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Eternal and Chaotic binaries

XV Black Hole Workshop - Lisbon 2022

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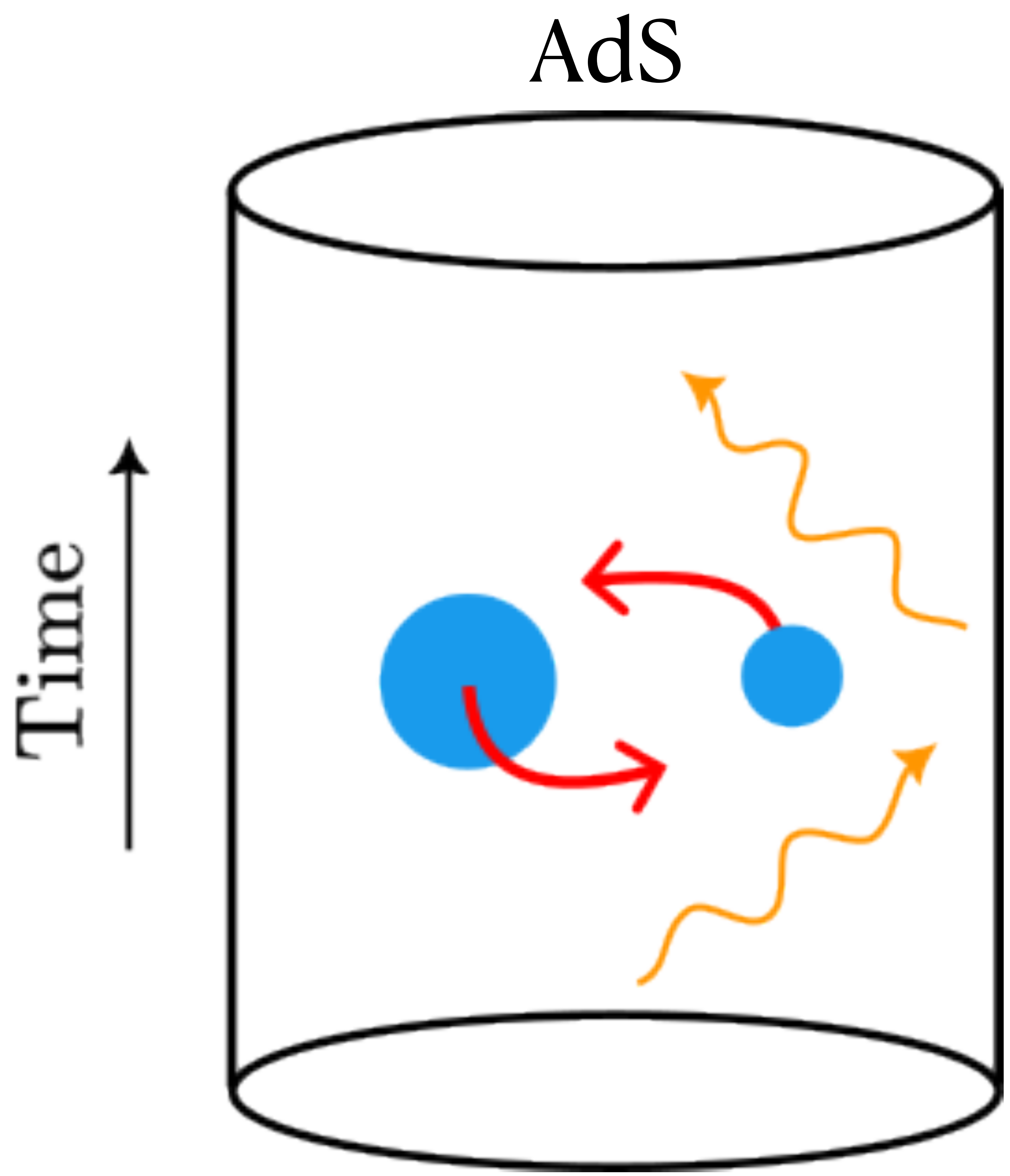
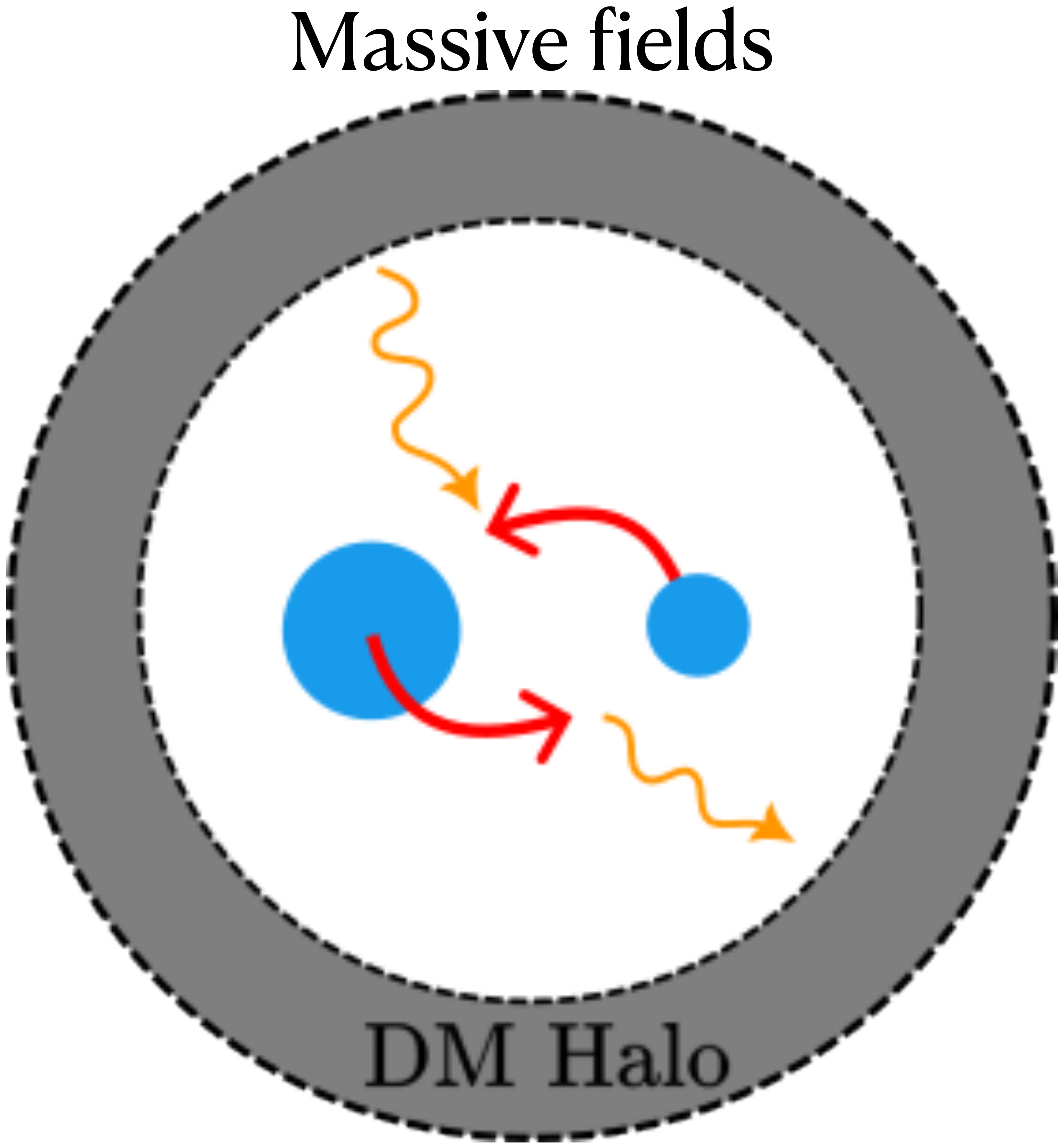
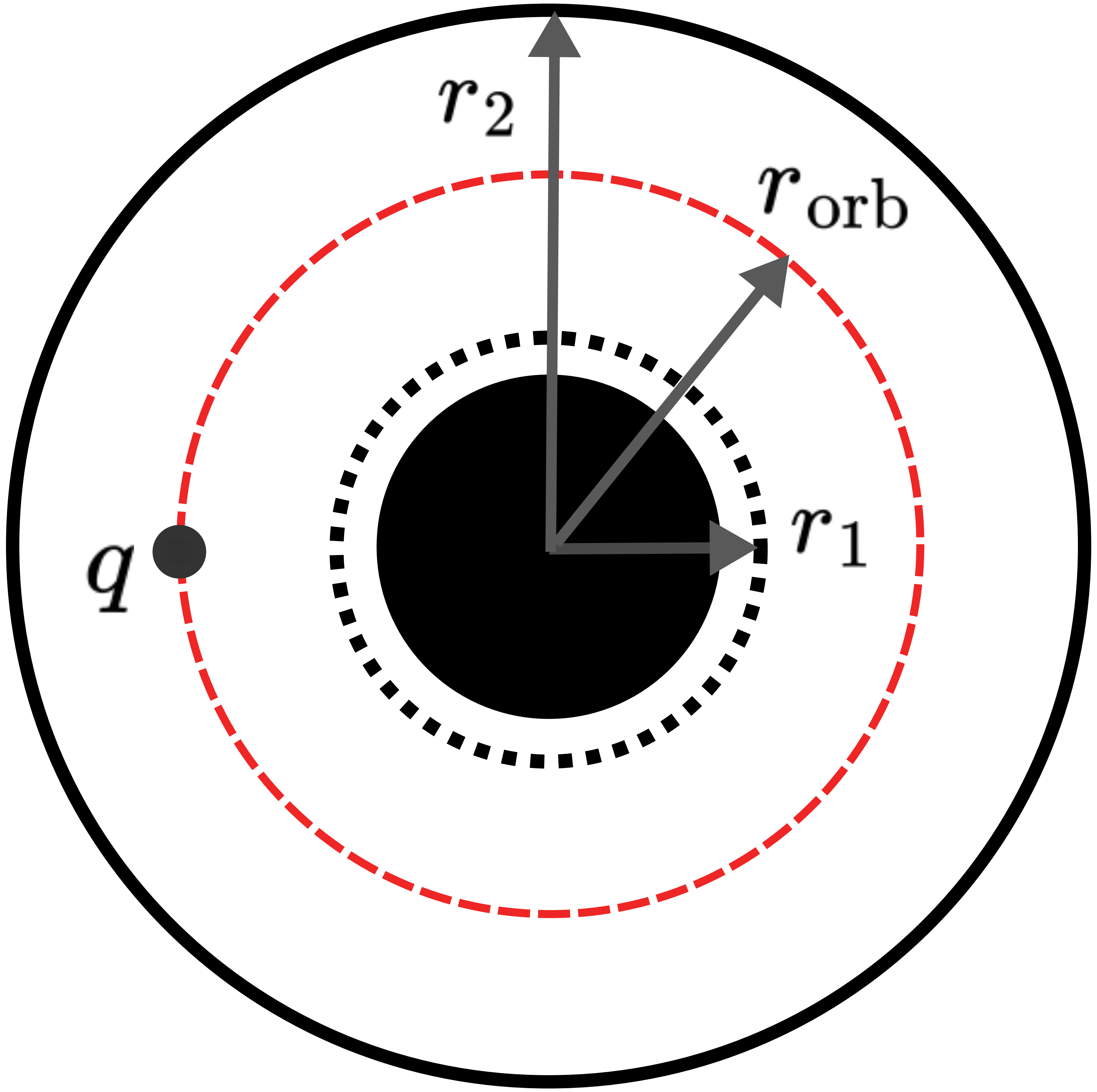
Binaries in a Cavity





Set-up

$$S = -\frac{1}{8\pi}\int d^4x\sqrt{-g}\; g^{\mu\nu}\Phi_{,\mu}\Phi_{,\nu} - \\ -m_0\int\left(1-\frac{q}{m_0}\right)\sqrt{-g_{\mu\nu}\dot{z}^\mu\dot{z}^\nu}\,d\tau$$

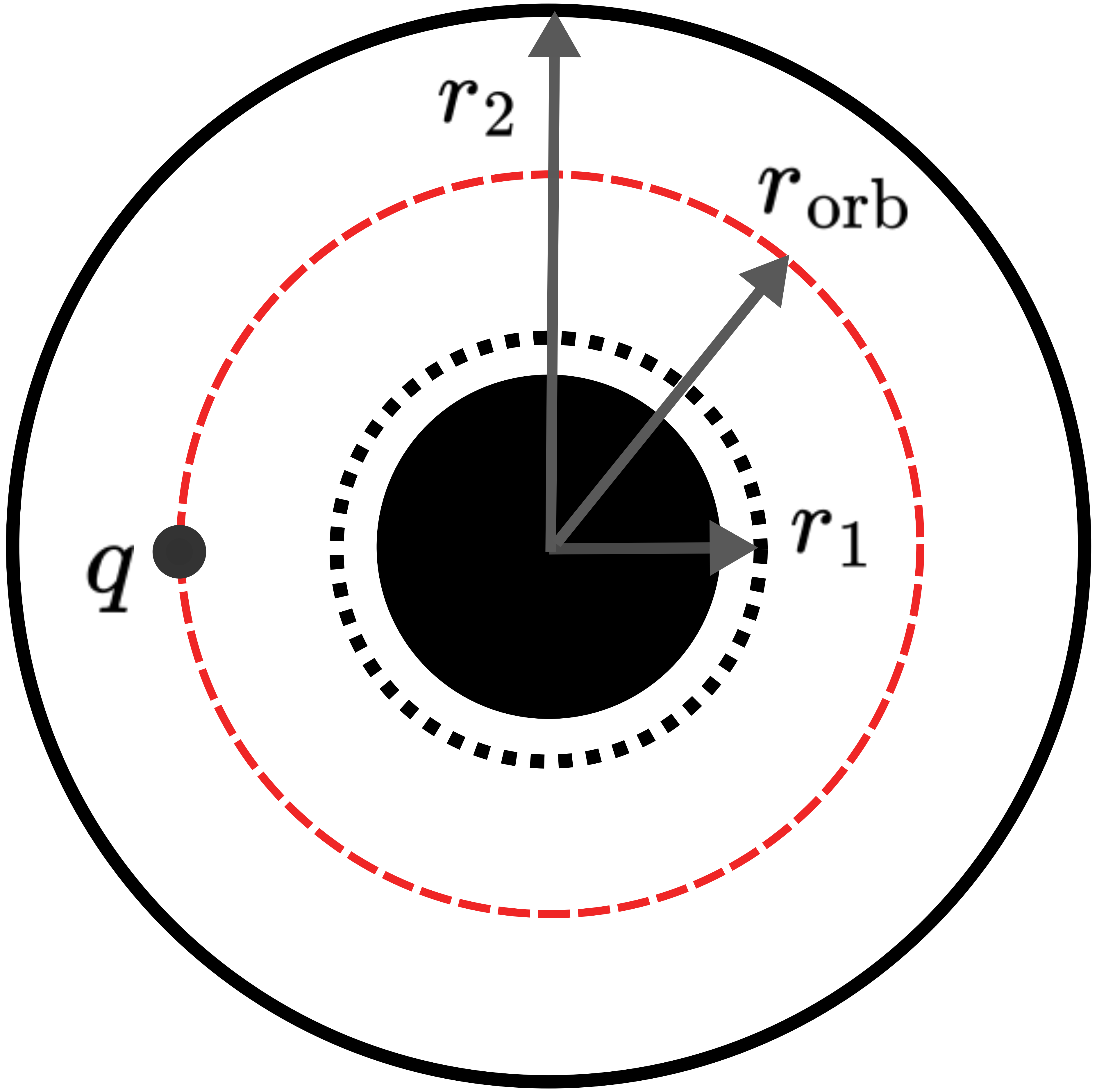


Set-up

$$\Box\Phi = -4\pi q \int d\tau \delta^{(4)}(x^\mu - z^\mu(\tau)),$$

$$m(\tau)\frac{du^\mu}{d\tau} = q(g^{\mu\nu} + u^\mu u^\nu)\Phi_{,\nu}(z),$$

$$\frac{dm}{d\tau} = -q\Phi_{,\mu}(z)u^\mu,$$



Self-Force Calculation: Frequency Domain

Warburton & Wardell (2014), arXiv: 1311.3104

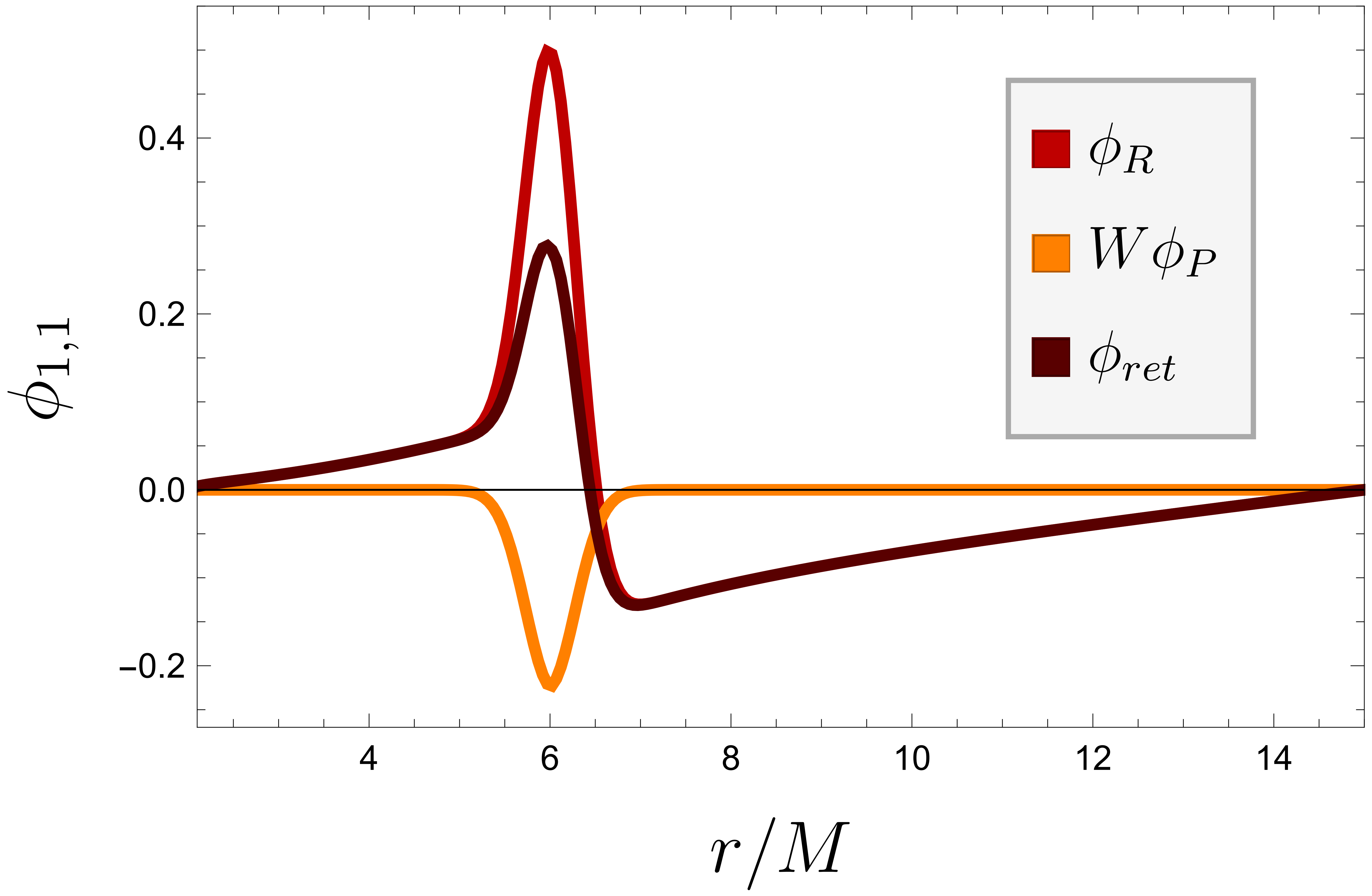
$$\Phi = \Phi_{\rm R} + W(x)\Phi_{\rm P}$$

$$\Box\Phi_R = \mathbf{S}_{\rm eff}$$

$$f_a = \nabla_a \Phi_R$$

$$f_t = 0 \sim \dot{E}$$

$$f_\varphi = 0 \sim \dot{J}$$



Self-Force Calculation: Initial Conditions

$$\Phi = \Phi_{\text{F.D.}} + \sum_n \lambda_n \Phi_n$$

Fixed by Initial Conditions

Q: Can I choose initial conditions such that all the $\lambda_n = 0$

$$\phi_{0,n}^{(\ell,m)} + \frac{\pi_{0,n}^{(\ell,m)}}{i\omega_{(\ell,m,n)}} = \frac{iS_{\text{eff,n}}^{(\ell,m)}}{\omega_{(\ell,m,n)} - \Omega_{\text{orb}}}$$

Backreaction: a toy model

$$H = \frac{1}{2}p^2 + \frac{1}{2L}\int_0^L dx(\pi^2 + \phi_{,x}^2) - \frac{\epsilon}{L}\cos(q/L)\int_0^L dx\frac{\phi(x)}{L}S(x),$$

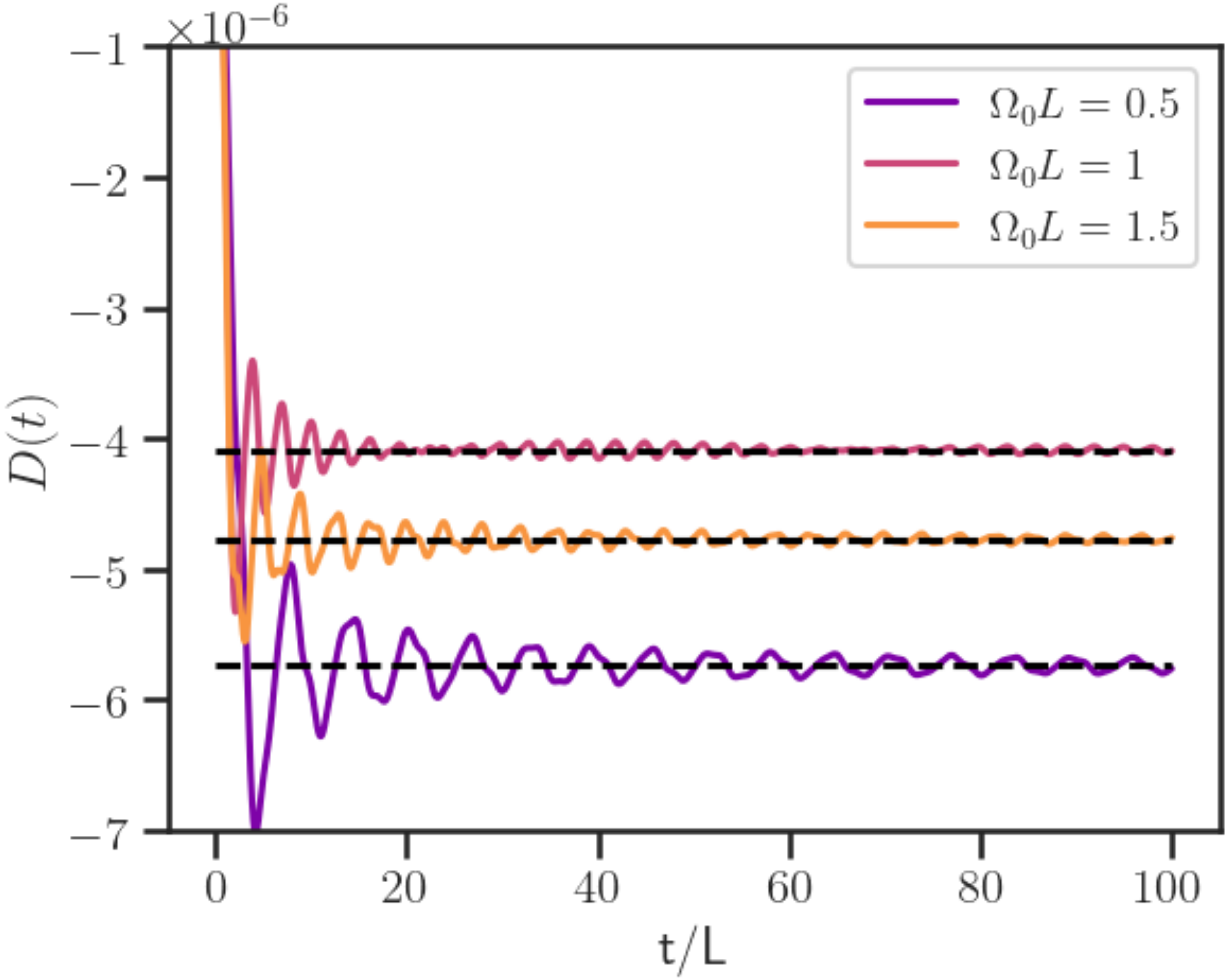
Oscillator — 1D Cavity — Coupling

- ✓ Solve perturbatively up to second order
- ✓ Solve numerically

Backreaction: a toy model

The frequency "drifts" from its starting value.

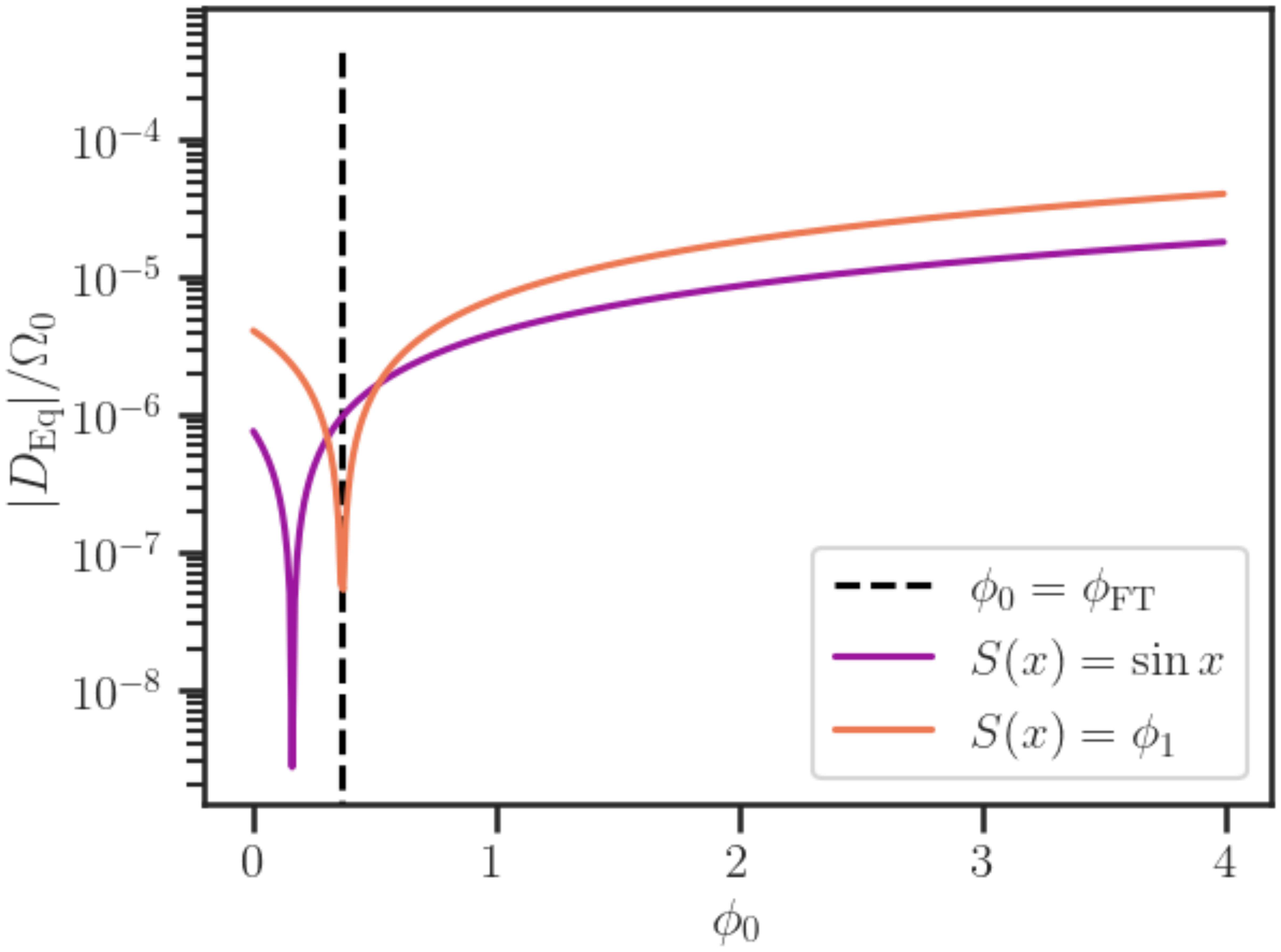
$$D(t) = \frac{1}{t}\int_0^t d\tau(\Omega(\tau) - \Omega_0)$$



Backreaction: a toy model

But we can find initial configurations where this is highly suppressed!

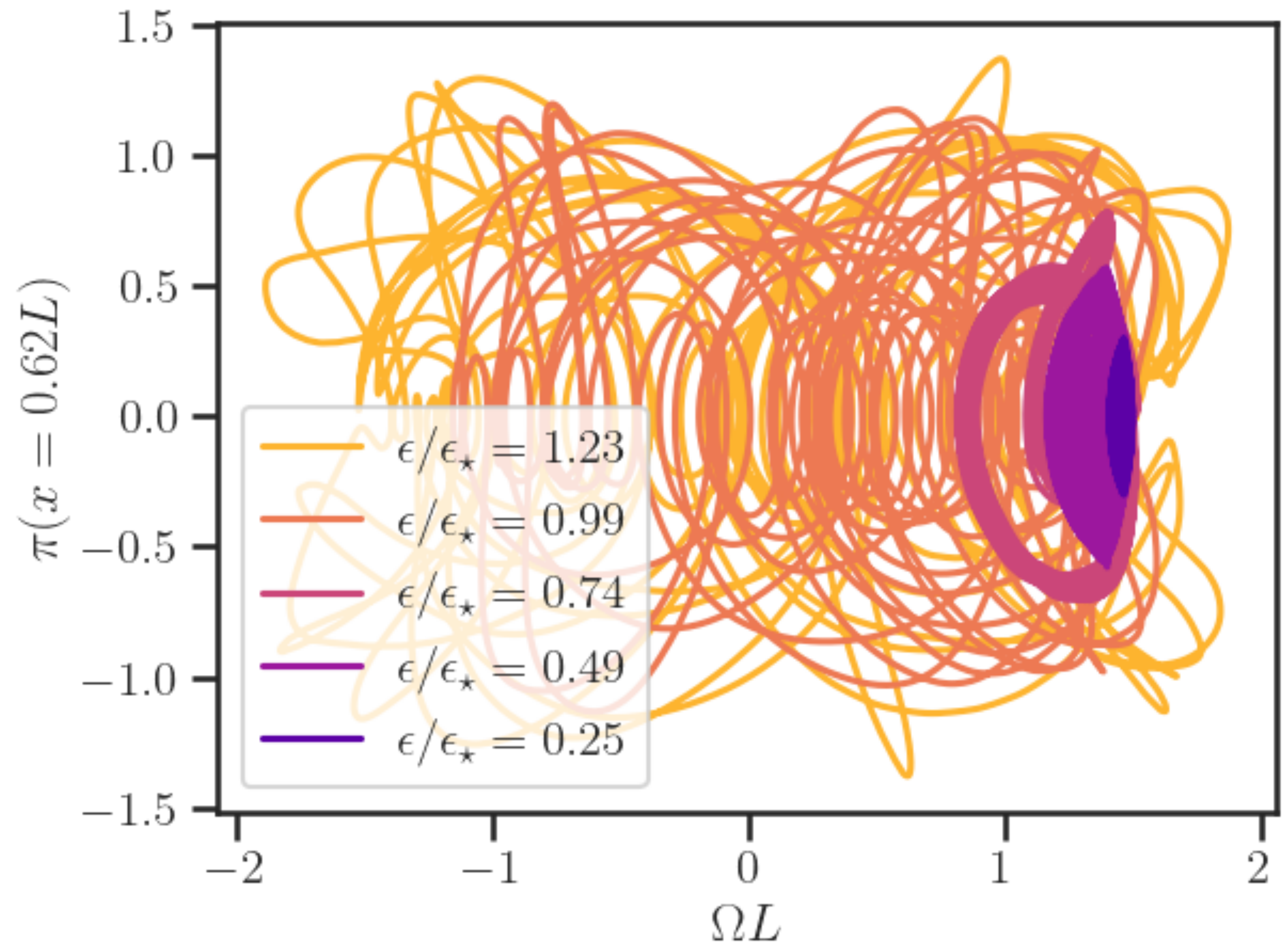
$$\phi_0^{\mathrm{FT}} = \frac{3\Omega_0^2 + \omega^2}{4\Omega_0^2(\omega^2 - \Omega_0^2)}$$



Backreaction: a toy model

If the coupling is strong enough, or the system is initialised near a resonance: chaos

$$\epsilon_\star / L = \frac{2\sqrt{\Omega_0 \omega}|\Omega_0^2 - \omega^2|}{\sqrt{\omega^2 + 3\Omega_0^2}}$$



Take-aways

- Confined systems depend crucially on the initial configuration
- We can use this to our advantage: without taking the back-reaction into account, the binary would stay on the same place —> Eternal binaries
- Even taking the back-reaction into account, we can find Eternal binaries (the general situation would involve some finite drift)
- When the coupling is strong or the system is close to a resonance, the binary can become Chaotic.
- Can this be extended to a full self-consistent evolution?