Nonlinear Dynamics of Preheating after Multifield Inflation with Nonminimal Couplings

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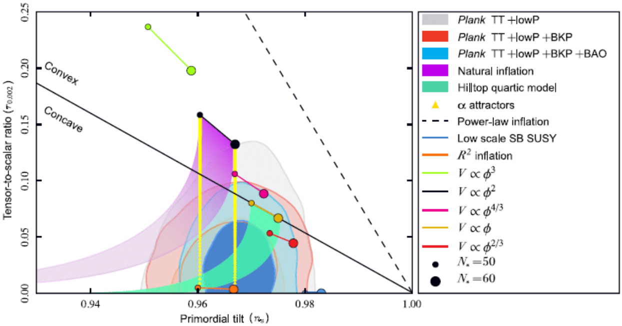
COSMO 2019, Aachen

based (mostly) on:

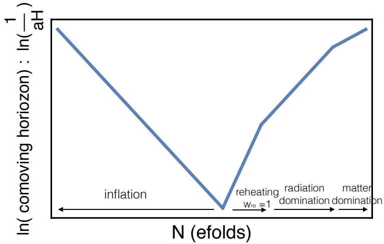
R. Nguyen, J. van de Vis, EIS, J. T. Giblin, D. I. Kaiser, arXiv:1905.12562 [hep-ph]

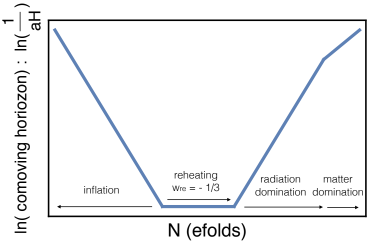
Hints from the sky



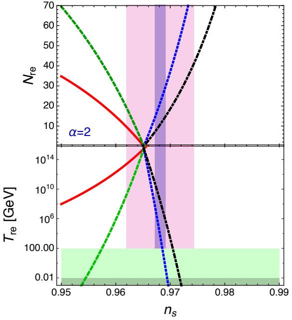
Plateau models of inflation are consistent with *Planck* data.

Reheating





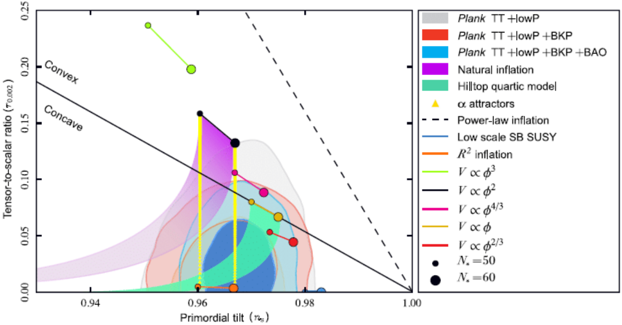
Cook et al. 2015



The **reheating history** connects the times of horizon exit & re-entry of perturbations $\Rightarrow$ **shifts CMB observables**

"The value of $\mathcal{N}_*$ is not well constrained and depends on unknown details of reheating"

CMB-S4 Science Book, 2016



Plateau models of inflation are STILL consistent with *Planck* data,

$\Rightarrow$ the time of horizon-exit is being constrained.

Non-Minimal Couplings & Conformal Transformations

Terms of the form $\xi\phi^2 R$ are generic in high energies (e.g. RG flow)

$$S_{\rm Jordan} = \int d^4x\sqrt{-\tilde{g}}\left[f(\phi^I)\tilde{R} - \frac{1}{2}\tilde{\mathcal{G}}_{IJ}\tilde{g}^{\mu\nu}\partial_\mu\phi^I\partial_\nu\phi^J - \tilde{V}(\phi^I)\right]$$

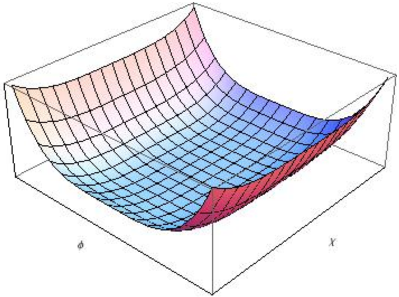
$$\boxed{g_{\mu\nu}(x) = \frac{2}{M_{\rm Pl}^2}f(\phi^I(x))\,\tilde{g}_{\mu\nu}(x)}$$

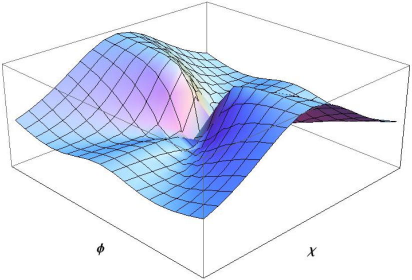
$$S_{\rm Einstein} = \int d^4x\sqrt{-g}\left[\frac{M_{\rm Pl}^2}{2}R - \frac{1}{2}\mathcal{G}_{IJ}g^{\mu\nu}\partial_\mu\phi^I\partial_\nu\phi^J - V(\phi^I)\right]$$

$$\boxed{V(\phi^I) = \frac{M_{\rm Pl}^4}{4f^2(\phi^I)}\tilde{V}(\phi^I)}$$

Potential: Jordan vs Einstein

Potential "stretching" factor: $f(\phi,\chi) = \frac{1}{2}\left[M_{Pl}^2 + \xi_\phi \phi^2 + \xi_\chi \chi^2\right]$





$V(\phi,\chi) = \frac{\lambda_\phi}{4}\phi^4 + \frac{\lambda_\chi}{4}\chi^4 + \frac{g}{2}\phi^2\chi^2$

concave (flat) potential

$$V(\phi^I) \to \frac{M_{Pl}^2}{4}\frac{\lambda_I}{\xi_I} \Rightarrow H = \frac{M_{Pl}}{\sqrt{12}}\sqrt{\frac{\lambda}{\xi^2}}$$

Einstein-frame Field-space

In the Einstein frame, the field-space manifold is curved:

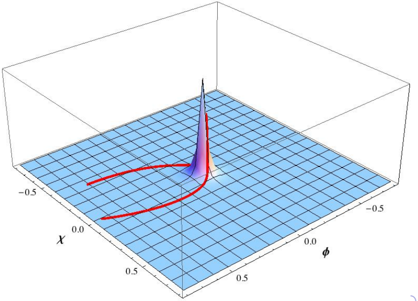
$$\mathcal{G}_{IJ}(\phi^K) = \left(\frac{M_{Pl}^2}{2f(\phi^K)}\right)\left[\delta_{IJ} + \frac{3}{f(\phi^K)} f_{,I} f_{,J}\right] \neq F(\phi^K)\delta_{IJ}$$

ϕ^I: coordinates in field space $\longleftrightarrow x^\mu$

$\mathcal{G}_{IJ}\left(\sim \frac{1}{\phi^2}\right)$: metric on field space $\longleftrightarrow g_{\mu\nu}$ (Note: $\mathcal{G}_{IJ} \propto \phi^{-2}$)

$\mathcal{D}_J A^I = \partial_J A^I + \Gamma^I_{JK} A^K$

We can "turn off" the potential and visualize the effects of the field-space metric alone.

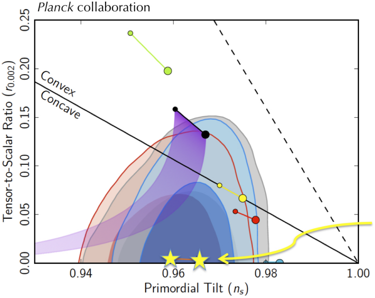


Observables

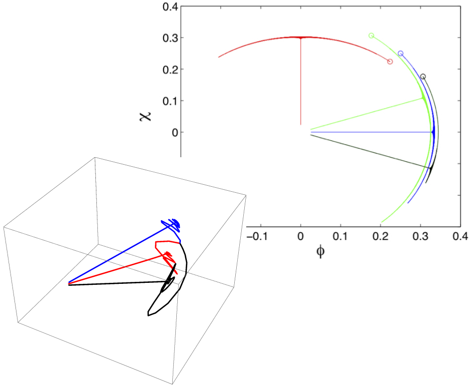
Starting from **generic** initial conditions the inflaton quickly reaches an **attractor** solution

⇒ Starobinsky-like predictions

$$n_s \simeq 1 - \frac{2}{N}\,, \qquad r \simeq \frac{12}{N^2}$$



D.I. Kaiser & E.I.S., **PRL** 2014



Results for the spectral tilt, running of the tilt and tensor to scalar ratio are insensitive to **initial conditions** AND **couplings**.

Effective Mass-squared Ingredients

$$\partial_\tau^2 \delta\phi_k + (k^2 + a^2 m^2_{\text{eff},\phi})\delta\phi_k = 0 \quad , \quad \partial_\tau^2 \delta\chi_k + (k^2 + a^2 m^2_{\text{eff},\chi})\delta\chi_k = 0$$

$$\boxed{m^2_{\text{eff,I}} = m^2_{1,I} + m^2_{2,I} + m^3_{3,I} + m^2_{4,I}}$$

$$m^2_{1,\phi} \equiv \mathcal{G}^{\phi K}\left(\mathcal{D}_\phi \mathcal{D}_K V\right) \longleftrightarrow \text{potential gradient}$$

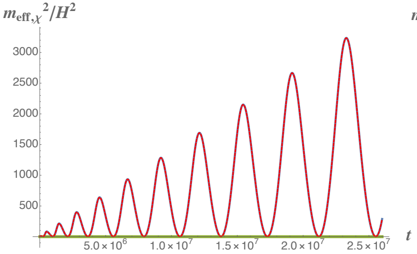
$$m^2_{2,\phi} \equiv -\mathcal{R}^{\phi}{}_{LM\phi}\dot{\varphi}^L \dot{\varphi}^M \longleftrightarrow \text{non-trivial field-space manifold}$$

$$m^3_{3,\phi} \equiv -\frac{\delta^\phi_I \delta^J_\phi}{M^2_{\text{Pl}} a^3}\mathcal{D}_t\left(\frac{a^3}{H}\dot{\varphi}^I \dot{\varphi}_J\right) \longleftrightarrow \text{coupled metric perturbations}$$

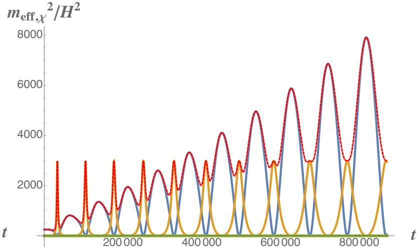
$$m^2_{4,\phi} \equiv -\frac{1}{6}R \longleftrightarrow \text{changes in the background spacetime}$$

Effective Mass-squared: spectator field χ

$\underline{\xi = 1}$



$\underline{\xi = 10}$



$$m^2_{\mathrm{eff}} \approx m_1^2 + m_2^2 + m_3^3$$

$$m^2_{\mathrm{eff}} \approx \textit{potential} + \textit{fieldspace} + \textit{metric}$$

Effective Mass-squared: $\xi = 100 \gg 1$

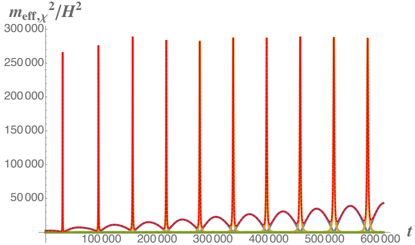
An "unusual" way for **adiabaticity violation**

We define

$$\mathcal{A}_{(\phi,\chi)}(k,\eta) \equiv \frac{\Omega'_{(\phi,\chi)}(k,\eta)}{\Omega^2_{(\phi,\chi)}(k,\eta)}$$

where

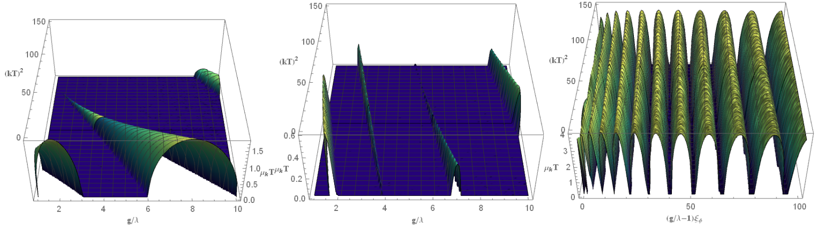
$$\Omega^2_{(\phi,\chi)}(k,\eta) = k^2 + a^2 m^2_{\mathrm{eff},\phi}(\eta)$$

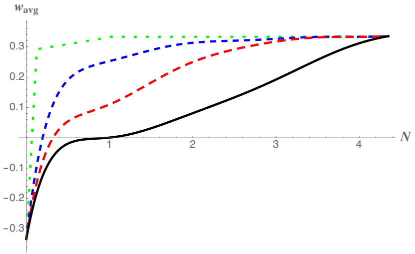


Adiabaticity is violated for $\Omega' \gg \Omega^2$, rather than $\Omega \approx 0$.

A broad range of wavenumbers is excited $k \lesssim \xi_\phi H_{\mathrm{end}}$

$\xi = 0$ $\quad$ $\xi = 10$ $\quad$ $\xi = 100$

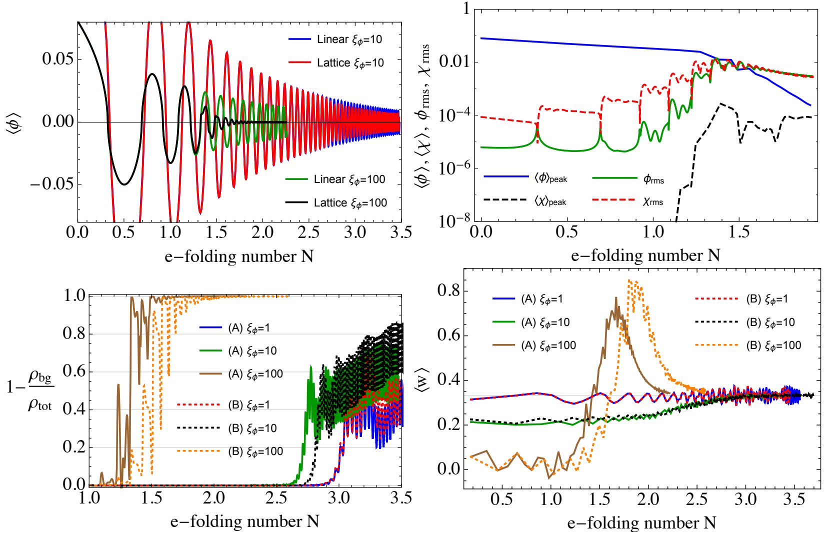




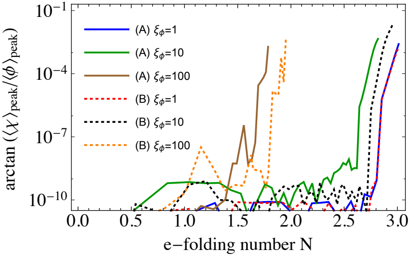
Particle production and the equation of state can be altered by **nonlinear effects**

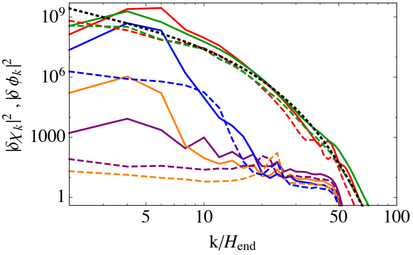
$\Rightarrow$ Need for **lattice simulations**

Lattice results



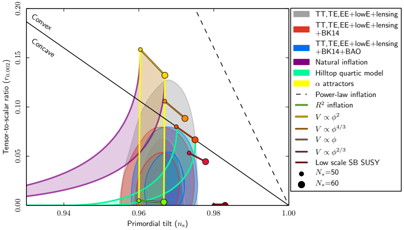
Summary





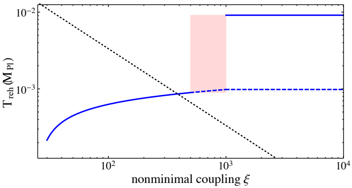
- Fast preheating for $\xi \gtrsim 100$
- Efficient thermalization
- Robust single-field attractor
- Fast approach to $w \to 1/3$

> Non-minimal couplings quickly lead to a thermal radiation bath while preserving CMB predictions



Testing plateau models requires reduced theoretical error-bars of the $n_s - r$ plot

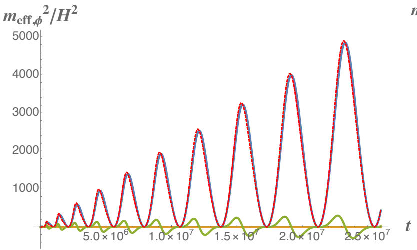
For **Higgs inflation**, where the SM Higgs is the non-minimally coupled inflaton, the full decay to SM particles can be computed.



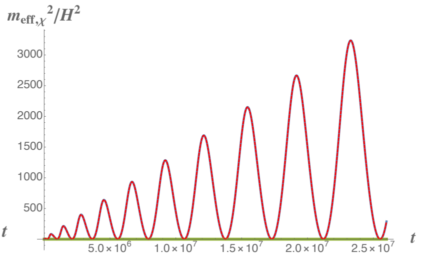
EIS & van de Vis, 2018

Effective Mass-squared: $\xi = 0.1 \ll 1$

Inflaton ϕ



Spectator χ



$$m_{\text{eff}}^2 \approx m_1^2 + m_2^2 + m_3^3$$

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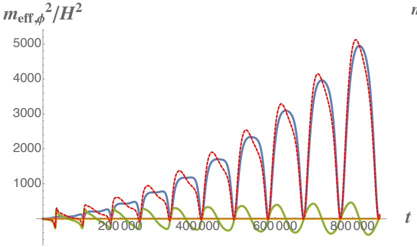
Effective Mass-squared: $\xi = 10$

Inflaton ϕ



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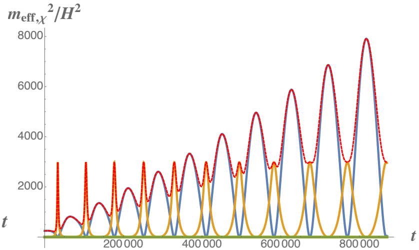

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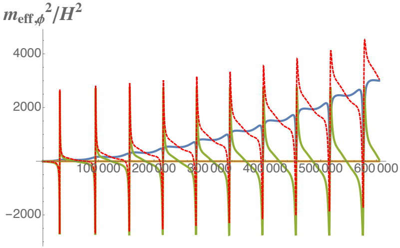

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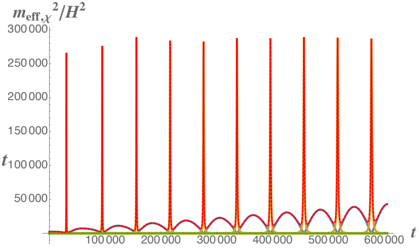

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