INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES

NON-MINIMAL M-FLATION

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PASCOS 2019

Based on

A.A. & Kazem Rezazadeh, *in preparation*

and also

A.A. & M. M. Sheikh-Jabbari, Phys.Lett. B739 (2014) 391-399

A.A., B. Fung, R. B. Mann, M. Oltean, M. M. Sheikh-Jabbari, JCAP 03 (2014) 020

A.A., U. Danielsson & M. M. Sheikh-Jabbari, Phys.Lett. B713 (2012) 353-357

A.A. & M. M. Sheikh-Jabbari, JCAP 1106 (2011) 014

A.A., H. Firouzjahi & M. M. Sheikh-Jabbari, JCAP 1005 (2010) 002

A.A., H. Firouzjahi & M. M. Sheikh-Jabbari, JCAP 0906 (2009) 018

Introduction

❖ Planck 2018 supports the paradigm of inflation.

❖ The experiment suggests a slightly red, adiabatic and almost gaussian scalar spectrum.

$$n_s = 0.9649 \pm 0.0084 \text{ (95\% C.L.)}$$

❖ It also suggests that the tensor-to-scalar ratio, $r_{0.002} < 0.064$.

❖ Energy scale of Inflation could be close to the GUT scale,

$$\Lambda_{\rm Inf} \equiv V_{\rm Inf}^{1/4} = 1.06 \times 10^{16} {\rm GeV} \left(\frac{r_{0.002}}{0.01}\right)^{1/4}$$

❖ Large r would correspond to super-Planckian displacement in field space:

$$\frac{\Delta\phi}{M_{\rm Pl}} \gtrsim 1.06 \times \left(\frac{r_{0.002}}{0.01}\right)^{1/2}$$

Lyth (1997)

Introduction

❖ Challenges for embedding inflationary models with large grav. waves scenarios in more fundamental theories:

- Embedding such models in supergravity, one has to insure the flatness of the potential on scales beyond the limit of validity of the theory.

Lyth (1997)
McAllister (2004)

- In stringy models of inflation, one usually finds the geometrical size of the region in which inflation can happen to be $\lesssim M_{\rm Pl}$

Baumann & McAllister (2007)

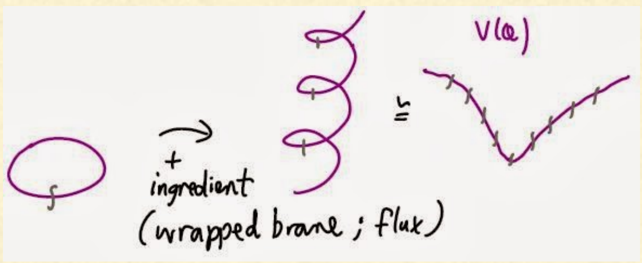
- In the context of Swampland conjecture (Ouguri & Vafa (2005, 2018)), this is known as distance conjecture.

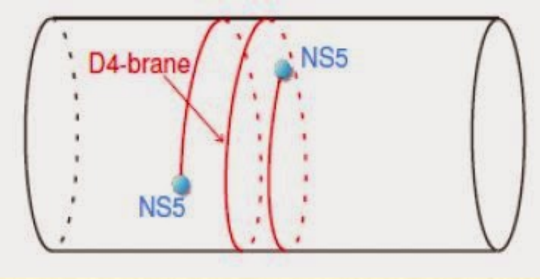
$$\text{As} \quad \Delta\phi \to M_{\rm Pl} \quad \longrightarrow \quad m_i \sim \Lambda e^{-\alpha \Delta\phi / M_{\rm Pl}}$$

- Since $r_{0.002}^{\textsc{planck}} < 0.064$, large field models are of phenomenological interest.

Introduction

❖ Single-Field approach:





Monodromy Inflation, Silverstein & Westphal (2008)

McAllister, Silverstein, Westphal (2009)

- Only considering multifield effects and the curved field space → $\Delta\phi_{\text{eff}} < M_{\text{Pl}}$

A. Landete & G. Shiu (2018)

❖ Many Field approach:

- Even though $\Delta\phi_{\text{eff}} > M_{\text{Pl}}$, because of large number of fields, $\Delta\phi_i < M_{\text{Pl}}$

N-flation, Kachru et. al (2006)
Multiple M5 brane Inflation, A. Krause, M. Becker, K, Becker (2005)
Cascade Inflation, A. Ashoorioon & A. Krause (2006)

Outline

❖ Minimal Matrix Inflation ($\mathbb{M}$-flation) setup

❖ Spectra of spectator modes in $\mathbb{M}$-flation

❖ Spectators as preheat field in $\mathbb{M}$-flation

❖ Issues with $\mathbb{M}$-flation

❖ Non-Minimal Matrix Inflation (Non- $\mathbb{M}$-flation)

❖ Prediction of Non-$\mathbb{M}$-flation

❖ Preheating in non-$\mathbb{M}$-flation

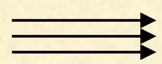
❖ Conclusions

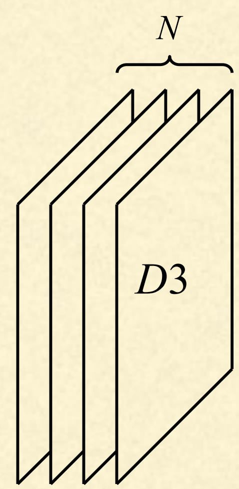
$\mathbb{M}$-flation Setup

A.A., H. Firouzjahi, M. M. Sheikh-Jabbari (2009)

A. A., M. M. Sheikh-Jabbari (2011)

$$C^{(6)}_{+123ij} = \frac{2\hat{\kappa}}{3}\epsilon_{ijk}x^k$$





i, j, k: 3 large dim's $\perp D3$'s *

x^K: 3 dim's $\parallel D3$'s & 5 dim's$\perp D3$'s

$a, b : 0, 1, 2, 3$

$I, J : 4, 5, \cdots, 9$

$M, N : 0, 1, \cdots 9$

$$ds^2 = 2dx^+dx^- - \hat{m}^2\sum_{i=1}^{3}(x^i)^2(dx^+)^2 + \sum_{K=1}^{8} dx_K dx_K$$

$$S = \frac{1}{(2\pi)^3 l_s^4 g_s}\int d^4x \ \mathrm{STr}\left(1 - \sqrt{-|g_{ab}|}\sqrt{|Q^I_J|} + \frac{ig_s}{4\pi l_s^2}\left[X^I, X^J\right] C^{(6)}_{IJ0123} - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}\right)$$

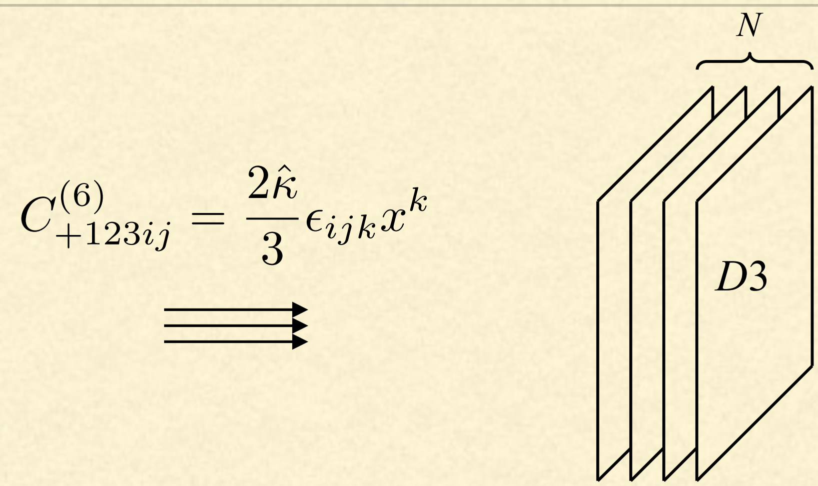
$$g_{ab} = G_{MN}\partial_a X^M \partial_b X^N \qquad\qquad Q^{IJ} = \delta^{IJ} + \frac{i}{2\pi l_s^2}\left[X^I, X^J\right]$$

* In principle, we could have used all 6 dimensions$\perp$ to the $D3$'s

$\mathbb{M}$-flation Setup

A.A., H. Firouzjahi, M. M. Sheikh-Jabbari (2009)

A. A., M. M. Sheikh-Jabbari (2011)



- If $\hat{m}^2 = \frac{4g_s^2\hat{k}^2}{9}$ $\Rightarrow$ with constant dilaton, the background is a solution to SUGRA in 10d.

- Expanding the DBI action, and using the field redefinition $\Phi_i = \frac{X_i}{\sqrt{(2\pi)^3 g_s l_s^2}}$

$$V = \mathrm{Tr}\left(-\frac{\lambda}{4}\left[\Phi_i,\Phi_j\right]\left[\Phi_i,\Phi_j\right] + \frac{i\kappa}{3}\epsilon_{jkl}\left[\Phi_k,\Phi_l\right]\Phi_j + \frac{m^2}{2}\Phi_i^2\right)$$

$$\lambda = 8\pi g_s$$

$$\kappa = \hat{\kappa} g_s\sqrt{8\pi g_s}$$

$$\hat{m}^2 = m^2$$

- Under $C^{(6)}$ two of the dimensions $\perp D3$'s blow up to a fuzzy S^2

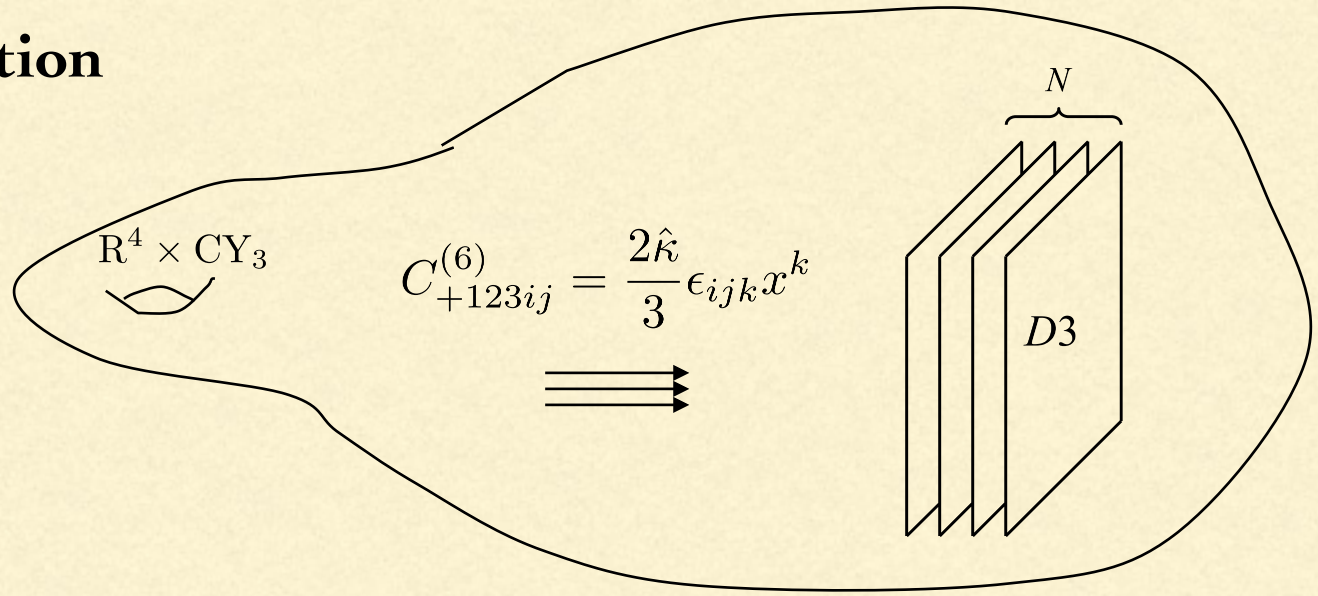
- In A.A., H. Firouzjahi, M. M. Sheikh-Jabbari (2009), $\hat{m}^2 = \frac{4g_s^2\hat{k}^2}{9}$ was relaxed.

$\mathbb{M}$-flation Setup

A.A., H. Firouzjahi, M. M. Sheikh-Jabbari (2009)

A. A., M. M. Sheikh-Jabbari (2011)

❖**Compactification**



- The issue of compactification & moduli stabilization has not been fully addressed so far.

- Up to now, it has been assumed that moduli fixing does not destabilize the inflationary potential.

- Also it is assumed that upon compactification to 4d, one gets minimal Einstein gravity.

$$S_{\mathbb{M}-\text{flation}} = \int d^4x\sqrt{-g}\left(\frac{M_{\rm Pl}^2}{2}\mathcal{R} - \frac{1}{2}\sum_{i=1}^{3}\mathrm{Tr}\left(D_\mu\Phi_i D^\mu\Phi_i\right) - V(\Phi_i,[\Phi_i,\Phi_j]) - \frac{1}{4}\mathrm{Tr}(F_{\mu\nu}F^{\mu\nu})\right)$$

$$D_\mu\Phi_i = \partial_\mu\Phi_i + ig_{\rm YM}[A_\mu,\Phi_i] \qquad F_{\mu\nu} = \partial_\mu A_\nu - \partial_n A_\mu + ig_{\rm YM}[A_\mu,A_\nu] \qquad g_{\rm YM}^2 = \frac{\lambda}{2} = 4\pi g_s$$

$\mathbb{M}$-flation Setup

A.A., H. Firouzjahi, M. M. Sheikh-Jabbari (2009)

A. A., M. M. Sheikh-Jabbari (2011)

- Φ_i's are matrices.

- One can show that there is a consistent truncation to the SU(2) sector:*

$$\Phi_i = \hat{\phi(t)} J_i \qquad\qquad i = 1, 2, 3$$

where J_i's are the generators of the SU(2) algebra.

- These representations could be reducible or irreducible

- A.A., H. Firouzjahi & M. M. Sheikh-Jabbari (2010) considered block diagonal representations.

- Using the SU(2) algebra for irrep. J_i

$$S = \int d^4x\sqrt{-g}\left[\frac{M_{\rm Pl}^2}{2}\mathcal{R} + {\rm Tr}J^2\left(-\frac{1}{2}\partial_\mu\hat{\phi}\partial^\mu\hat{\phi} - \frac{\lambda}{2}\hat{\phi}^4 + \frac{2\kappa}{3}\hat{\phi}^3 - \frac{m^2}{2}\hat{\phi}^2\right)\right]$$

$$\phi = [{\rm Tr}(J^2)]^{1/2}\hat{\phi}$$

$${\rm Tr}(J^2) = \sum_{i=1}^{3}{\rm Tr}(J_i^2) = \frac{N(N^2-1)}{4}$$

$$\lambda_{\rm eff} \equiv \frac{2\lambda}{{\rm Tr}(J^2)} = \frac{8\lambda}{N(N^2-1)} \qquad \kappa_{\rm eff} \equiv \frac{\kappa}{\sqrt{{\rm Tr}(J^2)}} = \frac{2\kappa}{\sqrt{N(N^2-1)}} \qquad m_{\rm eff}^2 = m^2$$

* One could play with all 6 spatial dim's perpendicular to the D3 branes and use rep's of SO(4).

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$$S = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}\mathcal{R} + \left(-\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{\lambda_{\rm eff}}{2}\phi^4 + \frac{2\kappa_{\rm eff}}{3}\phi^3 - \frac{m_{\rm eff}^2}{2}\phi^2\right)\right] \qquad \mathrm{Tr}(J^2) = \sum_{i=1}^{3}\mathrm{Tr}(J_i^2) = \frac{N(N^2-1)}{4}$$

$$\lambda_{\rm eff} \equiv \frac{2\lambda}{\mathrm{Tr}(J^2)} = \frac{8\lambda}{N(N^2-1)} \qquad \kappa_{\rm eff} \equiv \frac{\kappa}{\sqrt{\mathrm{Tr}(J^2)}} = \frac{2\kappa}{\sqrt{N(N^2-1)}} \qquad m_{\rm eff}^2 = m^2$$

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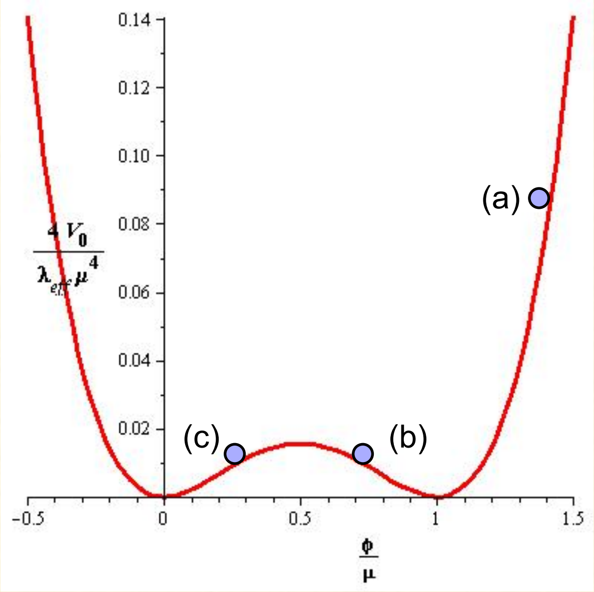
$\mathbb{M}$-flation Setup

A.A., H. Firouzjahi, M. M. Sheikh-Jabbari (2009)

A. A., M. M. Sheikh-Jabbari (2011)

- If $\hat{m}^2 = \frac{4g_s^2\hat{k}^2}{9}$ is imposed $V(\phi) = \frac{\lambda_{\rm eff}}{4}\phi^2(\phi-\mu)^2$ $\quad \mu \equiv \frac{\sqrt{2}m}{\lambda_{\rm eff}}$



- Match with the PLANCK2018 central value for n_S with $N_e = 60$

(a) $\phi > \mu$ $\quad \mu \simeq 95.65\ M_{\rm Pl}$ $\quad \lambda_{\rm eff} \simeq 6.03 \times 10^{-15}$

$r_{0.002} \simeq 0.1581$ $\quad$ ruled out by PLANCK 2018!

$\lambda \simeq 1$, one needs $N \simeq 109850$! $\quad \Delta\phi \simeq 8.18 \times 10^{-7} M_{\rm Pl}$

(b) & (c) $\phi < \mu$ $\quad \mu \simeq 41.87\ M_{\rm Pl}$ $\quad \lambda_{\rm eff} \simeq 4.86 \times 10^{-14}$

$r_{0.002} \simeq 0.0555$ $\quad$ Within 1σ region of PLANCK 2018!

$\lambda \simeq 1$, one needs $N \simeq 54820$! $\quad \Delta\phi \simeq 1.83 \times 10^{-6} M_{\rm Pl}$

- Individual physical field displacement is $\sim 10^{-6} M_{\rm Pl} \ll M_{\rm Pl}$
- The price: $N \sim 10^5$ D3 branes $\longrightarrow$ Backreaction, important & potentially dangerous

Spectra of spectator modes Ψ in $\mathbb{M}$-flation

A.A., H. Firouzjahi, M. M. Sheikh-Jabbari (2009)

A. A., M. M. Sheikh-Jabbari (2011)

- There are $5N^2-1$ more independent d.o.f. besides the SU(2) direction

(a) $(N-1)^2-1$ α-modes

$\omega_{\alpha_j}=-(j+2) \quad 0\le j\le N-2$

$$M^2_{\alpha_j}=\frac{\lambda_{\rm eff}}{2}\left[\phi^2(\omega^2_{\alpha_j}-\omega_{\alpha_j})+3\mu\phi\omega_{\alpha_j}+\mu^2\right]$$

with degeneracy of $2j+1$

(b) $(N+1)^2-1$ β-modes

$$M^2_{\beta_j}=\frac{\lambda_{\rm eff}}{2}\left[\phi^2(\omega^2_{\beta_j}-\omega_{\beta_j})+3\mu\phi\omega_{\beta_j}+\mu^2\right]$$

$\omega_{\beta_j}=j-1 \quad 1\le j\le N$

with degeneracy of $2j+1$

(c) $3N^2-1$ gauge-modes

$0\le j\le N-1$

with degeneracy of $2j+1$

$$M^2_{\mathrm{g}_j}=\frac{\lambda_{\rm eff}}{4}\phi^2 j(j+1)$$

$$\underbrace{(N-1)^2-1}_{\alpha-\text{modes}}+\underbrace{(N+1)^2-1}_{\beta-\text{modes}}+\underbrace{3N^2-1}_{\text{gauge modes}}=5N^2-1$$

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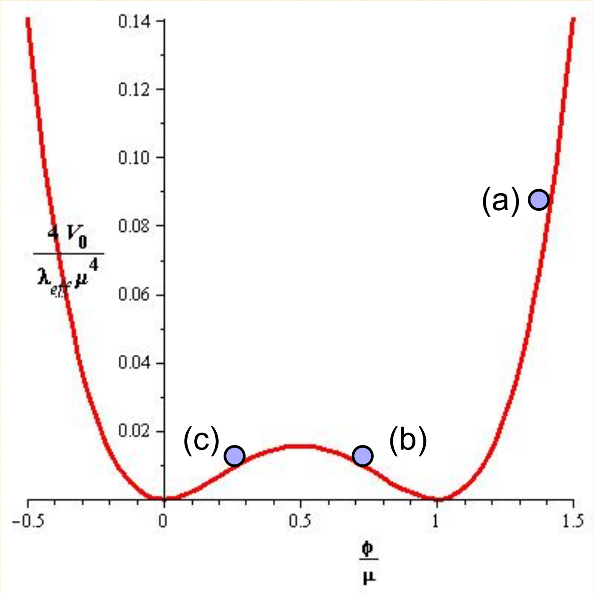


- For gauge modes: $M^2_{\mathrm{g}_{j\neq 0}} \geq 0$

- For α and β modes, $M^2(\phi) < 0$, for $\phi_1 < \phi < \phi_2$

$$\phi_{1,2} = \frac{-3\omega \pm \sqrt{5\omega^2 + 4\omega}}{\omega^2 - \omega}\frac{\mu}{2}$$

- Region (a): is never beset by this instability.

  Incompatible with PLANCK2018 though!

- Region (b): only $\omega = -3$ $(j = 1$ β mode$)$ becomes unstable, $\phi_2|_{\mu \simeq 41.87 M_{\mathrm{Pl}}} < \phi_{\mathrm{CMB}}$

  $\Delta\phi_{\mathrm{max}} \equiv \phi_2 - \phi_f \simeq 14.78\ M_{\mathrm{Pl}}$ can support ~109 e-folds of inflation.

* In this region, local attractor & compatible with PLANCK2018!

- Region (c): for $-79 \leq \omega \leq -3$ β-modes, SU(2) direction becomes unstable.

Spectators as preheat fields

A.A., B. Fung, R. B. Mann, M. Oltean, M. M. Sheikh-Jabbari (2014)

- Backreaction of spectator modes is negligible during inflation when slow-roll is held.

- When slow-roll is violated at the end of inflation, the situation could be different.

- However if inflation ends around $\phi = \mu$, stochastic resonance is not successful

$$M^2_{\alpha,\beta}\big|_{\phi=\mu} = \frac{\lambda_{\rm eff}\mu^2}{2}(\omega+1)^2 \qquad \omega_{\alpha_j} = -(j+2) \qquad \omega_{\beta_j} = j-1 \qquad M^2_{\rm g}\big|_{\phi=\mu} = \frac{\lambda_{\rm eff}\mu^2}{4} j(j+1)$$

$$\ddot{\psi}_{\alpha,\beta} + 3H\dot{\psi}_{\alpha,\beta} + \Omega^2_{k_{\alpha,\beta}}\psi_{\alpha,\beta} = 0 \qquad \ddot{\psi}_{\rm g} + H\dot{\psi}_{\rm g} + \Omega^2_{k_{\rm g}}\psi_{\rm g} = 0$$

- For all values of j

$$\left|\frac{\dot{\Omega}_k}{\Omega_k^2}\right| \ll 1$$

parametric resonance around $\phi = \mu$ is unsuccessful

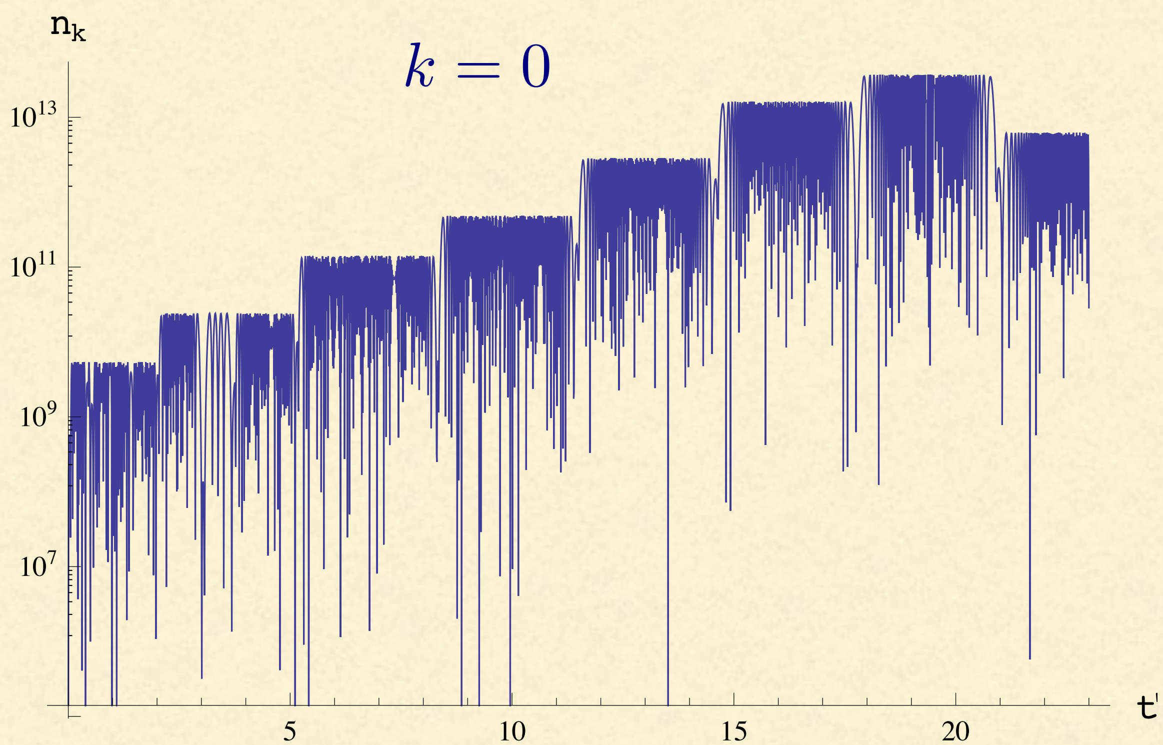
Spectators as preheat fields

A.A., B. Fung, R. B. Mann, M. Oltean, M. M. Sheikh-Jabbari (2014)

- If inflation ends around $\phi = 0$, stochastic resonance is quite successful

- For large values of j

$$\left|\frac{\dot{\Omega}_k}{\Omega_k^2}\right| \gg 1$$



inflationary trajectory that ended in $\phi = 0$ was unstable.

Issues with $\mathbb{M}$-flation

- $N_{D3} \gg 1$ $\longrightarrow$ Backreaction on the geom. is important & potentially dangerous

- Region (a) of the potential, where eternal inflation can be supported and is a local attractor, not compatible with PLANCK anymore.

- Region (b) of the potential, which is compatible with Planck, can sustain a limited number of e- folds>60, but cannot support eternal inflation.

- Embedded preheating mechanism, using the spectator fields, does not work for regions (a) & (b)

A.A., B. Fung, R. B. Mann, M. Oltean, M. M. Sheikh-Jabbari (2014)

- Region (c), which enjoys the embedded preheating mechanism, is not a local attractor.

Non-Minimal M-flation (Non-$\mathbb{M}$-flation)

- In top-down approaches,

Moduli stabilization sector + inflationary sector $\longrightarrow$ **corrections** $\propto \mathcal{R}\phi^2 \longrightarrow \eta$ **problem**

- In presence of vacuum energy, V, soft masses, including the inflaton's, receives

$$\Delta m^2 \simeq \frac{V}{M_{\rm Pl}^2} = 3H^2$$

McAllister (2005)

- For example in $\mathbb{K}$L$\mathbb{M}$T, volume stabilization of volume modulus leads to such a correction.

$$\delta V = \frac{2V_0}{3M_{\rm Pl}^2}\phi\bar{\phi} \sim \frac{1}{6}\mathcal{R}\phi\bar{\phi}$$

- If the superpotential has dependence on the D3-brane position moduli,

$$V(\rho_c, \phi) = V_0(\rho_c) + \left(\frac{\alpha V_0(\rho_c)}{2\rho_c} + \frac{\Delta(\rho_c)}{\rho_c^\alpha}\right)\phi\bar{\phi} + \ldots$$

Non-Minimal M-flation (Non-$\mathbb{M}$-flation)

- We posit that

$$S_{\mathrm{Non-\mathbb{M}-flation}} = \int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}\left(1+\frac{\xi}{M_P^2}\mathrm{Tr}\sum_{i=1}^{3}\left(\Phi_i^2\right)\right)\mathcal{R} - \frac{1}{2}\sum_{i=1}^{3}\sum \mathrm{Tr}\left(D_\mu\Phi_i D^\mu\Phi_i\right) - V\left(\Phi_i,[\Phi_i,\Phi_j]\right) - \frac{1}{4}\mathrm{Tr}(F_{\mu\nu}F^{\mu\nu})\right]$$

- One can again
  - go to the SU(2) sector
  - go to the Einstein frame using the canonical renormalization $\tilde{g}_{\mu\nu} = \Omega^2(\phi)g_{\mu\nu}$

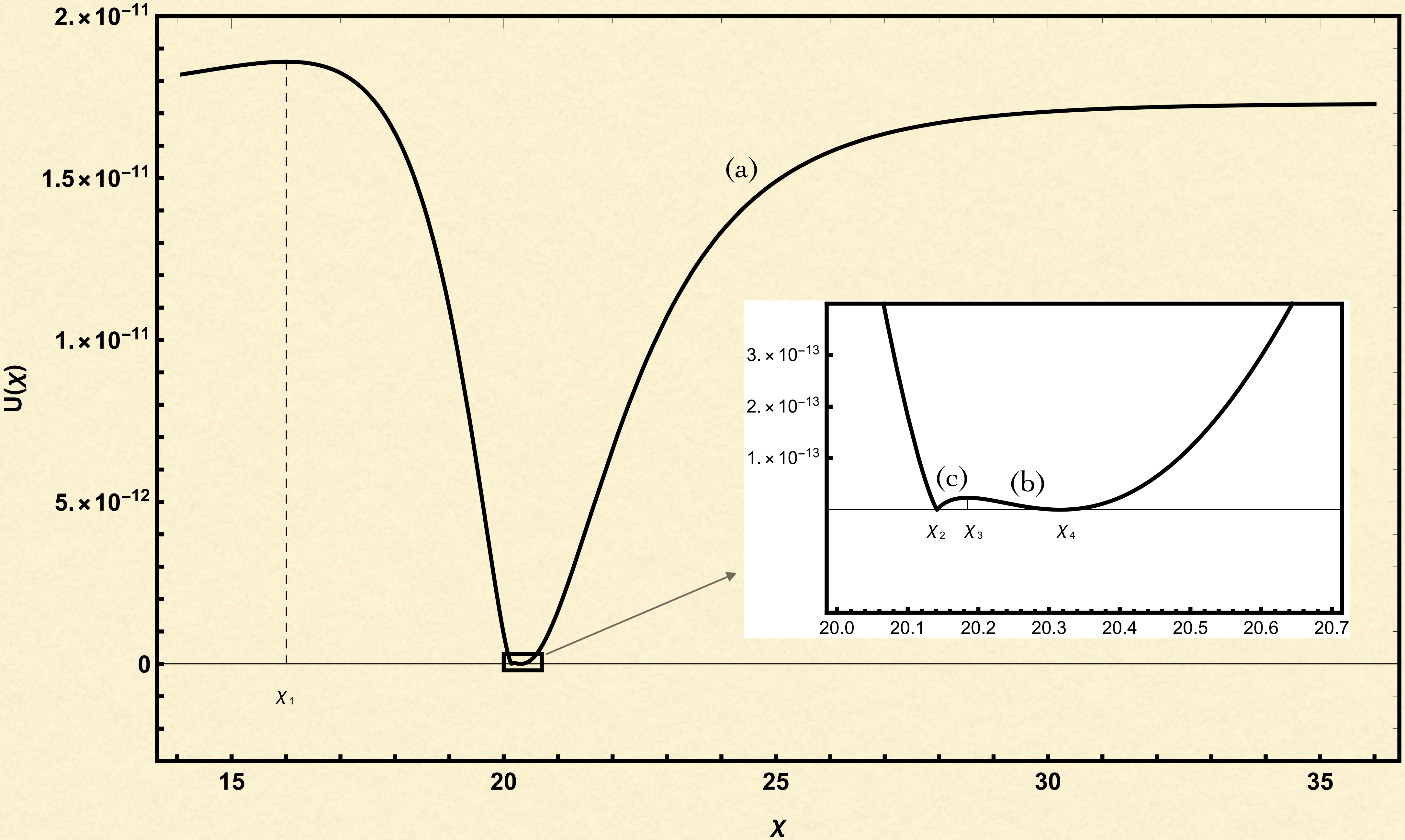
$$\Omega^2 = 1 + \frac{\xi}{M_P^2}\phi^2$$

  - defining a field with canonical kinetic term and rescaling the time coordinate

$$\frac{d\chi}{d\phi} = \sqrt{\frac{\Omega^2 + 6\xi^2\phi^2/M_P^2}{\Omega^4}} \qquad d\tilde{t} = \Omega dt$$

$$S_{\mathrm{E}} = \int d^4x\sqrt{-\tilde{g}}\left[\frac{M_P^2}{2}\tilde{R} + \frac{1}{2}\left(\frac{d\chi}{d\tilde{t}}\right)^2 - U(\chi)\right] \qquad U(\chi) \equiv \frac{V\left(\phi(\chi)\right)}{\Omega^4\left(\phi(\chi)\right)}$$

Non-𝕄-flation



Non-$\mathbb{M}$-flation

❖ Spectators' Lagrangian

$$S_{\rm E} = \int d^4x\sqrt{-\tilde{g}}\left[\frac{M_{\rm Pl}^2}{2}\tilde{\mathcal{R}} + \frac{1}{2}\left(\frac{d\chi}{d\tilde{t}}\right)^2 - U(\chi) + \frac{1}{2}\frac{1}{\Omega^2}\left(\frac{d\Psi_i}{d\tilde{t}}\right)^2 - \tilde{V}_{(2)}\left(\chi, \Psi_i\right)\right]$$

$$\tilde{V}_{(2)}\left(\chi, \Psi_i\right) \equiv \frac{V_2(\chi, \Psi_i)}{\Omega(\phi(\chi))^4} = \frac{1}{2}\frac{M_{\Psi_i}^2(\phi(\chi))}{\Omega(\phi(\chi))^4}\Psi_i^2$$

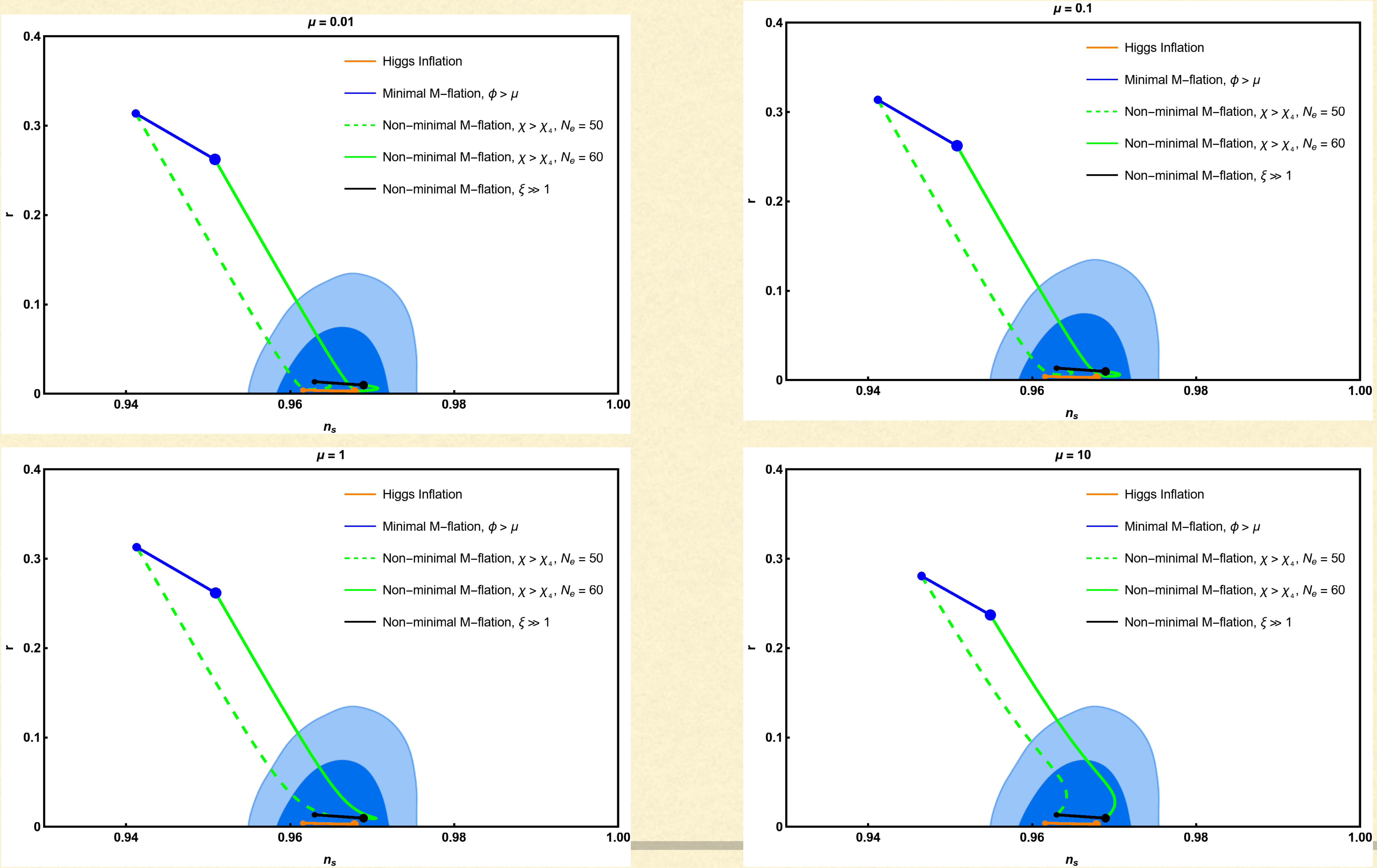
$$M_{\Psi_{\alpha,\beta}}^2(\phi(\chi)) = \frac{\lambda_{\rm eff}^2}{2}\left[\phi(\chi)^2(\omega^2-\omega) + 3\mu\omega\phi(\chi) + \mu^2\right]$$

$$M_{\Psi_{\alpha,\beta}}^2(\phi(\chi)) = \frac{\lambda_{\rm eff}^2}{2}\phi(\chi)^2$$

❖ We see that the whole region (a) and the corresponding part of region (b), in the χ space, are again local attractors.

Non-𝕄-flation Predictions

❖ Region (a) $\chi > \chi_4$



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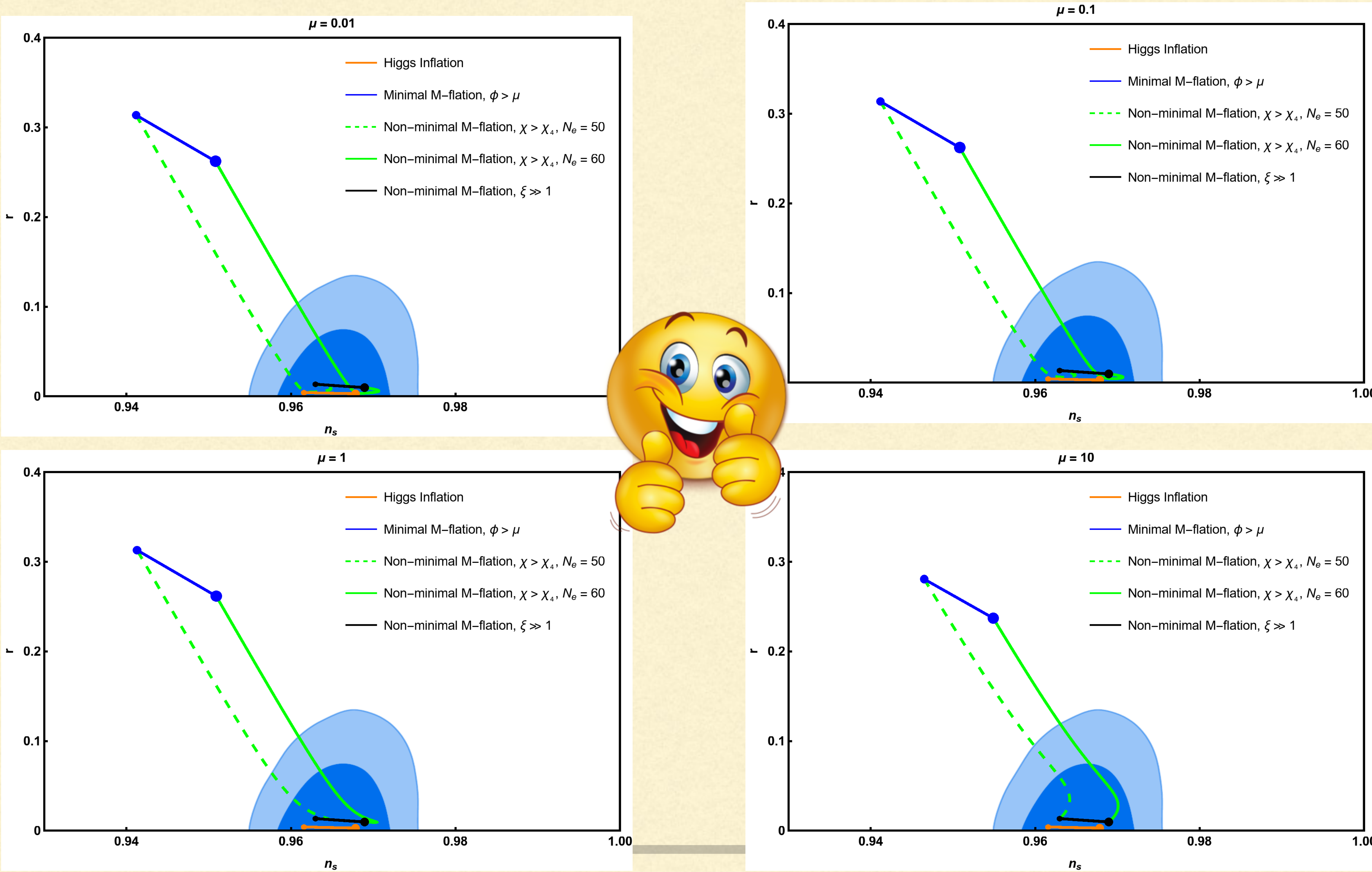

Non-$\mathbb{M}$-flation Predictions

❖ Region (a): $\chi > \chi_4$

- Some examples from the RHS of the potential:
  - $\mu = 0.01 \ M_{\rm Pl}$ $\xi \simeq 1519.91$ $n_s \simeq 0.9707$ $r \simeq 0.0061$ $N \simeq 16$
  - $\mu = 0.01 \ M_{\rm Pl}$ $\xi \simeq 265.609$ $n_S \simeq 0.970078$ $r \simeq 0.00442$ $N \simeq 58$
  - $\mu = 1 \ M_{\rm Pl}$ $\xi = 100$ $n_S \simeq 0.9689$ $r \simeq 0.0098$ $N \simeq 84$
  - $\mu = 10 \ M_{\rm Pl}$ $\xi \simeq 572.237$ $n_s \simeq 0.96895$ $r \simeq 0.0098156$ $N \simeq 26$
  - $\mu = 100 \ \rm M_{Pl}$ $\xi \simeq 284.803$ $n_s \simeq 0.96895$ $r \simeq 0.009818$ $N \simeq 81$

❖ With $\xi \sim$ few $\times\, 100$ one can make region (a) compatible with Planck2018 and $N \lesssim 100$

Non-$\mathbb{M}$-flation Predictions

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  - $\mu = 100\ \mathrm{M_{Pl}}$ $\xi \simeq 284.803$ $n_s \simeq 0.96895$ $r \simeq 0.009818$ $N \simeq 81$

❖ With $\xi \sim \text{few} \times 100$ one can make region (a) compatible with Planck2018 and $N \lesssim 100$

Non-$\mathbb{M}$-flation Predictions

❖ Isocurvature Spectra:

$$S_{\mathrm{E}} = \int d^4x \sqrt{-\tilde{g}} \left[\frac{M_{\mathrm{Pl}}^2}{2} \tilde{\mathcal{R}} + \frac{1}{2} \left(\frac{d\chi}{d\tilde{t}} \right)^2 - U(\chi) + \frac{1}{2} \frac{1}{\Omega^2} \left(\frac{d\Psi_i}{d\tilde{t}} \right)^2 - \tilde{V}_{(2)}\left(\chi, \Psi_i\right) \right]$$

$$S_{\mathrm{E}} = \int d^4x \sqrt{-\tilde{g}} \left[\frac{M_{\mathrm{Pl}}^2}{2} \tilde{\mathcal{R}} + \frac{1}{2} \left(\frac{d\chi}{d\tilde{t}} \right)^2 - U(\chi) + \frac{e^{2b(\chi)}}{2} \left(\frac{d\Psi_i}{d\tilde{t}} \right)^2 - \tilde{V}_{(2)}\left(\chi, \Psi_i\right) \right]$$

Lalak, Langlois, Pokorski, Turzynski (2007)

$$b(\chi) \equiv -\ln \Omega(\phi(\chi))$$

Non-$\mathbb{M}$-flation Predictions

❖ Region (a): $\chi > \chi_4$

- Scalar Isocurvature Spectra

$j=1$ $\beta-\text{mode}$	$\mathcal{P}_{\beta_1} \simeq 9.3 \times 10^{-25}$
$j=1$ $\alpha-\text{mode}$	$\mathcal{P}_{\alpha_1} \simeq 9.3 \times 10^{-25}$

Isocurvature spectra
are likely unobservable
in non-$\mathbb{M}$-flation too !

Preheating in Non-$\mathbb{M}$-flation

✤ When slow-roll ends there is a possibility of particle production:

$$S_{\rm E}=\int d^4x\sqrt{-\tilde{g}}\left[\frac{M_{\rm Pl}^2}{2}\tilde{\mathcal{R}}+\frac{1}{2}\left(\frac{d\chi}{d\tilde{t}}\right)^2-U(\chi)+\frac{1}{2}\frac{1}{\Omega^2}\left(\frac{d\Psi_i}{d\tilde{t}}\right)^2-\tilde{V}_{(2)}\left(\chi,\Psi_i\right)\right]$$

$$\tilde{V}_{(2)}\left(\chi,\Psi_i\right)\equiv\frac{V_2(\chi,\Psi_i)}{\Omega(\phi(\chi))^4}=\frac{1}{2}\frac{M_{\Psi_i}^2(\phi(\chi))}{\Omega(\phi(\chi))^4}\Psi_i^2 \qquad \Psi_i=\Omega\tilde{\Psi}_i$$

$$S_{\rm E}=\int d^4x\sqrt{-\tilde{g}}\left[\frac{M_{\rm Pl}^2}{2}\tilde{\mathcal{R}}+\frac{1}{2}\left(\frac{d\chi}{d\tilde{t}}\right)^2-U(\chi)+\frac{1}{2}\left(\frac{d\tilde{\Psi}_i}{d\tilde{t}}\right)^2-\tilde{\tilde{V}}_{(2)}\left(\chi,\tilde{\Psi}_i\right)-\frac{\tilde{\Psi}_i}{2\Omega}\frac{d\tilde{\Psi}_i}{d\tilde{t}}\frac{d\Omega}{d\tilde{t}}\right]$$

$$\tilde{\tilde{V}}_{(2)}\left(\chi,\tilde{\Psi}_i\right)=\frac{1}{2}\left[\frac{M_{\Psi_i}^2}{\Omega(\chi)^2}+\frac{1}{\Omega^2}\left(\frac{d\Omega}{d\tilde{t}}\right)^2\right]\tilde{\Psi}_i^2$$

$$\tilde{\tilde{V}}_{(2)}\left(\chi,\tilde{\Psi}_i\right)=\frac{1}{2}\left[\frac{M_{\Psi_i}^2}{\Omega(\chi)^2}+\frac{1}{\Omega^2}\left(\frac{d\Omega}{d\chi}\right)^2\left(\frac{d\chi}{d\tilde{t}}\right)^2\right]\tilde{\Psi}_i^2$$

Preheating in Non-$\mathbb{M}$-flation

- When slow-roll ends there is a possibility of particle production:

$$S_{\rm E} = \int d^4x\sqrt{-\tilde{g}}\left[\frac{M_{\rm Pl}^2}{2}\tilde{\mathcal{R}} + \frac{1}{2}\left(\frac{d\chi}{d\tilde{t}}\right)^2 - U(\chi) + \frac{1}{2}\frac{1}{\Omega^2}\left(\frac{d\Psi_i}{d\tilde{t}}\right)^2 - \tilde{V}_{(2)}\left(\chi,\Psi_i\right)\right]$$

$$\tilde{V}_{(2)}\left(\chi,\Psi_i\right) \equiv \frac{V_2(\chi,\Psi_i)}{\Omega(\phi(\chi))^4} = \frac{1}{2}\frac{M^2_{\Psi_i}(\phi(\chi))}{\Omega(\phi(\chi))^4}\Psi_i^2 \qquad \Psi_i = \Omega\tilde{\Psi}_i$$

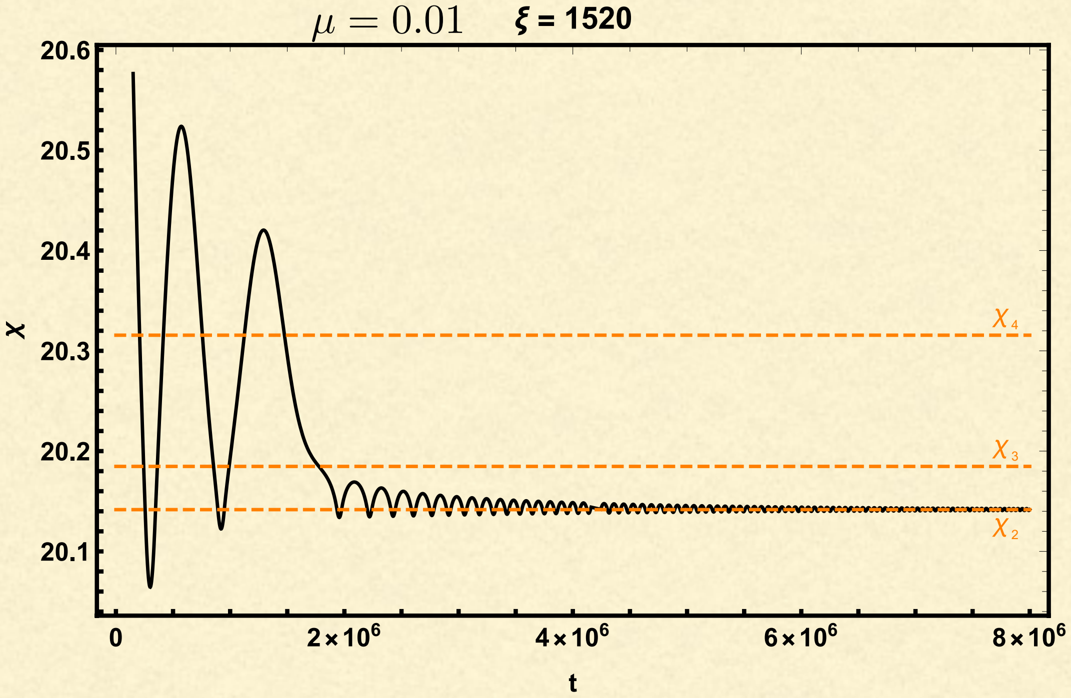
kinetic mixing

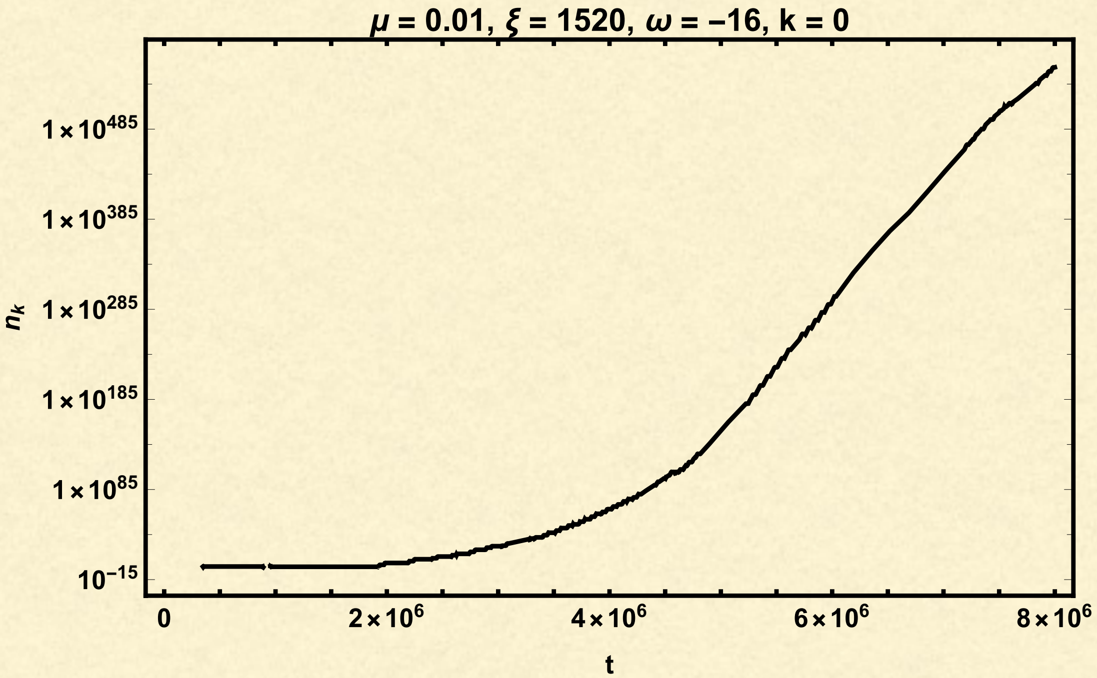
$$S_{\rm E} = \int d^4x\sqrt{-\tilde{g}}\left[\frac{M_{\rm Pl}^2}{2}\tilde{\mathcal{R}} + \frac{1}{2}\left(\frac{d\chi}{d\tilde{t}}\right)^2 - U(\chi) + \frac{1}{2}\left(\frac{d\tilde{\Psi}_i}{d\tilde{t}}\right)^2 - \tilde{\tilde{V}}_{(2)}\left(\chi,\tilde{\Psi}_i\right) - \boxed{\frac{\tilde{\Psi}_i}{2\Omega}\frac{d\Omega}{d\chi}\frac{d\tilde{\Psi}_i}{d\tilde{t}}\frac{d\chi}{d\tilde{t}}}\right]$$

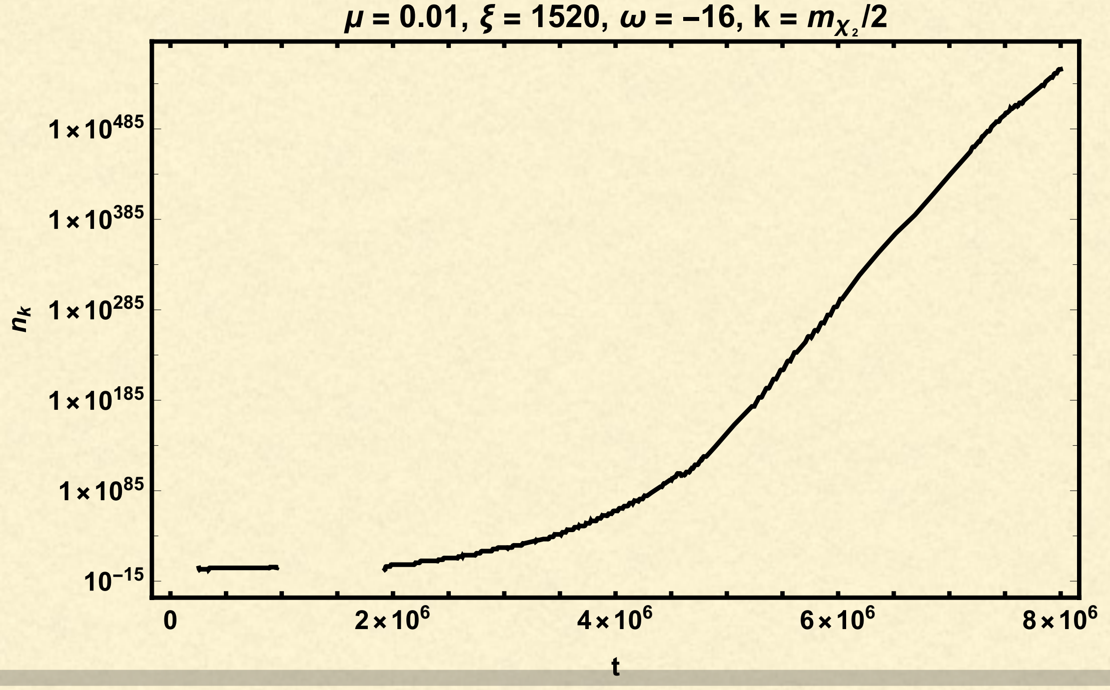
$$\tilde{\tilde{V}}_{(2)}\left(\chi,\tilde{\Psi}_i\right) = \frac{1}{2}\left[\frac{M^2_{\Psi_i}}{\Omega(\chi)^2} + \frac{1}{\Omega^2}\left(\frac{d\Omega}{d\tilde{t}}\right)^2\right]\tilde{\Psi}_i^2$$

$$\tilde{\tilde{V}}_{(2)}\left(\chi,\tilde{\Psi}_i\right) = \frac{1}{2}\left[\frac{M^2_{\Psi_i}}{\Omega(\chi)^2} + \frac{1}{\Omega^2}\left(\frac{d\Omega}{d\chi}\right)^2\left(\frac{d\chi}{d\tilde{t}}\right)^2\right]\tilde{\Psi}_i^2$$

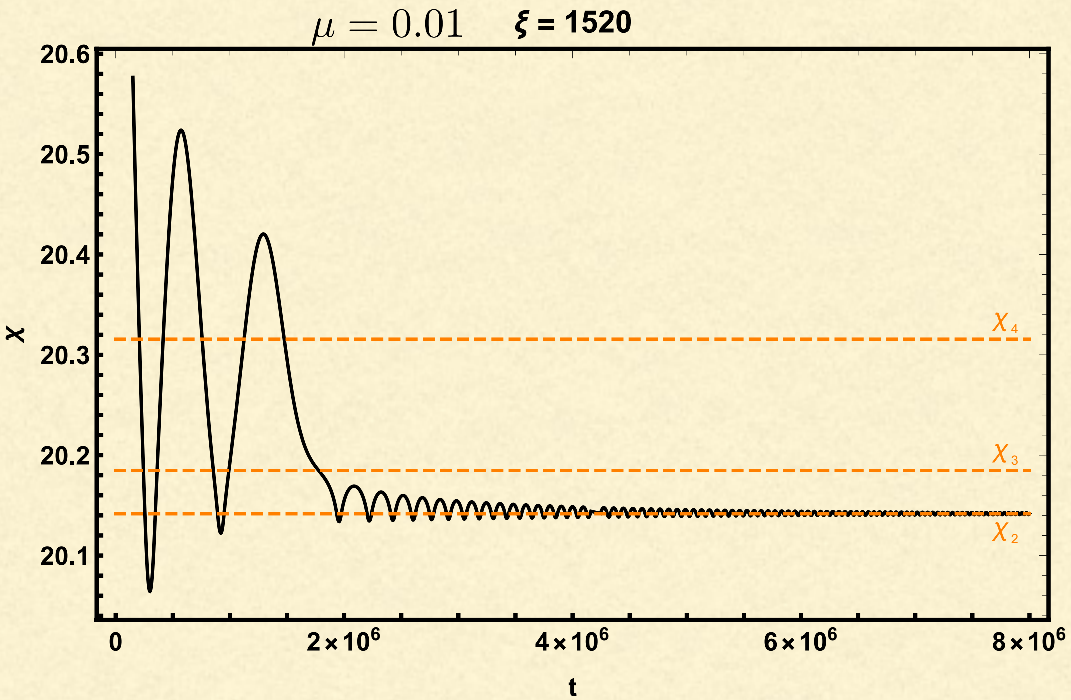
Preheating in Non-$\mathbb{M}$-flation

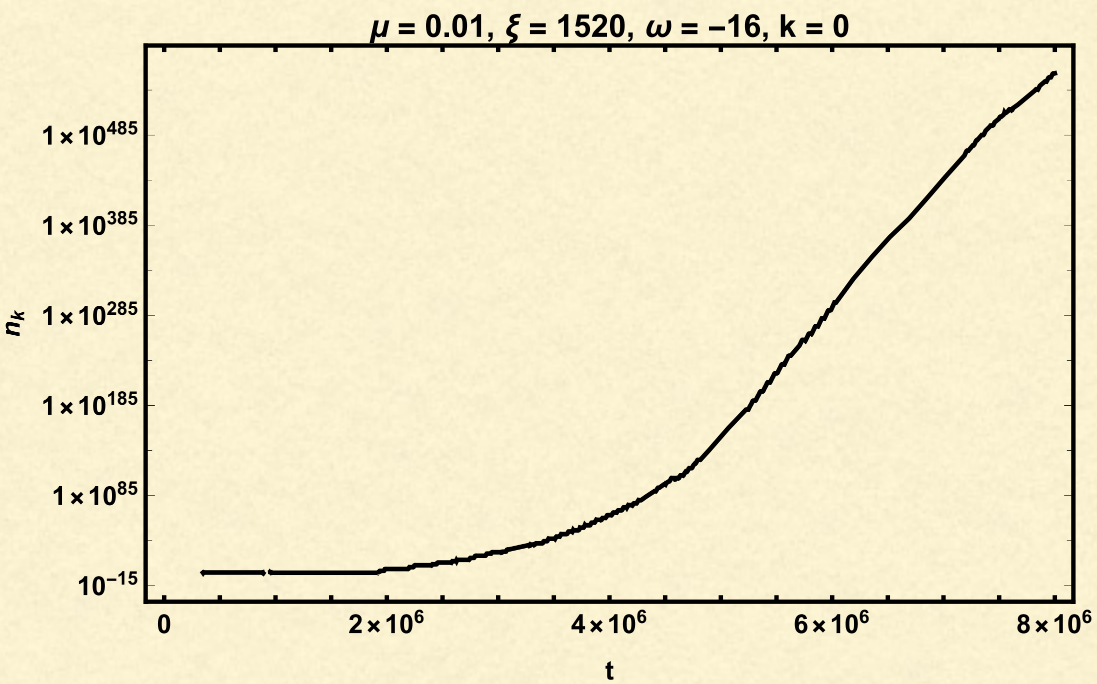


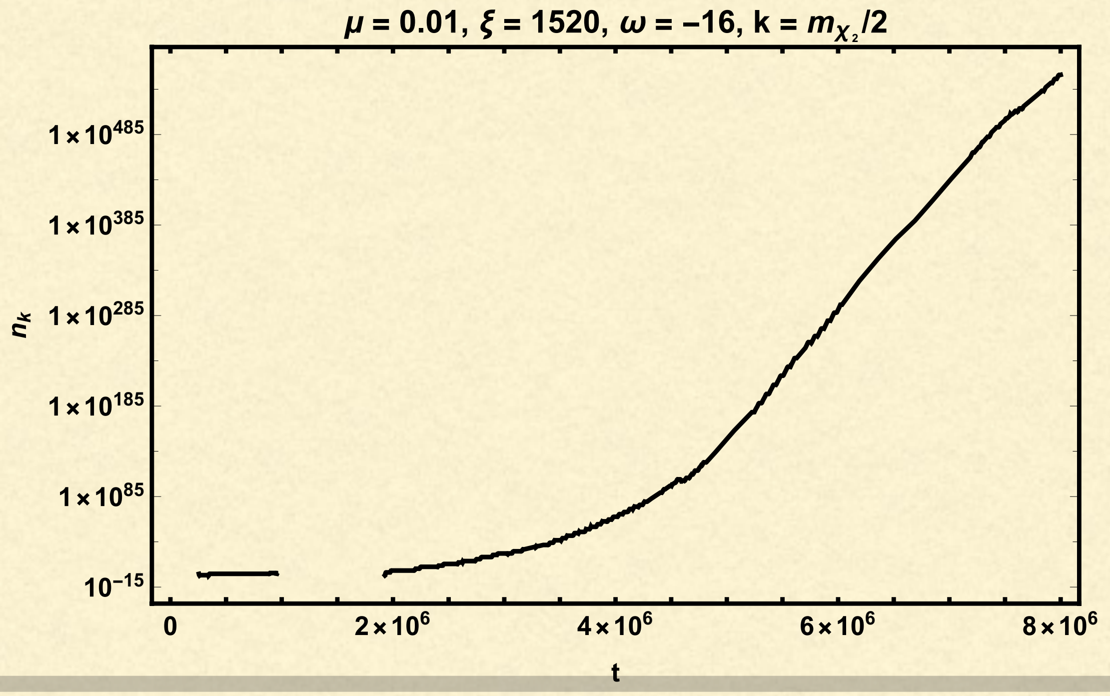




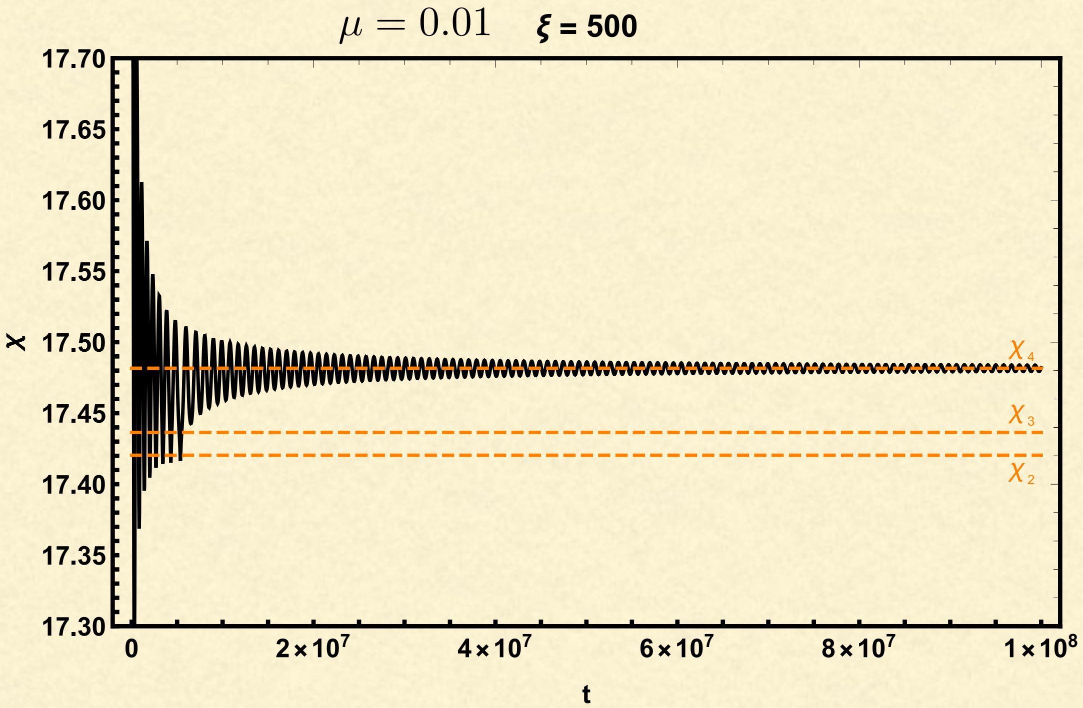
Preheating in Non-$\mathbb{M}$-flation

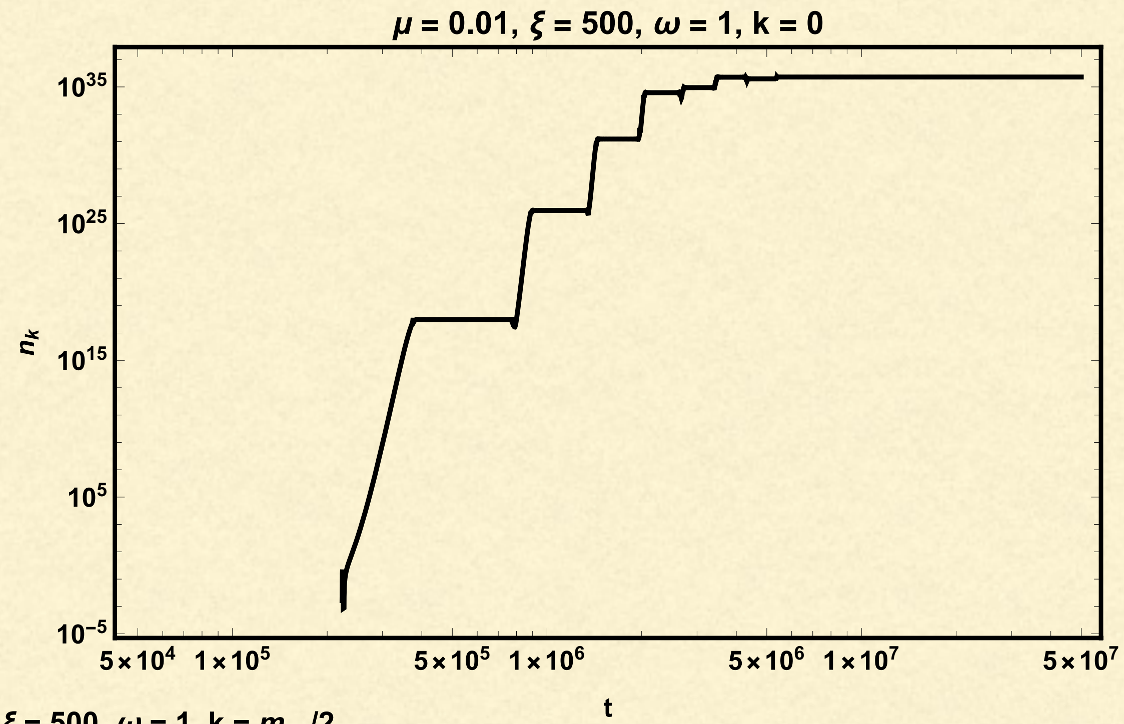


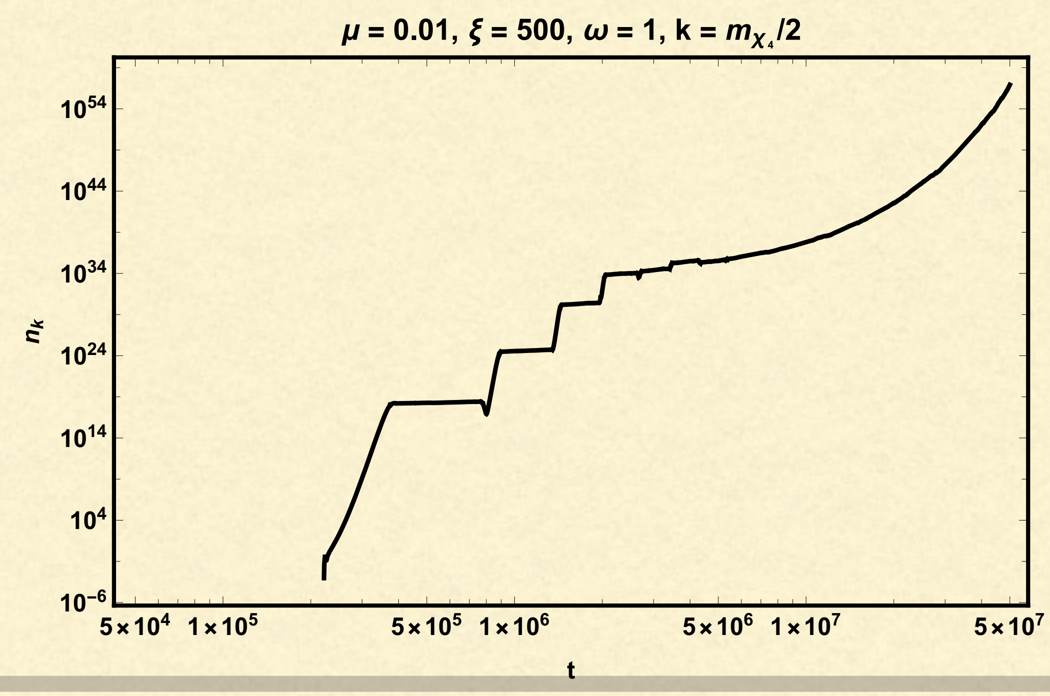




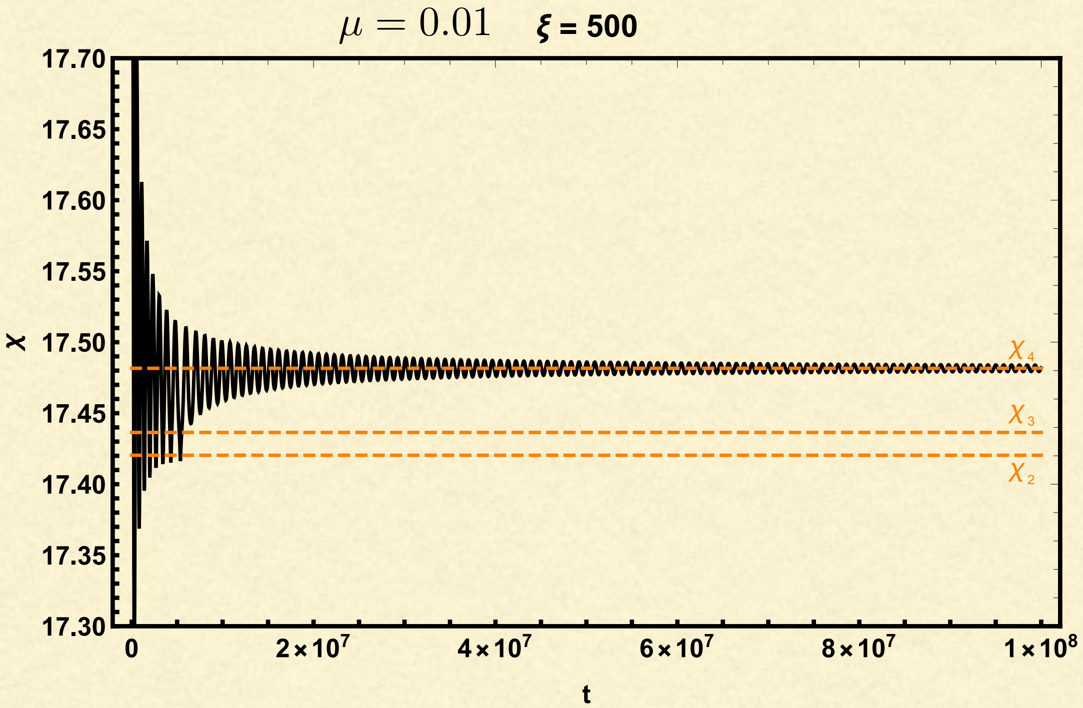
Preheating in Non-$\mathbb{M}$-flation

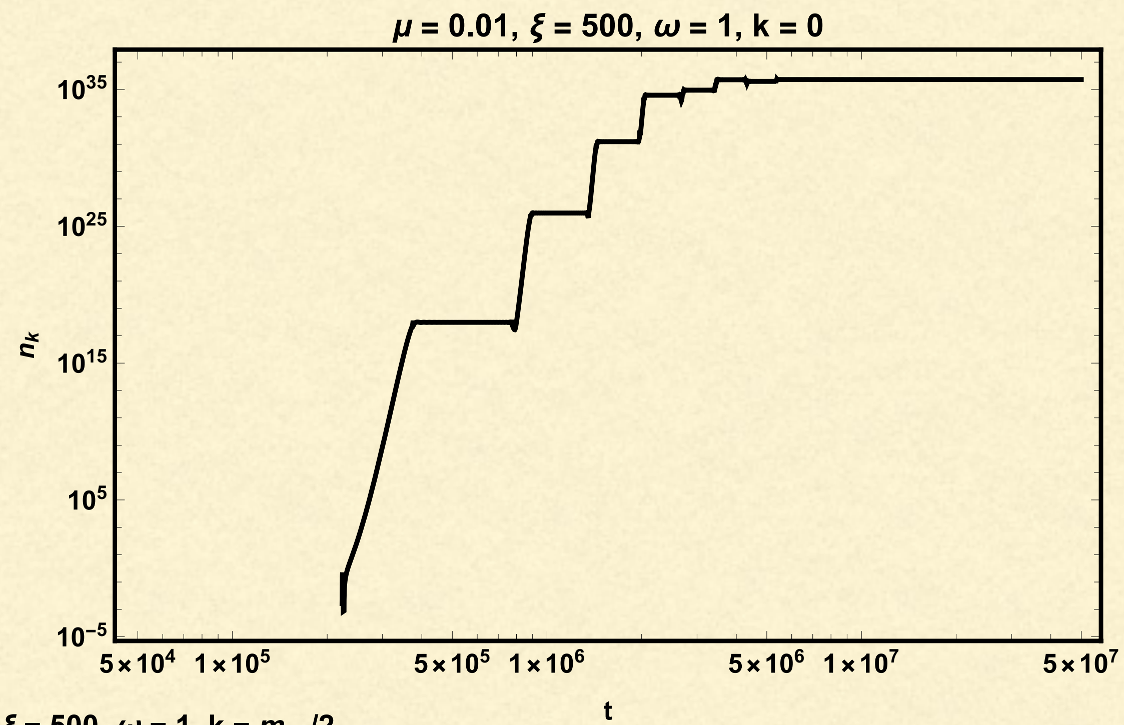


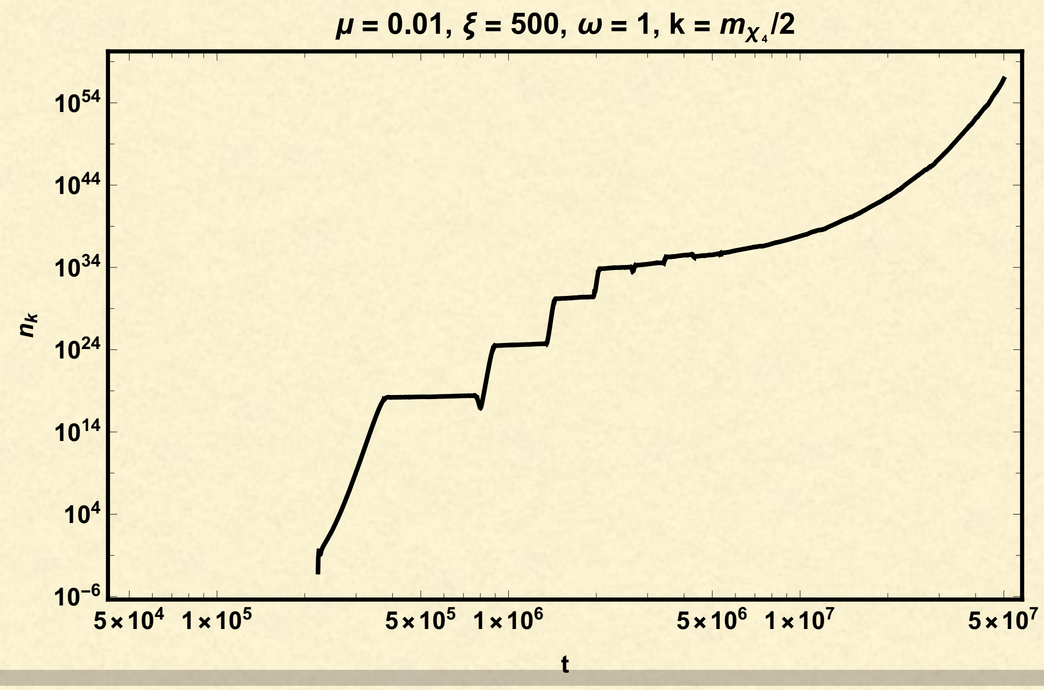




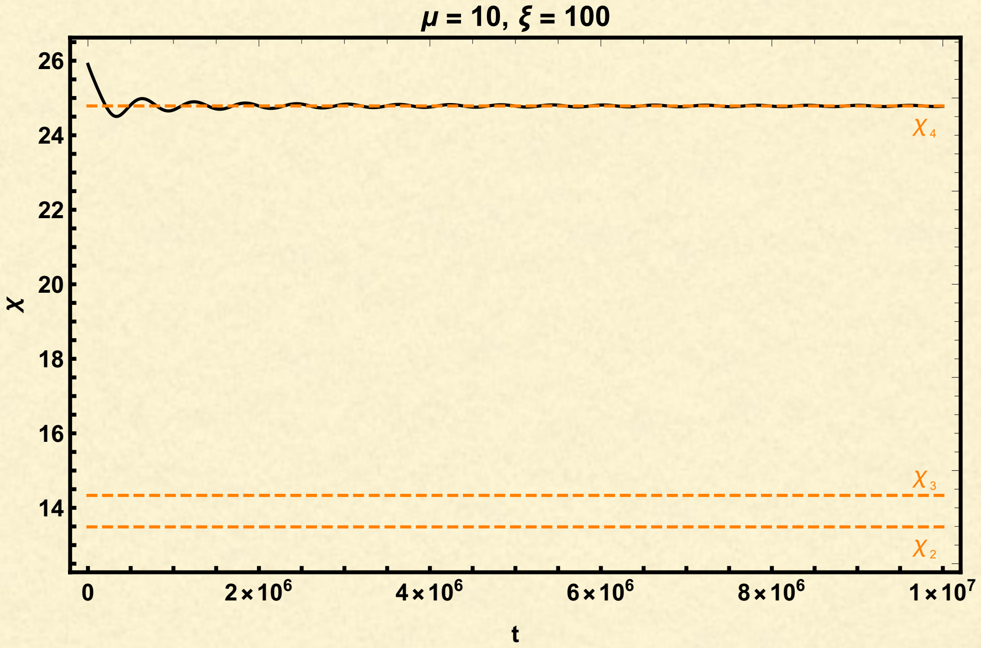
Preheating in Non-$\mathbb{M}$-flation

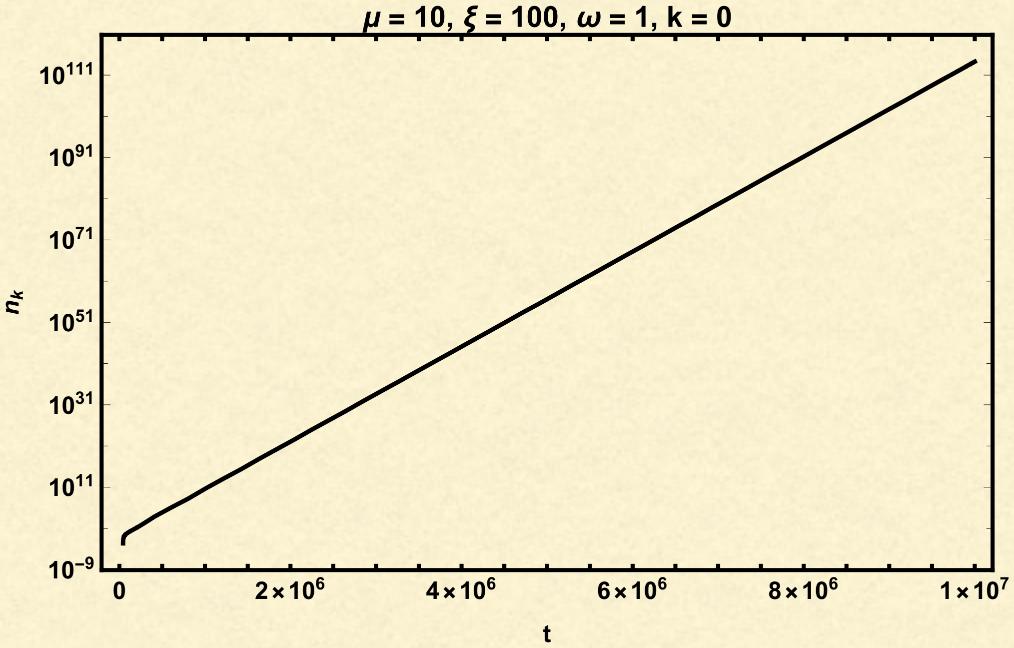


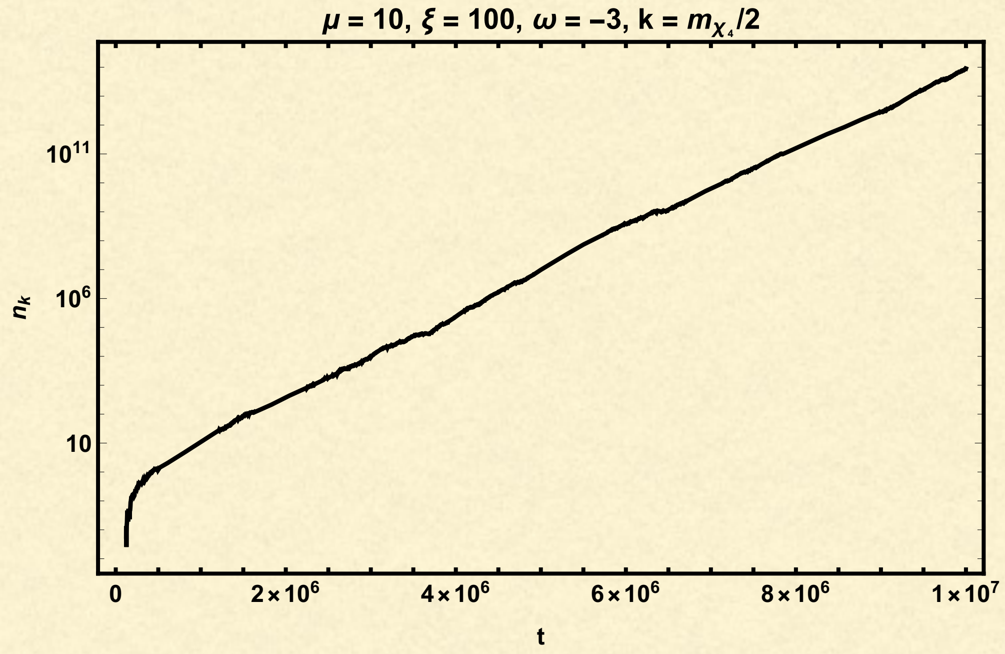




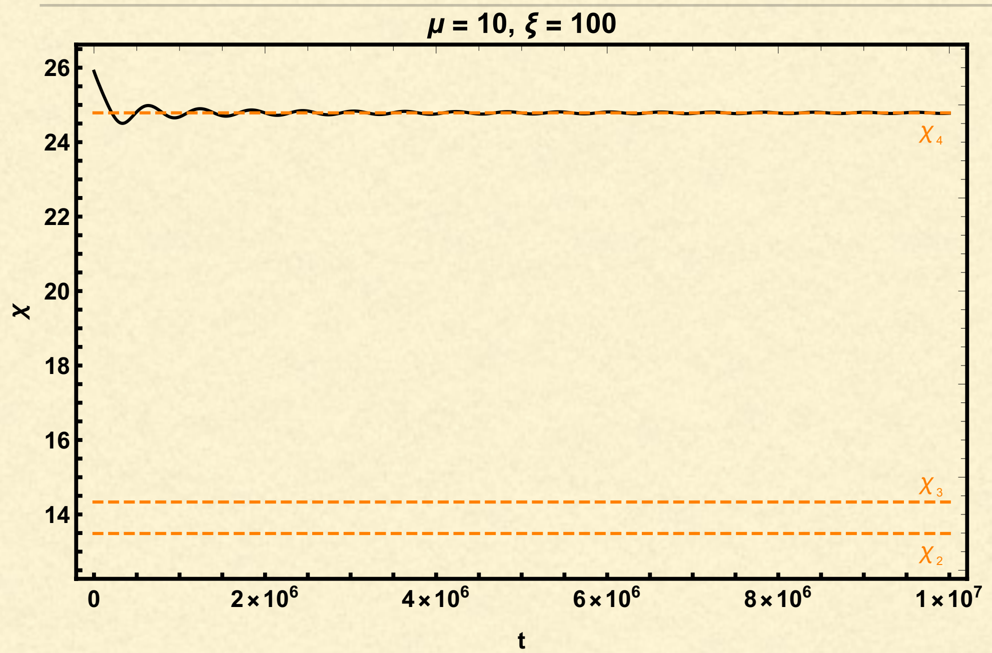
Preheating in Non-$\mathbb{M}$-flation

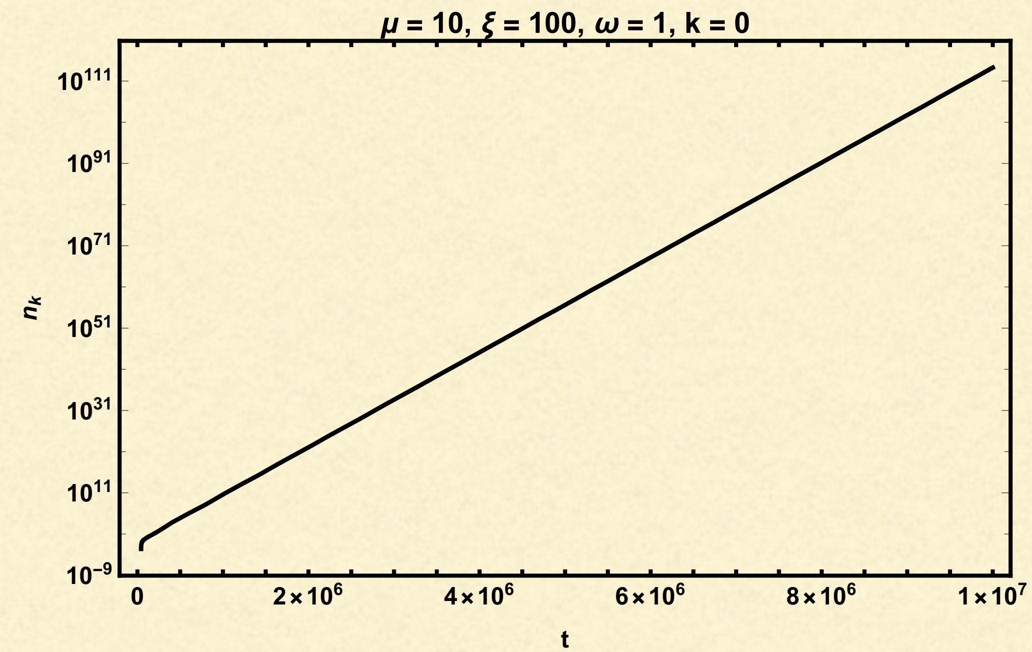


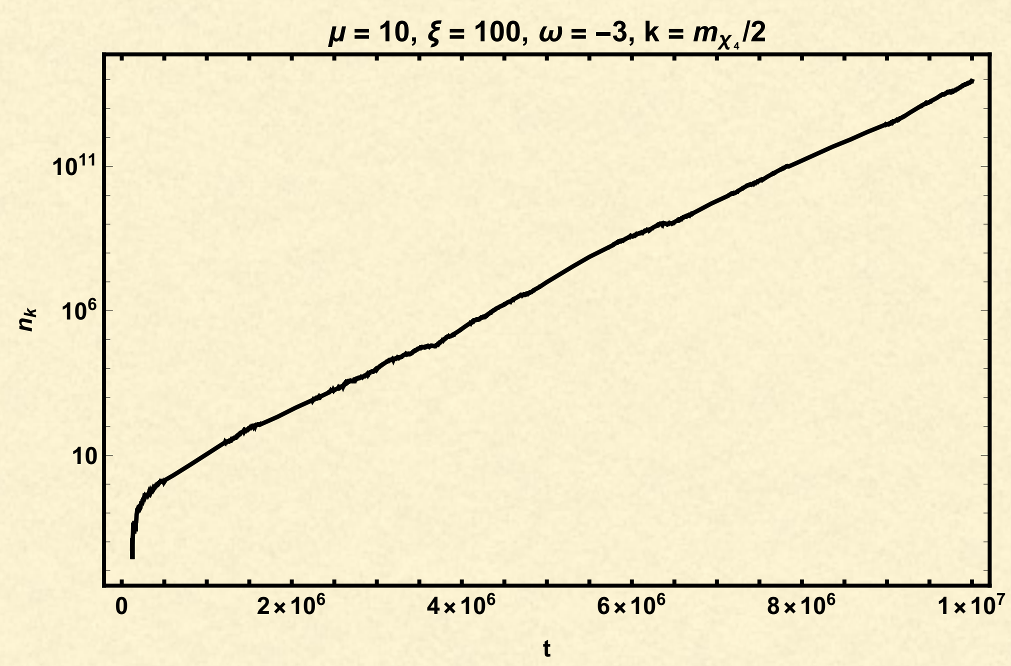




Preheating in Non-$\mathbb{M}$-flation







Conclusions

- Number of D3-branes can be reduced substantially, $N_{D3} \lesssim 10^2$

- Region (a) of the potential, where eternal inflation can be supported and is a local attractor, is now compatible with PLANCK.

- Embedded preheating mechanism, using the spectator fields, now works!

- Non- $\mathbb{M}$-flation is a string theory-motivated inflationary model with interesting phenomenology

Thank you for your attention!