

An Open System Approach to Gravity

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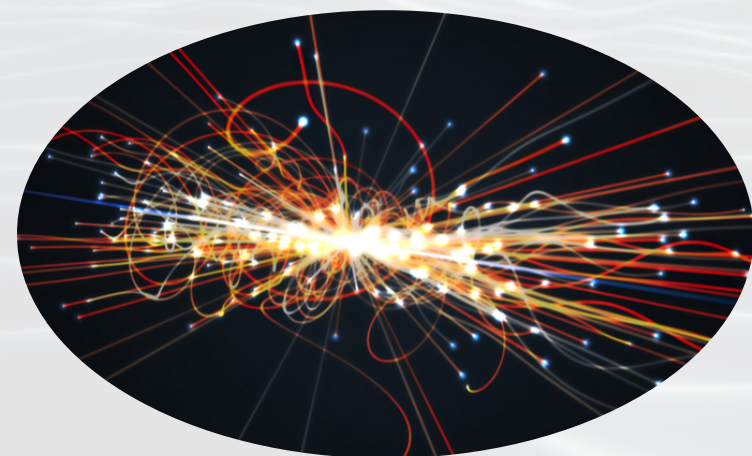
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Interests: Cosmology 🔭🪐

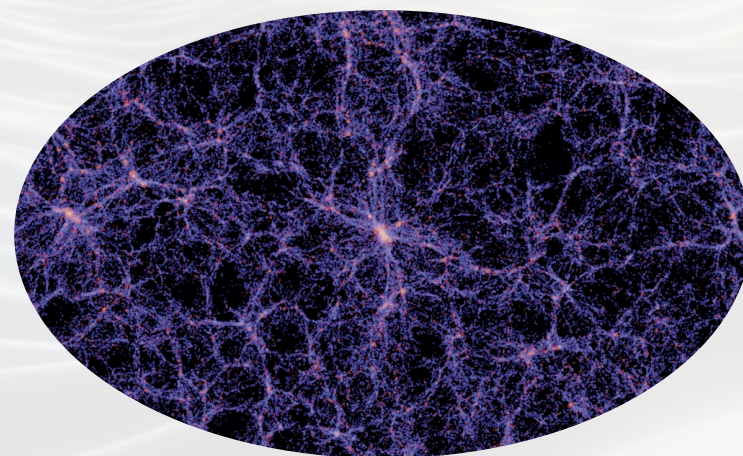
Besides physics: 🎾⚽🏂🌱

Motivation

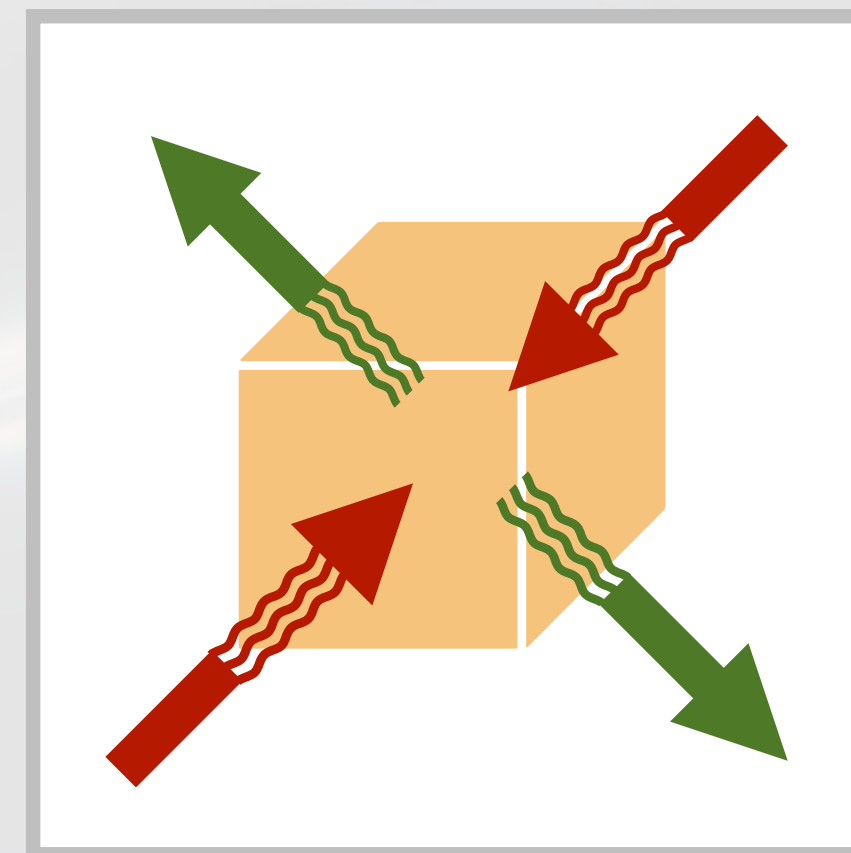
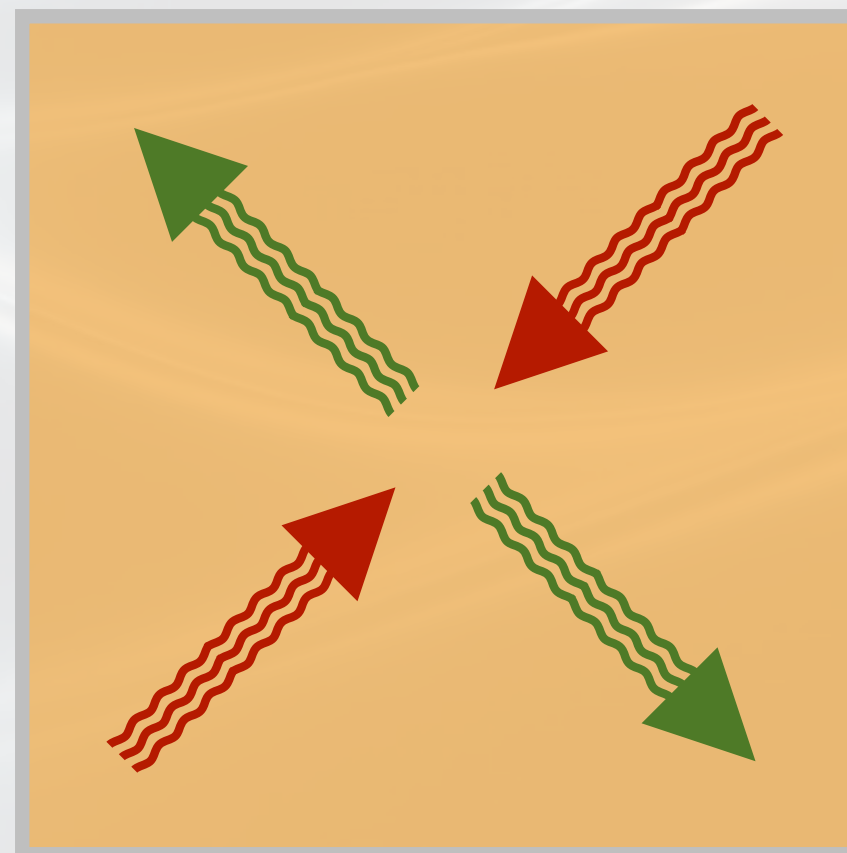
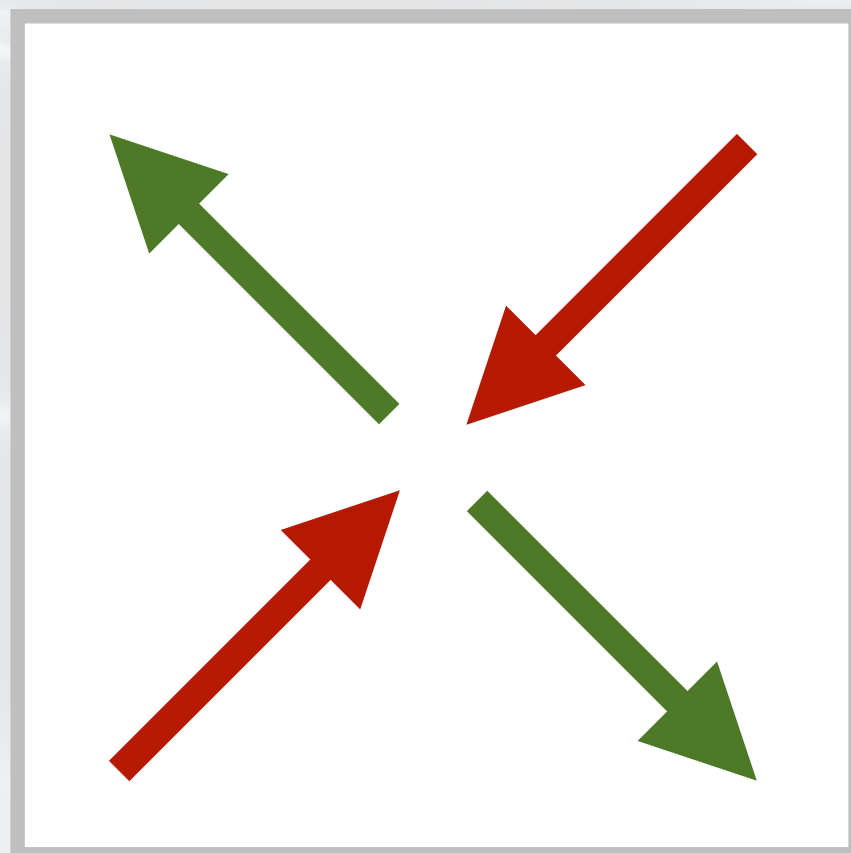
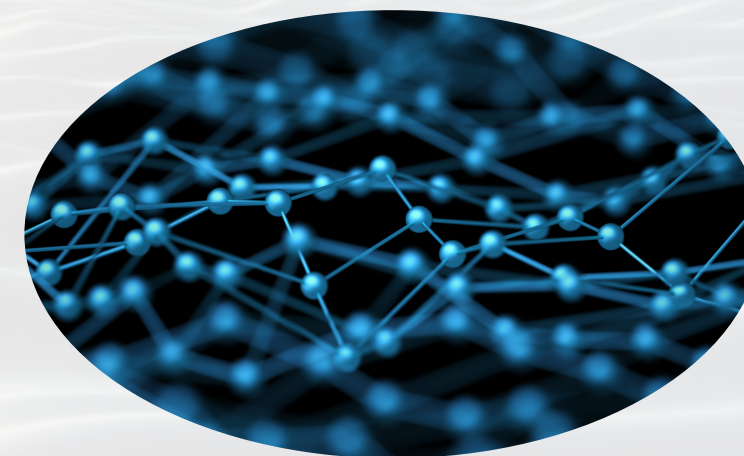
Particle Physics



Cosmology



Condensed matter



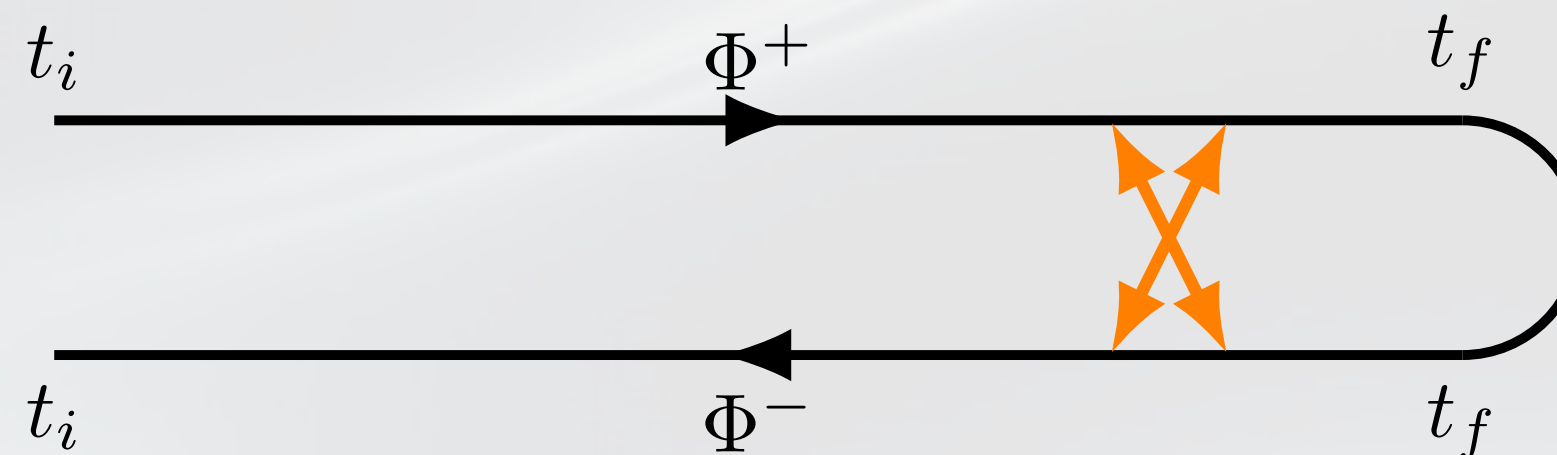
Schwinger-Keldysh formalism

Closed system - transition amplitude:

$$\langle \varphi_f | U(t_f, t_i) | \varphi_i \rangle = \int_{\varphi_i}^{\varphi_f} \mathcal{D}\Phi e^{iS[\Phi]}$$


Open system - density matrix:

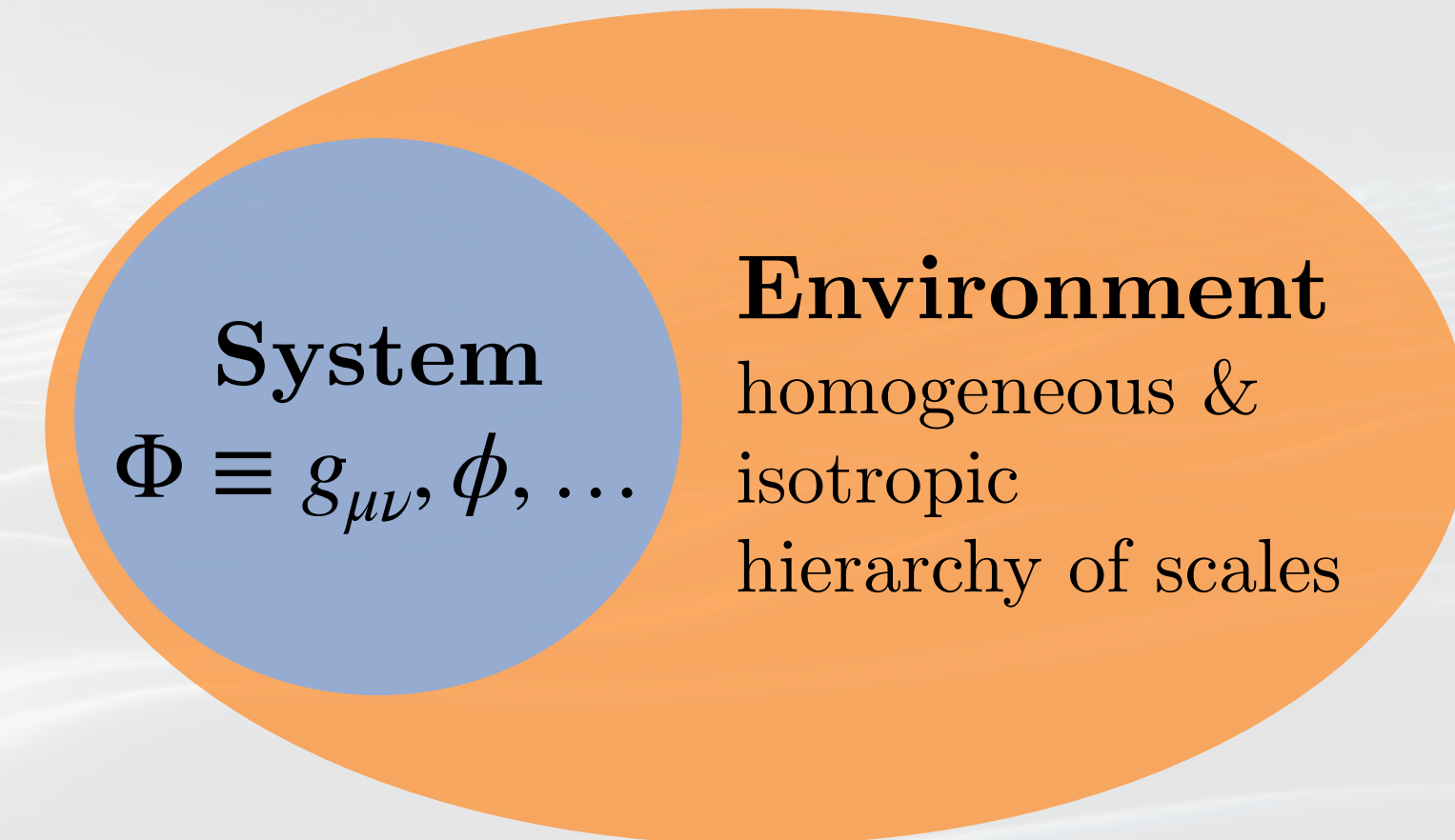
$$\langle \varphi_f | \hat{\rho}(t) | \varphi_i \rangle = \langle \varphi_f | U(t_f, t_i) \hat{\rho}_0 U(t_f, t_i)^\dagger | \varphi_i \rangle = \sum_{\varphi_3, \varphi_4} \int_{\varphi_4}^{\varphi_f} \mathcal{D}\Phi_+ \int_{\varphi_3}^{\varphi_i} \mathcal{D}\Phi_- e^{iS[\Phi_+] - iS[\Phi_-]} \langle \varphi_4 | \hat{\rho}_0 | \varphi_3 \rangle$$



In presence of an environment: $S[\Phi_+] - S[\Phi_-] \rightarrow S_{\text{eff}}[\Phi_+, \Phi_-]$

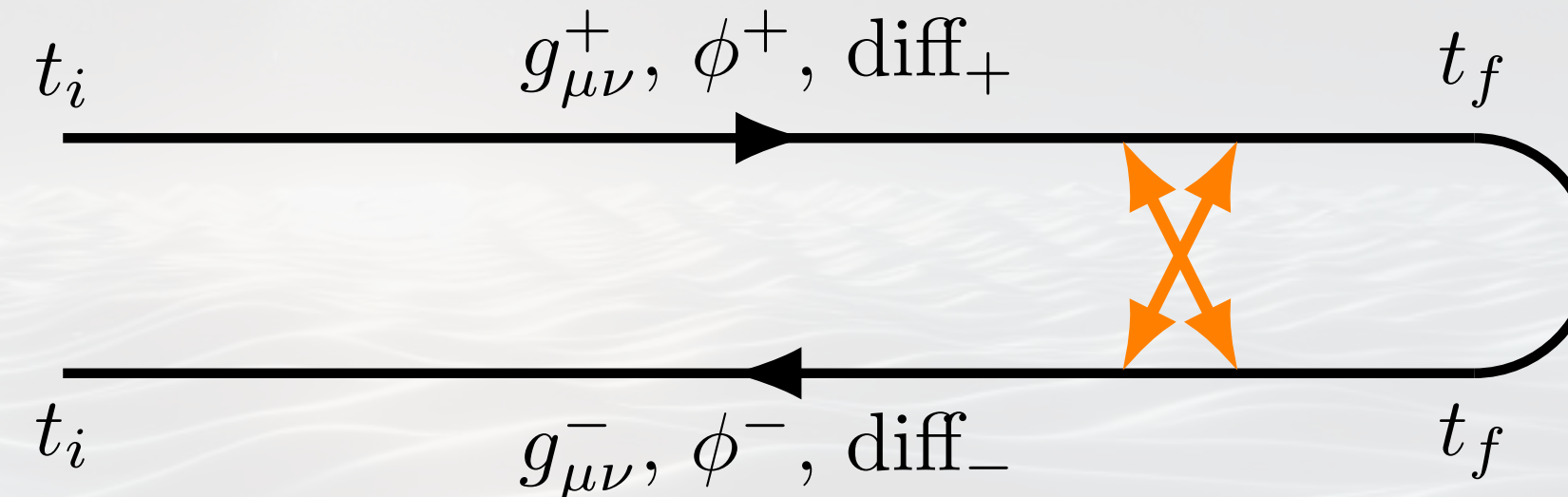
Influence functional S_{eff} :

- expand as EFT
- **mixes** +/- branches



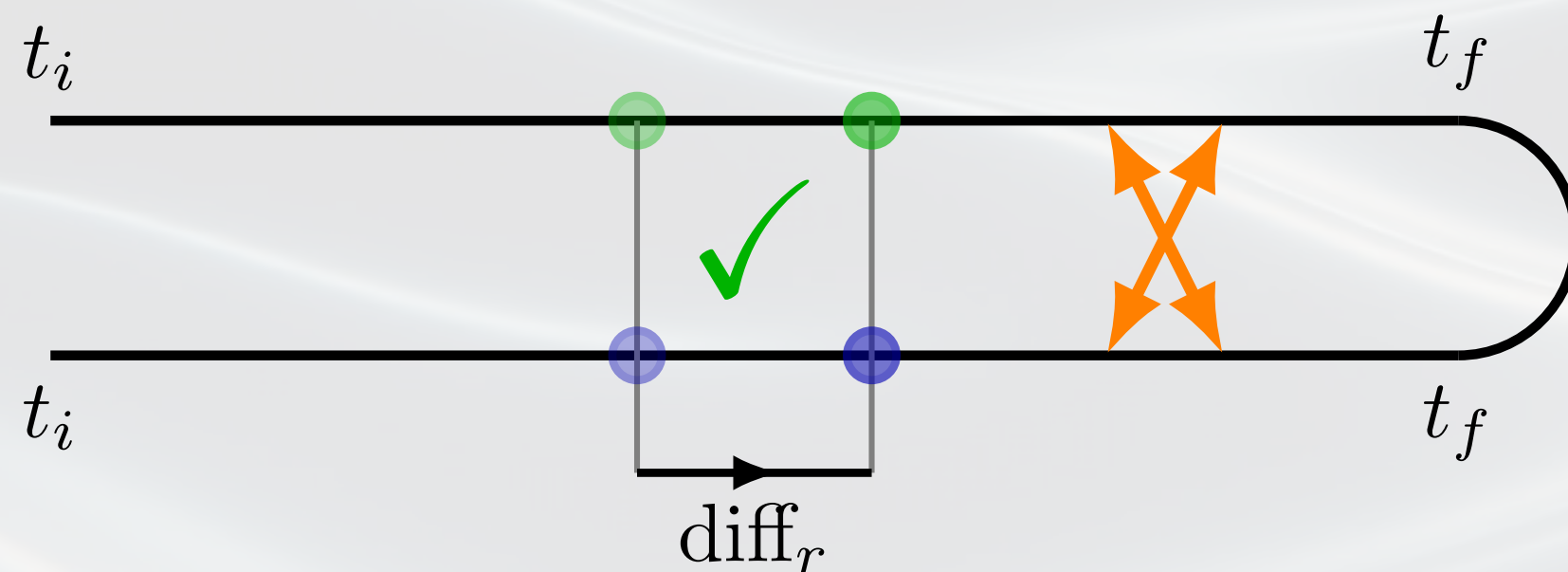
Construction of S_{eff}

In “single clock” cosmologies:

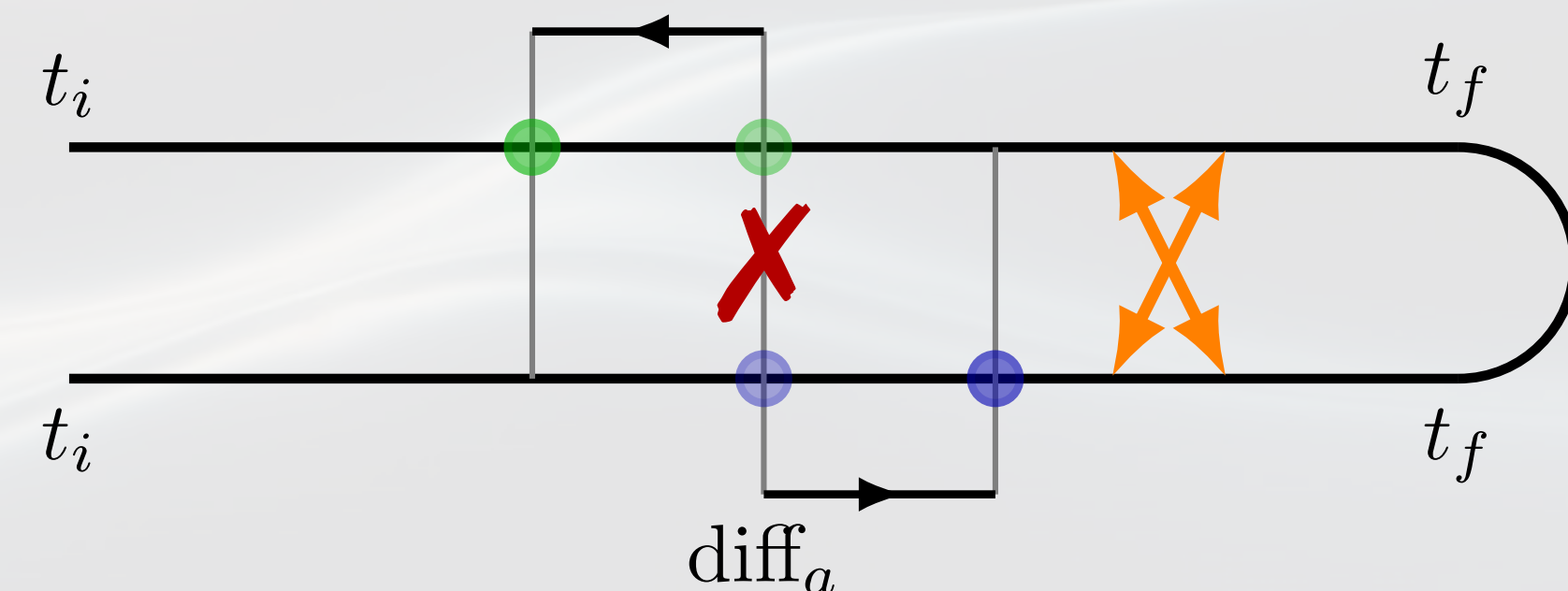


Work with $\begin{pmatrix} \text{diff}_+ \\ \text{diff}_- \end{pmatrix} \rightarrow \begin{pmatrix} \text{diff}_r \\ \text{diff}_a \end{pmatrix}$:

“Retarded” diffs - same direction:



“Advanced” diffs - opposite direction:



Overall: $(4\text{d-diff}_+ \times 4\text{d-diff}_-) \simeq (4\text{d-diff}_a \times 4\text{d-diff}_r) \xrightarrow{\text{open}} (4\text{d-diff}_r) \xrightarrow{\text{clock}} (3\text{d-diff}_r)$

$\Rightarrow S_{\text{eff}}$ most generic action invariant under 3d-diff_r (see paper for explicit construction)

Application: Open EFT of Inflation

Scalar sector:

Inflaton perturbations sourced by environmental noise
[Agüi-Salcedo et al. 2024]

Tensor sector - modified propagation of GWs:

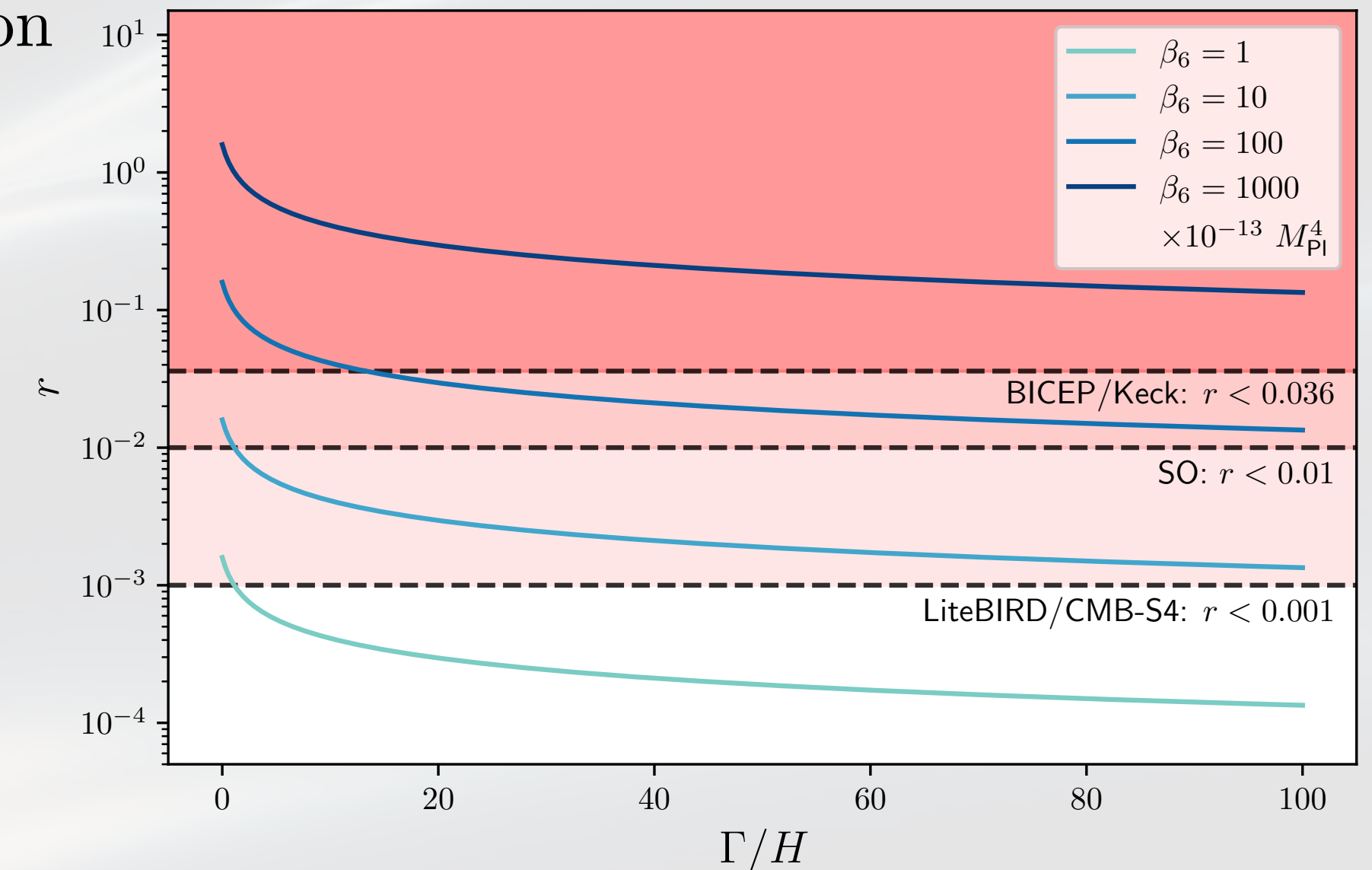
$$\ddot{h}_{ij} - c_T^2 \frac{\nabla^2}{a^2} h_{ij} + (\Gamma_T + 3H) \dot{h}_{ij} + \frac{\chi}{a} \epsilon_{imn} \partial_m \dot{h}_{nj} = \xi_{ij}$$

c_T^2 : Speed of propagation

Γ_T : Dissipation

χ : Birefringence

ξ_{ij} : Noise



EFT of inflation:

all single-field
inflationary models
[Cheung et al. 2008]

Open EFT of
inflation:

additional presence
of environment