

Massless Preheating and Electroweak Vacuum Metastability

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[arXiv:2105.06939]

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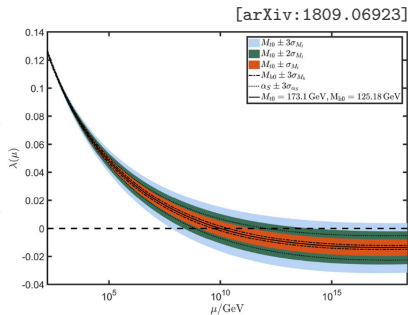
PHENO 2021

Monday, May 24th, 2021

Metastability of Electroweak Vacuum

- Current measurements of SM parameters suggest the Higgs self-coupling $\lambda_h(\mu)$ **runs negative** at energy scales $\mu \gtrsim 10^{10}$ GeV

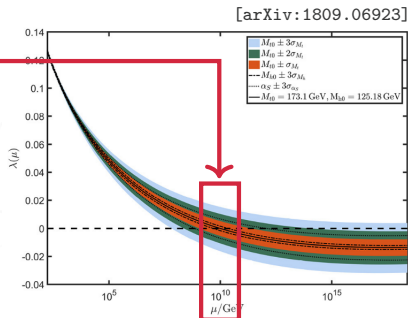
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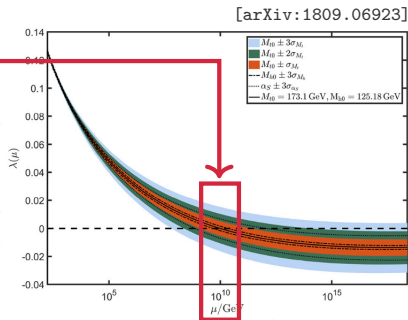


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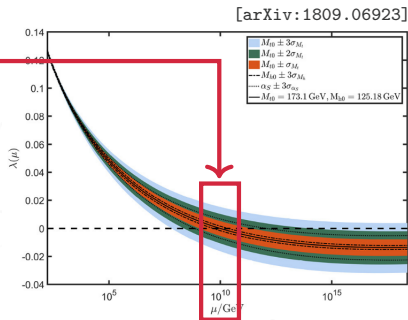
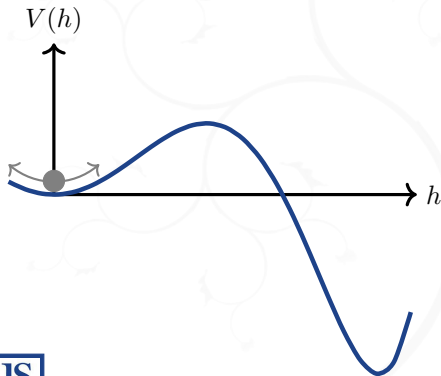


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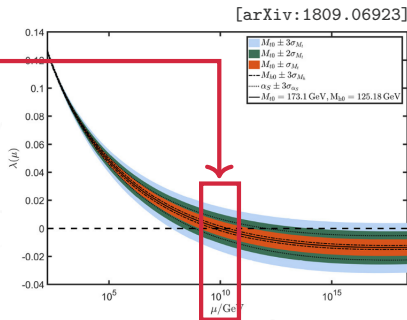
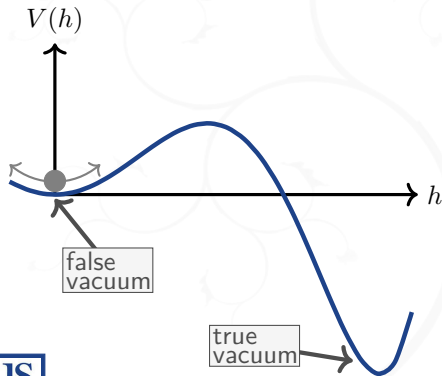


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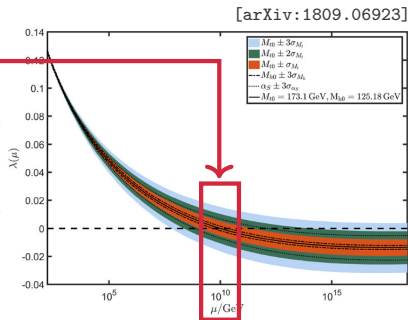
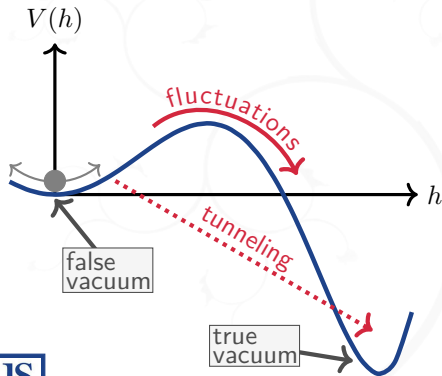


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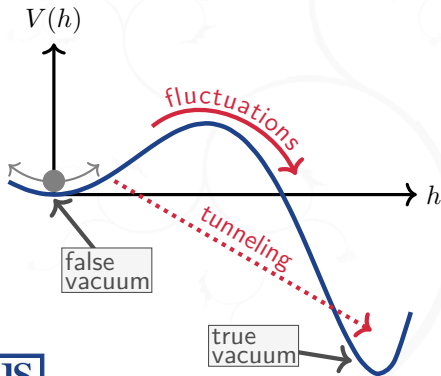


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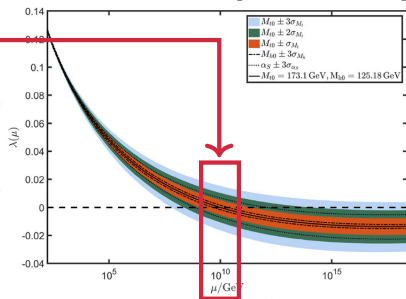
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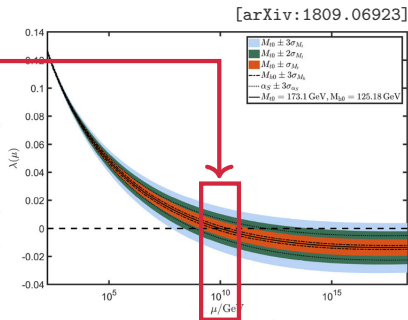
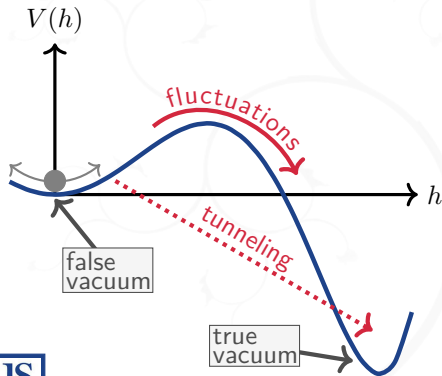
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The fact that false vacuum has *persisted* may provide *window* into *early-universe* dynamics involving the Higgs field.

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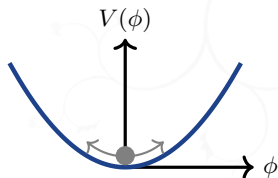
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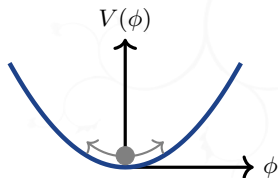
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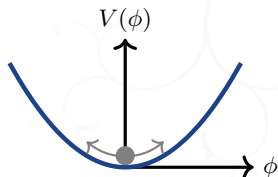
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$$\frac{d^2\varphi}{d\eta^2} + \lambda_\phi\varphi^3 = 0$$

for conformal time η and $\varphi \equiv a\phi$

$$\varphi(x) = \bar{\varphi} \operatorname{cn}\left(x - x_0, \frac{1}{\sqrt{2}}\right),$$

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Similarly, Higgs fluctuations grow *steadily* and **uninterrupted**—appears catastrophic for EW metastability.

on closer inspection,
is there a **regime of viability**
for massless preheating?

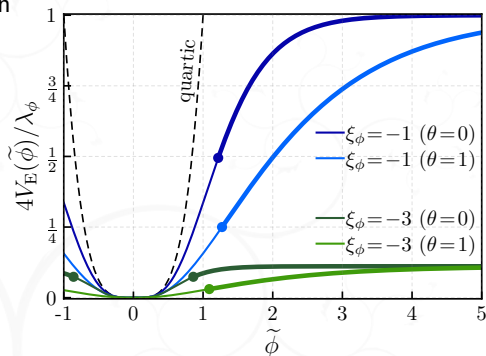
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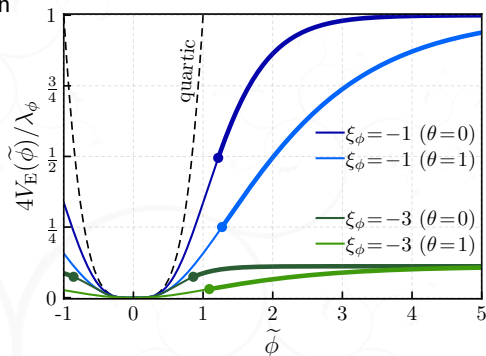


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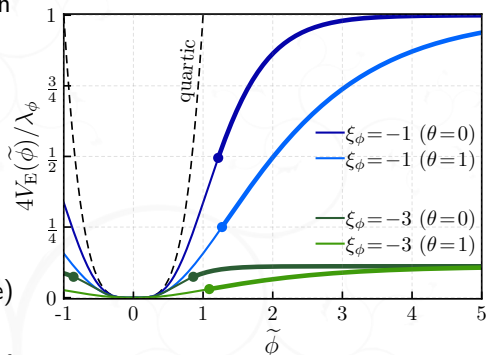
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- For generality, we also consider both the **metric** ($\theta = 1$) and **Palatini** formulations ($\theta = 0$) of gravity.
- Overall, we have the (Einstein-frame) potential in the inflationary regime

$$V_E(\tilde{\phi}) = \frac{\lambda_\phi}{4\xi_\phi^2} \begin{cases} \tanh^4(\sqrt{-\xi_\phi}\tilde{\phi}) & \text{for } \theta = 0 \\ (1 - e^{-\sqrt{\frac{2}{3}}\tilde{\phi}})^2 & \text{for } \theta = 1 \end{cases}$$

where $\tilde{\phi}$ is the canonical inflaton field.



Production of Higgs Particles

- The effective masses of Higgs fluctuations (in Einstein frame) are

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$$n_h \simeq \frac{1}{8} \left(\sqrt{\lambda_\phi \bar{\varphi}} \right)^3 \left(\frac{3^{9/4} \sqrt{\xi}}{2\pi x^2} \right)^{3/2} \left(\frac{x}{x_0} \right)^4 \sqrt{\frac{2\xi}{3\sqrt{3}}} \quad \text{for } x \lesssim \sqrt{6\xi} \text{ (and } \xi > 0)$$

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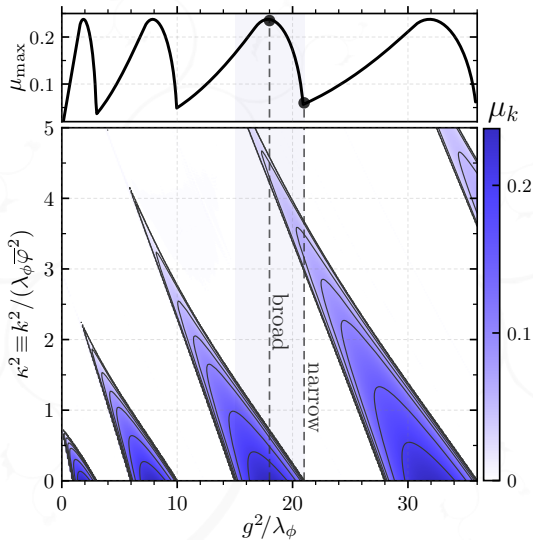
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growth rate μ_{\max} has non-trivial dependence on coupling g^2/λ_ϕ

Higgs modes grow as $n_{h_k} \propto e^{2\mu_k x}$
 [for parametric resonance]

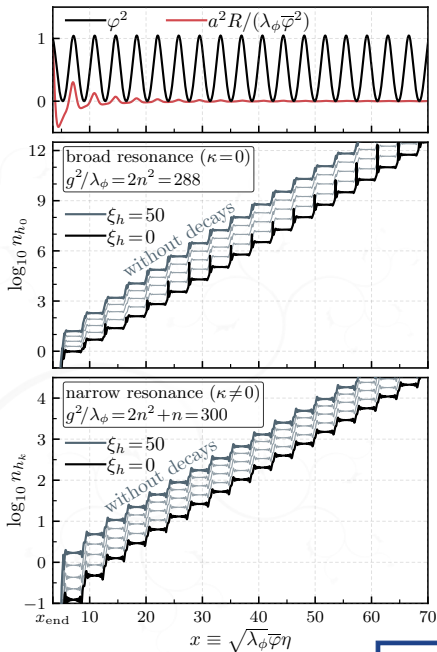


Two important effects neglected thus far:

- ① **perturbative decays** of produced Higgs particles
- ② **backreaction** of particle production on the system

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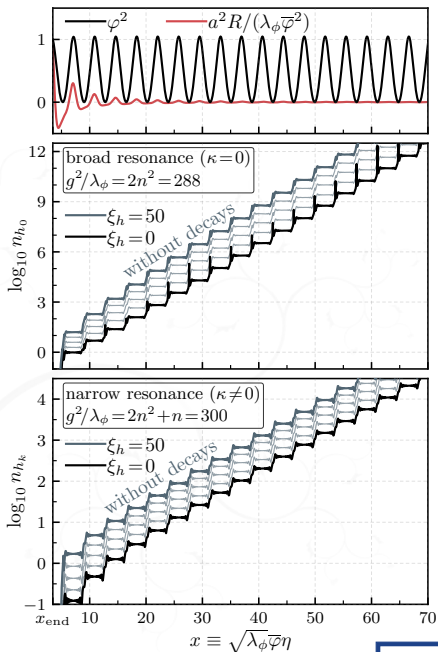


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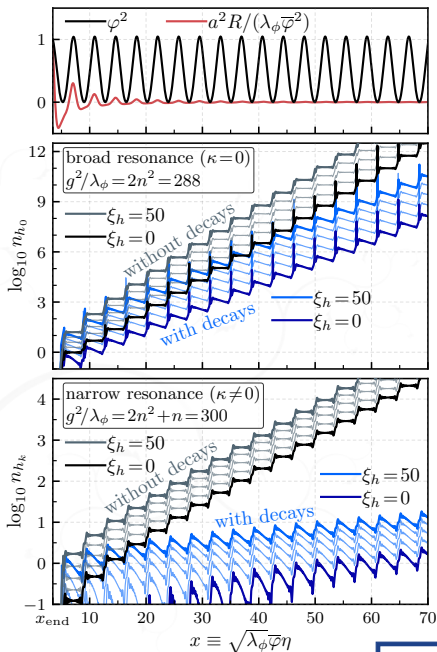
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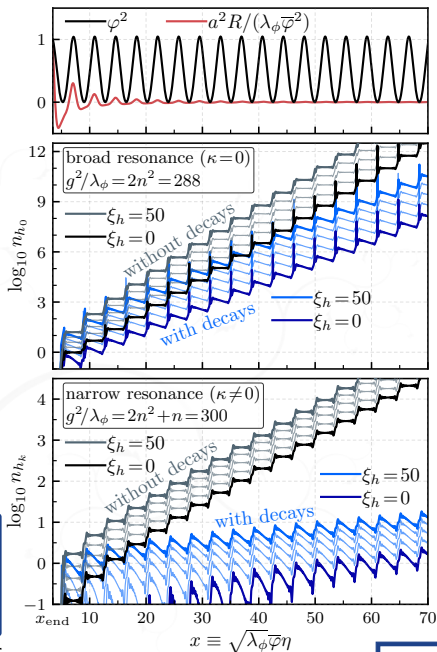
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The decay exponent depends **linearly** on time, same as growth exponents $2\mu_k x$.
 \Rightarrow decays could **entirely suppress production** of Higgs particles.

does not occur in massive preheating



② Backreaction

- Although fluctuations grow unimpeded, eventually their energy density will be comparable to inflaton background

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Ultimately due to $\langle\phi^2\rangle$, ending linear stage at $x_{\text{NL}} \approx 405$ (with $\lambda_{\phi} = 10^{-10}$).

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- Although fluctuations grow unimpeded, eventually their energy density will be comparable to inflaton background

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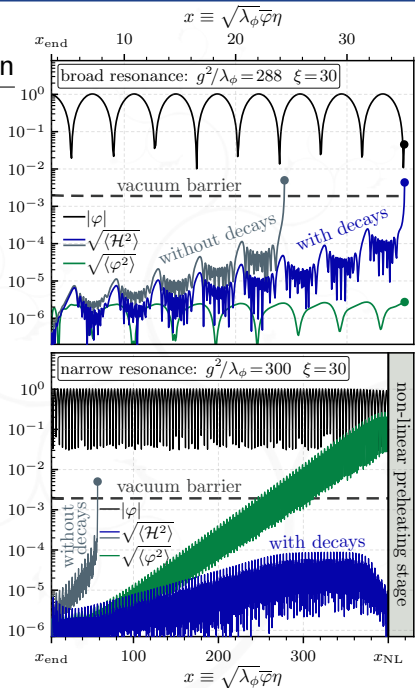
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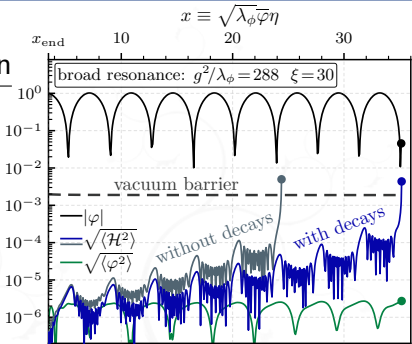
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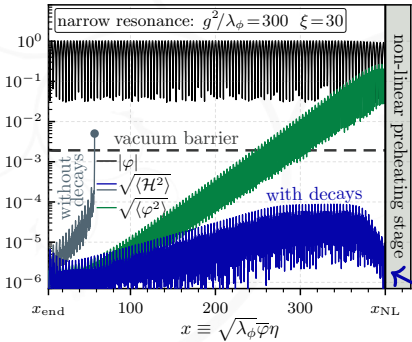
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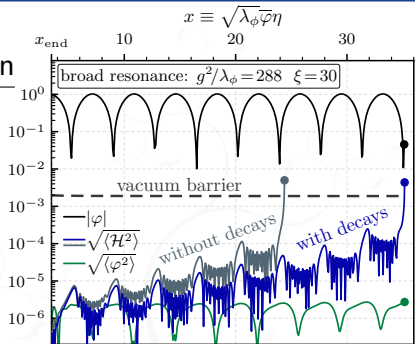


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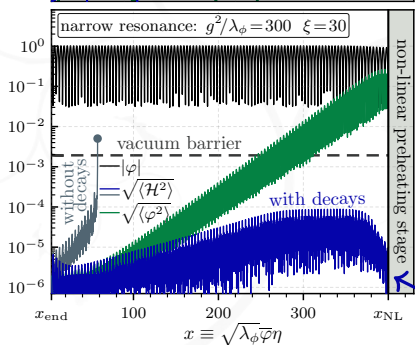


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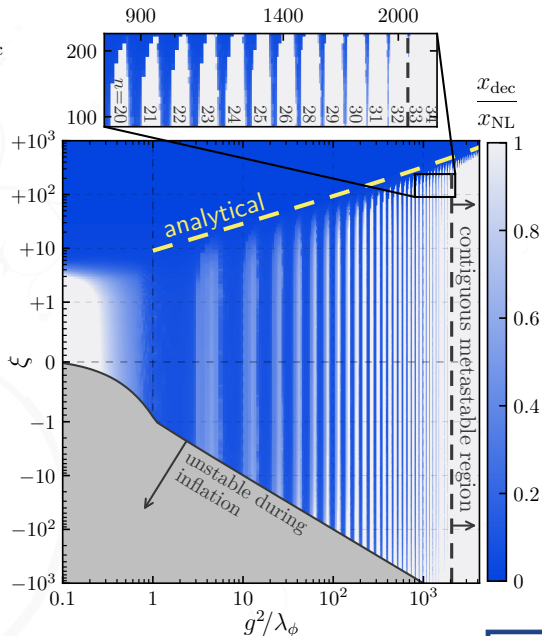


inflaton fluctuations terminate linear stage of preheating

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Summary of Results

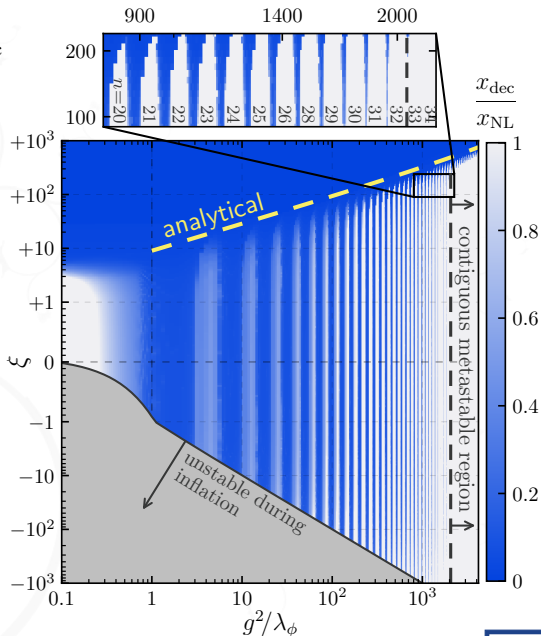
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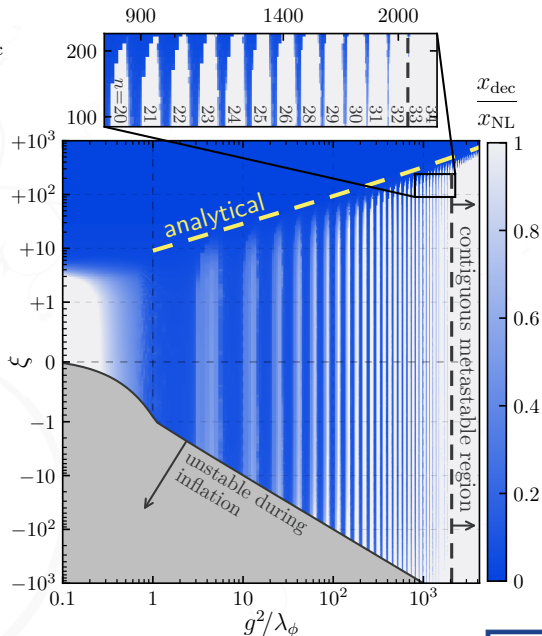


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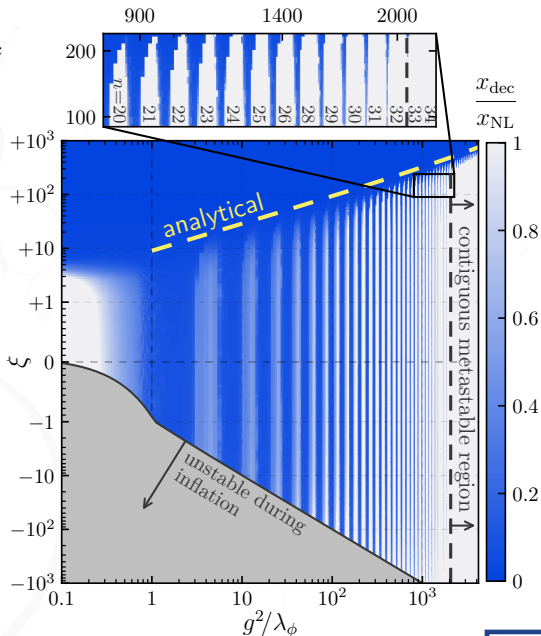


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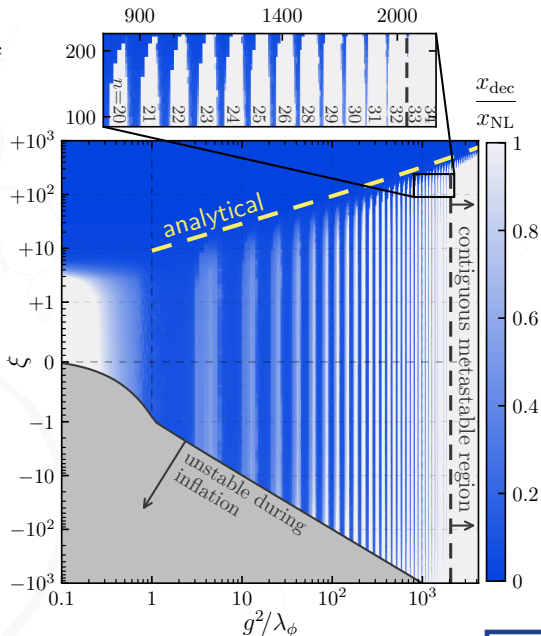


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- curvature coupling imposes envelope over metastable regions at $\xi \lesssim g^2/\lambda_\phi$ —i.e., **large ξ viable** as long as g^2/λ_ϕ is similarly large.



TAKE-HOME MESSAGE:

- Although models that lead to massless preheating appear catastrophic for electroweak vacuum metastability, fully accounting for backreaction and perturbative decays reveals a **large number of disjoint (meta)stable regions**.
- In contrast to other (massive) preheating scenarios, the Higgs-inflaton coupling is ultimately **bounded from below** to ensure viability.

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- Inclusion of terms in inflaton potential, *e.g.*, small mass terms, that break scale invariance—new phases of evolution would be considered.
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THANK YOU FOR YOUR ATTENTION!