On reheating in alpha attractor models of inflation

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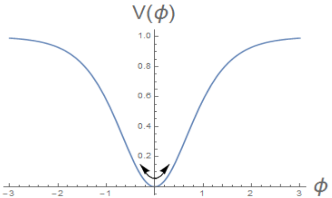
Introduction

- Cosmological inflation - simultaneous solution for many problems in cosmology
  - horizon problem
  - flatness problem
  - magnetic monopoles problem
- However:
  - Remains very general theory
  - The relation of inflaton field (or fields) with standard model of particle physics still unclear
- Consequently: the physics of reheating - not well known
- Nevertheless, there exist possible scenarios for reheating!

Parametric Resonance

- Coherent oscillations



$$\mathcal{V}(\phi,\chi) = \frac{1}{2}\left(m^2\phi^2 + m_\chi^2\chi^2 + g^2\phi^2\chi^2 + \dots\right)$$

$$\ddot{\phi} + m^2\phi \simeq 0$$

$$\phi(t) \propto \sin(mt)$$

- Time dependent mass

$$\ddot{\chi}_k + \left(k^2 + m_{\chi,eff}^2\right)\chi_k = 0, \qquad m_{\chi,eff}^2 \equiv m_\chi^2 + g^2\phi^2$$

χ_k - the Fourier component of field χ

- Parametric resonance $\Rightarrow$ particle production!

Kofman, Linde, Starobinsky
hep-th/9405187

Dufaux, Felder, Kofman, Peloso, Podolsky
hep-ph/0602144

Brandenberger, Traschen
Phys. Rev. D42, 2491

- The number density of particles:

$$n_{\chi,k} = \frac{1}{2\omega_{\chi,k}}\left(|\dot{\chi}_k|^2 + \omega_{\chi,k}^2|\chi_k|^2\right) - \frac{1}{2}, \qquad \omega_{\chi,k} \equiv \sqrt{k^2 + m_\chi^2 + g^2\phi^2}$$

- By Floquet Theorem we have the solution:

$$\chi_k(t) = \sum_{i=1}^{2} \underbrace{\chi_{i,k}(t, t_0)}_{\text{periodic}} \exp(\mu_{\chi,k}^i(t - t_0))$$

$\mu_{\chi,k}^i$ - Floquet exponents - amplitude growth indicators

- the bigger the amplitude, the bigger the number of particles
- Big Floquet exponents indicate effective particle production!

Self resonance

- Inflaton oscillations can amplify their own perturbations

$$\phi(t,x) \equiv \phi(t) + \delta\phi(t,\mathbf{x}), \quad \delta\ddot{\phi}_k + \left(k^2 + V_{\phi\phi}\right)\delta\phi_k = 0$$

- time dependent, periodic mass - possible self resonance!
- we can use Floquet theorem!

$$n_{\delta\phi,k} = \frac{1}{2\omega_{\delta\phi,k}}\left(|\delta\dot{\phi}_k|^2 + \omega^2_{\delta\phi,k}|\delta\phi_k|^2\right) - \frac{1}{2}, \qquad \omega_{\delta\phi,k} \equiv \sqrt{k^2 + V_{\phi\phi}}$$

$$\delta\phi_k(t) = \sum_{i=1}^{2} \underbrace{\delta\phi_{i,k}(t,t_0)}_{\text{periodic}} \exp(\mu^i_{\delta\phi,k}(t-t_0))$$

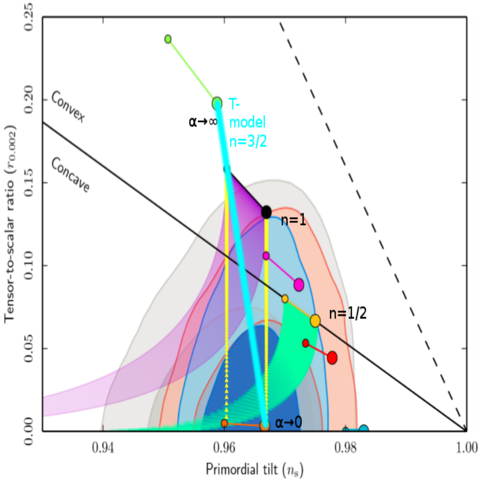
Amin, Lozanov
arXiv:1608.01213

Amin, Hertzberg, Kaiser, Karouby
arXiv:1410.3808

α-attractor models of inflation

- we will focus on the subgroup of α-attractor models called T-models
- α-attractors originate from supergravity models
- T-models consistent with data

Carrasco, Kallosh, Linde
arXiv:1506.00936



Planck Collaboration
arXiv:1502.01589

T-models

- Superpotential

$$W_H = \sqrt{\alpha}\mu S\left(\frac{T-1}{T+1}\right)^n$$

- Kähler potential

$$K_H = -\frac{3\alpha}{2}\log\left(\frac{(T-\bar{T})^2}{4T\bar{T}}\right)+S\bar{S}$$

$$\left|\frac{T-1}{T+1}\right|^2 = \left(\frac{\cosh(\beta\phi)\cosh(\beta\chi)-1}{\cosh(\beta\phi)\cosh(\beta\chi)+1}\right), \quad \beta = \sqrt{\frac{2}{3\alpha}}$$

- The potential and Lagrangian for T-models:

$$V(\phi,\chi) = M^4\left(\frac{\cosh(\beta\phi)\cosh(\beta\chi)-1}{\cosh(\beta\phi)\cosh(\beta\chi)+1}\right)^n\Big(\cosh(\beta\chi)\Big)^{2/\beta^2}$$

$$\mathcal{L} = \frac{1}{2}\Big(\partial_\mu\chi\partial^\mu\chi + \cosh^2(\beta\chi)\partial_\mu\phi\partial^\mu\phi\Big) - V(\phi,\chi)$$

- Effectively: one field inflation ($\chi \equiv 0$) with quantum perturbations of two fields

Background and first order equations

- the perturbed FRW metric:

$$ds^2 = -(1+2\Psi)dt^2 + a^2(1-2\Psi)d\mathbf{x}^2,$$

- background equations:

$$H^2 = \frac{1}{3M_P^2}\left[\frac{1}{2}\dot{\phi}^2 + V(\phi,0)\right], \quad \ddot{\phi} + 3H\dot{\phi} + V_\phi(\phi,0) = 0$$

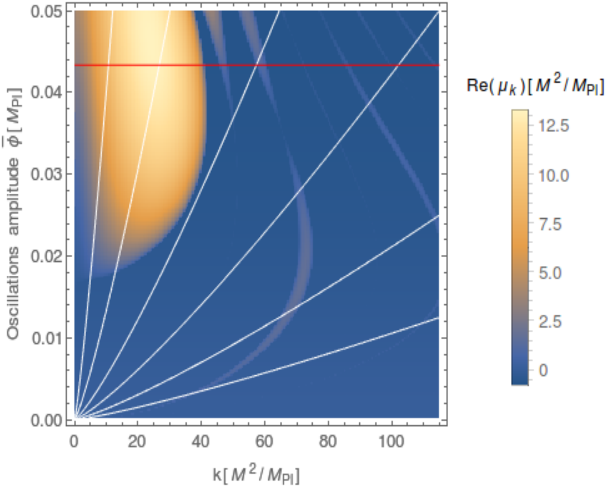
- first order equations:

$$\ddot{Q} + 3H\dot{Q} + \left(\frac{k^2}{a^2} + \underbrace{F(\phi)}_{\text{periodic}}\right)Q = 0, \quad Q \equiv \delta\phi + \frac{\dot{\phi}}{H}\Psi$$

$$\ddot{S} + 3H\dot{S} + \left(\frac{k^2}{a^2} + \underbrace{G(\phi)}_{\text{periodic}}\right)S = 0, \quad S \equiv \delta\chi + \frac{\dot{\chi}}{H}\Psi = \delta\chi$$

- $G(\phi)$ - may be strongly negative for small α because of non-canonical kinetic term for field ϕ

Floquet exponents for inflaton perturbations



$$\alpha = 10^{-4}$$

$$n = \frac{3}{2}$$

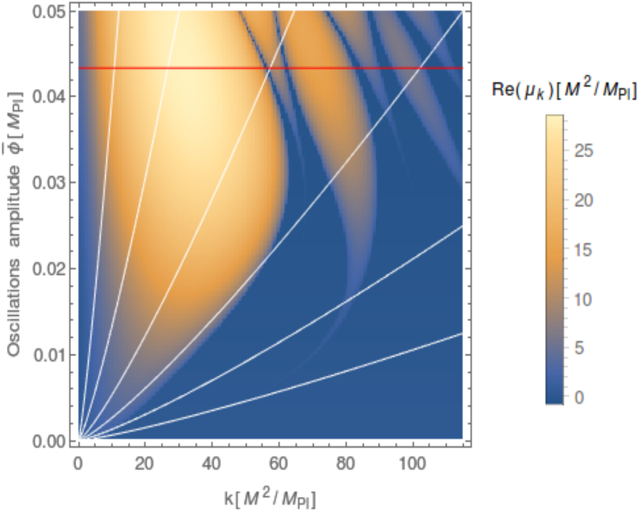
$$\bar{\phi}(t) \propto a^{-3/(n+1)}$$

$$k_{eff} = \frac{k}{a} \propto a^{-1}$$

cf.

Amin, Lozanov arXiv:1608.01213

Floquet exponents for spectator perturbations



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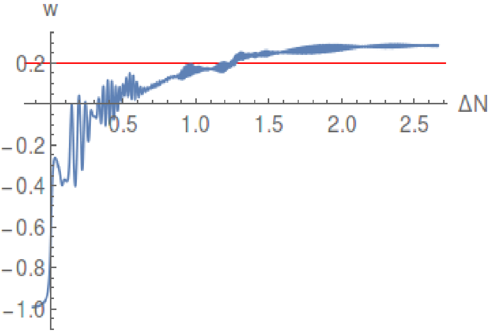
Results of one-field lattice simulations



$\alpha = 10^{-4}$

$n = \frac{3}{2}$

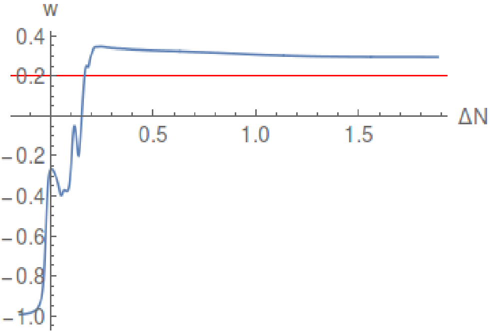
$w_{hom} = \frac{n-1}{n+1} = 0.2$

cf.

Amin, Lozanov arXiv:1608.01213

$$w \equiv \frac{\langle p \rangle}{\langle \rho \rangle} = \frac{\left\langle \left(\frac{e^{2b(\chi)}\dot{\phi}^2 + \dot{\chi}^2)}{2} - \frac{(e^{2b(\chi)}(\nabla\phi)^2 + (\nabla\chi)^2)}{6a^2} - V(\phi,\chi) \right\rangle}{\left\langle \frac{(e^{2b(\chi)}\dot{\phi}^2 + \dot{\chi}^2)}{2} + \frac{(e^{2b(\chi)}(\nabla\phi)^2 + (\nabla\chi)^2)}{2a^2} + V(\phi,\chi) \right\rangle}$$

Results of two-fields lattice simulations



$\alpha = 10^{-4}$

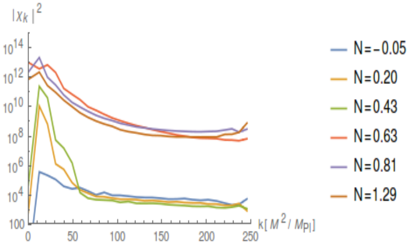
$n = \frac{3}{2}$

$w_{hom} = \frac{n-1}{n+1} = 0.2$

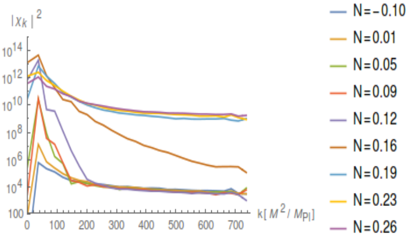
- very strong growth of amplified modes

Fourier analysis of growing modes

$\alpha = 10^{-3}$

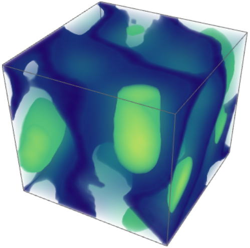


$\alpha = 10^{-4}$



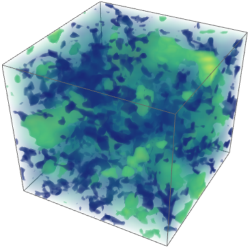
- the smaller α, the stronger tachyonic instability
- the unstable modes backreact causing the destabilization of higher frequency modes

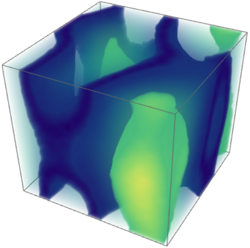
The destabilization of higher frequency modes



$\alpha = 10^{-3}$

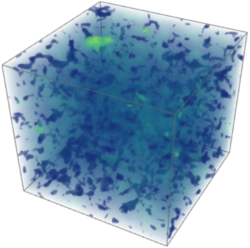
$\Delta N = 0.2$
$\rightarrow$
$\Delta N = 1.29$





$\alpha = 10^{-4}$

$\Delta N = 0.05$
$\rightarrow$
$\Delta N = 0.26$



Conclusions

- For small values of parameter α in α-attractor T-model, the parametric resonance mechanism can be effective and hence can play the crucial role in reheating.
- The spectator in that model become important after the end of inflation and may growth strongly because of its tachyonic instability. It leads to drastic growth of equations of state parameter w.
- If α is too small, the instability is very hard to tract numerically and the growth of perturbations can possibly lead to primordial black holes formation.

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Thank you for your attention!