Preheating Axions in String Cosmology

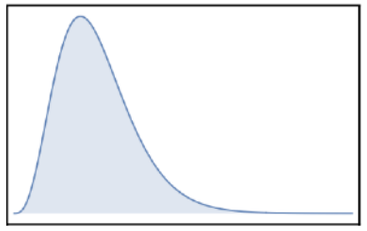
Nicole Righi

Work in progress with

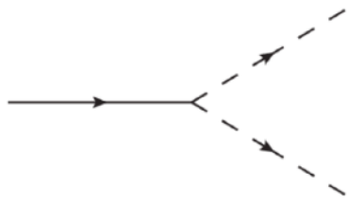
J. M. Leedom, M. Putti and A. Westphal

How to Produce an Axion Population

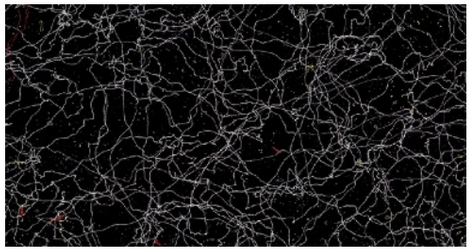
- thermal



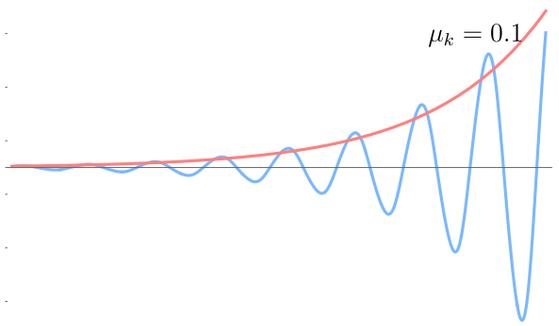
- particle decay



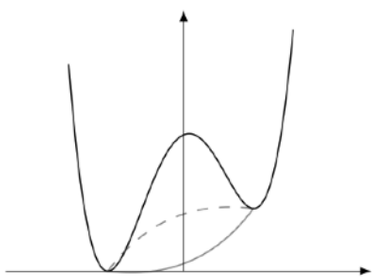
- topological defects decay



- parametric resonance



- misalignment mechanism



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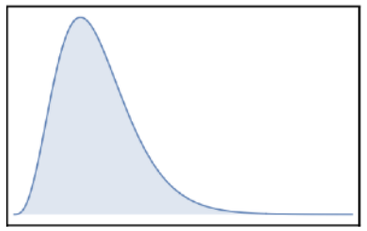

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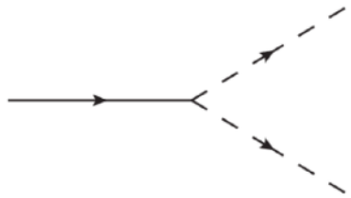

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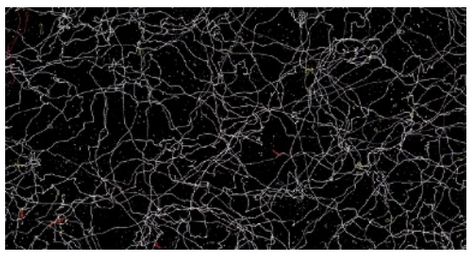

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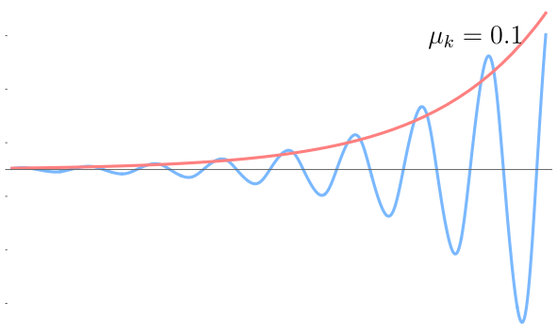

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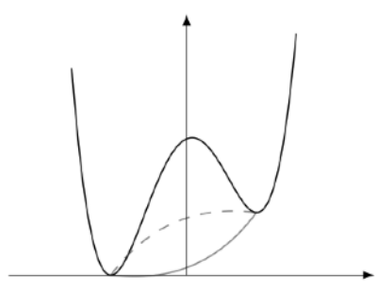

model dependent

model independent

Axion-Saxion Coupling

type IIB on CY 3-fold in the geometric regime:

$$T = \tau + i\theta \qquad \begin{cases} \mathscr{L}_{kin} \supset \dfrac{1}{\tau^2}(\partial\tau)^2 + \dfrac{1}{\tau^2}(\partial\theta)^2 \\ \\ V \supset \Lambda^4 e^{-a\tau}\cos(a\,\theta) \end{cases}$$

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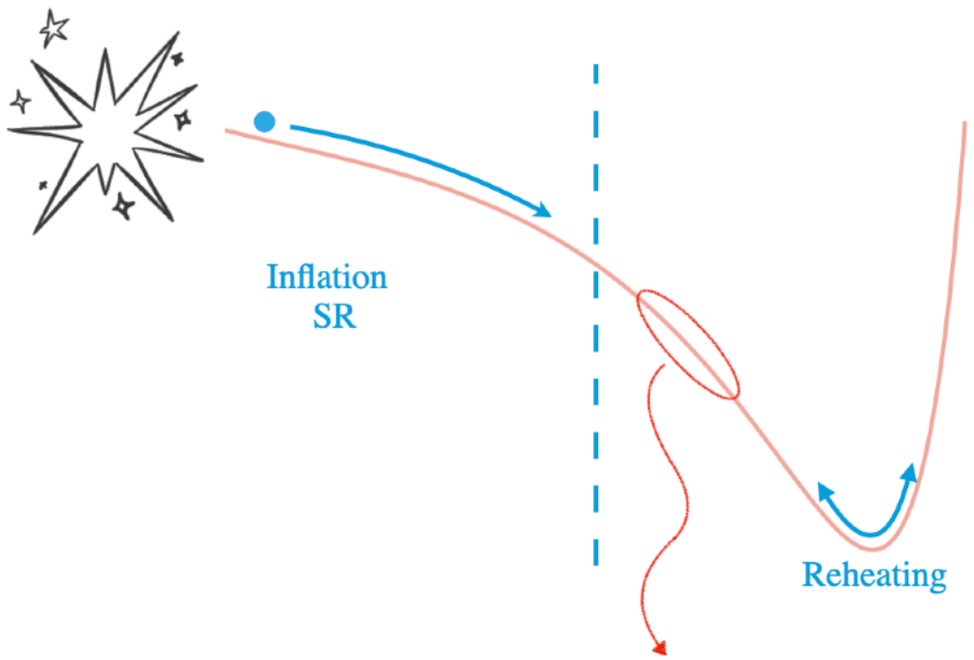
$\Rightarrow$ Very simple, but generic!

Preheating



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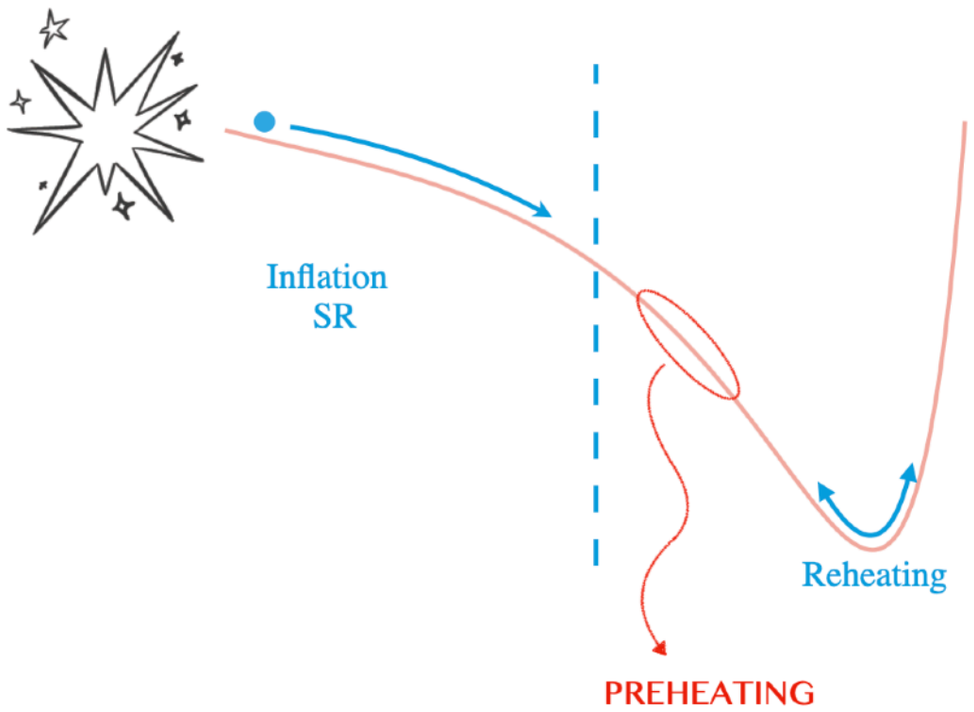

$$\phi \simeq \langle \phi \rangle + \Delta\phi \cos(m_\phi t)$$

$$\chi(t, \vec{x}) \simeq \langle \chi \rangle + \delta\chi_k(t, \vec{x})$$

$$\chi_k'' + \underbrace{\left(\frac{4k^2}{m_\phi^2} + \frac{\partial^2 V(\chi, \phi)}{\partial \chi^2} \right)}_{\omega_k^2(t)} \chi_k = 0$$

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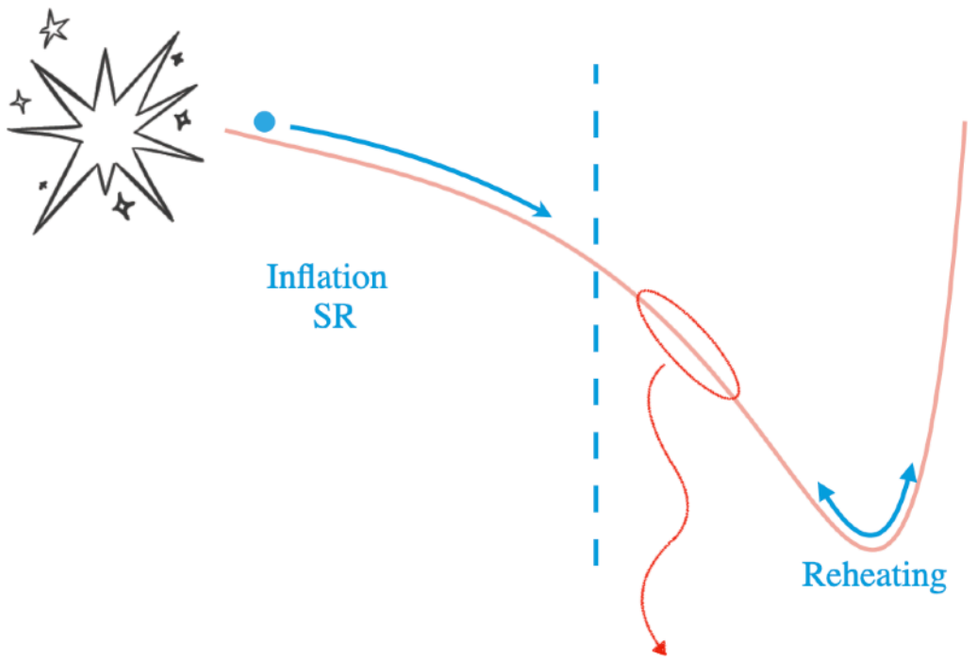

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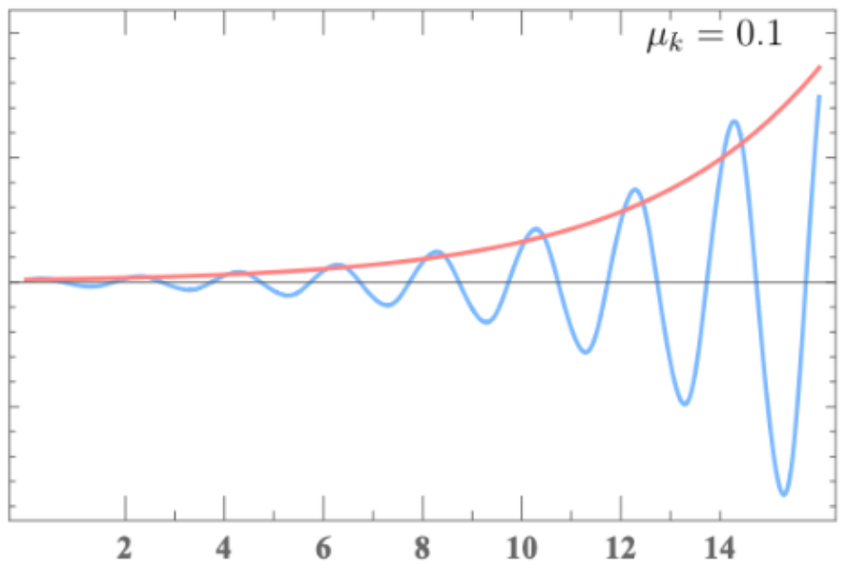

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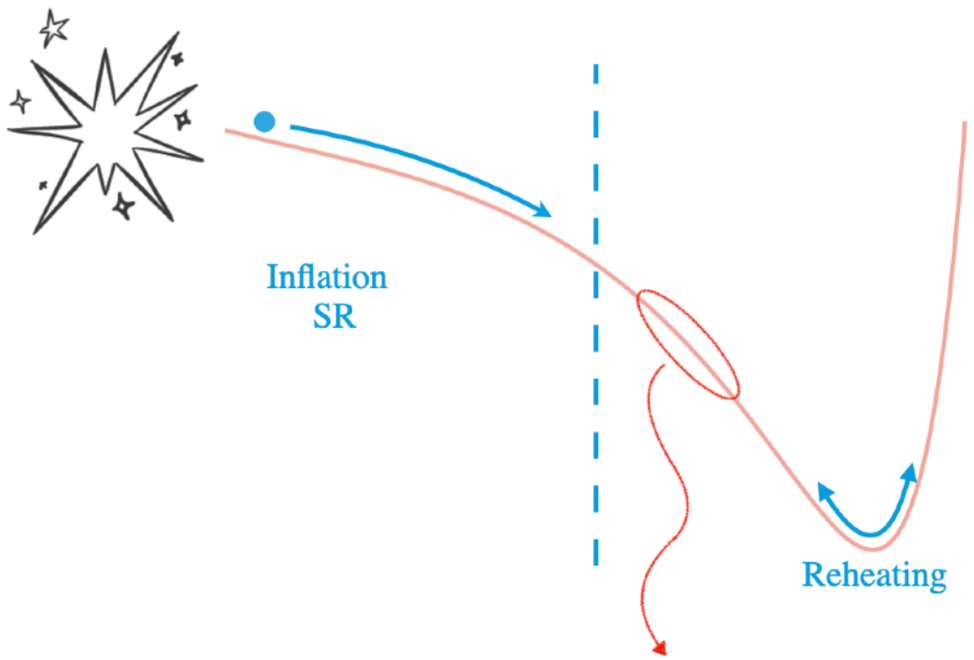

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comoving occupation n.

$$n_k = \frac{\omega_k}{2}\left(\frac{|\dot{\chi}_k|^2}{\omega_k} + |\chi_k|^2\right) - \frac{1}{2}$$

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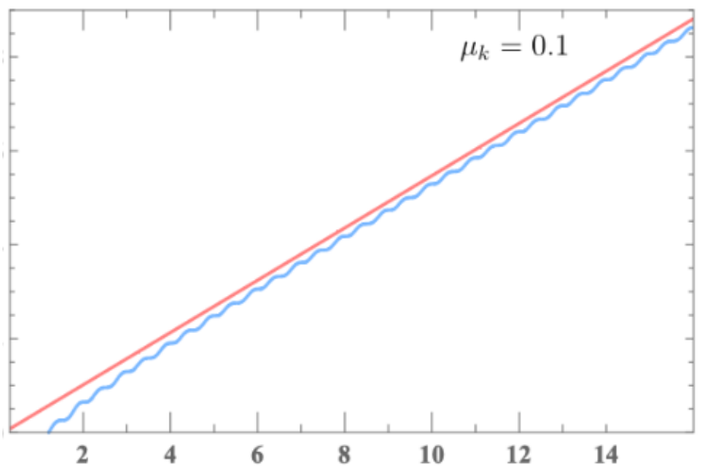

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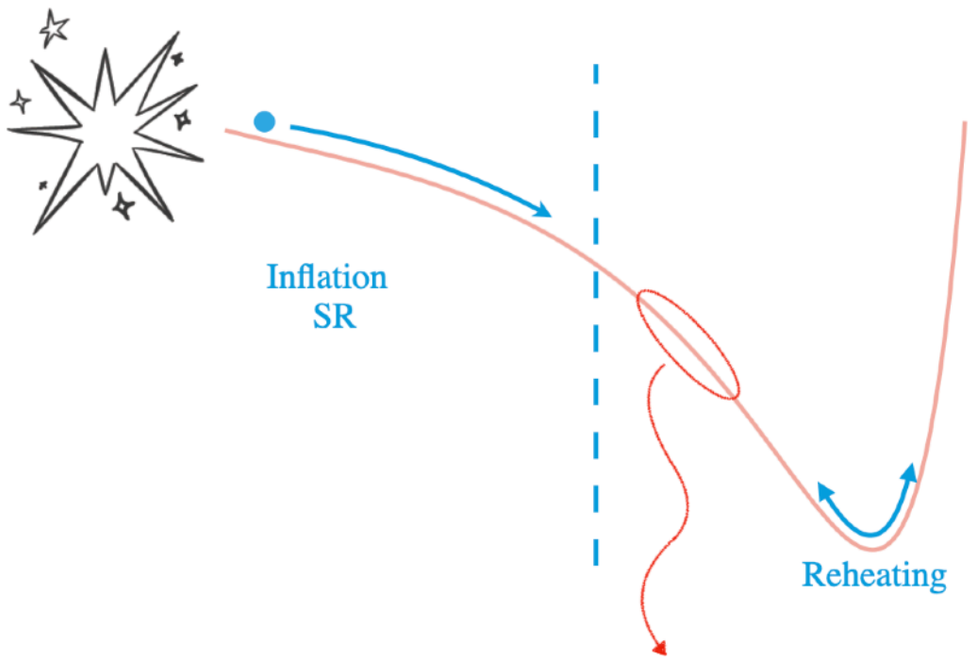

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$$\downarrow$$

$$n_\chi(t) = \frac{1}{(2\pi a)^3}\int d^3k\, n_k(t)$$

Preheating in String Theory

No expansion: Whittaker-Hill equation

$$\ddot{\chi}_k - 2\beta\frac{\Delta\tau}{\langle\tau\rangle}\dot{\chi}_k\sin(m_\tau t) + \left(\frac{4k^2}{m_\tau^2} + \underbrace{\Lambda^4\frac{4a_\tau}{m_\tau^2}e^{-a_\tau\langle\tau\rangle}\left(\langle\tau\rangle + \Delta\tau\cos(m_\tau t)\right)e^{-a_\tau\Delta\tau\cos(m_\tau t)}}\right)\chi_k = 0$$

resonance parameter $q = 4a_\tau\Delta\tau\frac{m_\chi^2}{m_\tau^2}\left(1 - \frac{1}{a_\tau\langle\tau\rangle}\right)$

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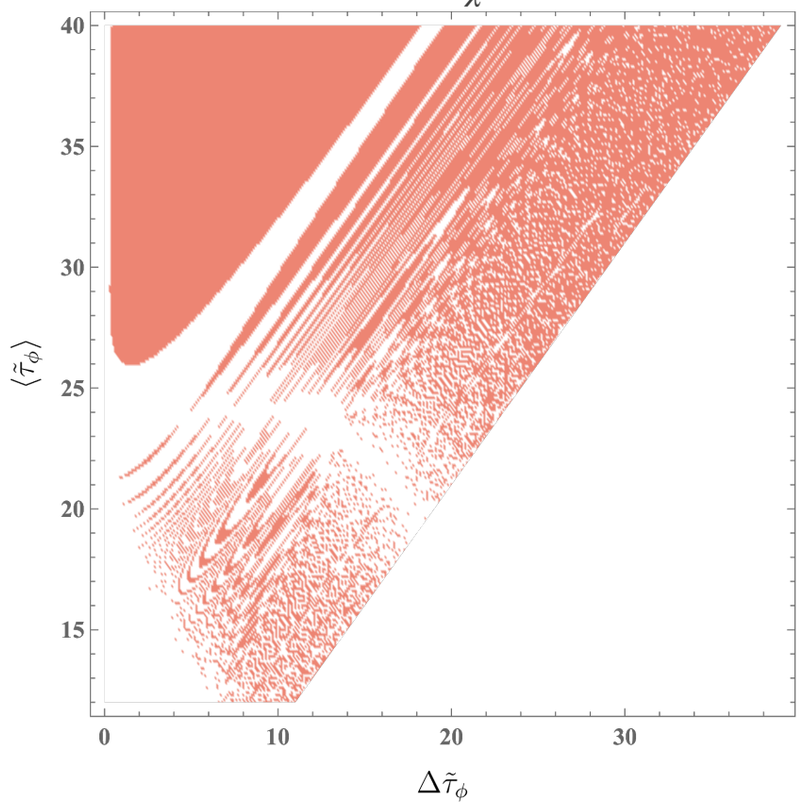
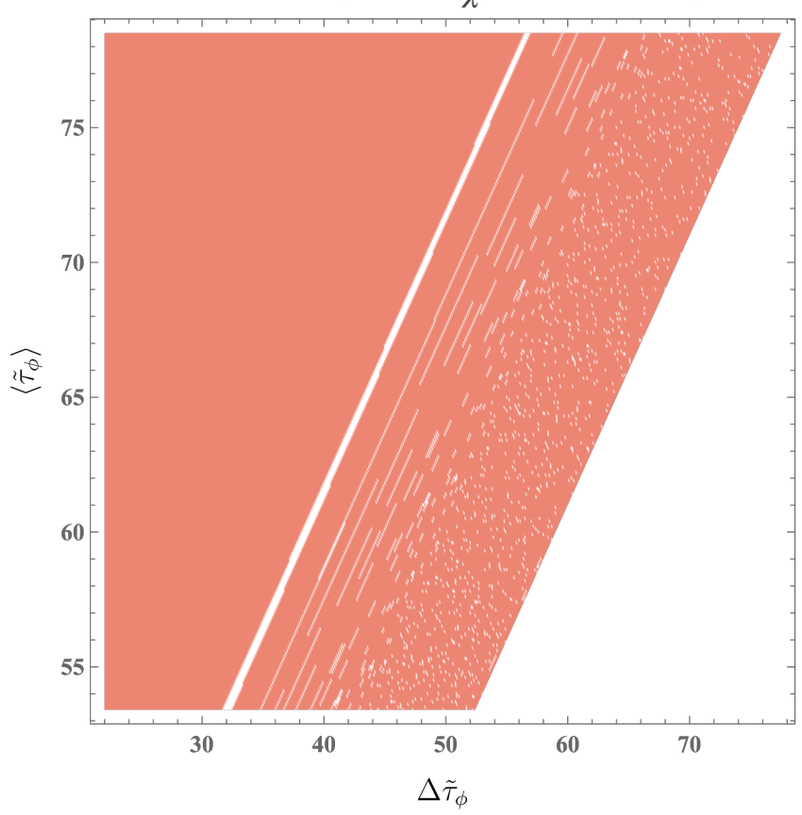
- dark radiation: $m_\chi \lesssim 10^{-31}M_P$
- dark matter $\quad \Omega_\chi^0 = \dfrac{m_\chi\, n_\chi(a_0)}{\rho_c^0}$

$10^{-38}M_P \le m_\chi \le 10^{-31}M_P$



$10^{-11}M_P \le m_\chi \le 10^{-5}M_P$



Preheating in String Theory

Expanding universe

$$\ddot{\chi}_k + \left(3H - 2\beta\frac{\Delta\tau}{\langle\tau\rangle}\dot{\chi}_k \sin(m_\tau t)\right) + \omega^2\chi_k = 0$$

$$\omega^2 = \frac{4k^2}{m_\tau^2 a^2} + \Lambda^4\frac{4a_\tau}{m_\tau^2}\left(\langle\tau\rangle + \Delta\tau\frac{1}{t}\cos(m_\tau t)\right)e^{-\langle a_\tau\rangle\tau}e^{-\Delta\tau\frac{a_\tau}{t}\cos(m_\tau t)}$$

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$\Lambda \simeq 0.4$

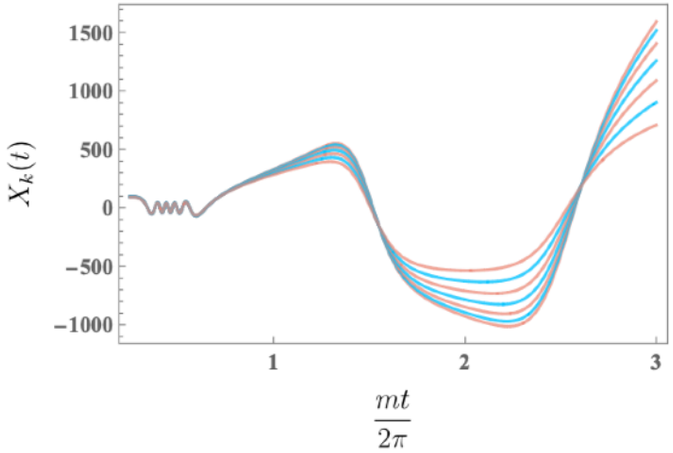
$m_\tau \simeq 5\times 10^{-5} M_P$

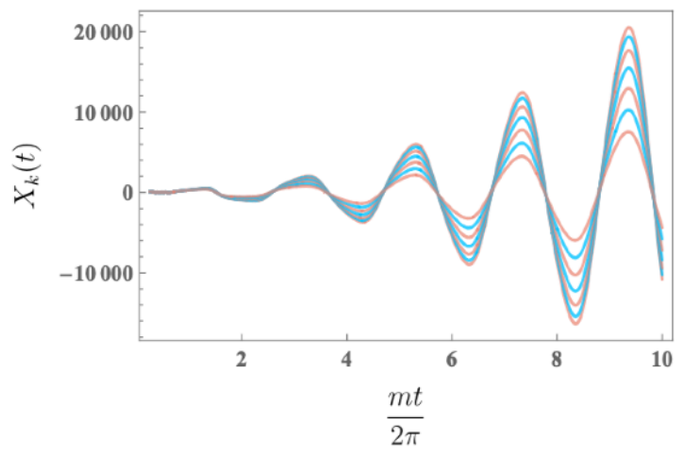
$a_\tau\langle\tau\rangle = 7.5\pi$

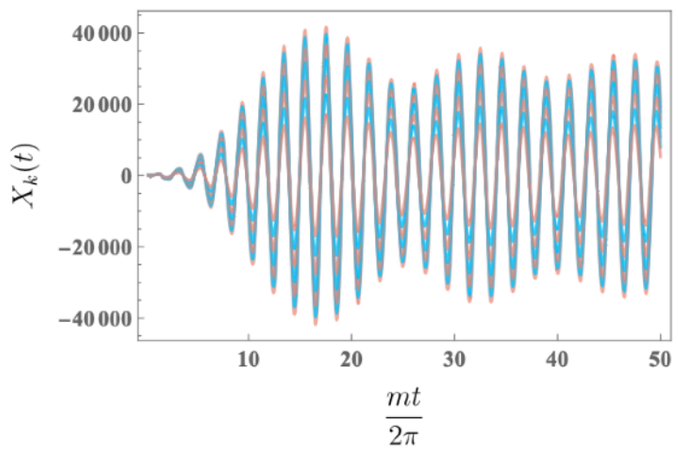
$a_\tau\Delta\tau = 5\pi$

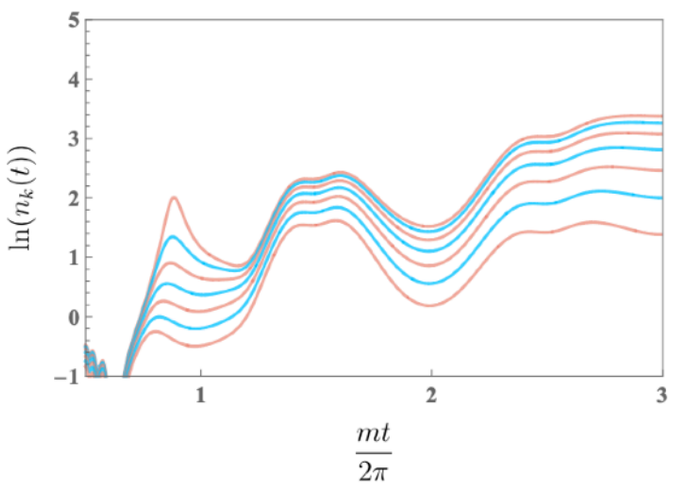
$\Downarrow$

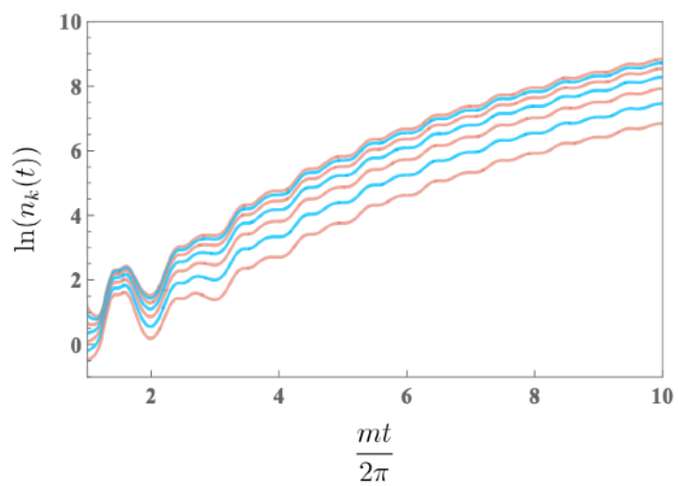
$m_\chi \simeq 5\times 10^{-6} M_P$

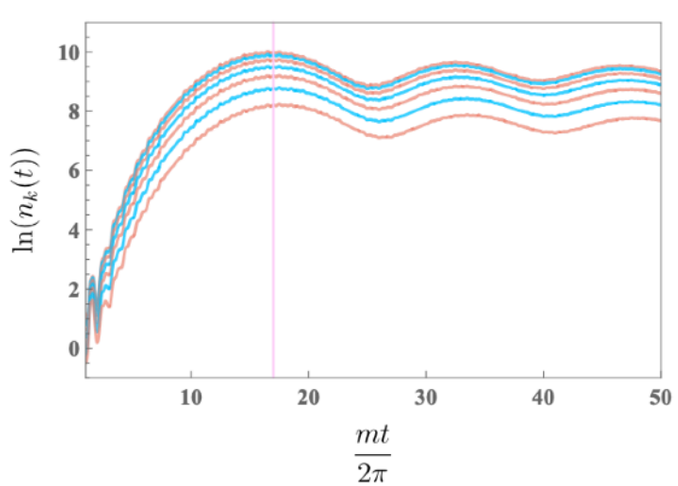












Cosmological Consequences

SM on D7-branes

- SM lives on D7-branes wrapped around inflaton 4-cycle (fibre)

- SM talks to inflaton and hidden sector

- If axion is light $q \to 0$: PR only via kinetic mixing.
  Contribution to $\Delta N_{eff} \lesssim 10^{-6}$

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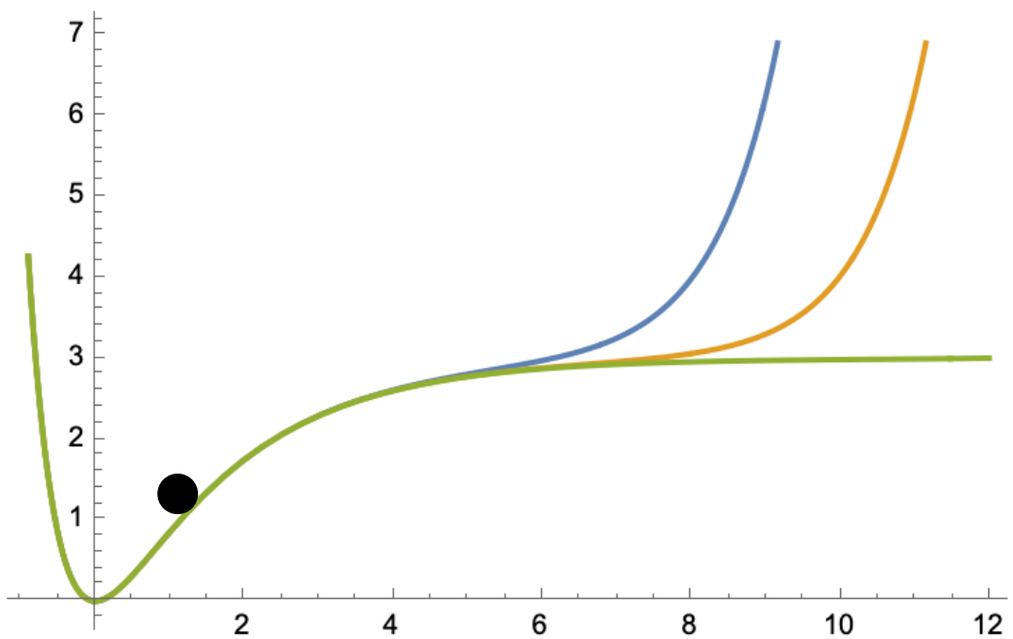
SM on D3-branes

- SM lives on D3-branes at signularities
- SM sequestered from inflaton
- If axion is light $q \to 0$: PR only via kinetic mixing.
  Contribution to $\Delta N_{eff} \lesssim 10^{-6}$
- If axion is heavy, it can decay into
  1. Massless gauge bosons
  2. Gravitons
  3. SM
  4. Light axions

Preheating in Fibre Inflation



[Burgess, Cicoli, Quevedo '08]

$$T_f = \tau_f + i\theta_f \qquad T_b = \tau_b + i\theta_b \qquad T_s = \tau_s + i\theta_s$$

$$\mathscr{V} = \sqrt{\tau_f}\,\tau_b - \tau_s^{3/2} \simeq \sqrt{\tau_f}\,\tau_b$$

$$K = -2\ln\left(\mathscr{V} + \xi/g_s^{3/2}\right)$$

$$W = W_0 + \sum_i A_i\, e^{-a_i T_i}$$

$$V_{ax} \supset \frac{a_f A_f W_0}{\mathscr{V}2}\tau_f e^{-a_f\tau_f}\cos(a_f\theta_f)$$

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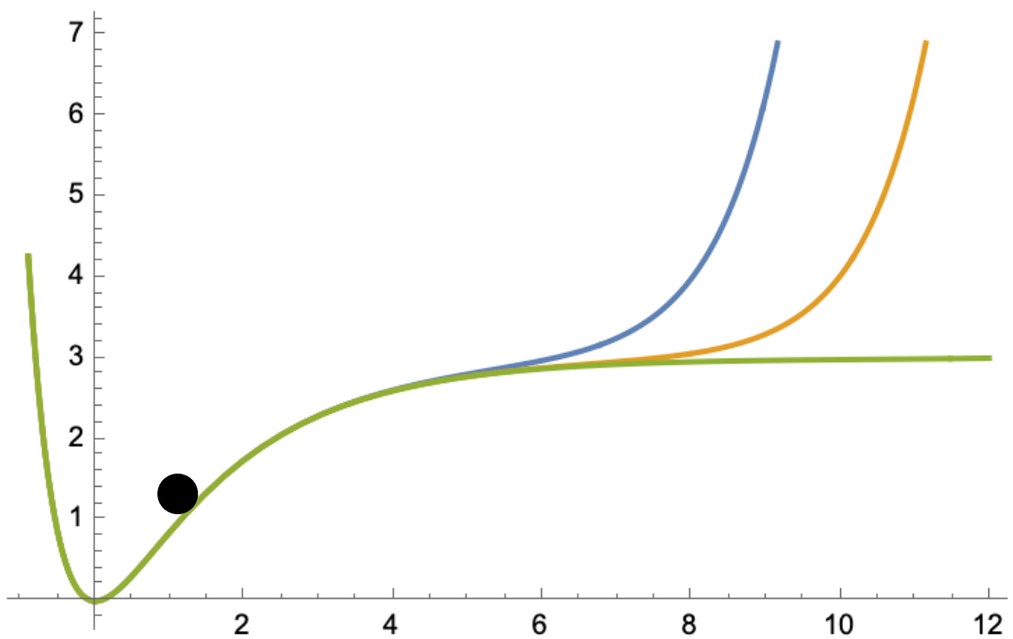

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from loop corrections

$$V_{inf} = \frac{W_0^2}{\mathcal{V}^2}\left(\frac{A}{\tau_f^2} - \frac{B}{\mathcal{V}\sqrt{\tau_f}} + \frac{C\tau_f}{\mathcal{V}^2}\right) \qquad \varphi = \frac{\sqrt{3}}{2}\ln\tau_f$$

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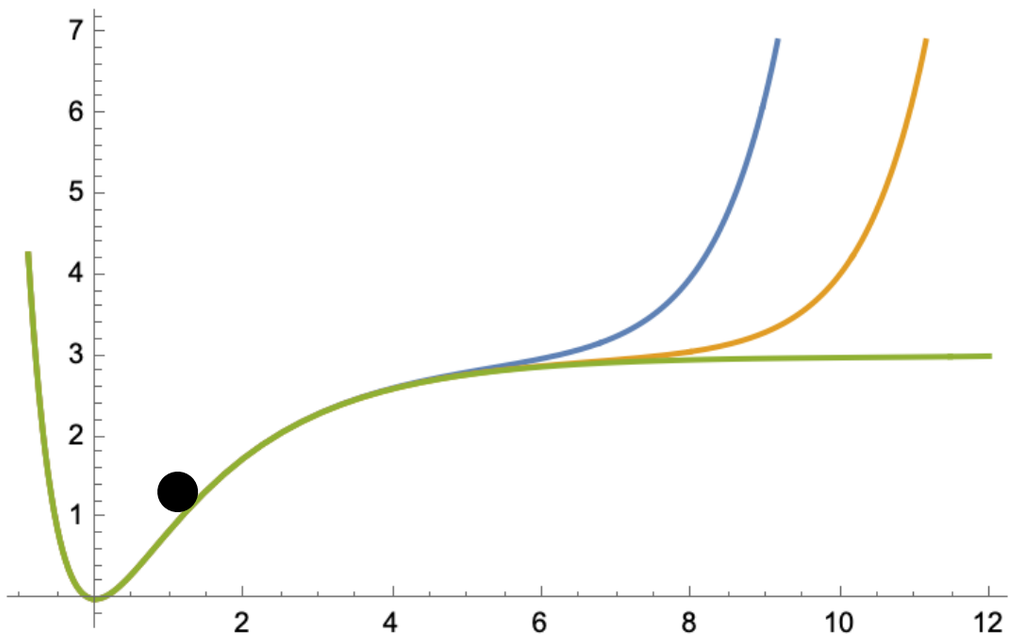

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$$X_k = a^{3/2} \theta_k$$

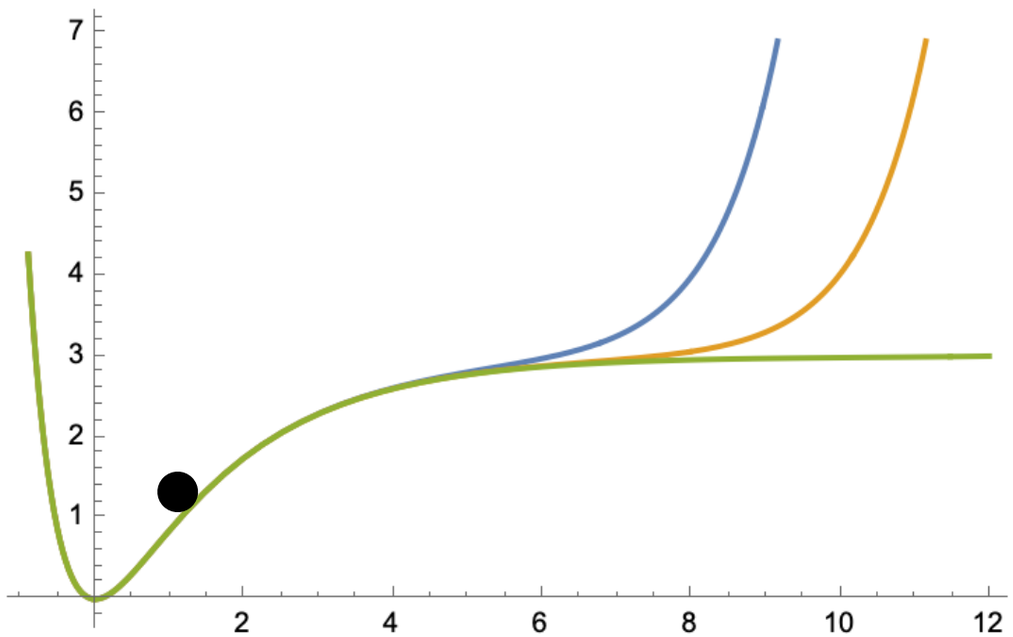
$$X_k'' + 2\varphi' X_k' + \left(\frac{4k^2}{m_\varphi^2} - \frac{\varphi'}{a^{3/2}} + 64 \frac{a_f^3 A_f W_0}{m_\varphi^2 \mathscr{V}^2} \langle \tau_f \rangle^2 (\langle \tau_f \rangle e^{\frac{2}{\sqrt{3}}\varphi}) e^{-\langle \tau_f \rangle e^{\frac{2}{\sqrt{3}}\varphi}} \right) X_k = 0$$

An example:

$$\langle \tau_f \rangle \simeq 7.5, \quad a_f = \frac{2\pi}{4}, \quad f_{\theta_f} \simeq 0.06 M_{Pl} \quad \rightarrow \; m_{\theta_f} \simeq 8 \times 10^{-5} M_P$$

$$\mathscr{V} \simeq 935.5\,, \quad \langle \tau_b \rangle = \frac{\mathscr{V}}{\sqrt{\langle \tau_f \rangle}} \simeq 341.2 \quad \rightarrow \quad m_{\theta_b} \simeq 0$$

Preheating in Fibre Inflation



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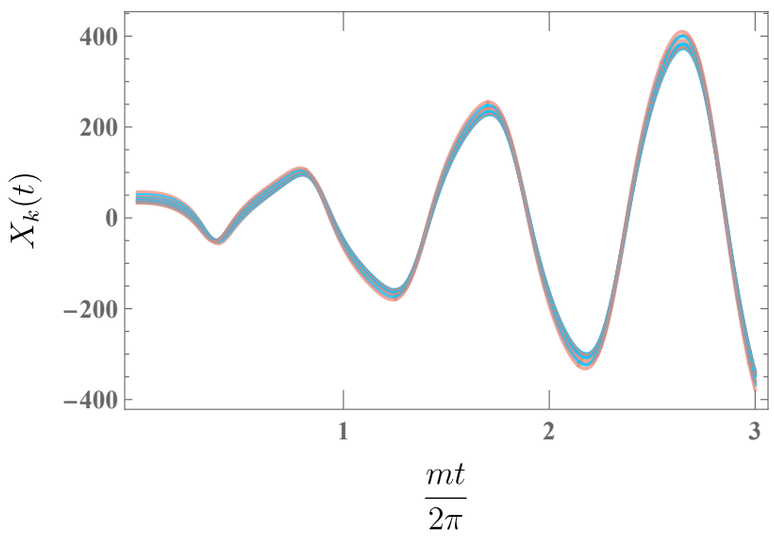

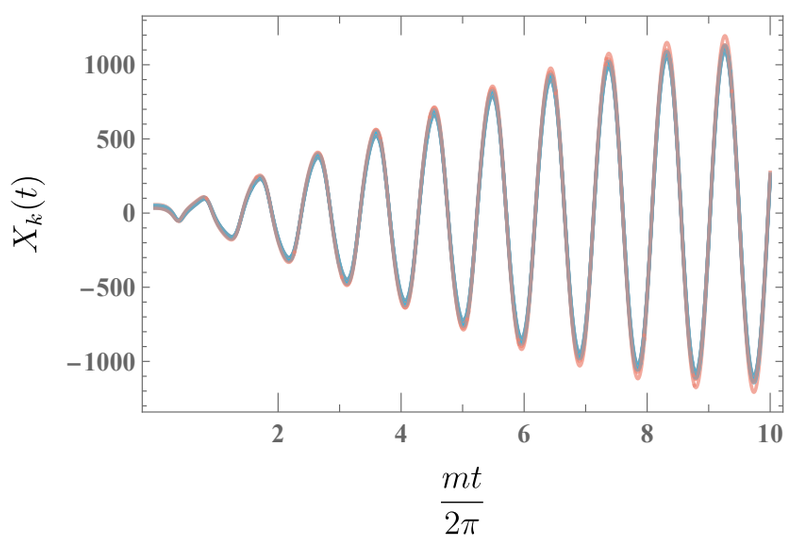

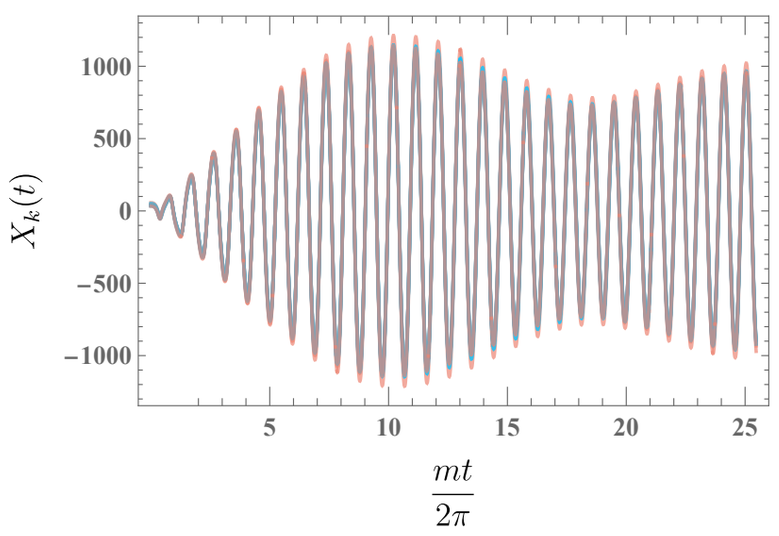

The Fate of Preheated Axions

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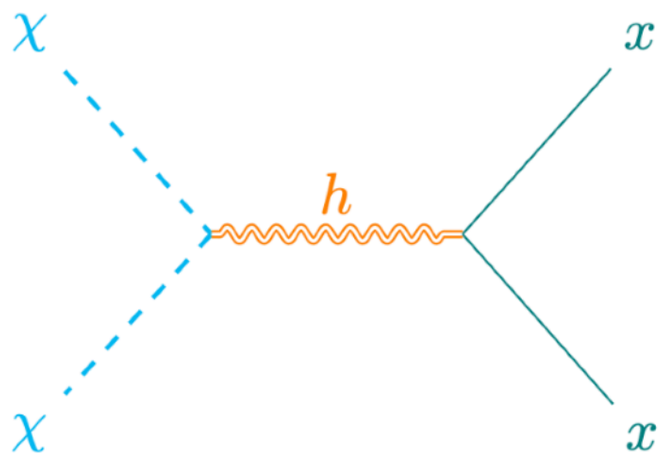

- If axion is heavy ($m_{\chi_f} \simeq 8 \times 10^{-5} M_{Pl}$), it can decay into

1. **Massless gauge bosons**
2. Gravitons
3. SM
4. Light axions
5. Condensing gauge group

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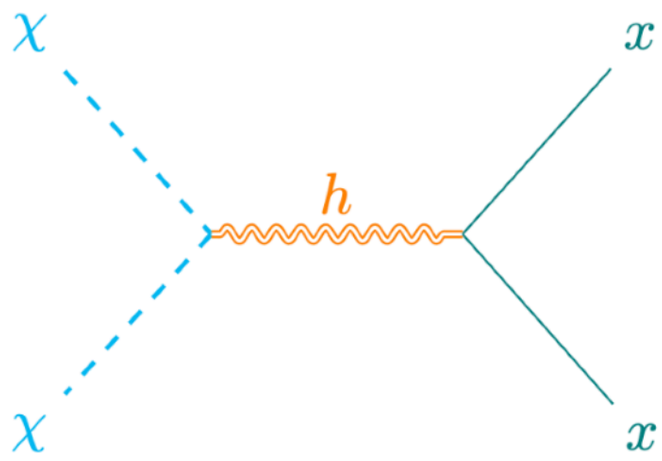


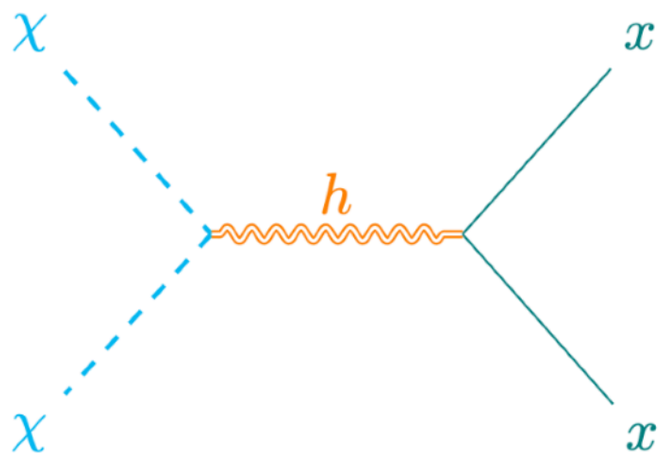
$$\mathscr{L} \supset -g_{a\tilde{\gamma}\tilde{\gamma}}\frac{a}{f}F\tilde{F}$$

$$\Gamma_{\theta\to\tilde{\gamma}\tilde{\gamma}} \simeq \frac{1}{64\pi}\frac{m_\theta^3}{f_\theta^2}$$

The Fate of Preheated Axions

SM on D3-branes

- SM on D7-branes → reheating
- SM lives on D3-branes at signularities → sequestered from inflation



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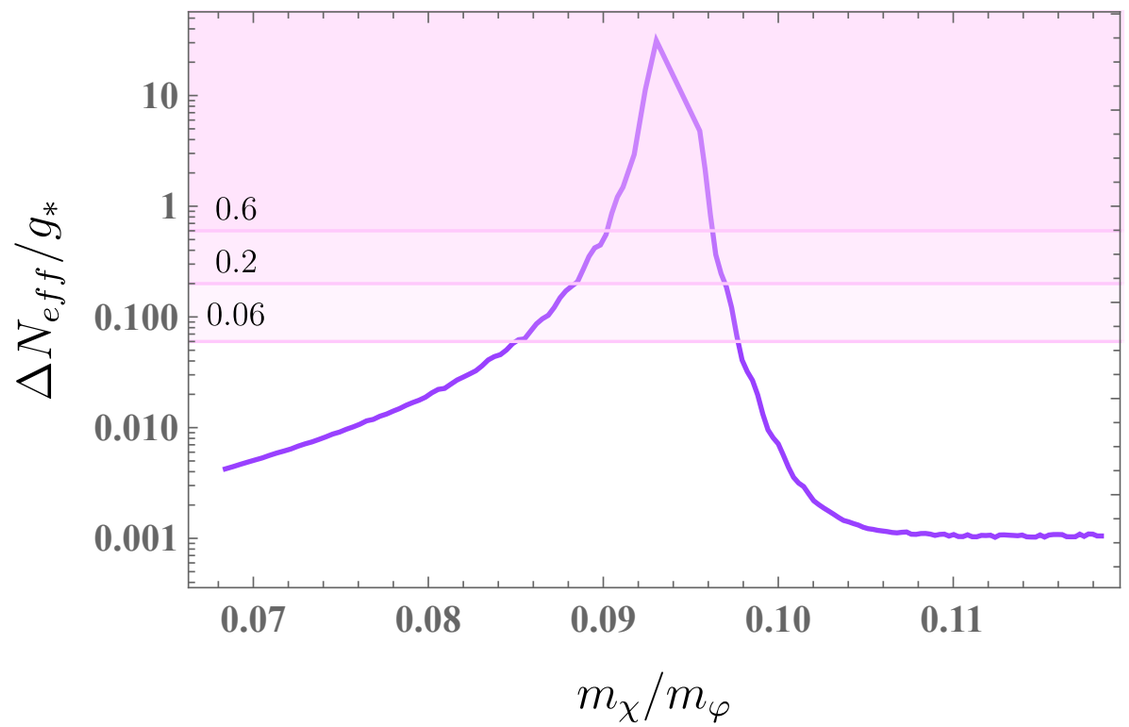
$$\Gamma_{\theta\to\tilde{\gamma}\tilde{\gamma}} \simeq \frac{1}{64\pi}\frac{m_\theta^3}{f_\theta^2}$$

$$\Delta N_{eff} = \frac{8}{7}\left(\frac{T}{T_\nu}\right)^4\frac{\rho_{\tilde{\gamma}}}{\rho_\gamma} = \frac{120}{7\pi^2}\left(\frac{11}{4}\right)^{4/3}\frac{\rho_{\tilde{\gamma}}^{dec}}{T_{reh}^4}\left(\frac{a_{dec}}{a_{reh}}\right)^4$$



What We Learnt

- parametric resonance in string inflation ≠ in EFT inflation
- production of heavy dark matter
- production of dark radiation

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Thank you!