COSMIC WISPERS CA21106

LEVERHULME TRUST

KING'S College LONDON

Nonperturbative production of axions in string inflation

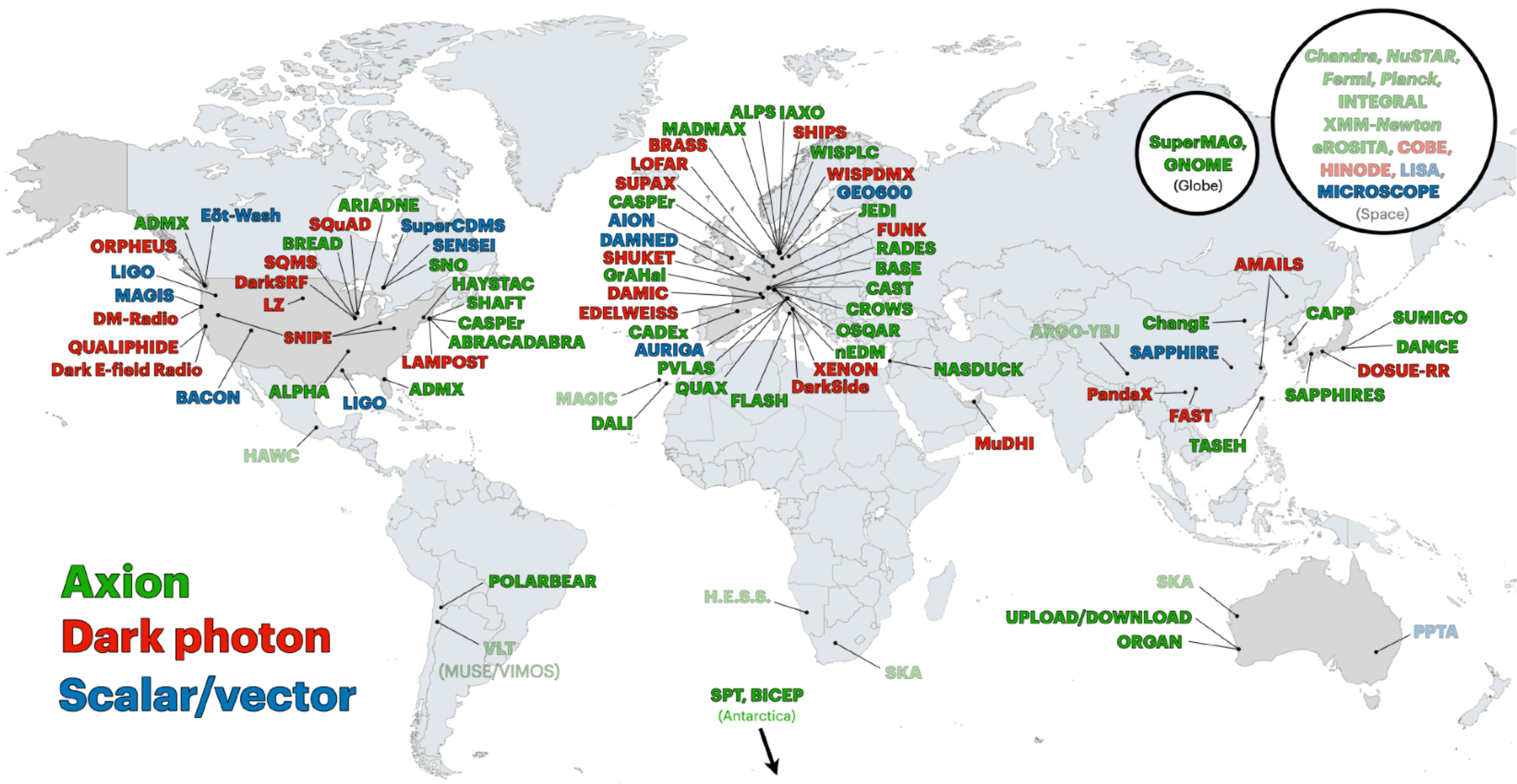
Nicole Righi

Work in progress with

Jacob Leedom, Margherita Putti and Alexander Westphal

Padova, String Phenomenology 2024

The Search for Axions



[O'Hare Website *AxionLimits*]

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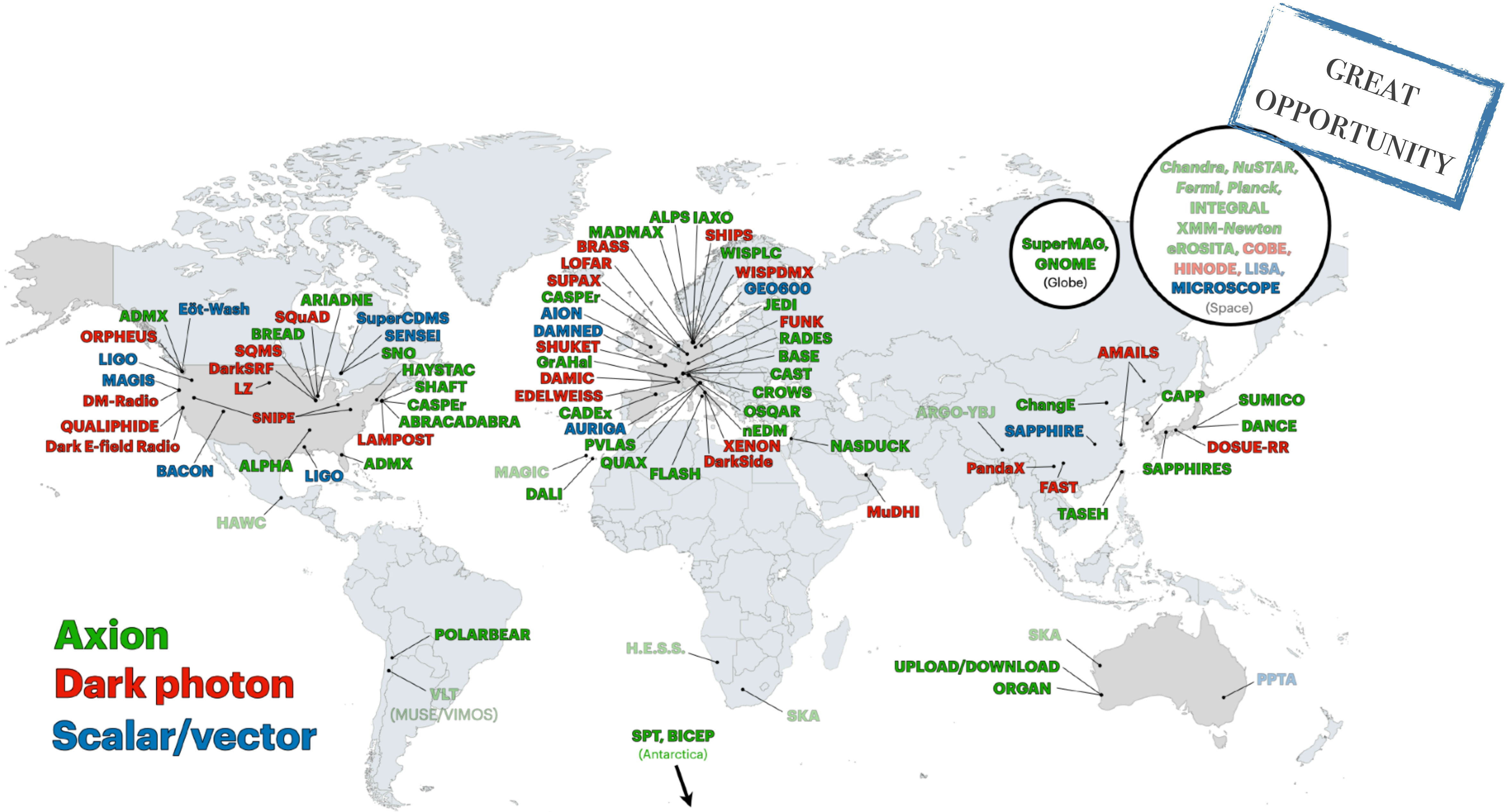
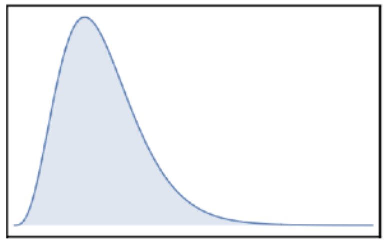


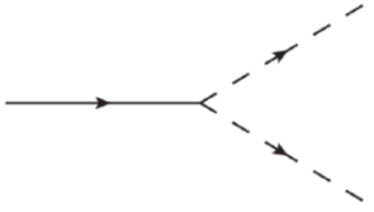
[O'Hare Website *AxionLimits*]

How to Produce an Axion Population

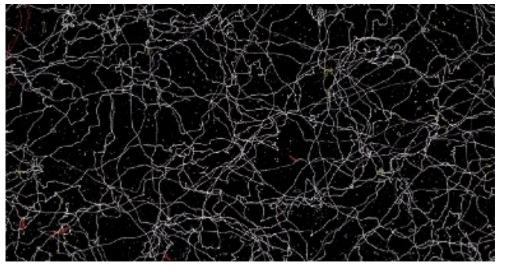
- thermal



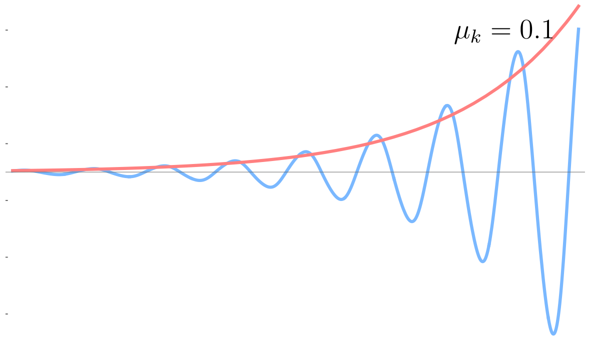
- particle decay



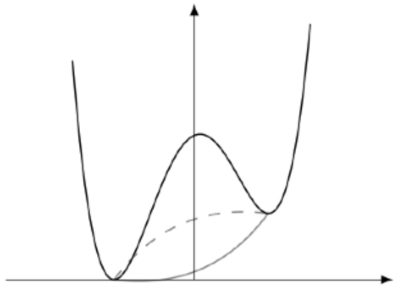
- topological defects decay



- parametric resonance



- misalignment mechanism



model dependent

model independent

Axion-Saxion Coupling

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

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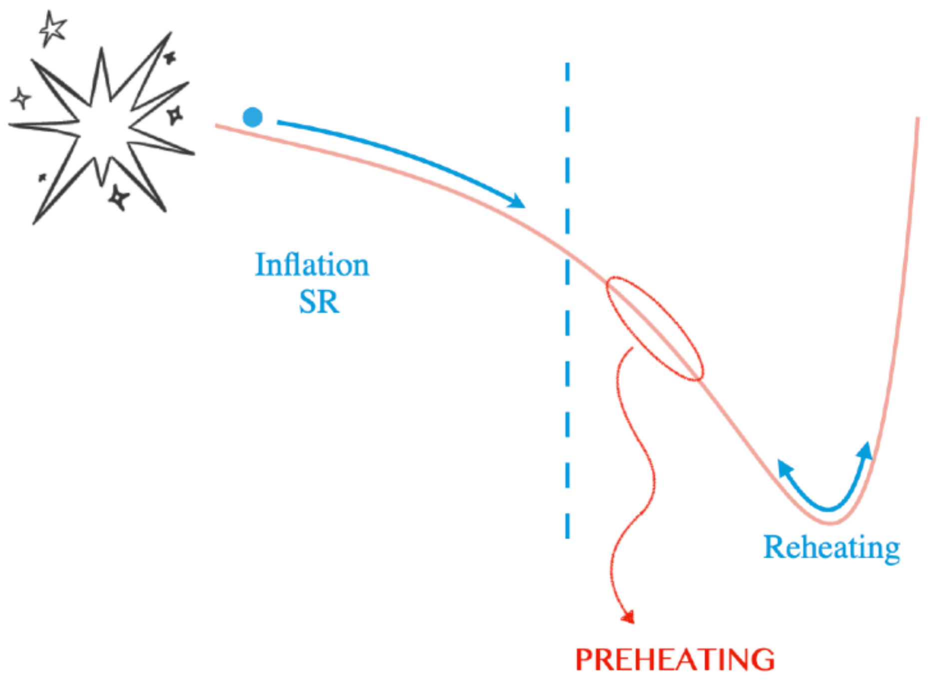
$\Rightarrow$ Very simple, but generic!

Parametric Resonance



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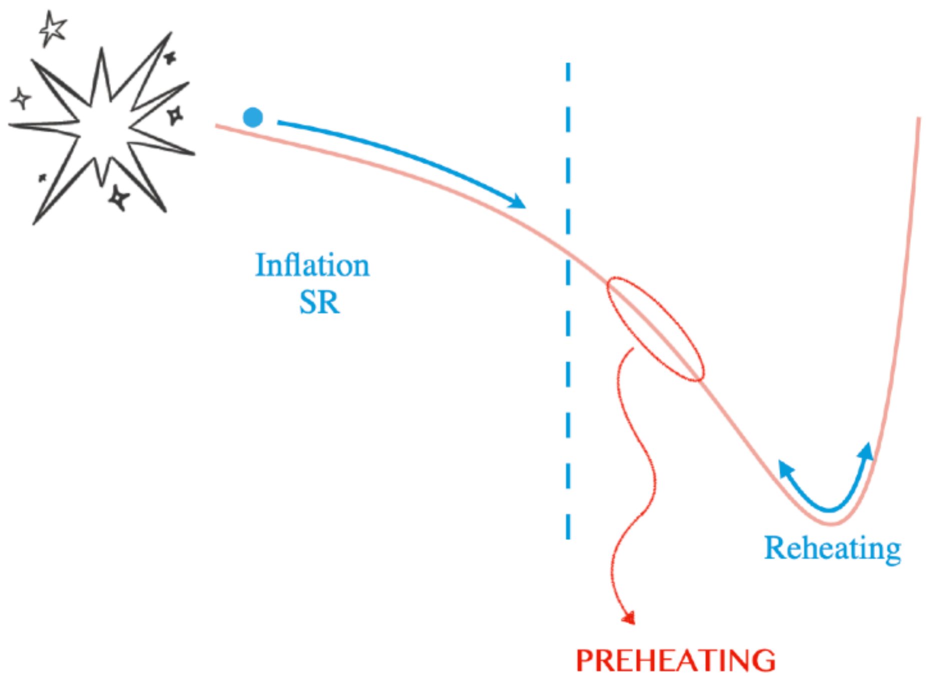


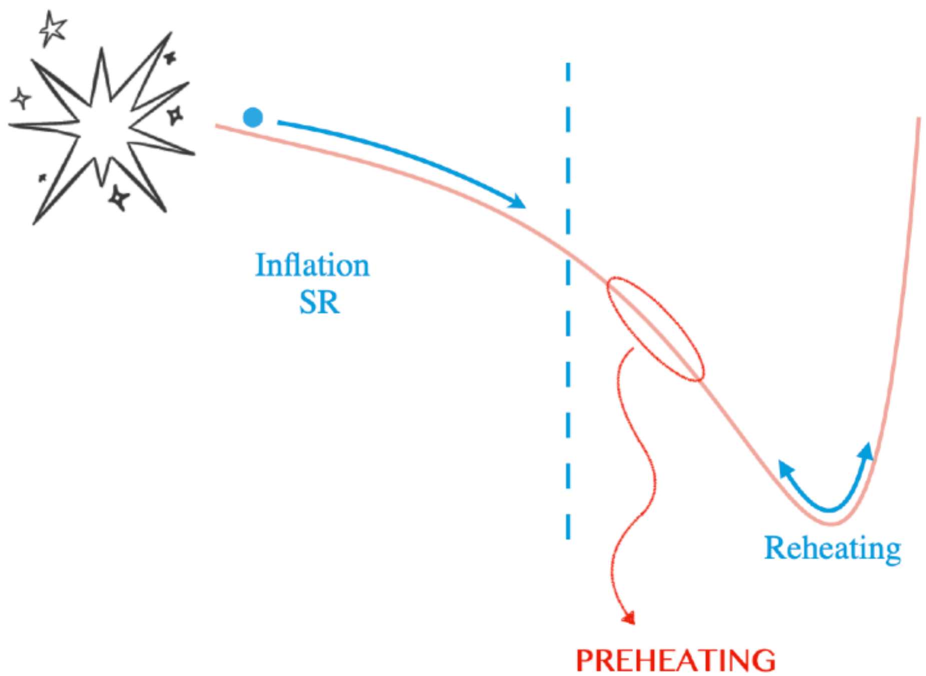
$$\mathscr{L} \supset -\frac{1}{2}m_\phi^2\phi^2 - g\phi^2\chi^2 - \frac{1}{2}m_\chi^2\chi^2$$

$$m^2_{\chi,eff}(\phi) = m_\chi^2 + 2g\phi^2$$

$$\phi(t) = \langle\phi\rangle + \frac{\Delta\phi}{t}\cos(m_\phi t)$$
$$\chi(t,\vec{x}) = \langle\chi\rangle + \delta\chi_k(t,\vec{x})$$

$\Rightarrow$ Apply Floquet theory

Parametric Resonance



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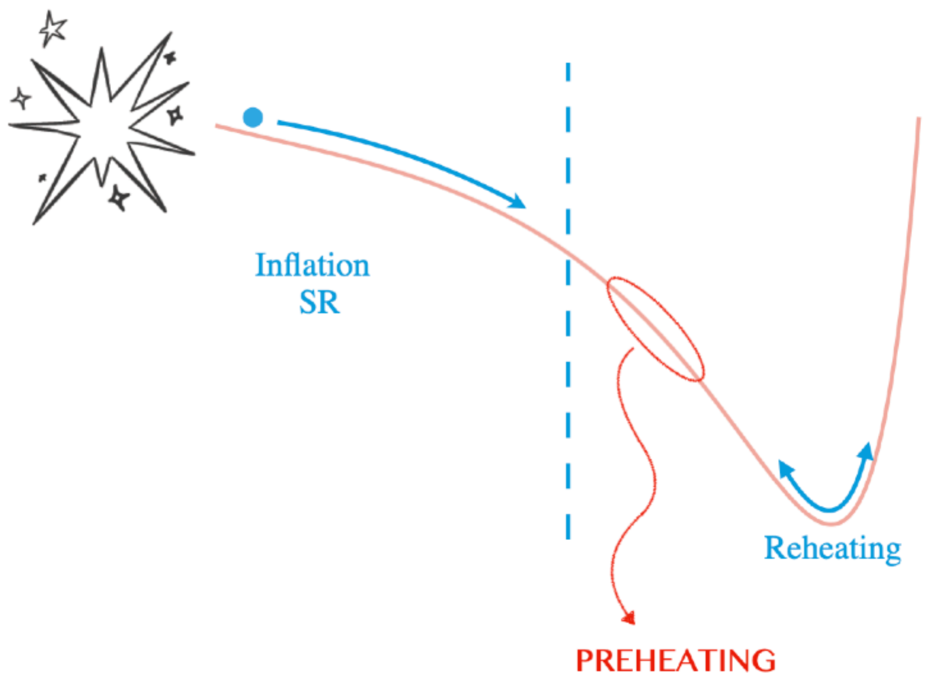
$$\ddot{\chi}_k + \left(k^2 + qF(t)\right)\chi_k = 0$$

Hill equation

Parametric Resonance



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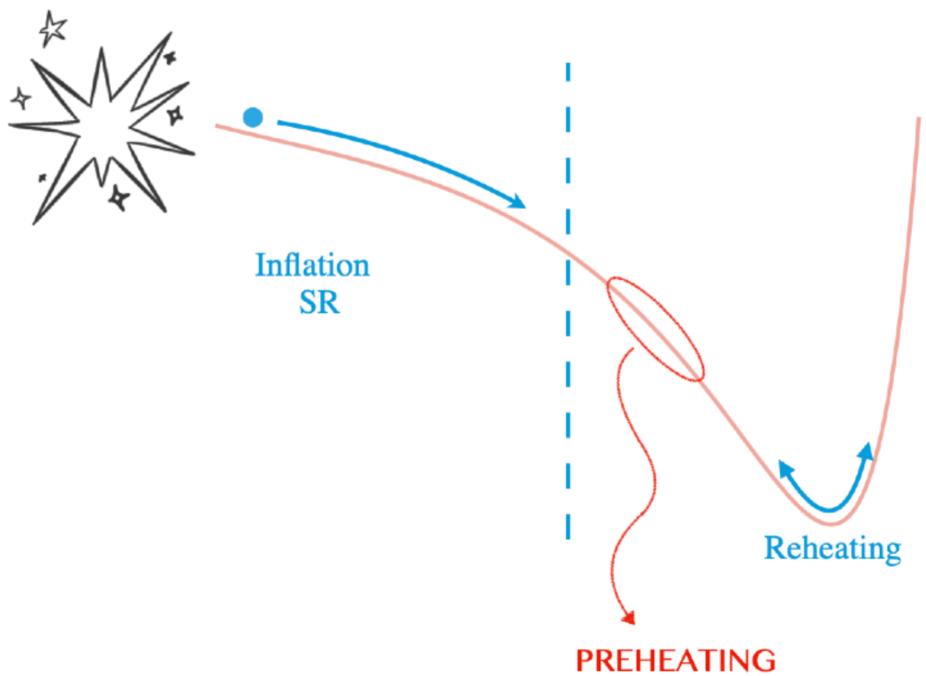

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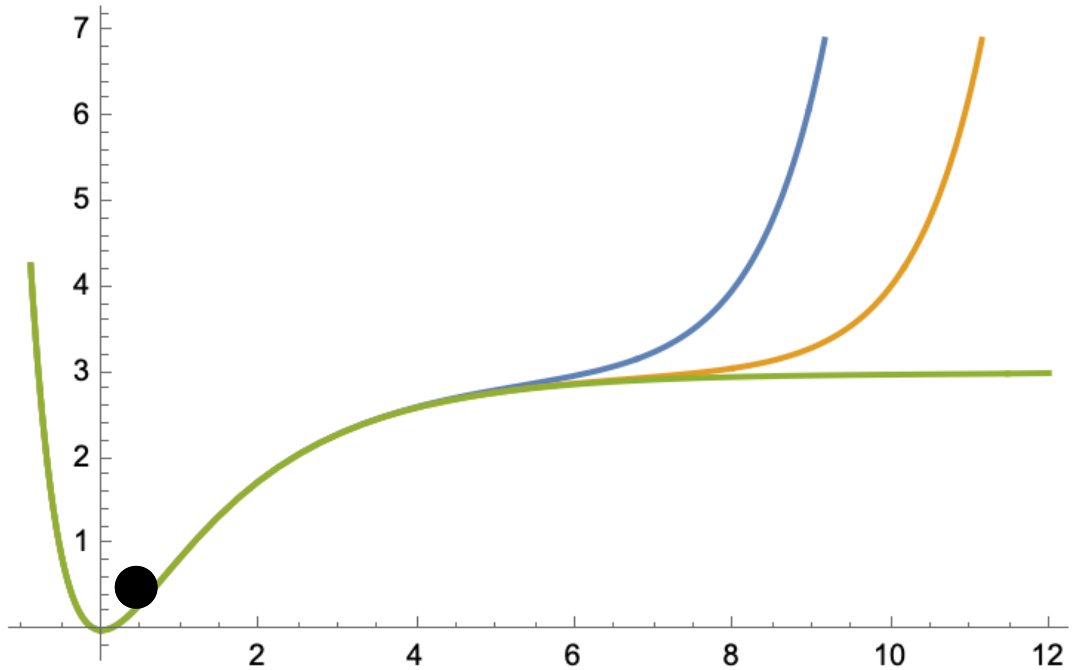
Hill equation

comoving occupation n.

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

Parametric Resonance in String Inflation

[Leedom, Putti, NR, Westphal *to appear*]



$$V \supset \Lambda\, e^{-a\tau}\left(1 + \cos(a\theta)\right)$$

$$m_\theta^2 \sim \Lambda\, e^{-a\langle\tau\rangle}$$

$$m_{\theta,eff}^2 = m_\theta^2 \left(1 + \frac{\Delta\tau}{\langle\tau\rangle}\frac{2}{m_\tau t}\right) e^{-\frac{2a\Delta\tau}{m_\tau t}\cos(m_\tau t)}$$

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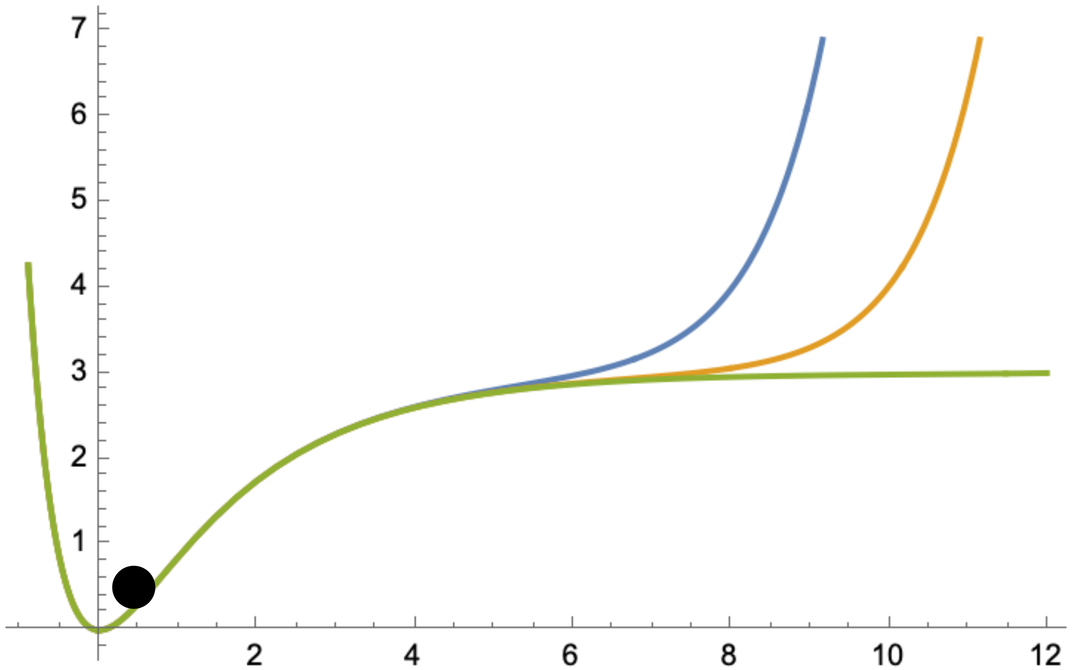

$$\tau \simeq \langle\tau\rangle + \Delta\tau \frac{1}{t}\cos(m_\tau t)$$
$$\theta(t,\vec{x}) = \langle\theta\rangle + \delta\theta(t,\vec{x})$$

$$V \supset \Lambda\, e^{-a\tau}\left(1+\cos(a\theta)\right)$$

$$m_\theta^2 \sim \Lambda\, e^{-a\langle\tau\rangle}$$

$$m_{\theta,eff}^2 = m_\theta^2 \left(1 + \frac{\Delta\tau}{\langle\tau\rangle}\frac{2}{m_\tau t}\right) e^{-\frac{2a\Delta\tau}{m_\tau t}\cos(m_\tau t)}$$

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

resonance parameter q

$$q = 4a\Delta\tau\frac{m_\theta^2}{m_\tau^2}\left(1 - \frac{1}{a\langle\tau\rangle}\right)$$

Parametric Resonance: Observables

[Leedom, Putti, NR, Westphal *to appear*]

$$q = 4a\Delta\tau\frac{m_\theta^2}{m_\tau^2}\left(1 - \frac{1}{a\langle\tau\rangle}\right)$$

- dark radiation: $m_a \lesssim 10^{-31}M_P \;\Rightarrow\;$ contribute to N_{eff} as ΔN_{eff}
- dark matter $\Omega_\theta = \dfrac{m_\theta\, n_\theta(a_0)}{\rho_c}$

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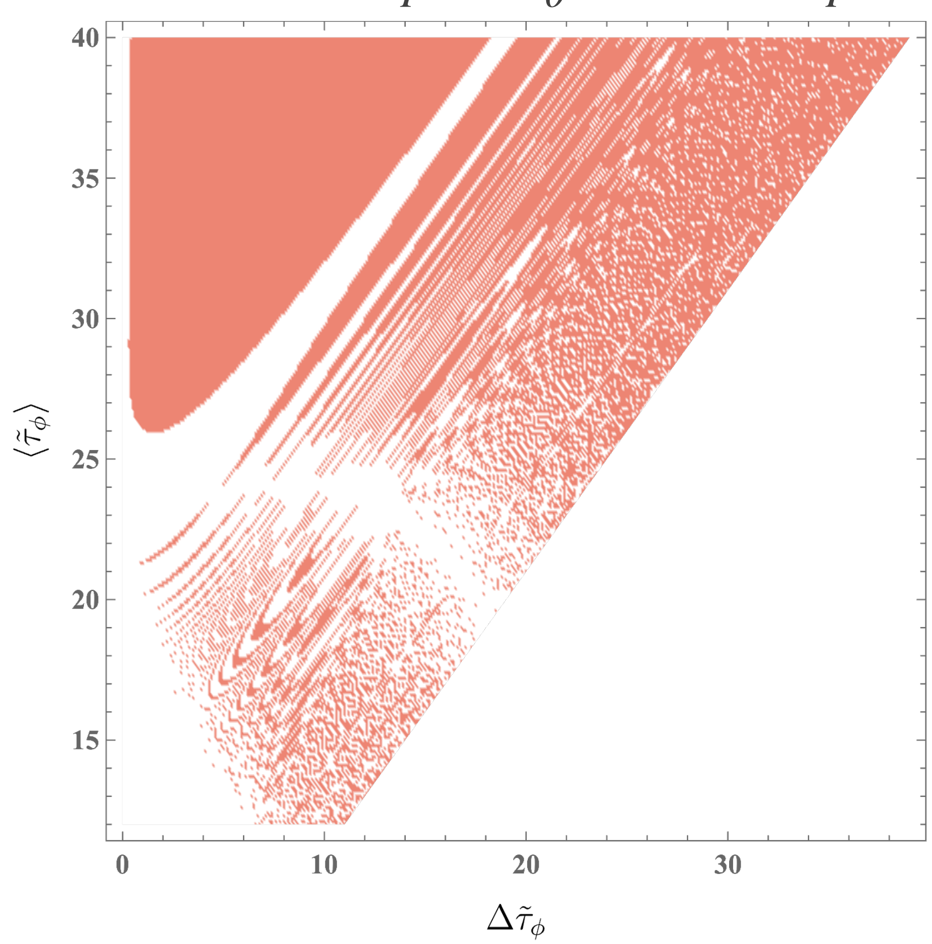
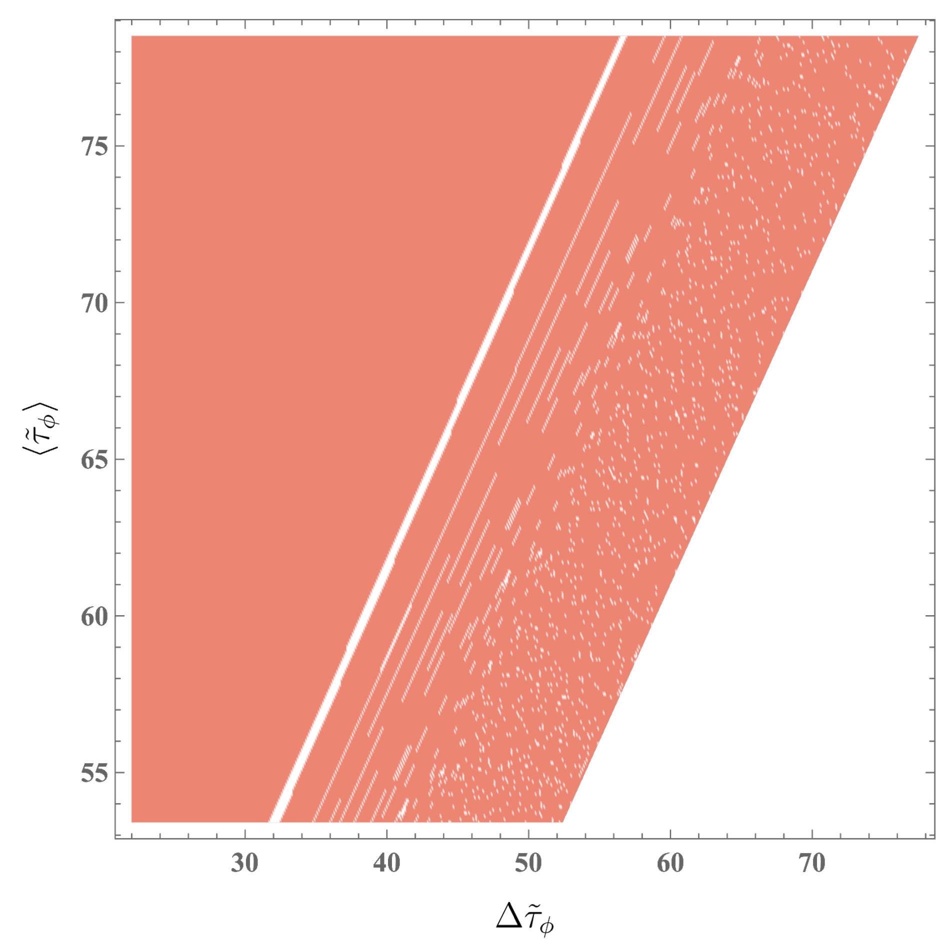
$10^{-38} M_P \leq m_\theta \leq 10^{-31} M_P$



$10^{-11} M_P \leq m_\theta \leq 10^{-5} M_P$



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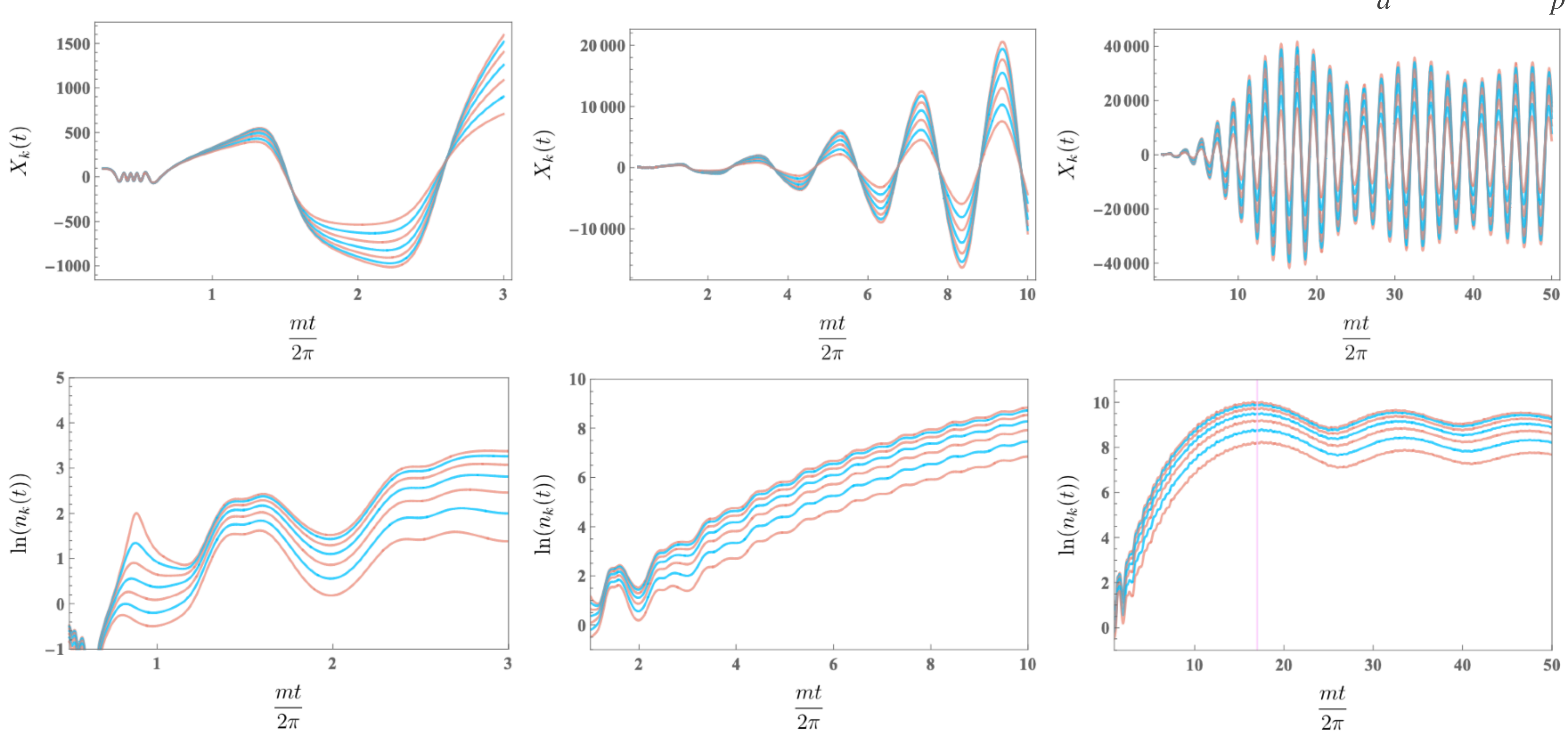
$m_a \sim 10^{-7} M_p$



Parametric Resonance: Consequences

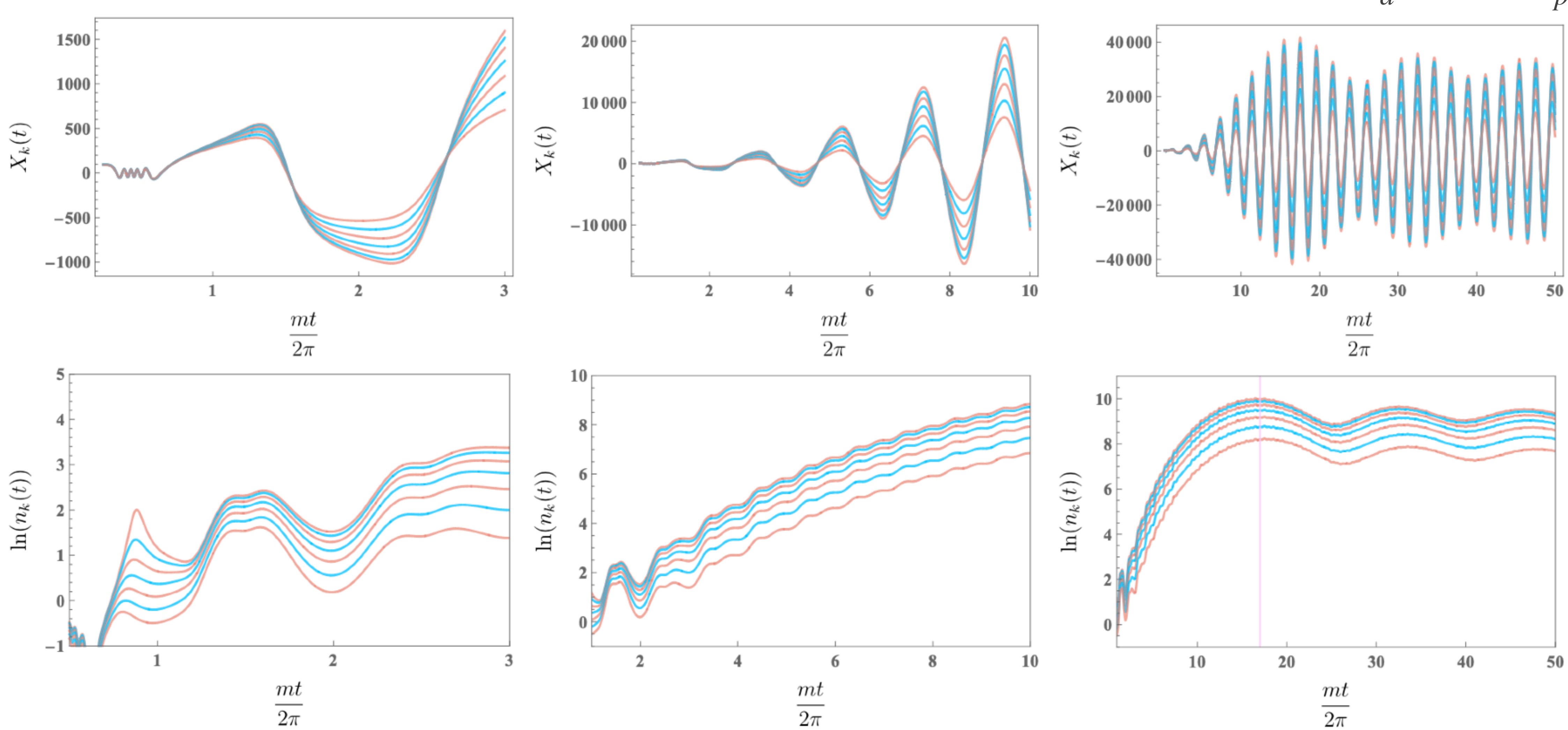
[Leedom, Putti, NR, Westphal *to appear*]

Application: fibre inflation

$$q = 4a\Delta\tau \frac{m_\theta^2}{m_\tau^2}\left(1 - \frac{1}{a\langle\tau\rangle}\right)$$

- dark radiation: no appreciable contribution $\Delta N_{eff} \sim 10^{-6}$
- dark matter $\frac{\Omega_\theta h^2}{0.12} \gg 1$

$m_a \sim 10^{-7} M_p$



What We Learnt

- parametric resonance in string inflation $\neq$ in EFT inflation
- great production of heavy dark matter
- very poor production of dark radiation

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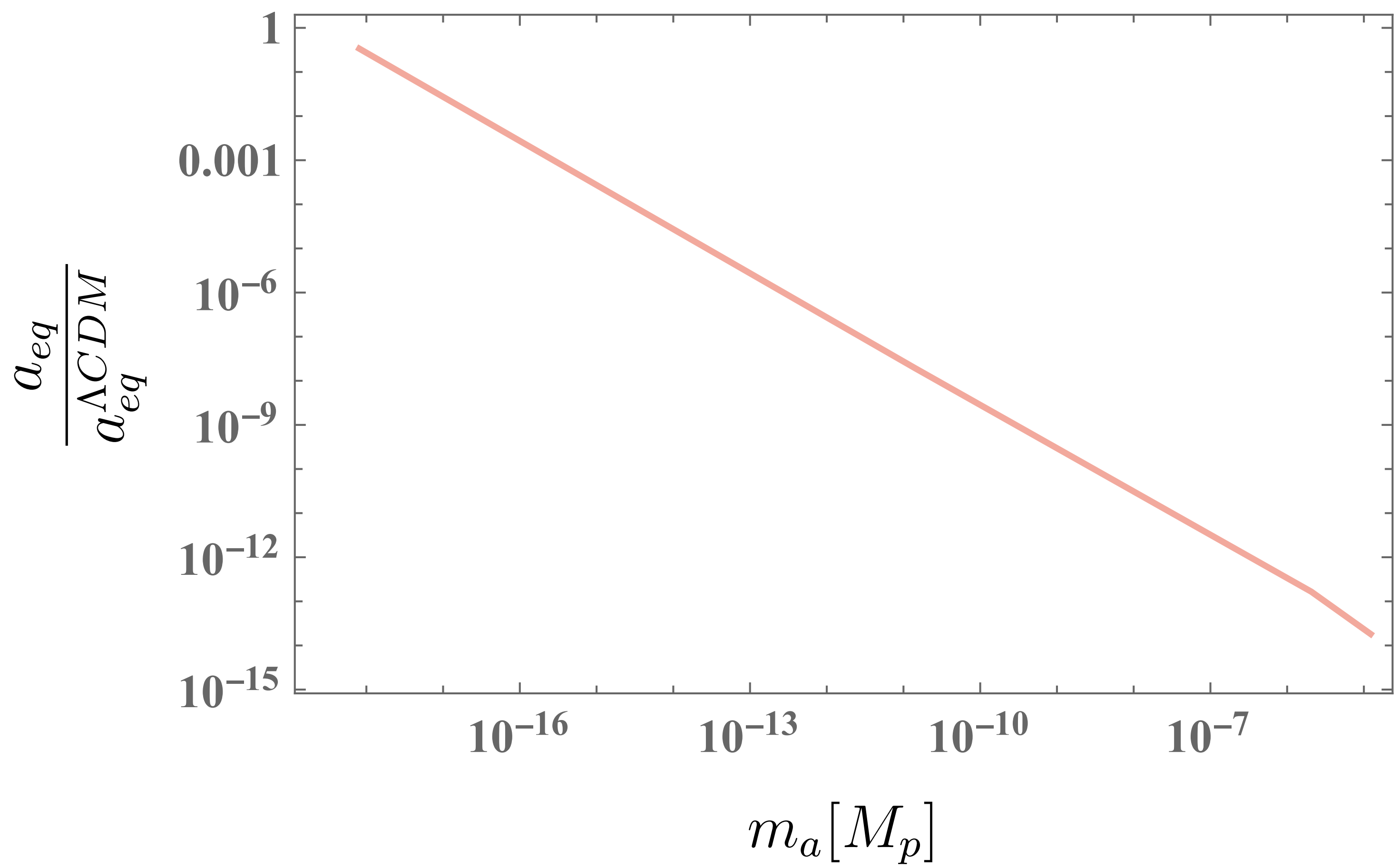
Thank you!



$\frac{a_{eq}}{a_{eq}^{\Lambda CDM}}$
1
0.001
10^{-6}
10^{-9}
10^{-12}
10^{-15}
10^{-16}
10^{-13}
10^{-10}
10^{-7}
$m_a[M_p]$