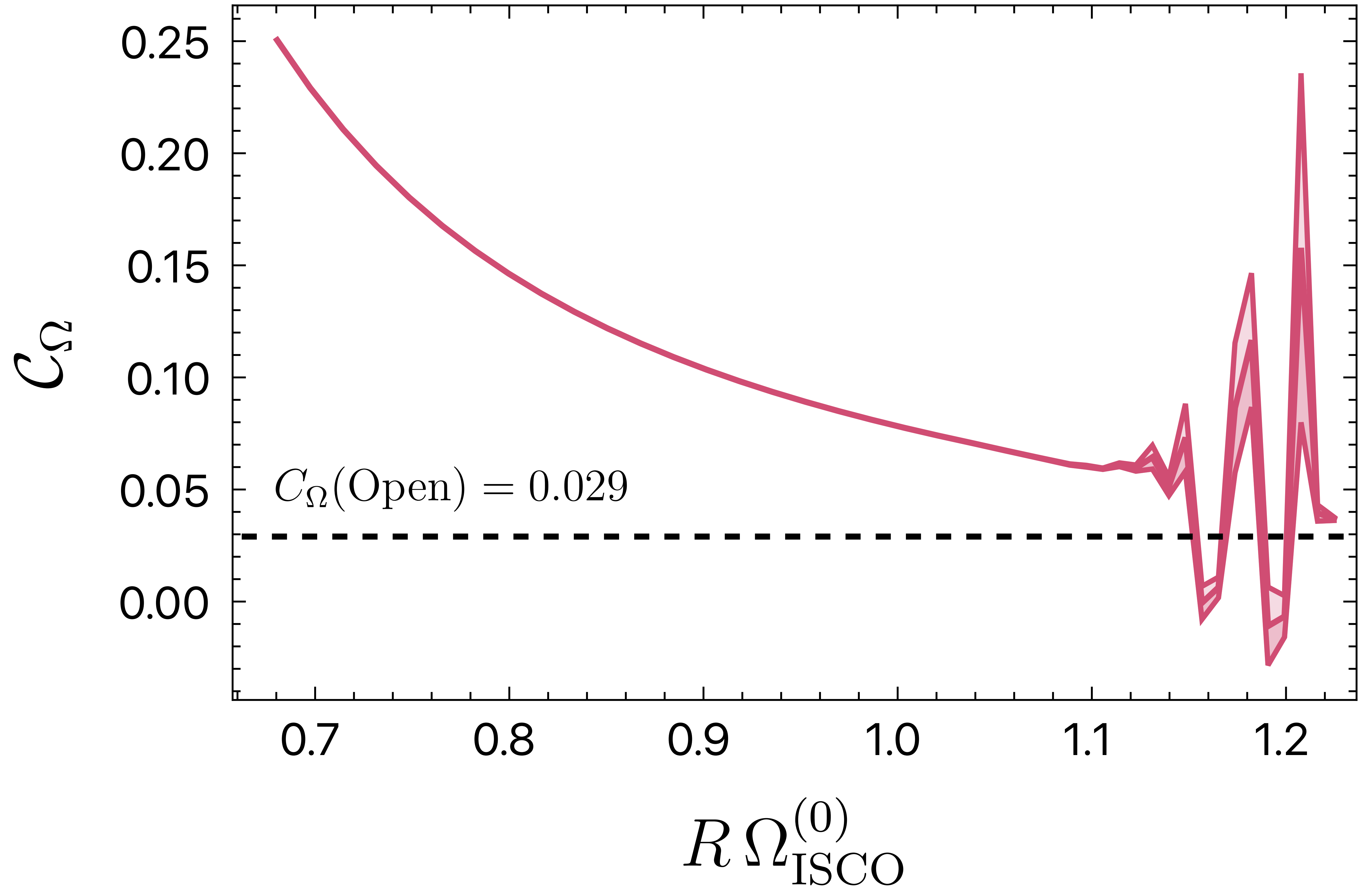


RESULTS

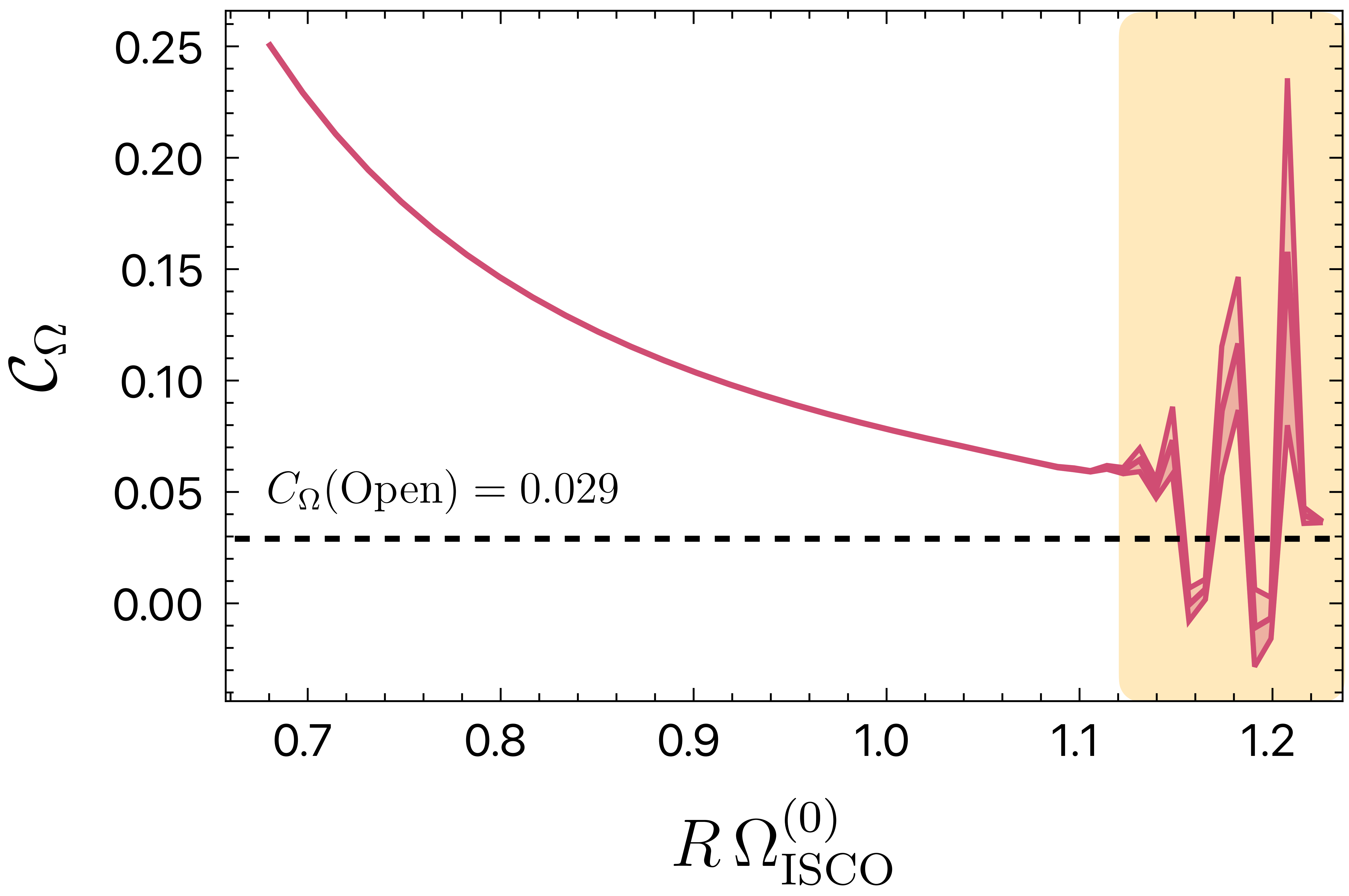
- Dissipative scalar self-force vanishes*

  * Depends on the initial conditions!

- ISCO frequency shifts

- The system has resonances

  (Only if the cavity is large enough)



$$\mathcal{L}_\omega \phi = S_\omega^{\text{eff}} + \mathcal{I}_\omega$$

RESULTS

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$$\Phi = \sum_k \left(A_k e^{i\omega_k t} + B_k e^{i\Omega t} \right) \phi_k$$

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$$\langle f_\mu^{\mathrm{Diss}} \rangle \propto A_k$$

$$A_k = \phi_k^{\mathrm{I}} + \frac{\pi_k^{\mathrm{I}}}{i\omega_k} + \frac{S_k}{i(\omega_k - \Omega)}$$

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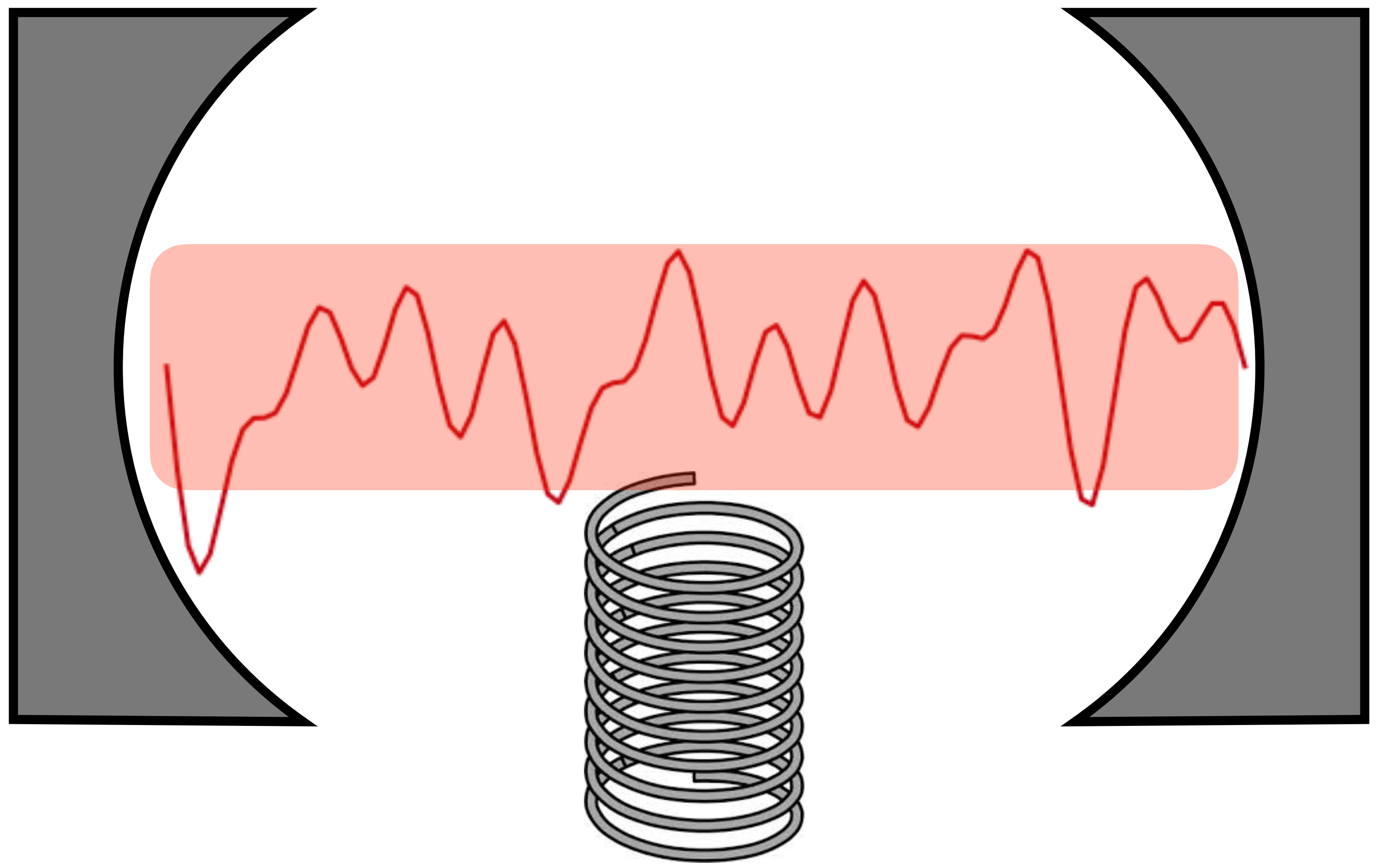
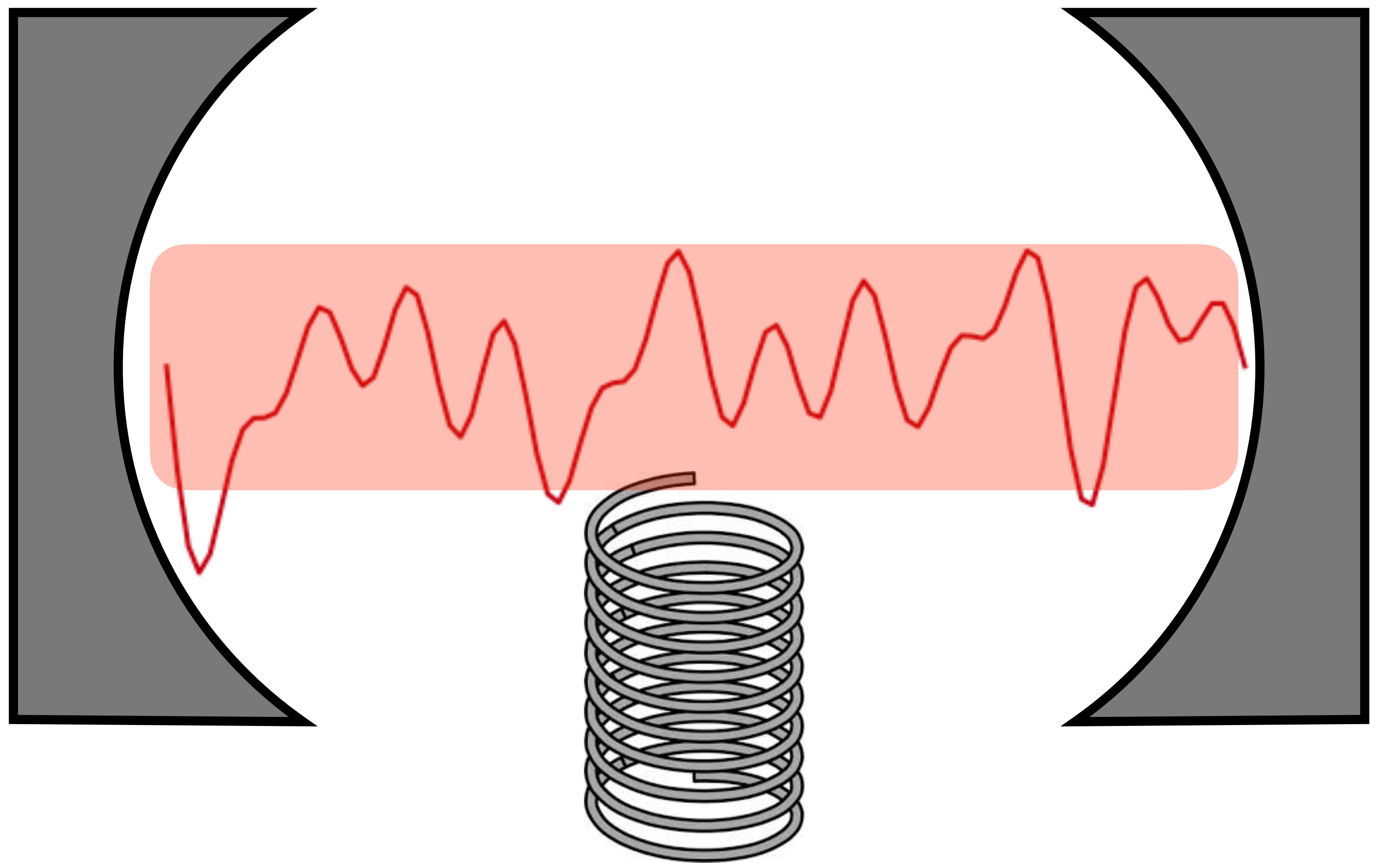
TIME EVOLUTION MATTERS



$$H = H_{\text{Cavity}}(\pi, \phi) + H_{\text{Osc}}(p, q) - \frac{\varepsilon}{L}\cos\left(\frac{q}{L}\right)\int_0^L dx\,\frac{\phi(x)S(x)}{L}$$

TIME EVOLUTION MATTERS



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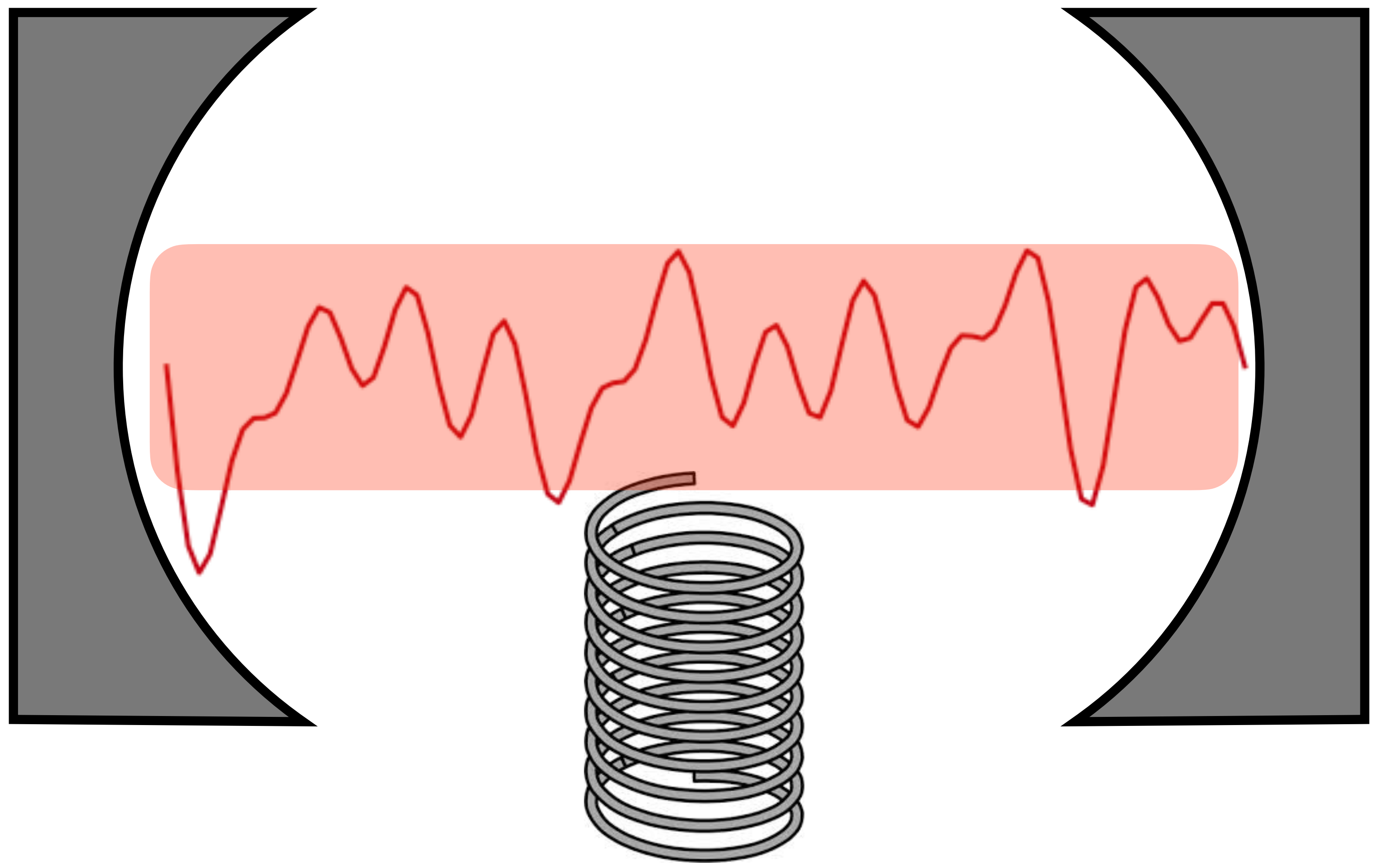
Near Identity Transformation

TIME EVOLUTION MATTERS



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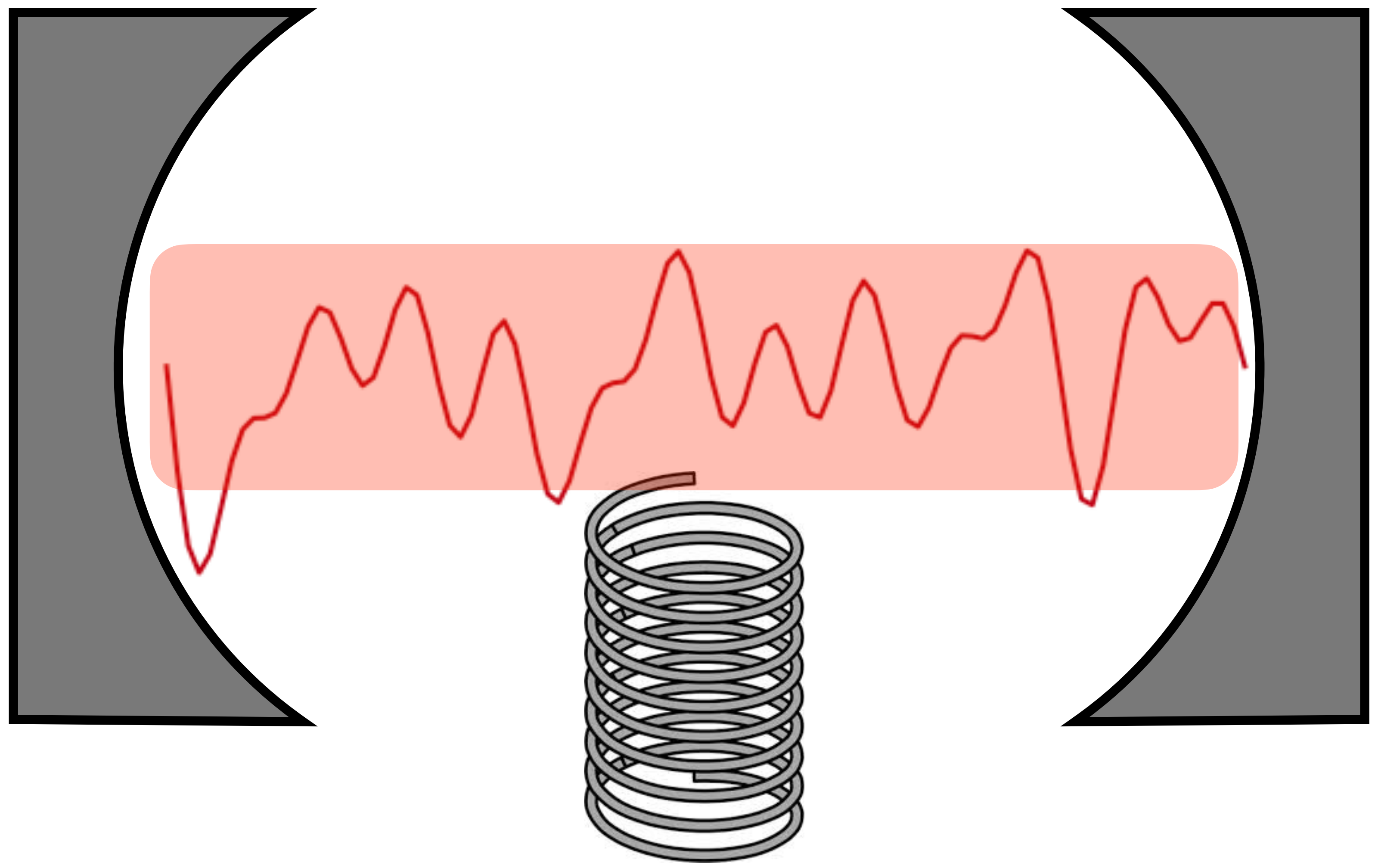
Near Identity Transformation

$$p \xrightarrow{t\to\infty} p_0 + \frac{\varepsilon}{\omega - p_0} F^{(1)}(\phi_0, \omega) + \varepsilon^2 F^{(2)}(\phi_0, \omega)$$

TIME EVOLUTION MATTERS



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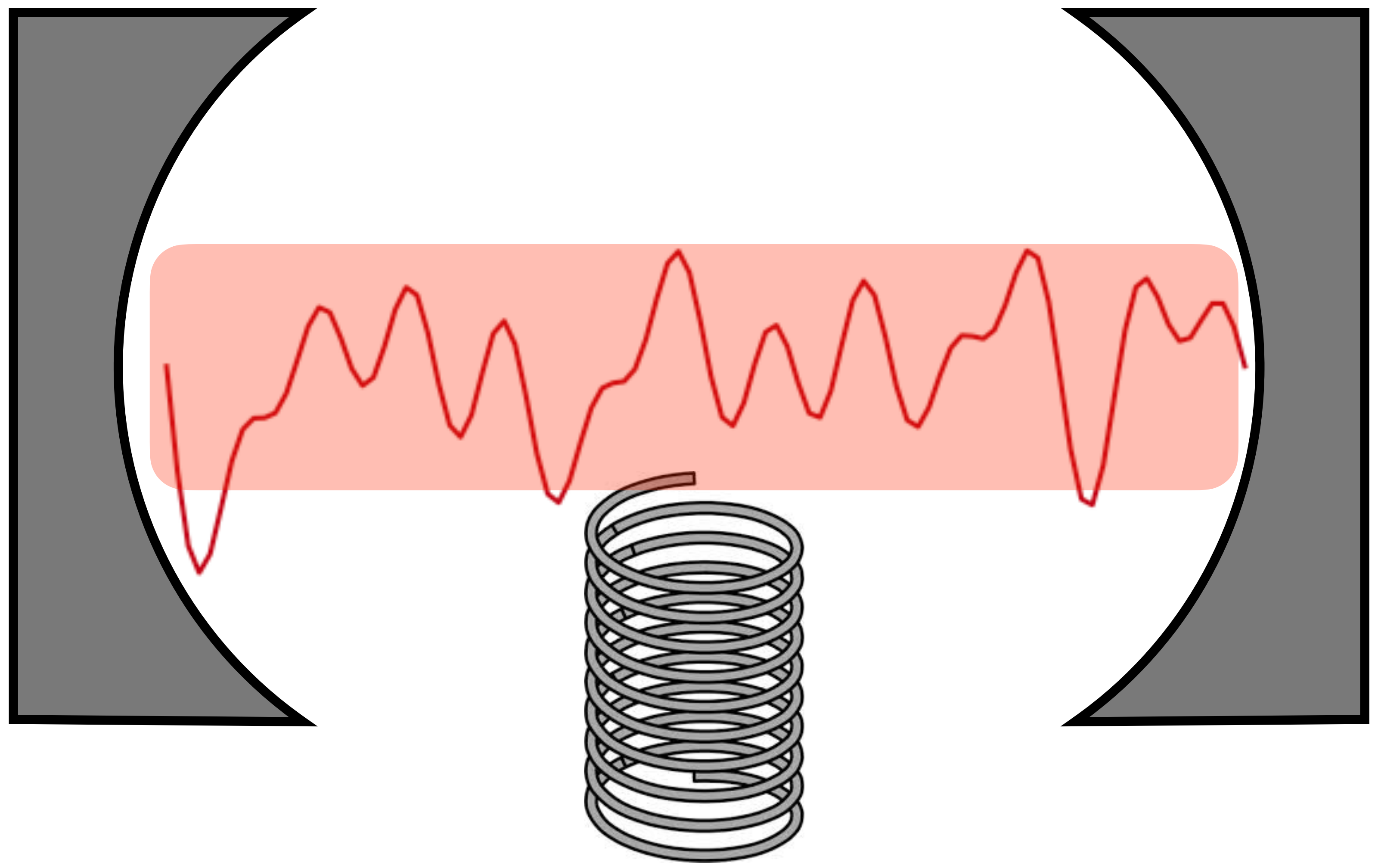
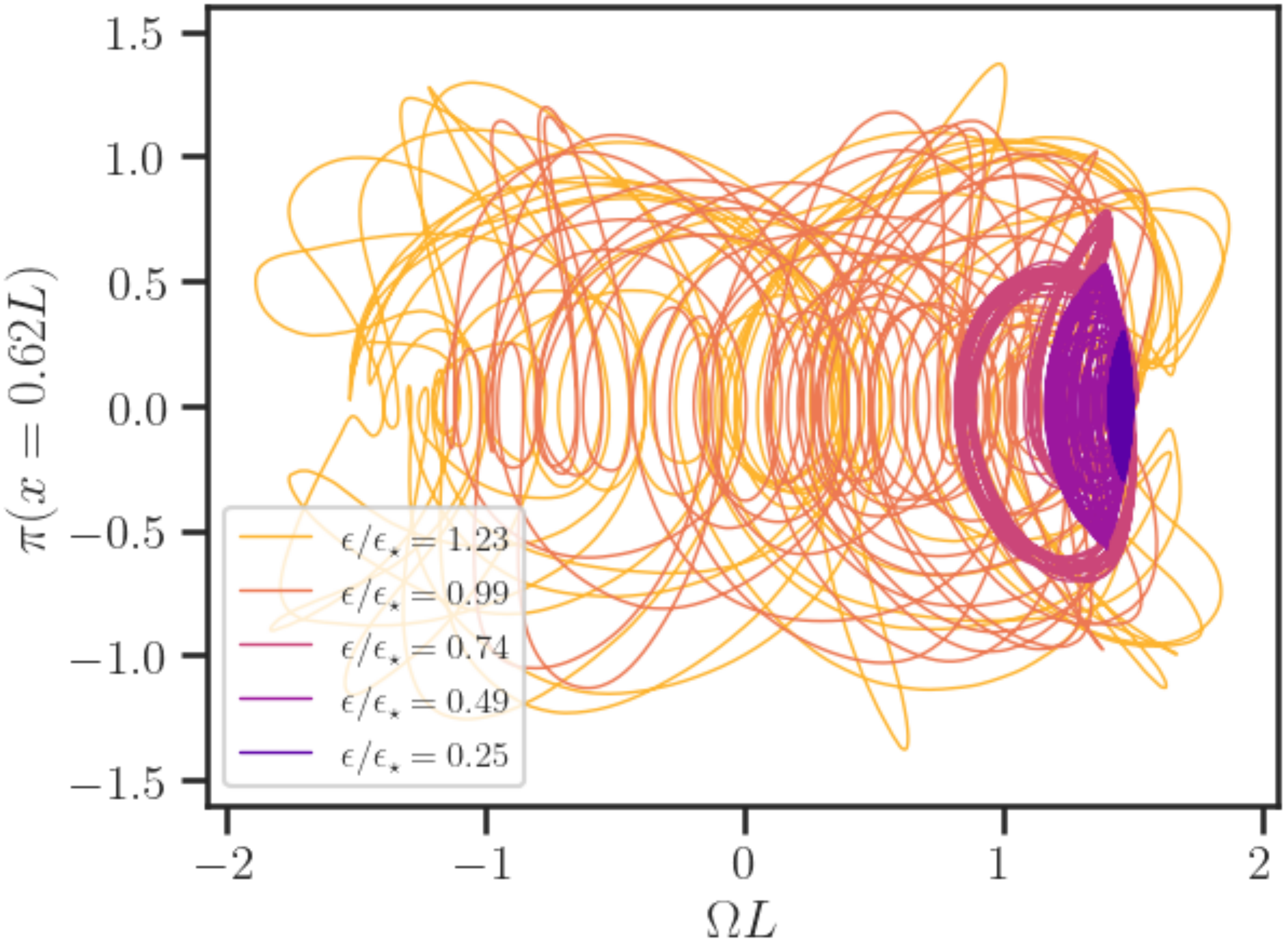
There exists ICs such that the drift vanishes up to second order!

TIME EVOLUTION MATTERS

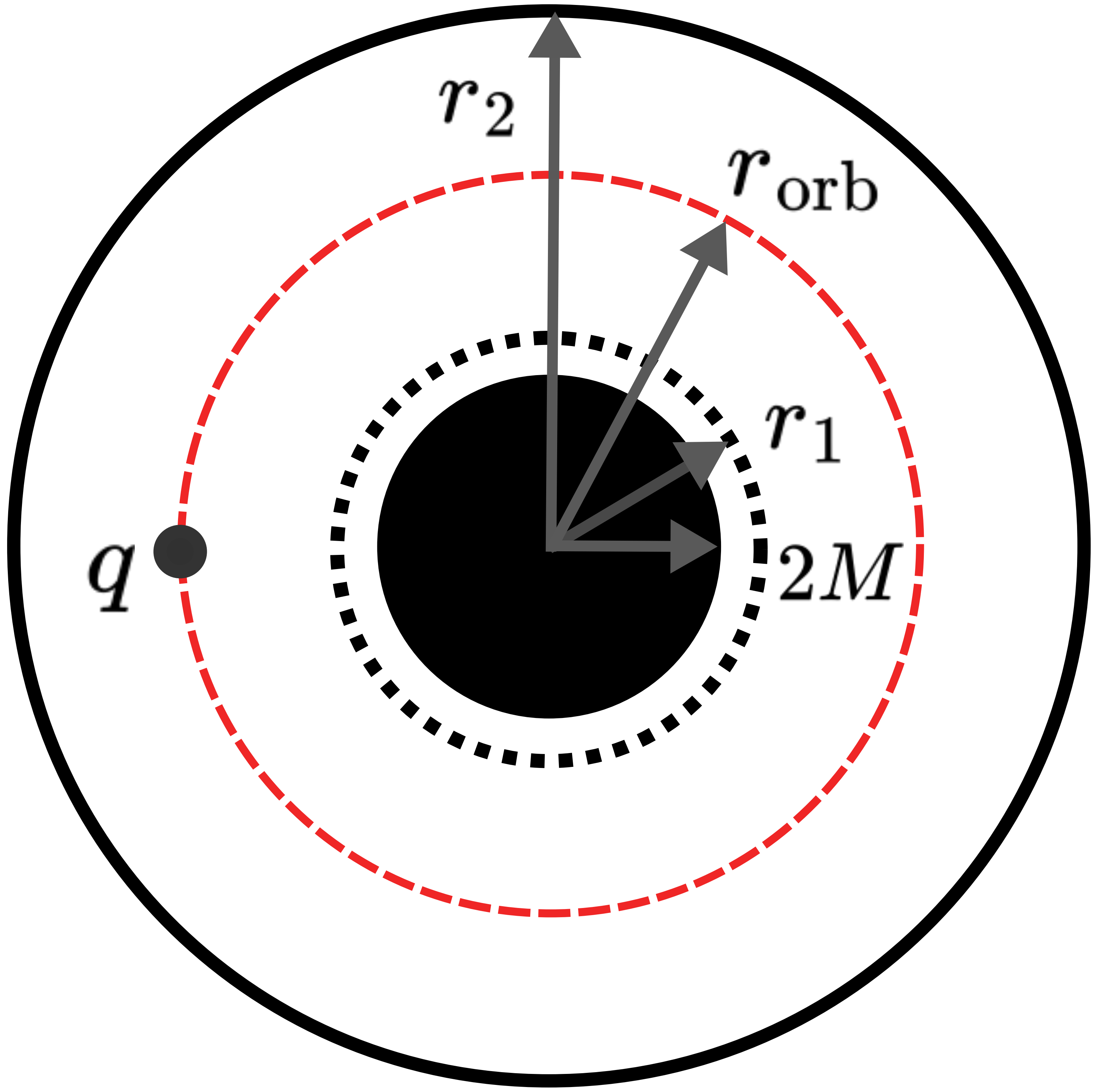




$$p \xrightarrow{t\to\infty} p_0 + \frac{\varepsilon}{\omega - p_0} F^{(1)}(\phi_0, \omega) + \varepsilon^2 F^{(2)}(\phi_0, \omega)$$

$$\epsilon_\star\,, \quad \text{s.t. } p - p_0 \sim |\omega_{n+1} - \omega_n|$$

POSSIBLE OUTCOMES



I. Eternal Orbit

II. Chaos

III. Merger

POSSIBLE OUTCOMES

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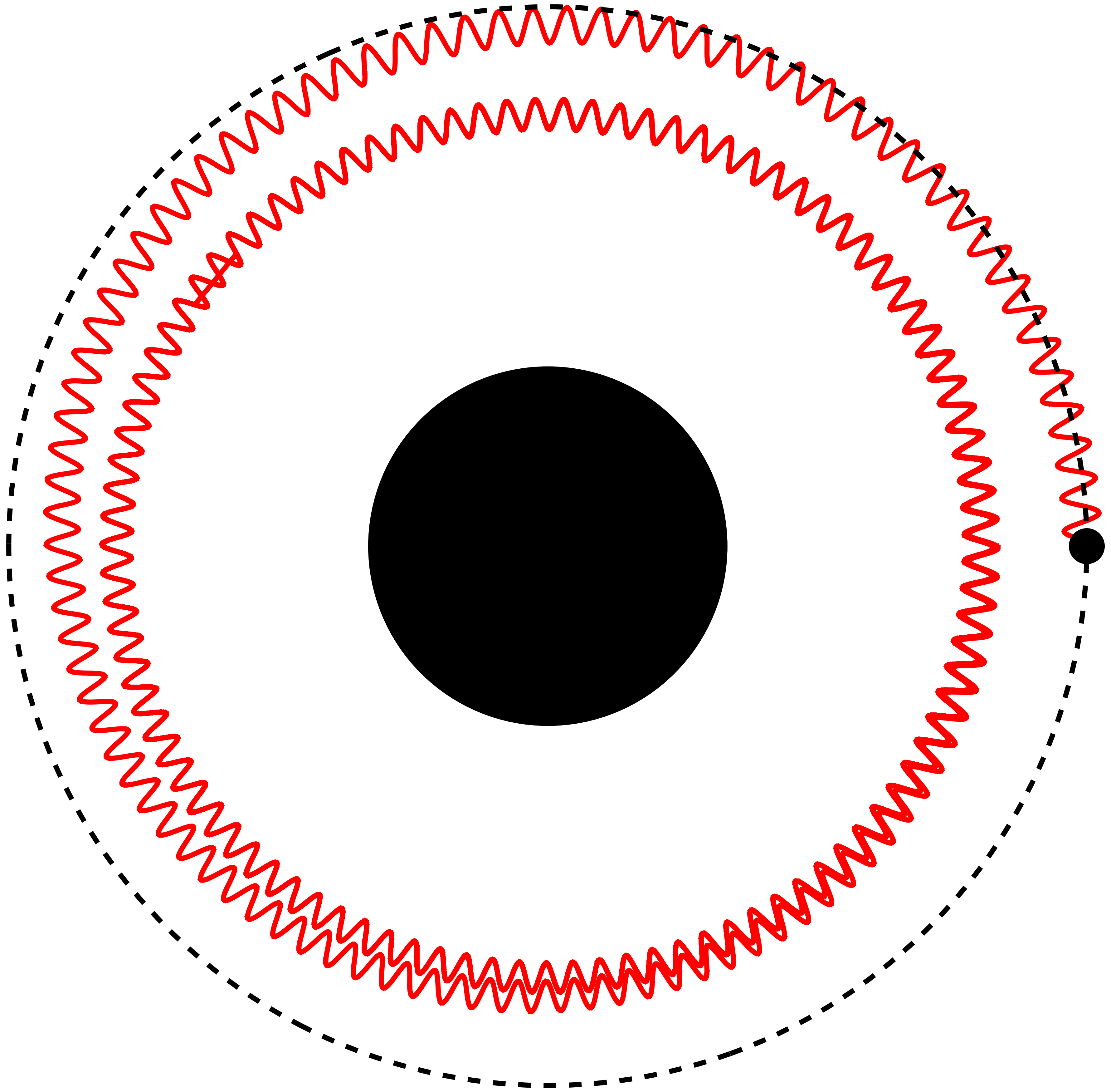
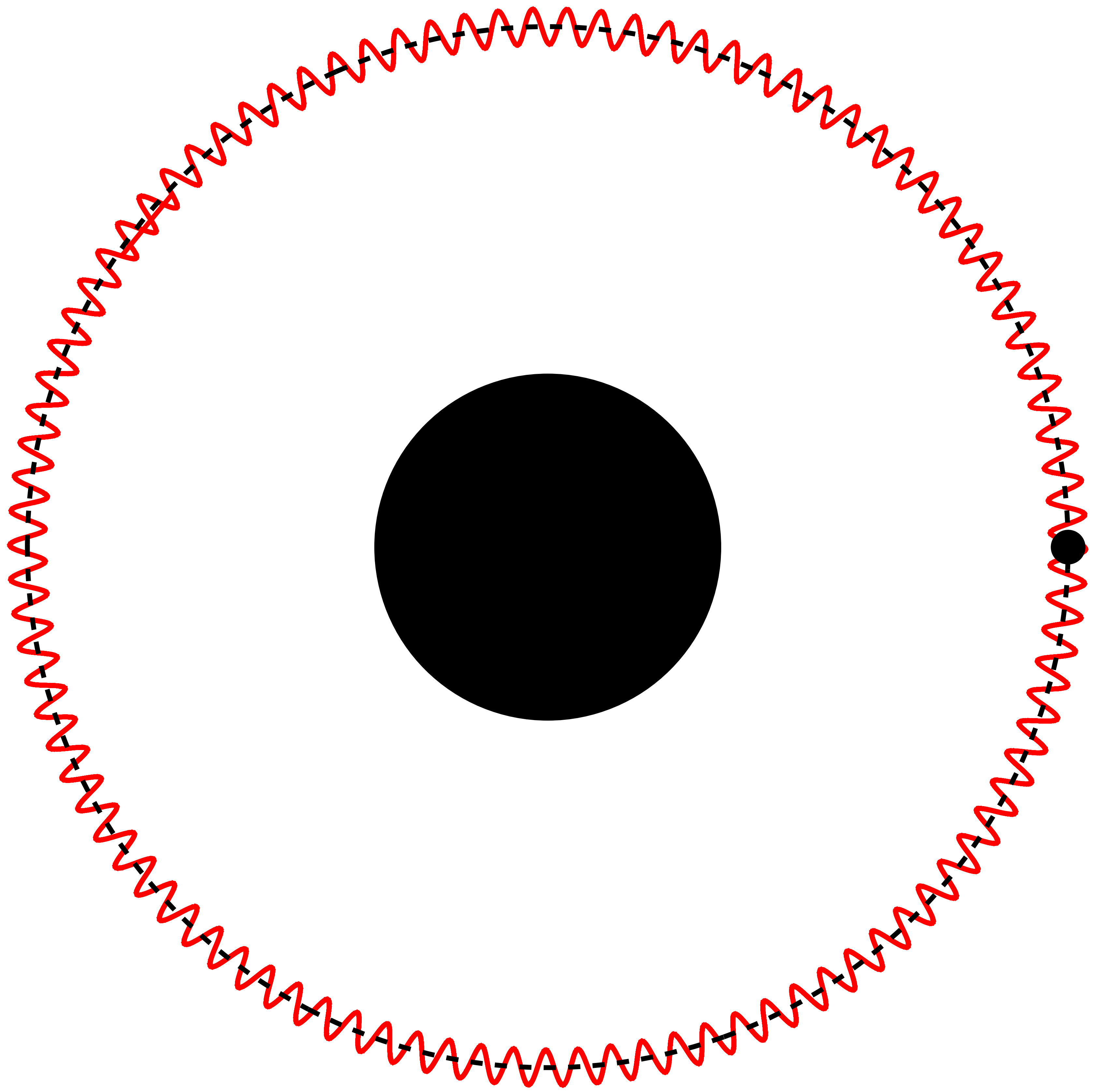


Fast dynamics
+ secular drift

POSSIBLE OUTCOMES

I. Eternal Orbit

\+ fine-tuned initial conditions

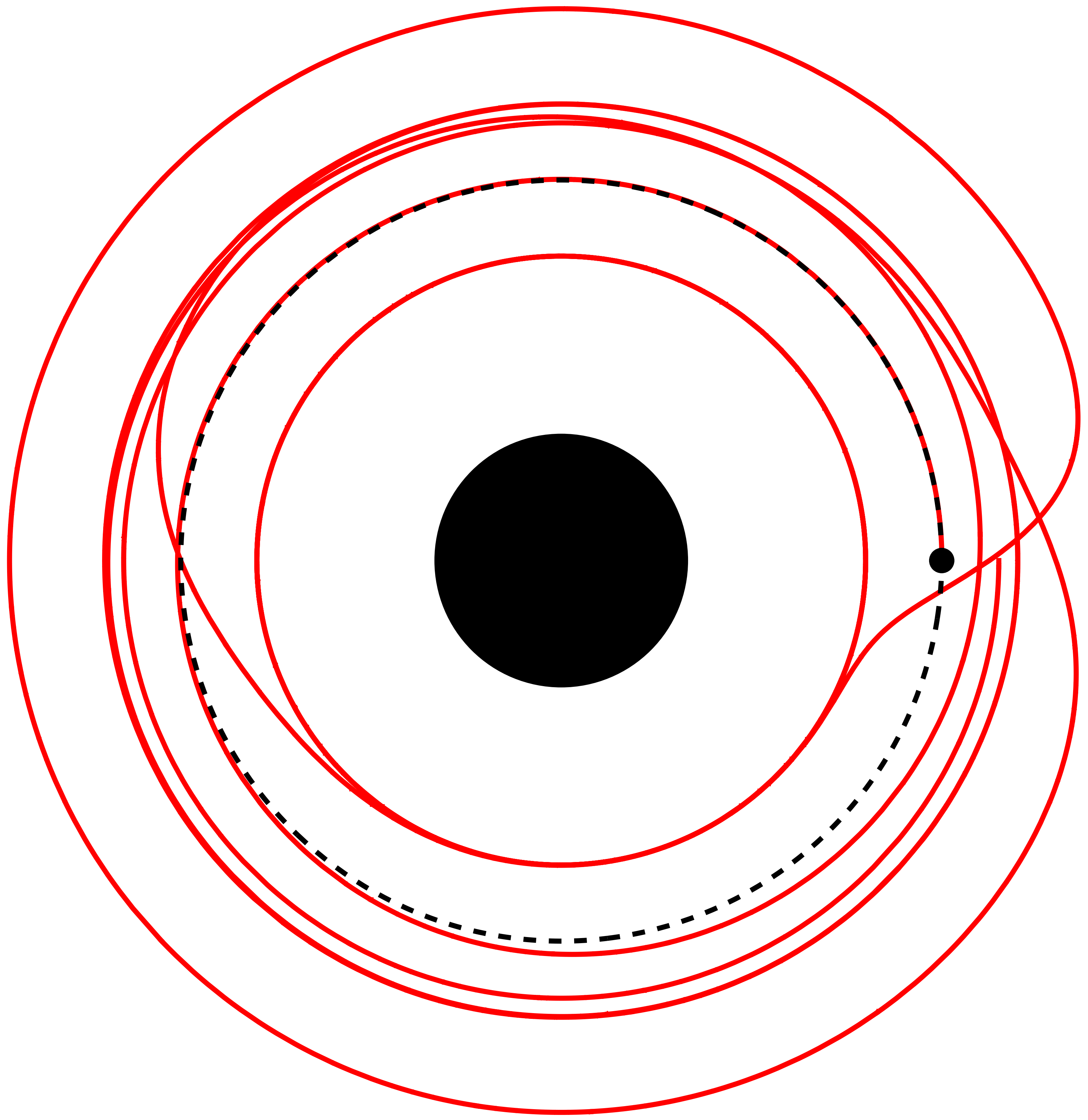


Fast dynamics
No secular piece

POSSIBLE OUTCOMES

II. Chaos

Only if the cavity is large enough

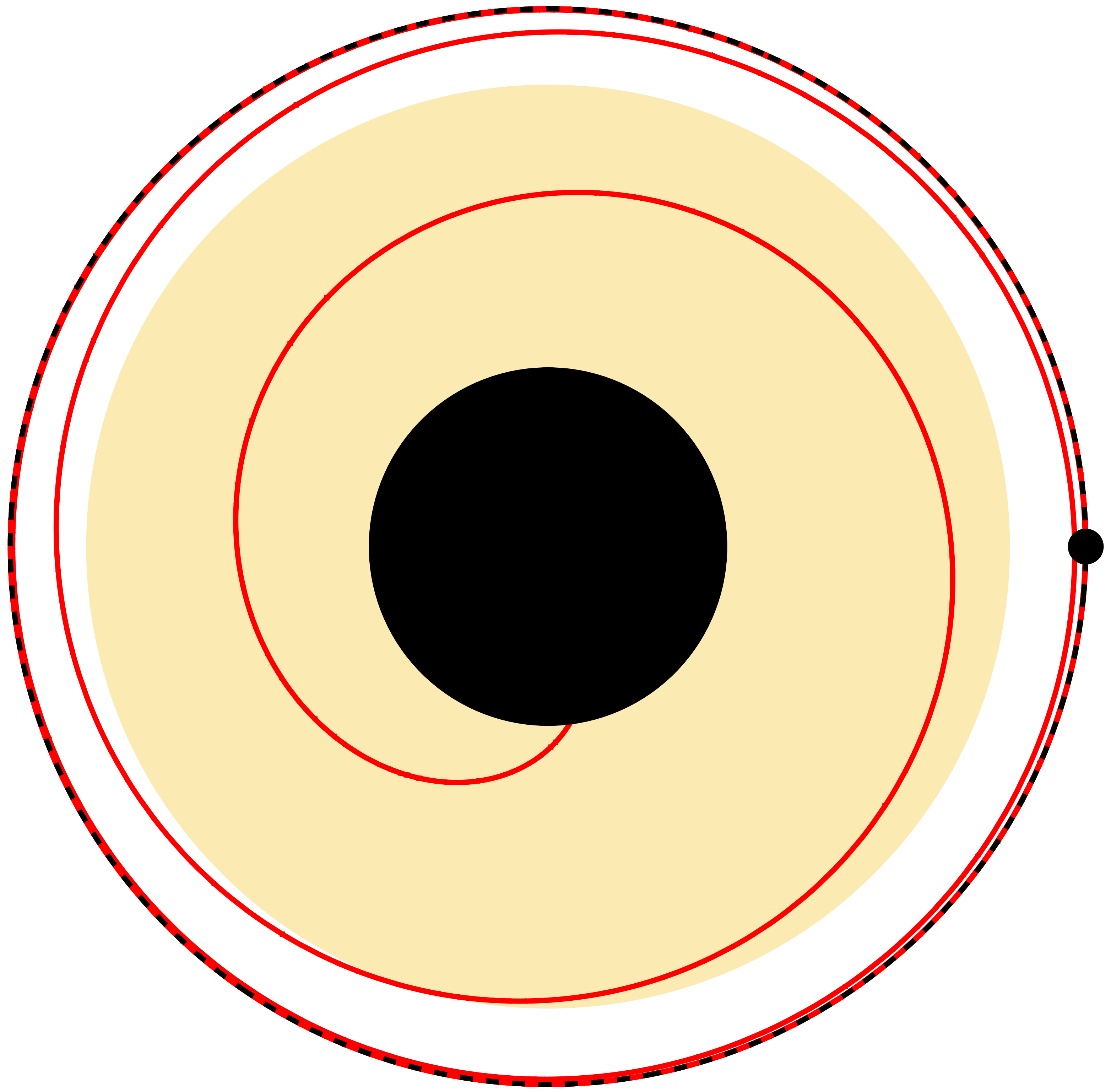


Needs large q/m

– or –

Starting close to a resonant orbit

III. Merger

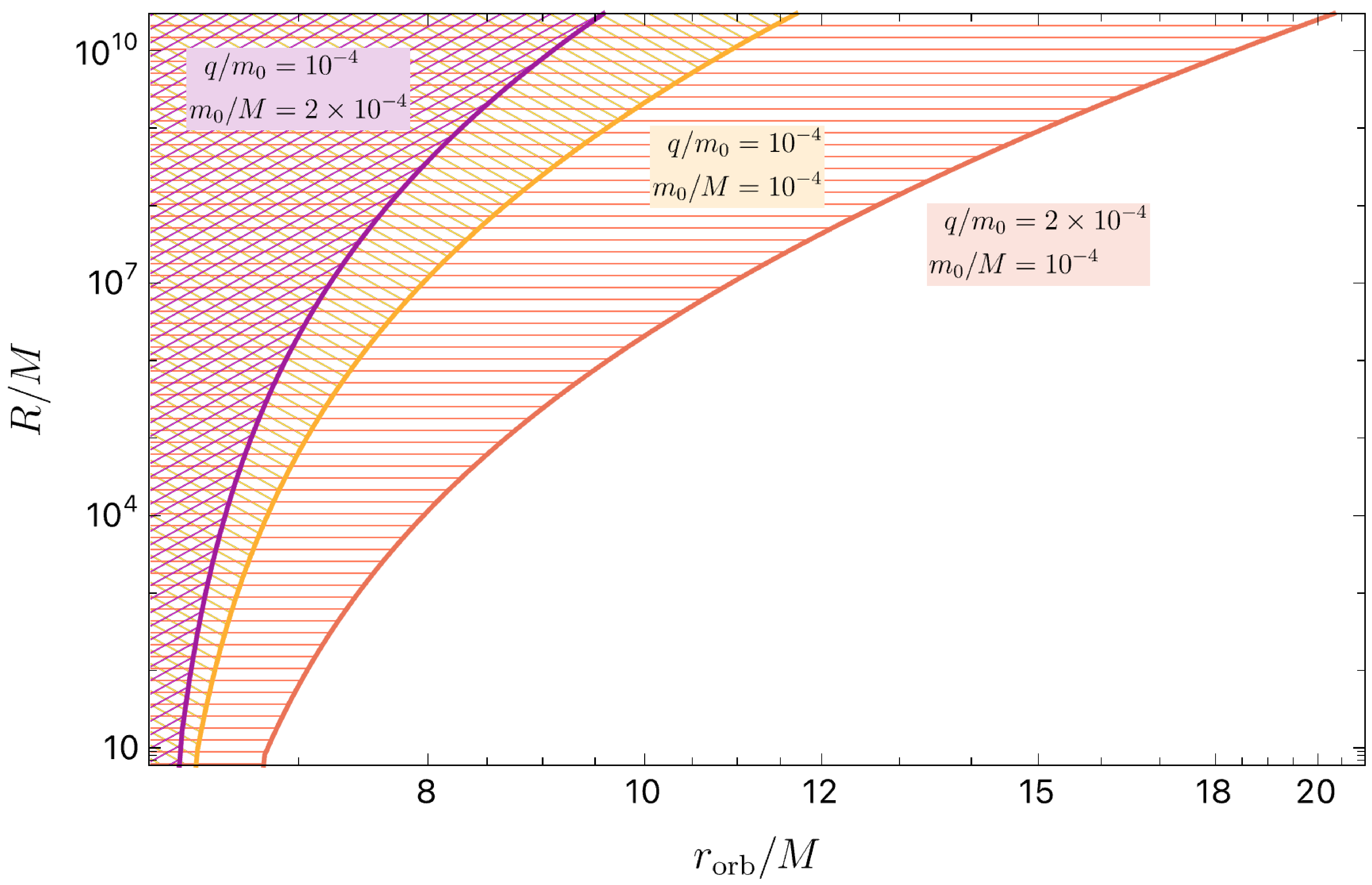


POSSIBLE OUTCOMES

III. Merger

If initially in vacuum

$$\frac{q}{m} \lesssim \sqrt{\frac{M}{m}} \left(\frac{R}{M}\right)^{\frac{1}{10}} \left(\frac{M}{r_{\rm orb} - r_{\rm ISCO}}\right)^{\frac{3}{4}}$$



TAKE-AWAYS

- Closed systems are useful to illustrate conservative effects
- There is astrophysical & theoretical motivation
- Secular effects appear depending on the initial conditions
- Resonances can drastically impact the dynamics: chaos(?)
- Problem of scales: large cavities have richer possibilities