On reheating in alpha attractor models of inflation

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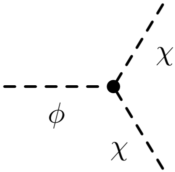
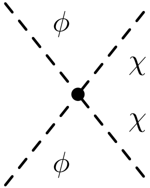
Introduction

- 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!

Reheating - perturbative approach

- First approach:
  - reheating treated as a perturbative process
  - individual quanta of inflaton decay independently of each other



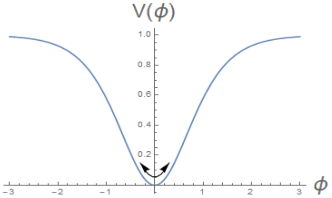


- Decays based on different interactions proposed and analysed:

Brandenberger, Traschen
Phys. Rev. D42, 2491

Breakdown of perturbative approach

- 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

Floquet Theory

- 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 its 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!

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

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

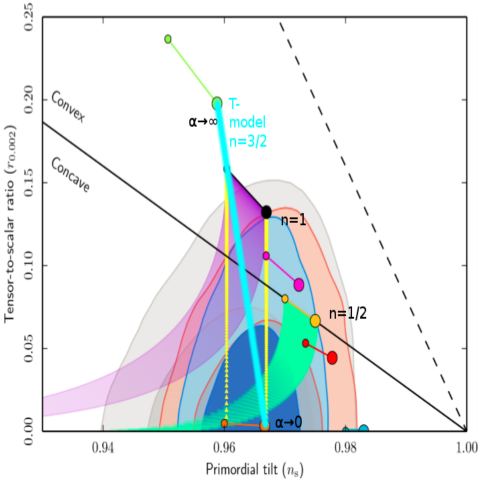
Amin, Lozanov
arXiv:1608.01213

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:

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

$$\mathcal{L} = \frac{1}{2}\left(\partial_\mu\chi\partial^\mu\chi + \mathrm{e}^{2b(\chi)}\partial_\mu\phi\partial^\mu\phi\right) - V(\phi,\chi), \qquad b(\chi) \equiv \log(\cosh(\beta\chi))$$

- 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:

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

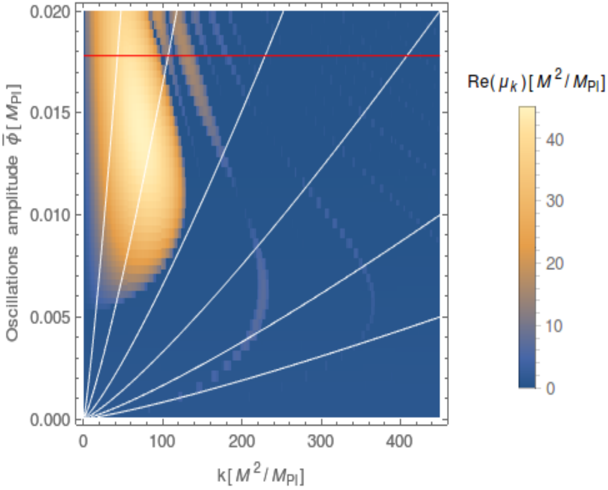
- first order equations:

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

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

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

Floquet exponents for inflaton perturbations



$$\alpha = 10^{-5}$$

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

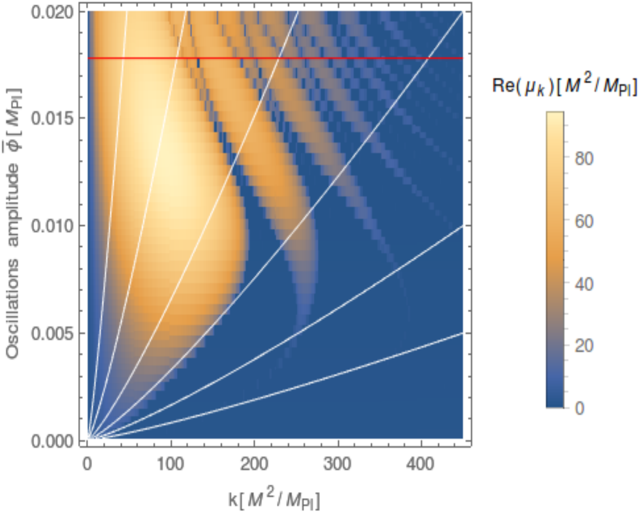
$$\bar{\phi}(t) \propto a^{-3/(n+1)}$$

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

cf.

Amin, Lozanov arXiv:1608.01213

Floquet exponents for spectator perturbations



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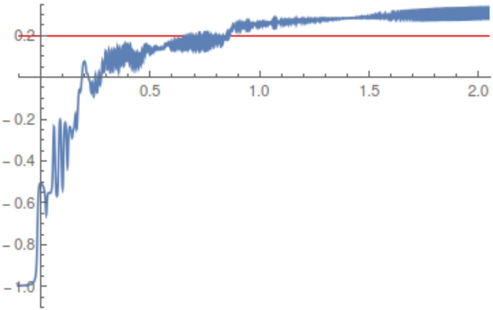

$$w_{hom} = \frac{n-1}{n+1} = 0.2$$

cf.

Amin, Lozanov arXiv:1608.01213

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

Conclusions

- For small values of parameter α in α-attractor T-models, the parametric resonance mechanism can be effective and hence can play the crucial role in preheating.
- The Floquet analysis suggests, that the second field in that model can become important after the end of inflation and should be incorporated in the analysis of preheating in this model.
- The inhomogeneities became significant soon after the end of inflation and lattice simulations are needed to obtain the valuable results.

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Thank you for your attention!