Floquet analysis of self-resonance in single-field inflationary models

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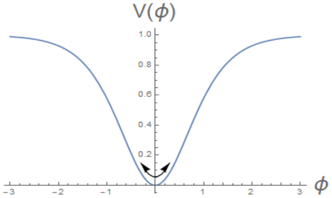
Based on work with:
K. Turzyński
arXiv:1808.00835

- Cosmological inflation - a natural ingredient of the standard big bang cosmological model
- However:
  - Remains very general theory (many models of inflation consistent with data)
  - 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!

- the natural scenario based on inflaton perturbations evolution

- Coherent oscillations



$\Rightarrow$

- Time dependent periodic mass for perturbations

$$\phi(t,x) \equiv \phi(t) + \delta\phi(t,\mathbf{x})$$

$$\delta\ddot{\phi}_k + \Big(k^2 + \underbrace{V_{\phi\phi}}_{\textit{periodic}}\Big)\delta\phi_k = 0$$

$\delta\phi_k$ - the Fourier component of $\delta\phi$

- Self-resonance $\Rightarrow$ inflaton fragmentation!

Kofman, Linde, Starobinsky
hep-th/9405187

Amin, Lozanov
Phys. Rev. Lett. 119 061301

Floquet theory

- By Floquet theorem we have the solution:

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

μ_k^i - Floquet exponents - amplitude growth indicators

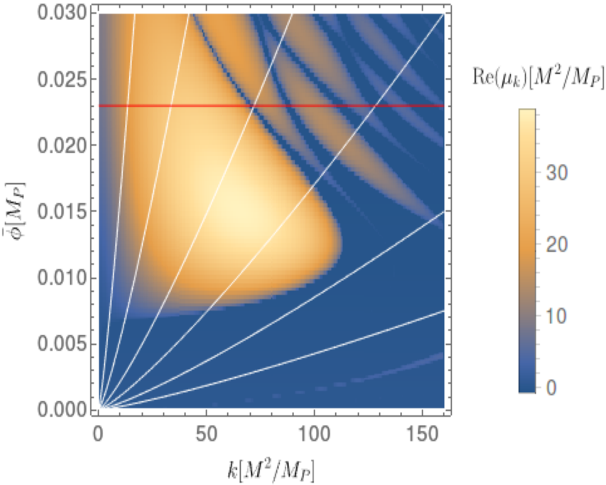
- Big Floquet exponents $\Rightarrow$ the inflaton condensate stops to be dominant $\Rightarrow$ back reaction $\Rightarrow$ inflaton fragmentation
- the equation of state parameter

$$w \equiv \frac{\langle p \rangle}{\langle \rho \rangle} = \frac{\left\langle \frac{1}{2}\dot{\phi}^2 - \frac{1}{6}(\nabla\phi)^2 - V(\phi) \right\rangle}{\left\langle \frac{1}{2}\dot{\phi}^2 + \frac{1}{2}(\nabla\phi)^2 + V(\phi) \right\rangle}$$

$$V_{min} \sim \phi^n \qquad \Rightarrow \qquad w_{hom} = \frac{n-2}{n+2}$$

- the inflaton fragmentation may change w and potentially lead to radiation domination ($w = \frac{1}{3}$)

Exemplary plot of Floquet exponents



$$V_{min} \approx M^4 \left(\frac{\phi}{M_P}\right)^n$$

$$\bar{\phi}(t) \propto a^{-6/(n+2)}$$

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

$$\mathrm{Re}(\mu_k) \gtrsim 5M^2/M_P$$

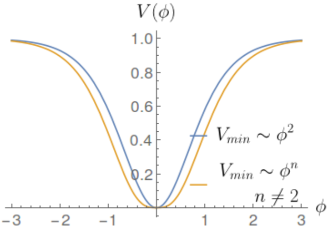
$$\Downarrow$$

effective fragmentation

Possibility of oscillons formation

- The condensate fragmentation may not be the sufficient condition to obtain the radiation dominated Universe!

- Two possible scenarios:
  - $V_{min} \sim \phi^2 \quad \Rightarrow$ Oscillons formation (effectively $w \equiv \frac{p}{\rho} = 0$)
  - $V_{min} \sim \phi^n; n \neq 2 \quad \Rightarrow$ Subsequent radiation domination ($w = \frac{1}{3}$)



- For reheating we need both the big Floquet exponents and non-quadratic potential at its minimum!:

Amin, Easther, Finkel
JCAP 1012 001

Amin, Easther, Finkel, Flauger, Hertzberg
Phys. Rev. Lett. 108 241302

Amin, Lozanov
Phys. Rev. D97, 023533

Investigated models

model	# parameters	Planck data OK?	large FE?
Higgs inflation (HI)	0	Yes	-
Exponential SUSY inflation (ESI)	1	Yes	-
Power law inflation (PLI)	1	No	-
Loop inflation (LI)	1	Yes	-
Arctan inflation (AI)	1	Yes	-
Constant n_s A inflation (CNAI)	1	Yes	-
Constant n_s B inflation (CNBI)	1	Yes	-
Radiatively corrected Quartic inflation (RCQI)	1	No	-
Horizon flow inflation at first order (HF1I)	1	No	-
Radiatively corrected Higgs Inflation (RCHI)	1	Yes	-
MSSM inflation (MSSMI)	1	Yes	-
Renormalizable inflection point inflation (RIPI)	1	Yes	-
Open string tachyonic inflation (OSTI)	1	Yes	-
Colemann Weinberg inflation (CWI)	1	Yes	-
Large field inflation (LFI)	1	Yes	No
Mixed Large field inflation (MLFI)	1	Yes	No
Radiatively corrected massive inflation (RCMI)	1	Yes	No
Natural inflation (NI)	1	Yes	No
Kahler Moduli inflation I (KMII)	1	Yes	No
Double well potential inflation (DWI)	1	Yes	No
$R + R^{2p}$ inflation (RpI)	1	Yes	No
Mutated hilltop inflation (MHI)	1	Yes	Yes
Radion gauge inflation (RGI)	1	Yes	Yes
Witten-O'Raifeartaigh inflation (WRI)	1	Yes	Yes
Small field inflation (SFI)	2	Yes	-
Intermediate inflation (II)	2	No	-
Logamediate inflation (LMI)	2	Yes	-
Brane SUSY breaking inflation (BSUSYBI)	2	No	-
β-exponential inflation (BEI)	2	Yes	-
Pseudo natural inflation (PSNI)	2	Yes	-
Non canonical Kahler inflation (NCKI)	2	Yes	-
Constant n_s C inflation (CNCI)	2	No	-
Inverse monomial inflation (IMI)	2	No	-
Brane inflation (BI)	2	Yes	-
Kahler moduli inflation II (KMIII)	2	Yes	-
Twisted inflation (TWI)	2	No	-
Generalized MSSM inflation (GMSSMI)	2	Yes	-
Constant spectrum inflation (CSI)	2	No	-
Orientifold inflation (OI)	2	No	-
Tip inflation (TI)	2	Yes	-
Supergravity brane inflation (SBI)	2	Yes	No
Spontaneous symmetry breaking inflation (SSBI)	2	Yes	No
Generalized renormalizable point inflation (GRIPI)	2	Yes	Yes
KKLT inflation (KKLTI)	2	Yes	Yes
Running-mass inflation (RMI)	3	Yes	-
Valley hybrid inflation (VHI)	3	Yes	-
Constant n_S D inflation (CNDI)	3	Yes	-
Logarithmic potential inflation (LPI)	3	Yes	No
Dynamical supersymmetric inflation (DSI)	3	No	-
Generalized mixed inflation (GMLFI)	3	No	-

Martin, Ringeval, Vennin *Encyclopaedia Inflationaris* Phys. Dark Univ. 5-6 75-235

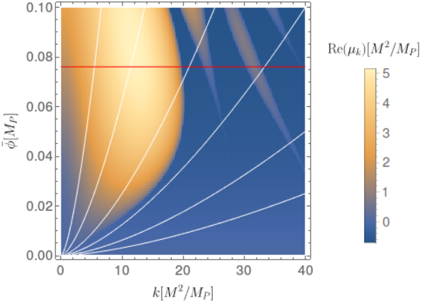
Planck Collaboration [arXiv:1807.06209 [astro-ph.CO]]

Models with positive Floquet exponents

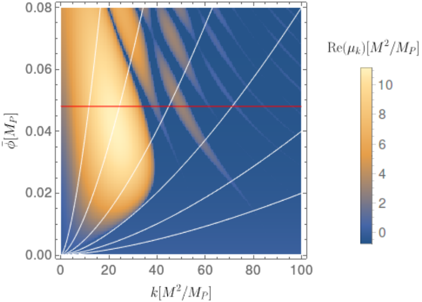
- Single-field models consistent with current cosmological data for which the Floquet exponents are positive:
  - Mutated hilltop inflation (MHI) $V(\phi) = M^4\left(1 - \mathrm{sech}\left(\frac{\phi}{\mu}\right)\right)$
  - Radion gauge inflation (RGI) $V(\phi) = M^4 \frac{(\phi/M_P)^2}{\alpha + (\phi/M_P)^2}$
  - Witten-O'Raifeartaigh inflation (WRI) $V(\phi) = M^4 \ln^2\left(\frac{\phi}{\phi_0}\right)$
  - Generalized renormalizable point inflation (GRIPI)
    $V(\phi) = M^4\left(\left(\frac{\phi}{\phi_0}\right)^2 - \frac{4}{3}\alpha\left(\frac{\phi}{\phi_0}\right)^3 + \frac{1}{2}\alpha\left(\frac{\phi}{\phi_0}\right)^4\right)$
  - KKLT inflation (KKLTI) $V(\phi) = M^4\left(1 + \left(\frac{\phi}{\mu}\right)^{-p}\right)^{-1}$
- Only the KKLTI model for $p \neq 2$ has non-quadratic minimum!

$$V(\phi) = M^4\left(1 - \mathrm{sech}\left(\frac{\phi}{\mu}\right)\right)$$

$\mu = 0.04$

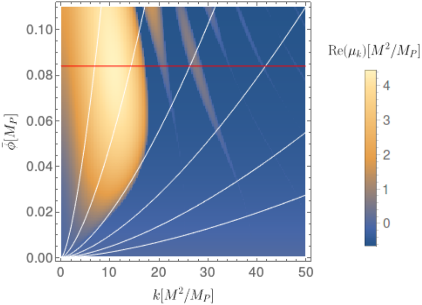


$\mu = 0.02$

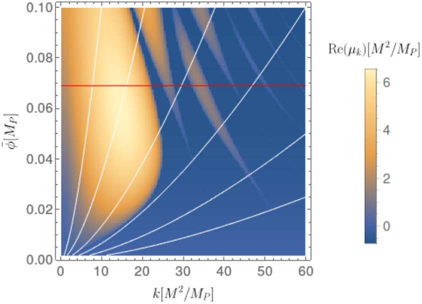


$$V(\phi) = M^4 \frac{(\phi/M_P)^2}{\alpha + (\phi/M_P)^2}$$

$\alpha = 0.004$



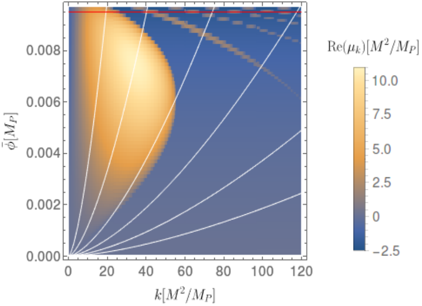
$\alpha = 0.002$



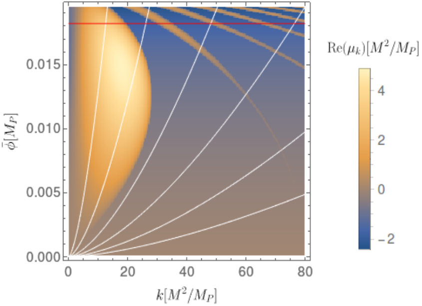
WRI

$$V(\phi) = M^4 \ln^2\left(\frac{\phi}{\phi_0}\right)$$

$\phi_0 = 0.01$

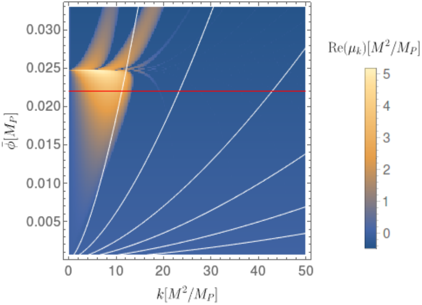


$\phi_0 = 0.02$

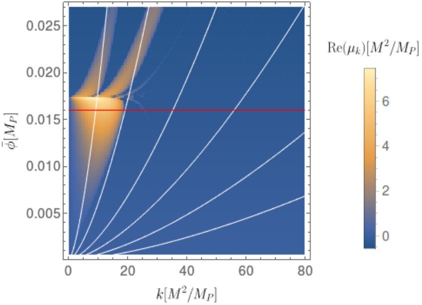


$$V(\phi) = M^4\left(\left(\frac{\phi}{\phi_0}\right)^2 - \frac{4}{3}\alpha\left(\frac{\phi}{\phi_0}\right)^3 + \frac{1}{2}\alpha\left(\frac{\phi}{\phi_0}\right)^4\right)$$

$\phi_0 = 0.07,\ \alpha = 1 - 10^{-11}$



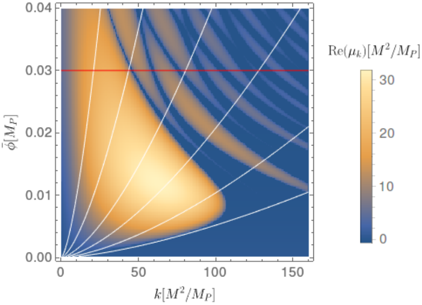
$\phi_0 = 0.05,\ \alpha = 1 - 10^{-11}$



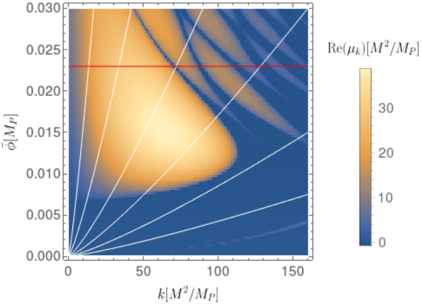
KKLTI

$$V(\phi) = M^4 \left(1 + \left(\frac{\phi}{\mu}\right)^{-p}\right)^{-1}$$

$\mu = 0.01, \; p = 2$

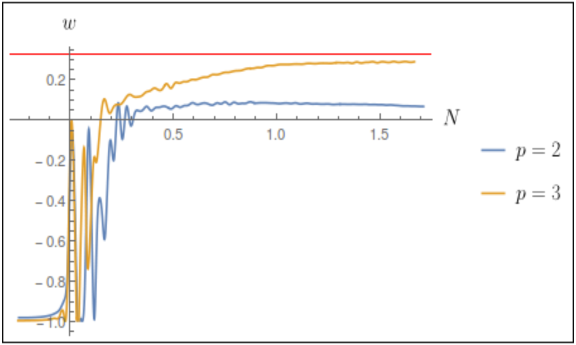


$\mu = 0.01, \; p = 3$



Results of lattice simulations for KKLTI model

- KKLTI model has quadratic minimum for $p = 2$ and nonquadratic minimum for $p = 3$
- the results of lattice simulations confirm the oscillons domination for $p = 2$ and effective reheating for $p = 3$



Conclusions

- From many single-field inflationary models described in *Encyclopaedia Inflationaris*, there are 5 characterized with both, agreement with cosmological data and the strong destabilization of inflaton perturbations via the self-resonance mechanism.
- Only one of these models, namely KKLT inflation model, has non-quadratic minimum, which prevents the formation of long-lived oscillons.
- Therefore only for the KKLT inflation model the self-resonance mechanism can be solely responsible for post-inflationary reheating.

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Thank you for your attention!