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WEIZMANN INSTITUTE OF SCIENCE

MINERVA STIFTUNG

Gravitational Wave Echo of Relaxion Trapping

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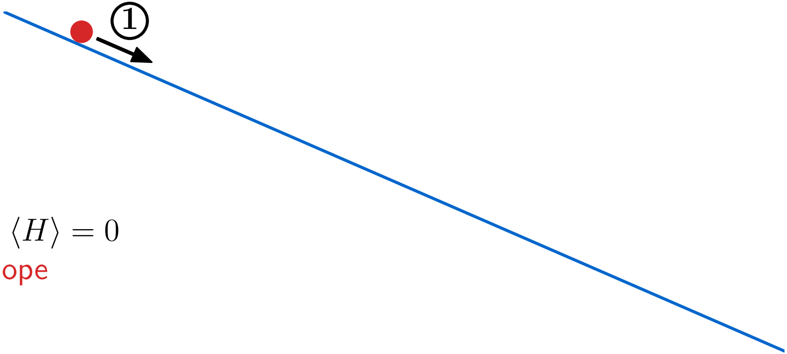
Relaxion (during inflation)

[Graham, Kaplan, Rajendran (2015)]

$$V(H,\phi) = \underbrace{\left(\Lambda^2 - g\Lambda\phi\right)}_{\mu_H^2(\phi)} |H|^2 + \lambda |H|^4 - cg\Lambda^3\phi - \Lambda_{\text{br}}^4 \frac{|H|^2}{v_H^2} \cos\frac{\phi}{f_\phi}$$



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   only linear slope

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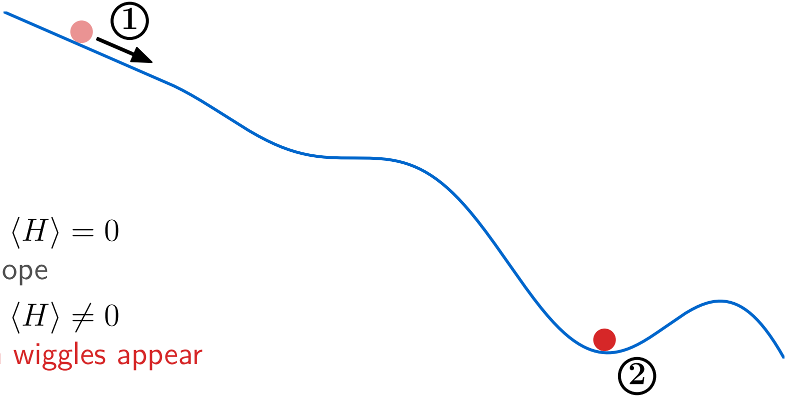

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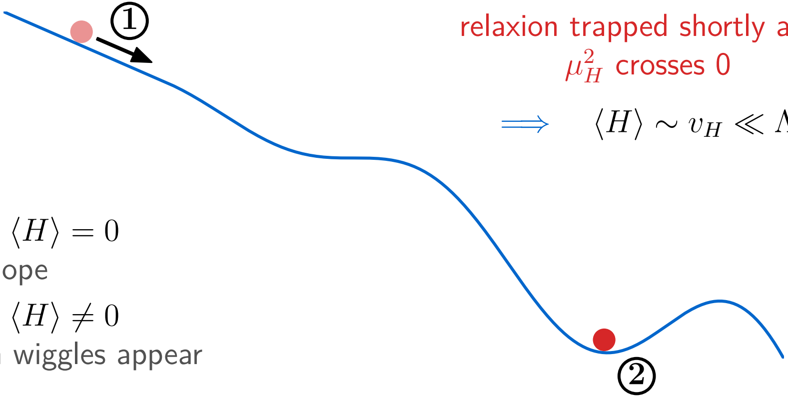

relaxion trapped shortly after μ_H^2 crosses 0

$$\Longrightarrow \quad \langle H \rangle \sim v_H \ll \Lambda$$

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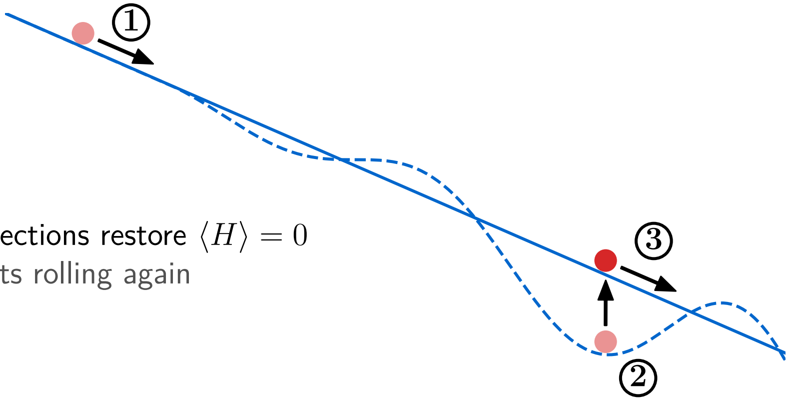

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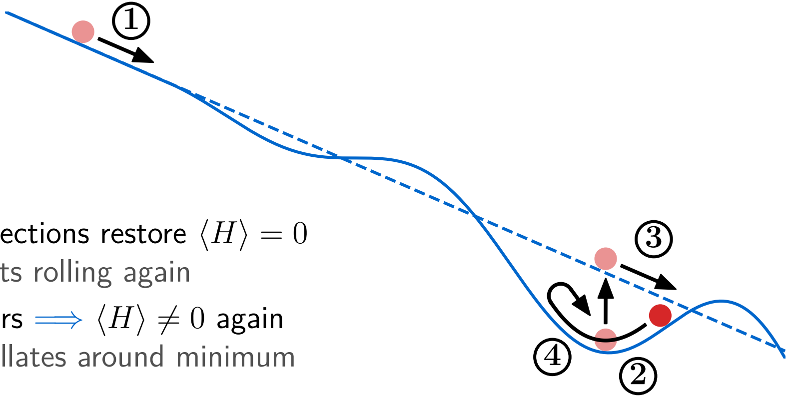

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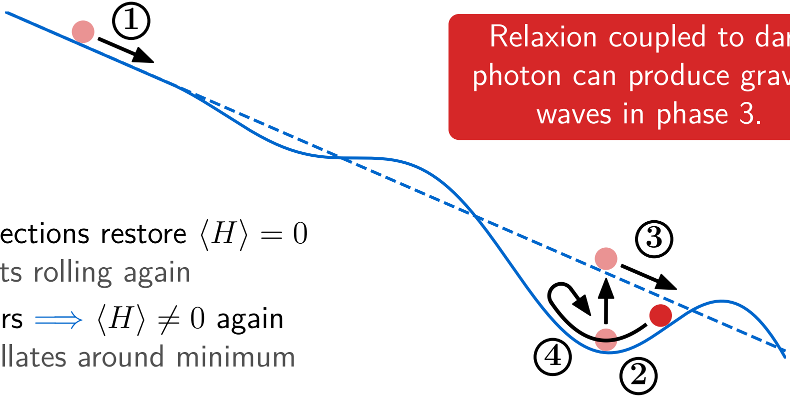

Relaxion coupled to dark photon can produce gravity waves in phase 3.

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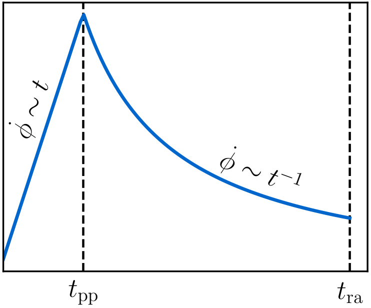
Relaxion and dark photon evolution

- relaxion coupled to dark photon X: $\mathcal{L} \supset -\frac{r_X}{4}\frac{\phi}{f_\phi} X_{\mu\nu}\tilde{X}^{\mu\nu}$

$$\Longrightarrow \qquad \ddot{\phi} + 3H\dot{\phi} - \frac{\Lambda_{\rm br}^4}{f_\phi} + \frac{r_X}{f_\phi}\frac{\langle \tilde{X}_{\mu\nu} X^{\mu\nu}\rangle}{4\,a^4} = 0$$

- relaxion reaches terminal velocity when $\frac{r_X}{4a^4}\langle \tilde{X} X\rangle \sim \Lambda_{\rm br}^4$:

$$\frac{\dot{\phi}}{f_\phi} = \frac{\xi H}{r_X} \qquad \xi \sim \mathcal{O}(10 - 100)$$



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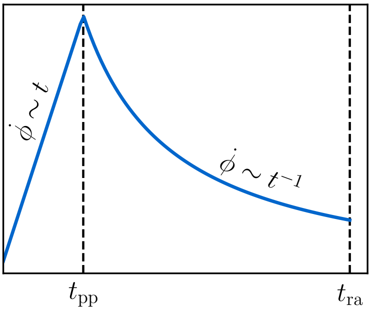

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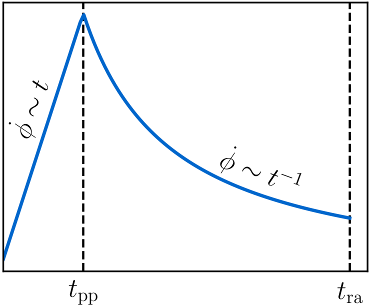

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- anisotropic stress in dark photon energy-momentum tensor sources GWs

$\Longrightarrow$ stochastic GW background

Gravitational wave spectra

- peak frequency: $$f_{\text{peak}} \sim 2\,\frac{k^X_{\text{peak}}}{a} \sim \frac{a_{\text{ra}}}{a_0}\xi H_{\text{ra}} \sim 1\,\mu\text{Hz}\left(\frac{\xi}{25}\right)\left(\frac{T_{\text{ra}}}{1\,\text{GeV}}\right)$$
- peak amplitude: $$\Omega^{\text{peak}}_{\text{GW}} \sim \frac{\left(\rho^{\text{ra}}_X / f^{\text{ra}}_{\text{peak}}\right)^2}{\rho_c\ M^2_{\text{Pl}}}\left(\frac{a_{\text{ra}}}{a_0}\right)^4 \sim 10^{-10}\left(\frac{25}{\xi}\right)^2\left(\frac{m_\phi f_\phi}{T^2_{\text{ra}}}\right)^4$$

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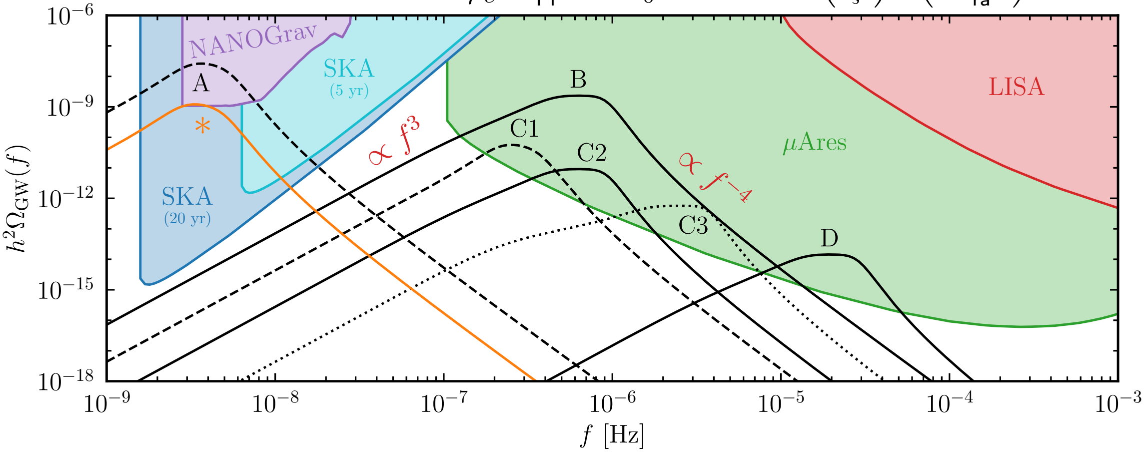
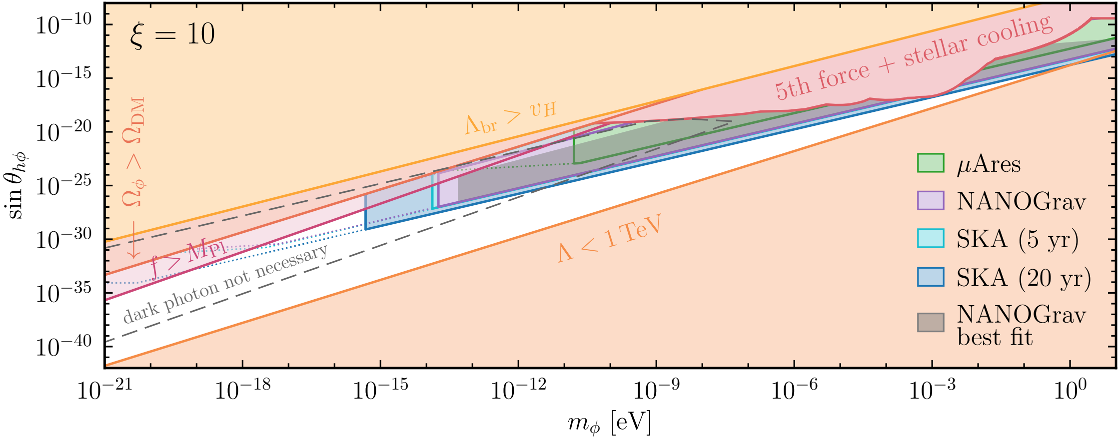


Parameter space

$$f_{\rm peak} \propto \xi\, T_{\rm ra} \qquad h^2\Omega_{\rm GW}^{\rm peak} \propto \xi^{-2}\, m_\phi^{-12}\, (\sin\theta_{h\phi})^{12}\, \Lambda^{-8}\, T_{\rm ra}^{-8}$$



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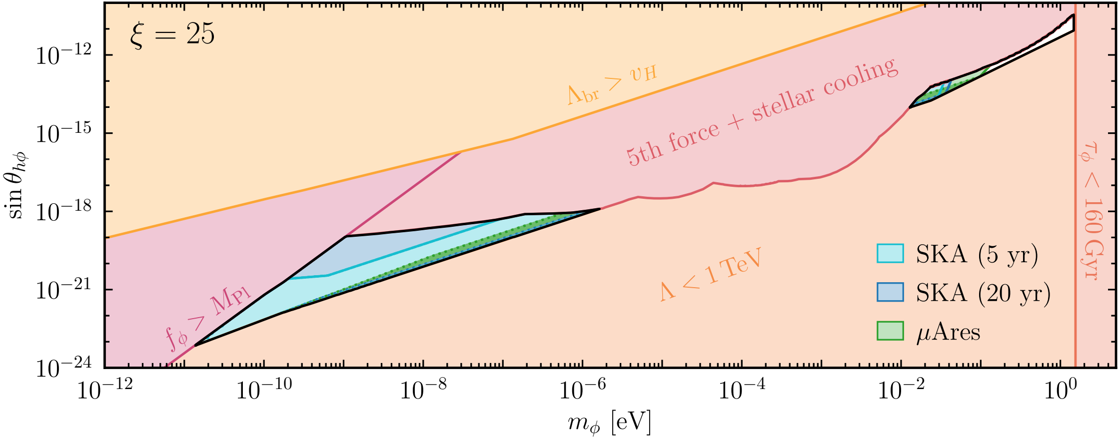
Relaxion dark matter

displaced relaxion oscillates $\Longrightarrow$ ultra-light dark matter [Banerjee, Kim, Perez (2018)]



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Conclusion

- Relaxion coupled to dark photon can produce gravitational waves:

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- SKA will be able to probe a part of the relaxion dark matter parameter space
- large portion of the parameter space will be accessible to μHz observatories such as μAres
- if the relaxion is not DM, we obtain constraints from NANOGrav

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Thank you for your attention!