On reheating in alpha attractor models of inflation

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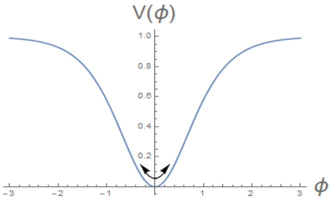
July 4, 2018

Based on work with:
T. Krajewski and K. Turzyński
arXiv:1801.01786

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!

- 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 $\Rightarrow$ inflaton fragmentation!

Kofman, Linde, Starobinsky hep-th/9405187

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

Brandenberger, Traschen Phys. Rev. D42, 2491

Floquet Theory and Self Resonance

- By Floquet Theorem we have the solution:

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

$\mu^i_{\chi,k}$ - Floquet exponents - amplitude growth indicators

- Big Floquet exponents ⇒ the inflaton condensate stops to be dominant ⇒ back reaction ⇒ inflaton fragmentation
- Inflaton oscillations can amplify their own perturbations - self resonance

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

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

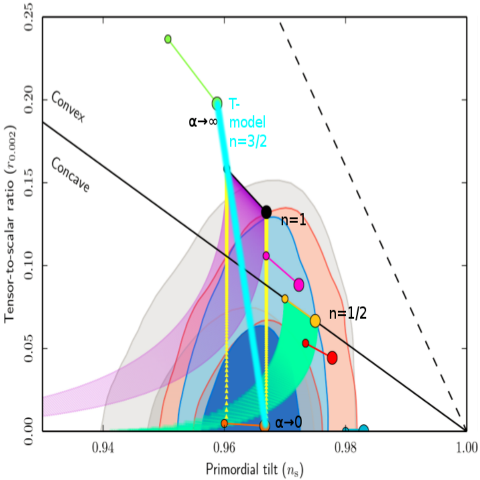
Amin, Lozanov
arXiv:1608.01213

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:

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

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

- 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:

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

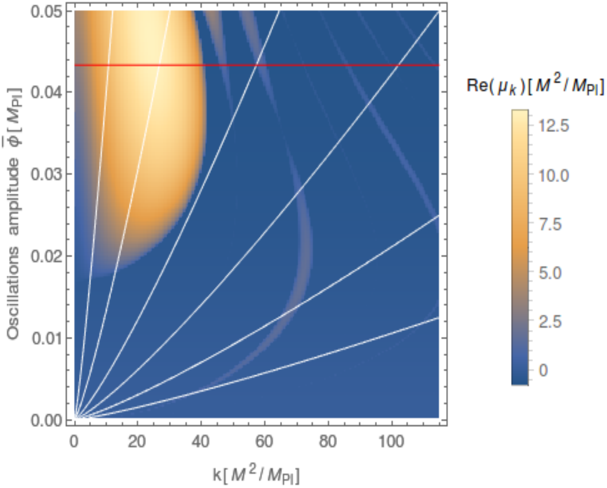
- first order equations:

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

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

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

Floquet exponents for inflaton perturbations



$\alpha = 10^{-4}$

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

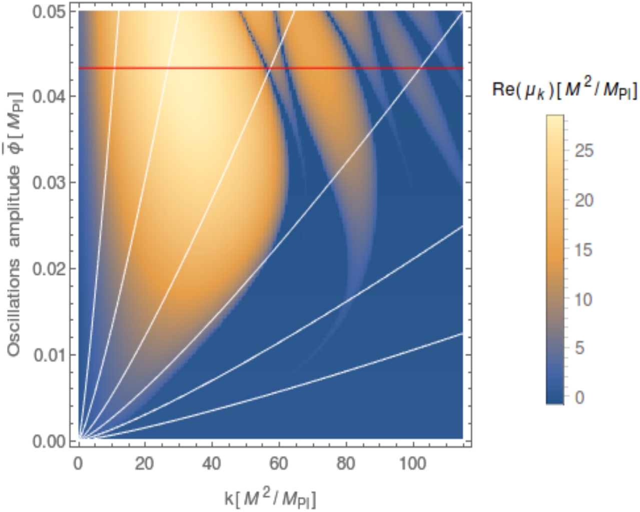
$\bar{\phi}(t) \propto a^{-3/(n+1)}$

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

cf.

Amin, Lozanov arXiv:1608.01213

Floquet exponents for spectator perturbations



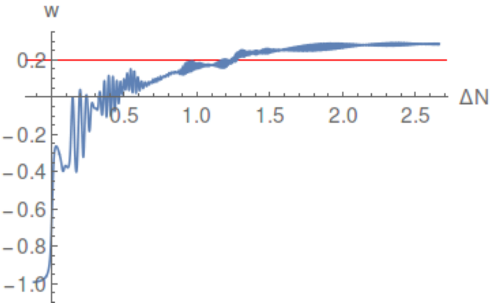
$$\alpha = 10^{-4}$$

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

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

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

Equation of state parameter for one field



$\alpha = 10^{-4}$

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

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

cf.

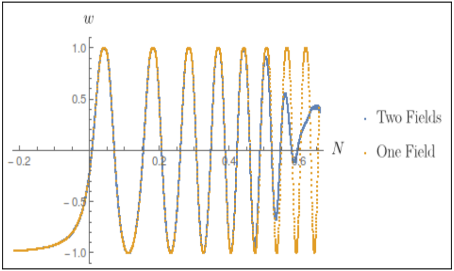
Amin, Lozanov
arXiv:1608.01213

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

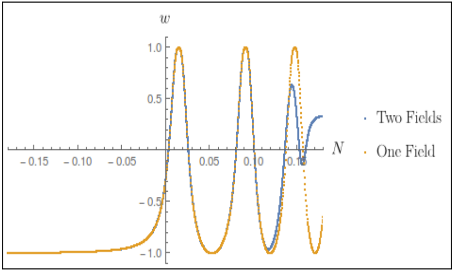
- Inflaton fragmentation leads to radiation domination!

Equation of state parameter for two fields

$\alpha = 10^{-3} \quad n = 1.5$



$\alpha = 10^{-4} \quad n = 1.5$

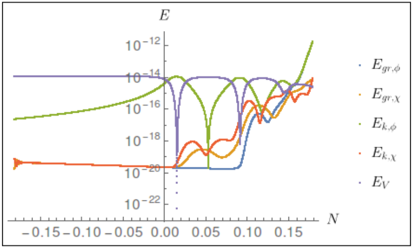


- the spectator's instability strongly affects the evolution of the equation of state parameter
- for small α the instability is so strong, that further evolution is very hard to tract numerically
- the smaller is α, the faster the instabilities emerge

Results of lattice simulations

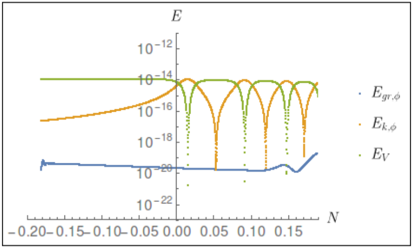
two fields

$\alpha = 10^{-4} \quad n = 1.5$



one field

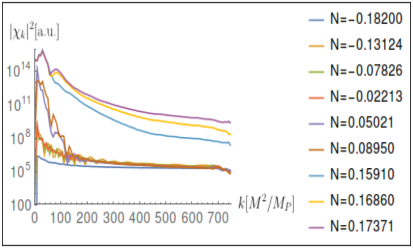
$\alpha = 10^{-4} \quad n = 1.5$



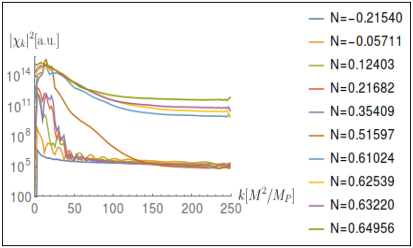
- For two fields the gradient energy ceases to be sub-dominant soon after the end of inflation
- The growth of spectator perturbations causes the rapid fragmentation of the inflaton condensate

Fourier analysis of growing modes

$\alpha = 10^{-4} \quad n = 1.5$



$\alpha = 10^{-3} \quad n = 1.5$



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

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 affects significantly the evolution of the equation of state parameter w and may cause the significant speed up of reheating.
- 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!