Multi-field effects in a simple extension of R^2 Inflation

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(KEK/SOKENDAI)

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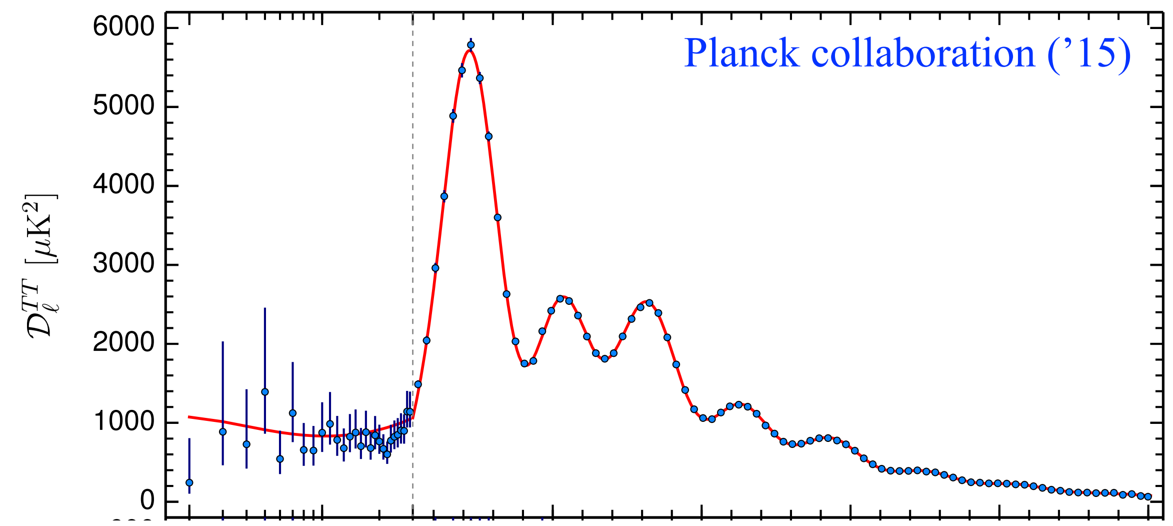
with Kaz Kohri(KEK) and Jonathan White

StringPheno18@Univ. of Warsaw 4/7/2018

Introduction

＊Inflation

- **Horizon problem**
- **Flatness problem**
- **Origin of large scale structure**



We can solve these problems with introducing accelerated expansion so-called Inflation and the predictions are in good agreement with CMB Observations

Introduction

＊Inflation

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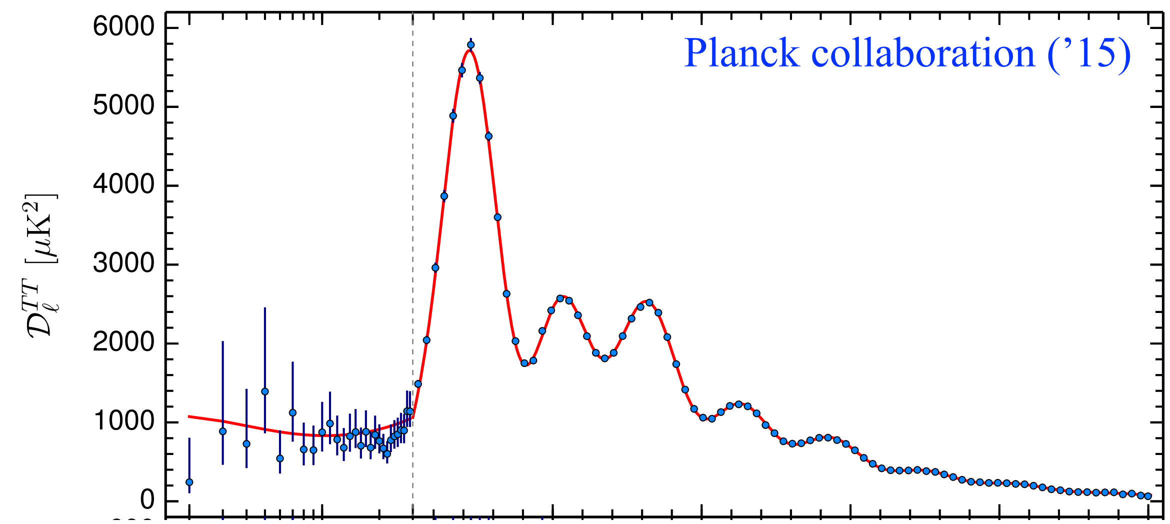

We can solve these problems with introducing **accelerated** expansion so-called **Inflation** and the predictions are in good agreement with CMB Observations

＊Motivation of Multi-field

- Supergravity or Superstring theory may provide many scalar fields

$\rightarrow$ **Multi-field models**

- In multi-field models, curvature perturbation is **NOT conserved** on super-horizon scale.

$\rightarrow$Any feature which single-field models don't have?

Set up : A simple extension of Starobinsky model

van de Bruck and Paduraru ('15)

Jordan frame

$$S_J = \int d^4x\sqrt{-g}\left[\frac{m_{pl}^2 R}{2} + \frac{\mu}{2}R^2\right] + \int d^4x\sqrt{-g}\left[-\frac{1}{2}g^{\mu\nu}\partial_\mu\chi\partial_\nu\chi - \frac{1}{2}m_\chi^2\chi^2\right]$$

Motivation :

- **Check the multi-field effects on asymptotic potential**
- **Essentially same with a class of models based on Supergravity** Ellis et al ('13-16)

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conformal transformation :

where

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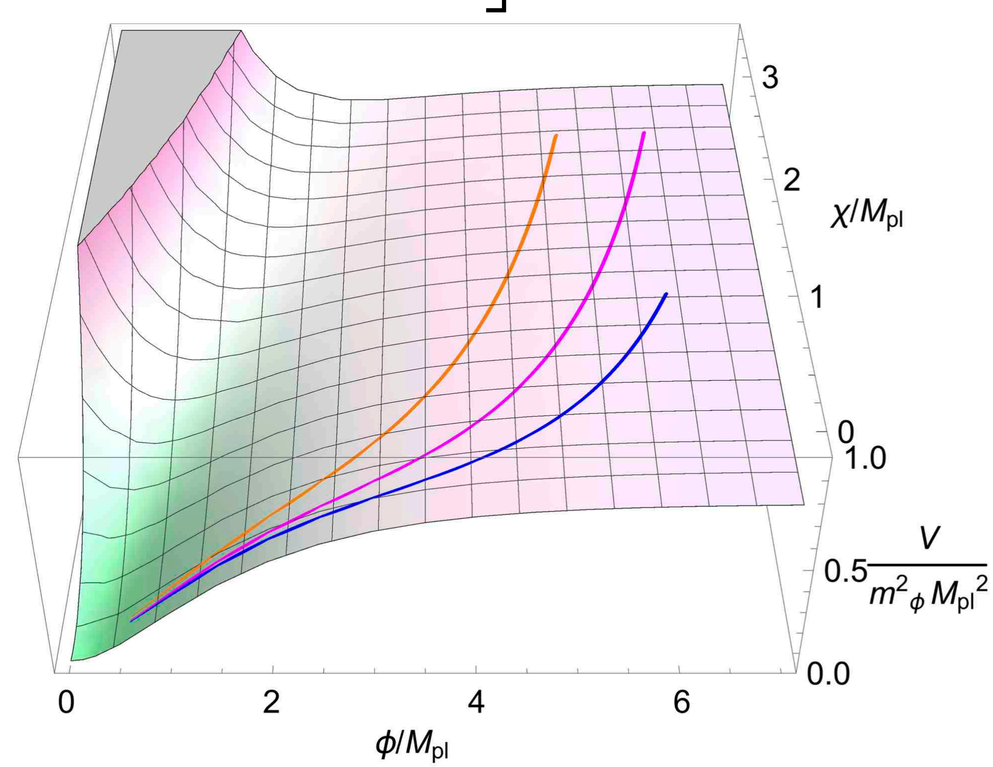

Curvature perturbation

＊Spectrums

$$\langle \zeta_{\mathbf{k_1}} \zeta_{\mathbf{k_2}} \rangle = (2\pi)^3 \delta(\mathbf{k_1} + \mathbf{k_2}) P_s(k_1)$$

$$\langle \zeta_{\mathbf{k_1}} \zeta_{\mathbf{k_2}} \zeta_{\mathbf{k_3}} \rangle = (2\pi)^3 \delta(\mathbf{k_1} + \mathbf{k_2} + \mathbf{k_3}) B_s(k_1, k_2, k_3)$$

$$n_s \equiv \frac{d \log P_s}{d \log k} \qquad r \equiv \frac{P_t}{P_s}$$

$$f_{\rm NL} \equiv \frac{B_s(k_1, k_2, k_3)}{P_s(k_1) P_s(k_2) + \text{cyc. perm.}}$$

Lyth, Malik and Sasaki ('04)

In single-field cases···

$$\dot{\zeta} \propto \left(\frac{k}{aH} \right)^2 \sim 0$$

conserved on super-horizon scale

Consistency relation:

in the squeezed limit

$$f_{\rm NL} \sim (1 - n_s) \sim \mathcal{O}(10^{-2})$$

Maldacena ('02)

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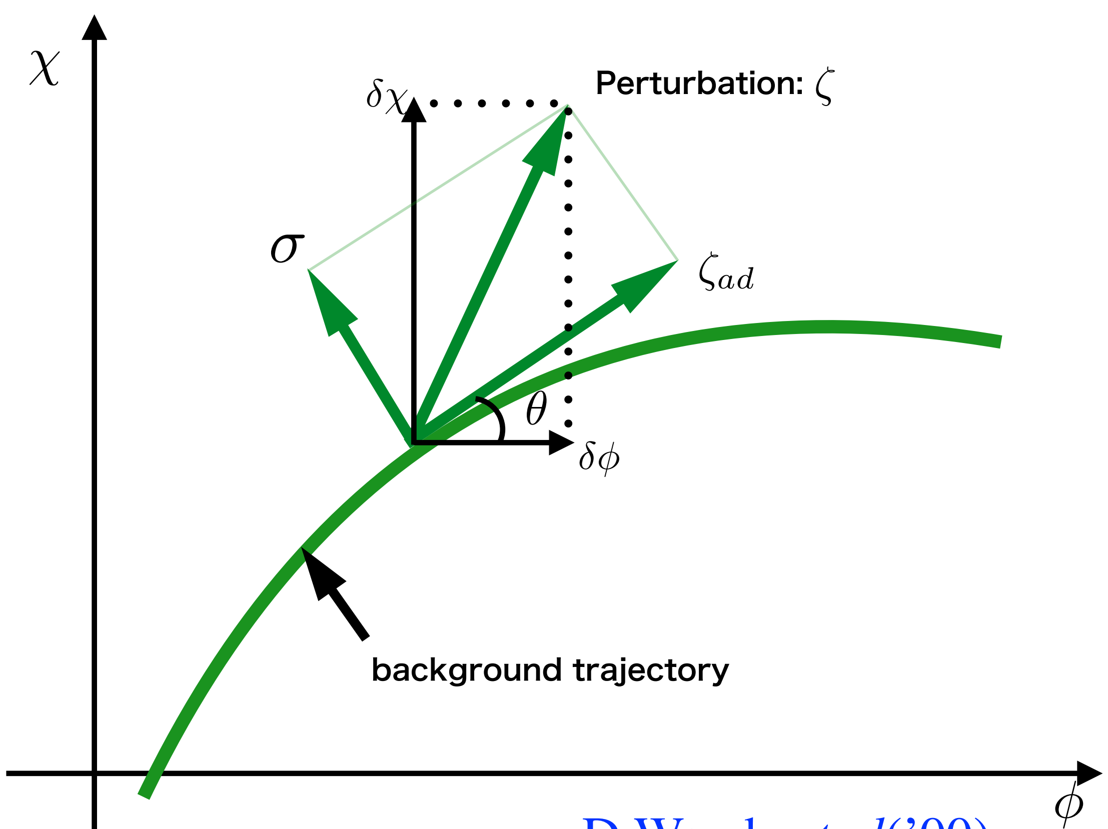
＊Multi-field effects



D.Wands *et al*('00)

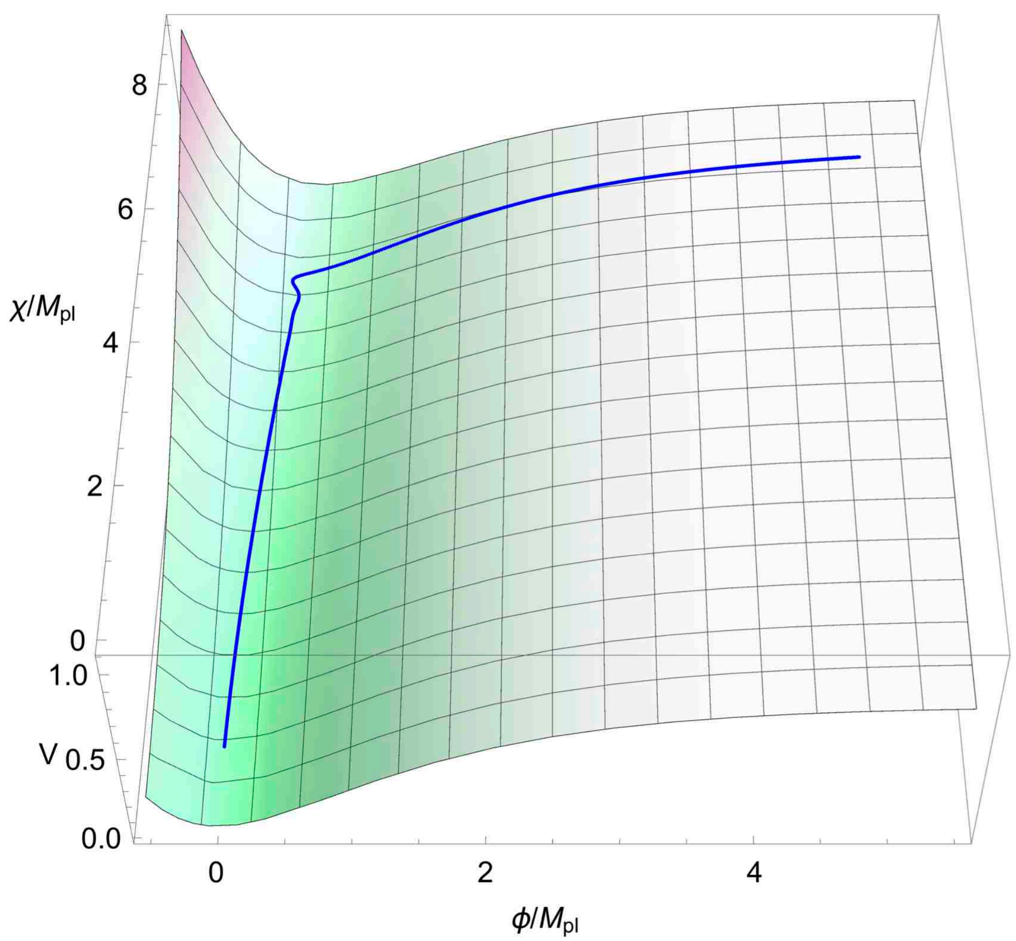
isocurvature mode can transfer to adiabatic mode, ζ evolves with time on super-horizon scale

→We need to take into account multi-field effects on each quantities.

＊ f_{NL} **can be enhanced by multi-field effects?**

Superhorizon evolution of perturbations

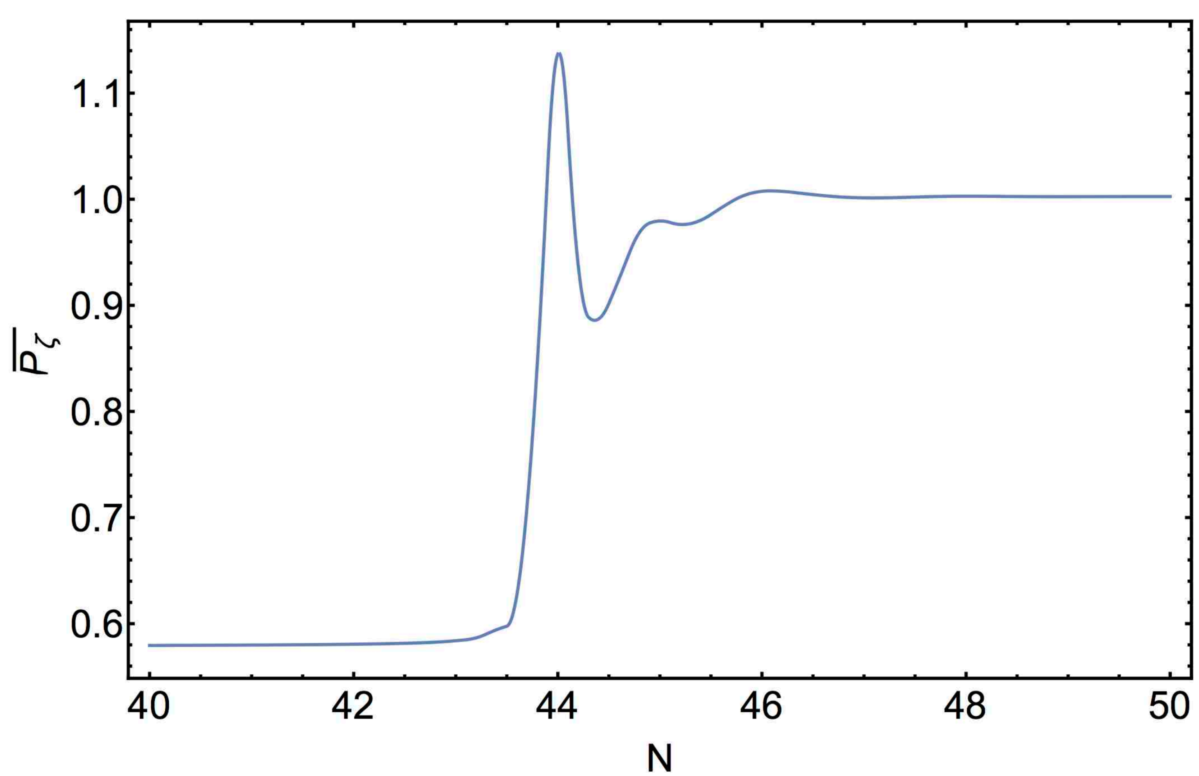
$m_\chi/m_\phi = 0.1$

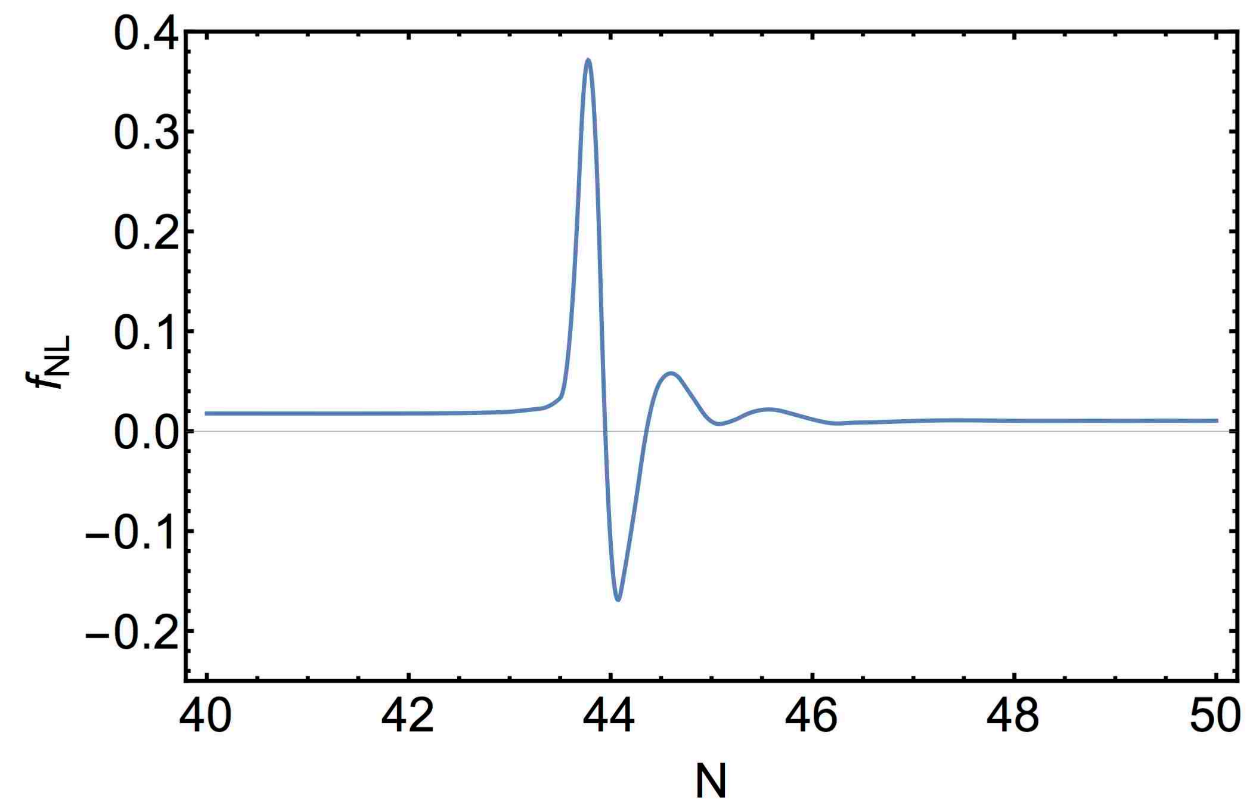


We developed numerical approach based on δN-formalism

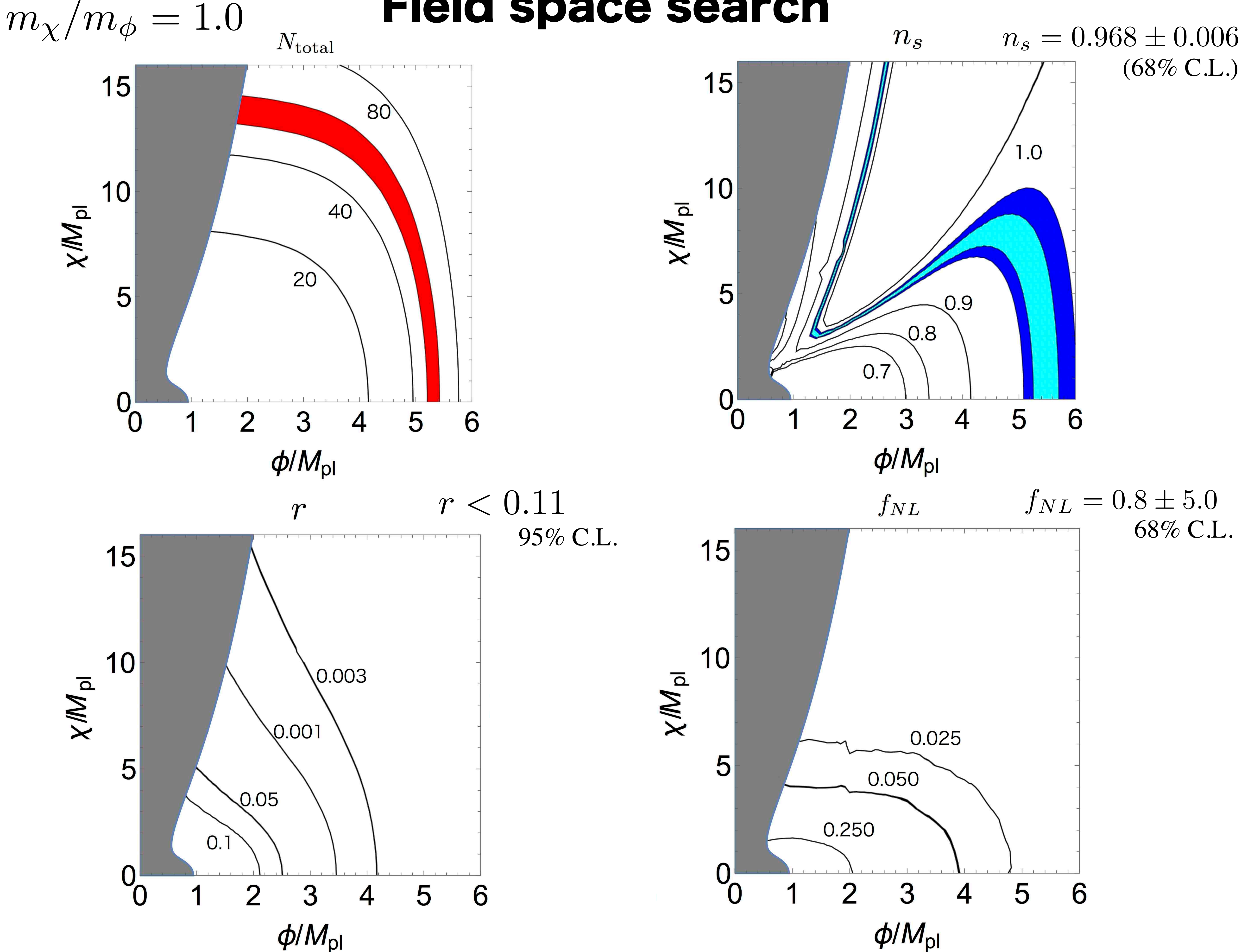
If a trajectory turns/oscillates, each quantities may have steps, peaks or oscillations.

Evolutions on supuerhorizon scale!



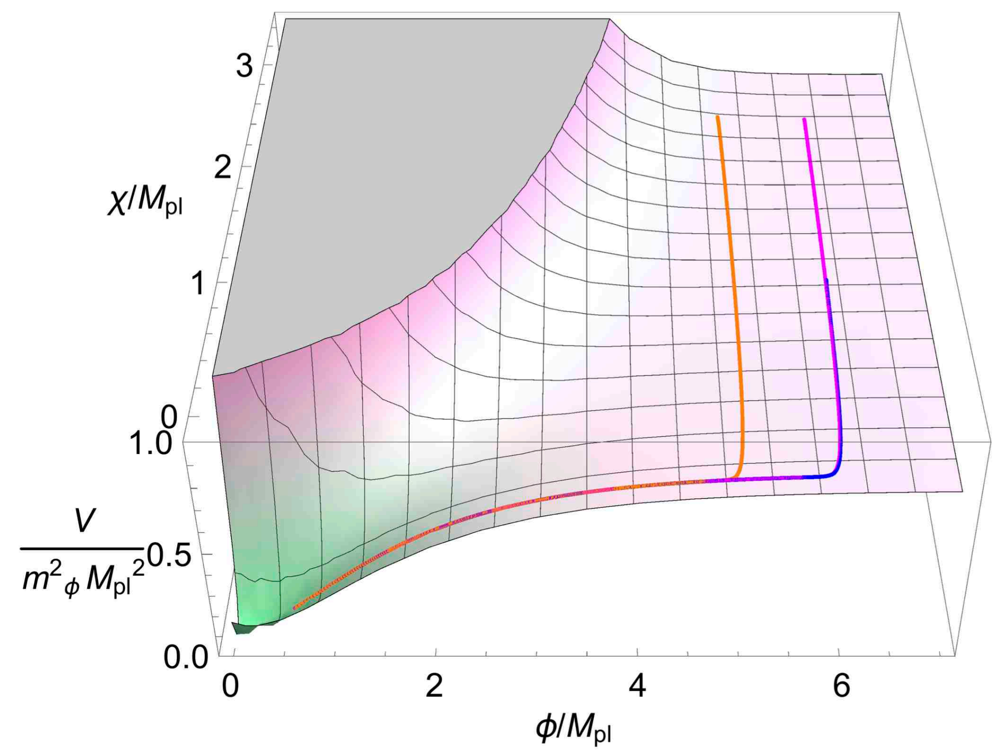


Field space search

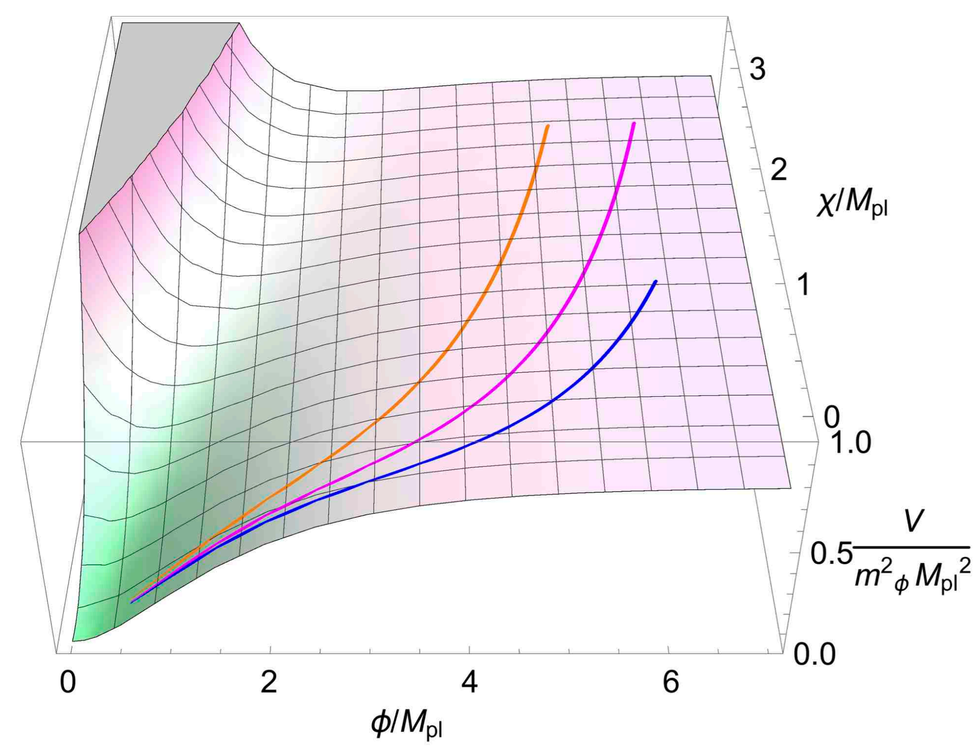


Various mass-ratios

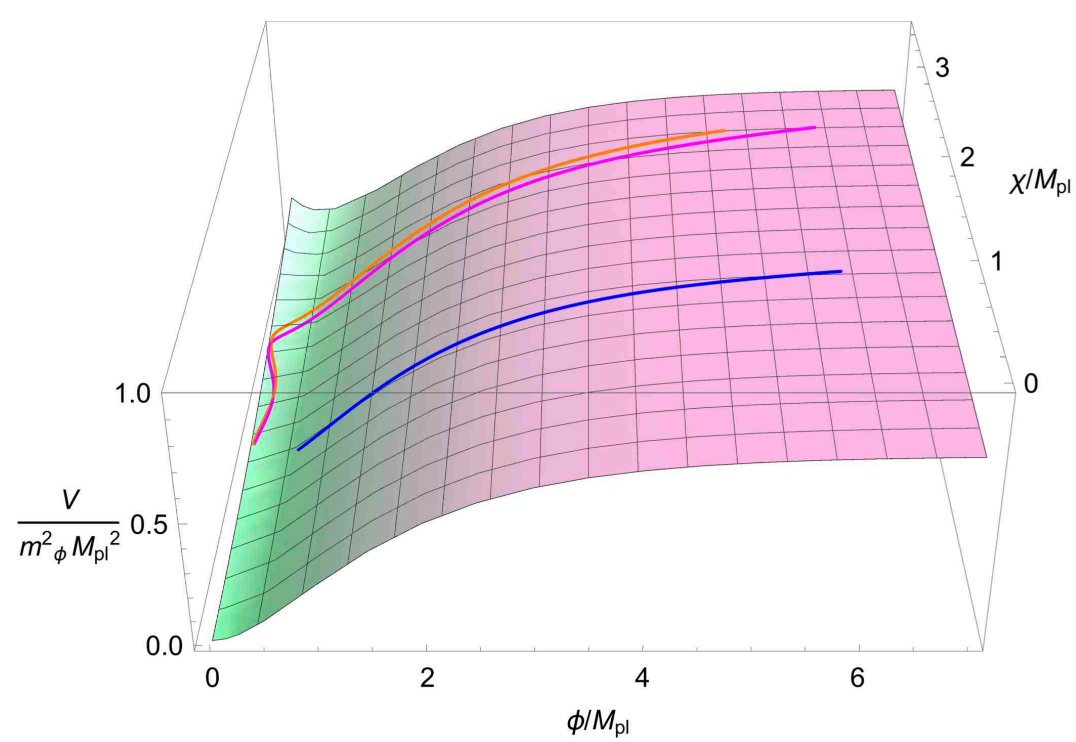
$m_\chi/m_\phi = 5.0$



$m_\chi/m_\phi = 1.0$



$m_\chi/m_\phi = 0.2$

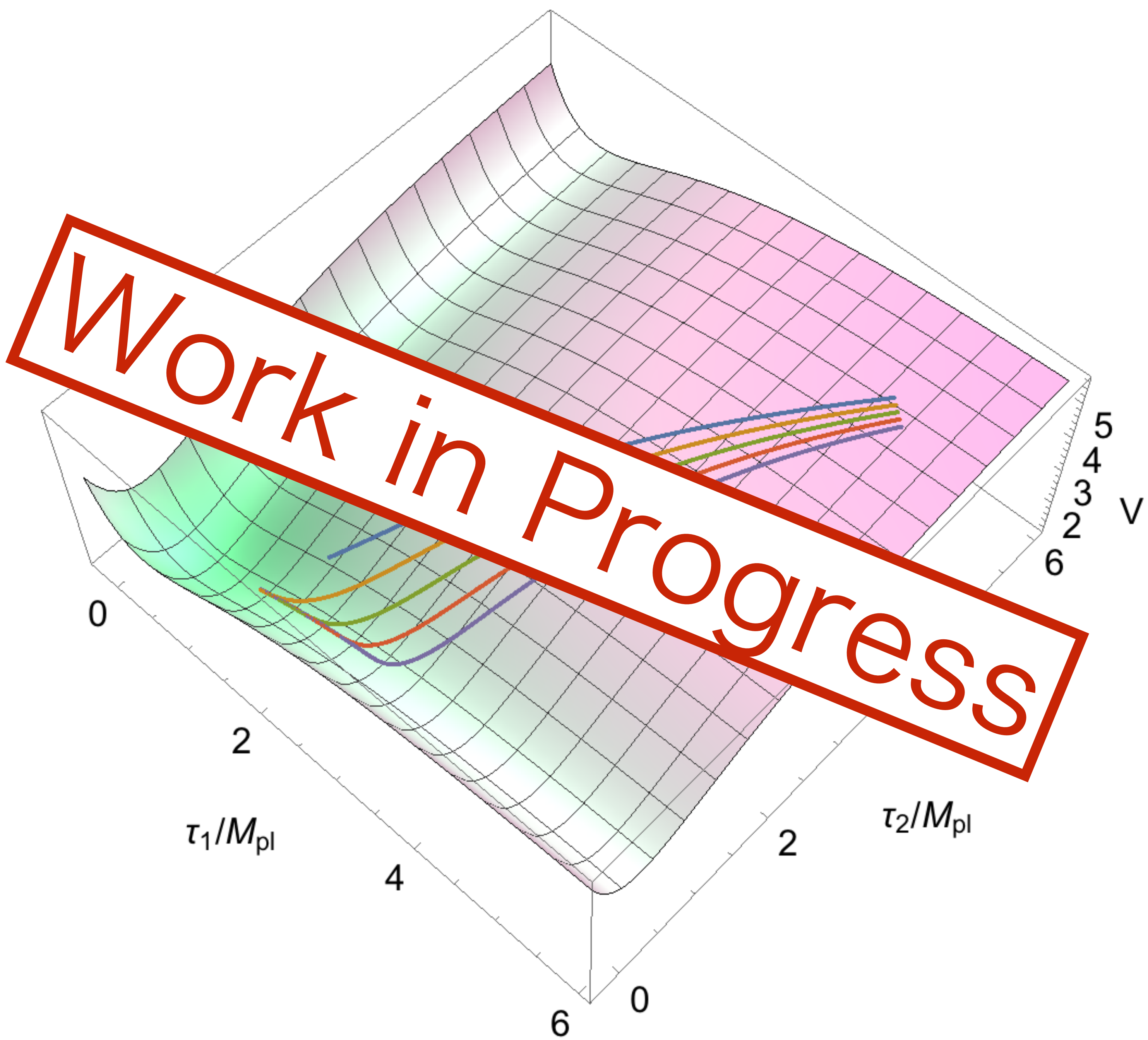


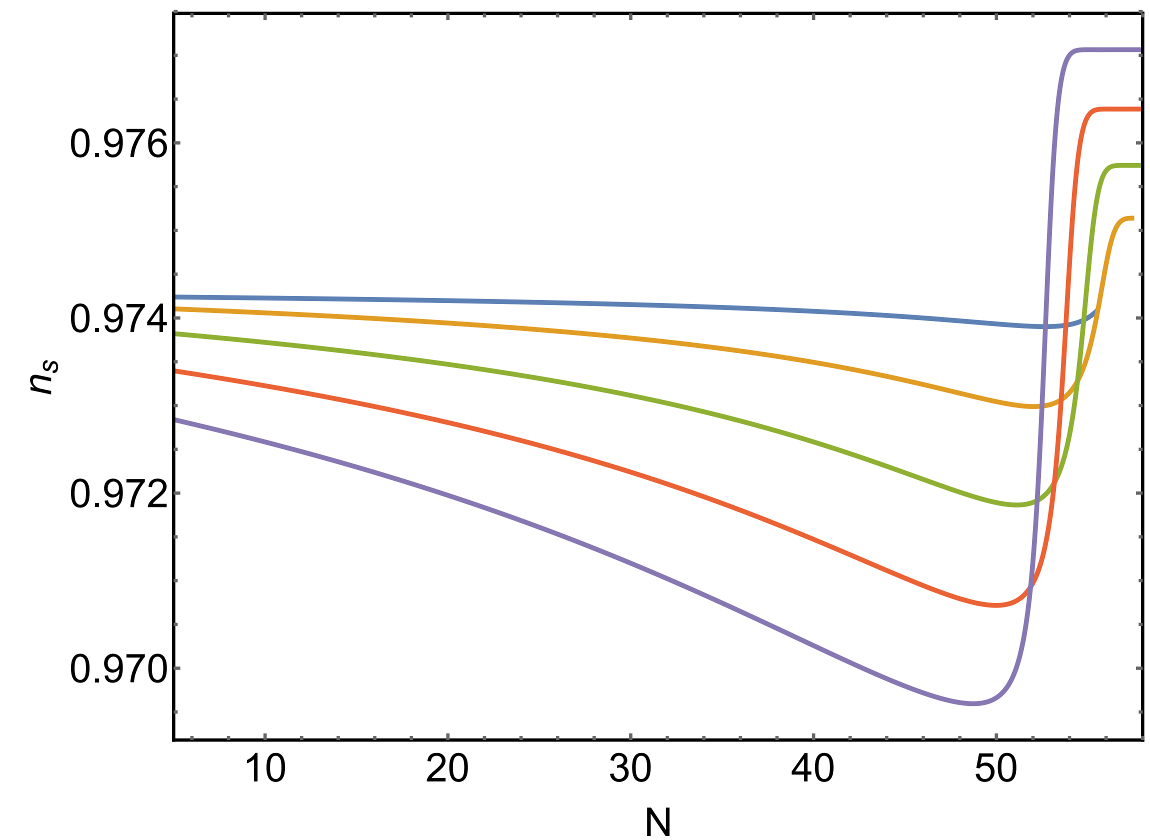
We investigated the mass-ratios

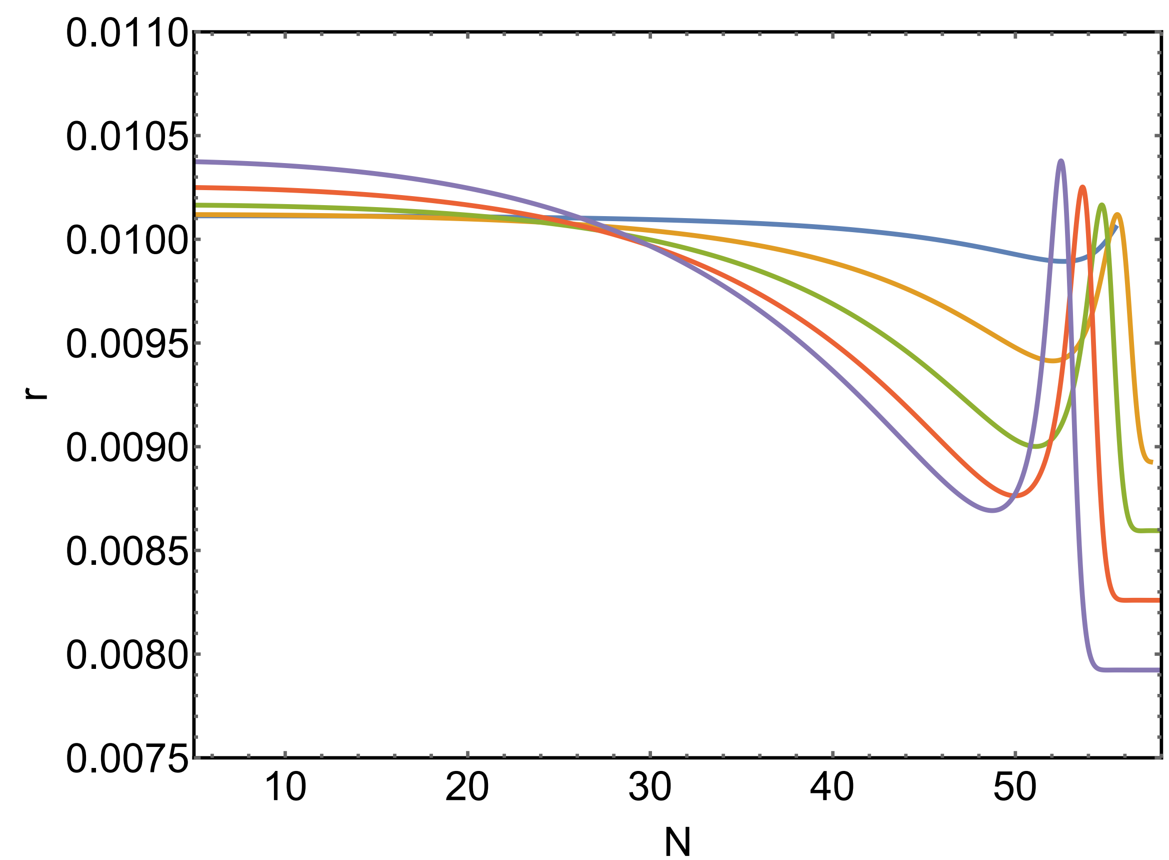
$$10^{-3} \leq m_\chi/m_\phi \leq 10^3$$

Multi-field model from string compactification

with Joe Conlon(Oxford), Kaz Kohri　18XX.XXXXX







Summary

- There is a strong motivation to consider multi-field inflation models in string/supergravity inspired model-building.

- In the case of multi-field, we need to take into account transfer of isocurvature perturbation.

- In this work, we established the method to compute predictions in interacting multi-field models with non-canonical kinetic terms.

- f_{NL} is as small as single field cases.

＊If you are interested in multi-field analysis,
I am happy to discuss with you!

BACK UP
だ！！！

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This model contains…

- **Two inflatons**
- **Interaction term**
- **Non-canonical kinetic term**

δN-formalism

Sasaki, Stewart('96) Wands *et al* ('00)

On super-horizon scale,

$$\zeta \sim \delta N \equiv \mathcal{N}(t_*, t\,;\mathbf{x}) - N(t_*, t)$$
$$= N_I \delta\phi^I + \frac{1}{2} N_{IJ} \delta\phi^I \delta\phi^J$$

I **: derivatives wrt** ϕ^I

To compute each quantities, we only need background dynamics and $N_I, \quad N_{IJ}$

∗Non-canonical kinetic terms: Curved field space

Yokoyama *et al*('08)

Elliston *et al*('12), Kaiser *et al*('13)

$$\mathcal{L}_{kin} = -\frac{1}{2} \mathcal{G}_{IJ} \partial^\mu \phi^I \partial_\mu \phi^J$$

$\mathcal{G}_{IJ}$ **can be interpreted as field space metric.**

In curved(non-trivial) field space, covariant formalism is useful.

Points:

1, Contracting with field space metric
2, Derivatives should be replaced with Covariant derivatives

$$\partial_I A_J$$
$$\Downarrow$$
$$\mathcal{D}_I A_J = \partial_I A_J - \Gamma^K_{IJ} A_K$$

δN-formalism

Power Spectrum :

$$P_s = \frac{H_*^2}{4\pi^2} N^I N_I, \qquad P_t = \frac{H_*^2}{4\pi^2}$$

spectral tilt :

$$n_s = 1 - 2\epsilon_* - 2\frac{1 + N_A(\frac{1}{3}R^{ABCD}\frac{V_B V_C}{V^2} - \frac{V^{;AD}}{V})N_D}{N^I N_I}$$

tensor-scalar ratio :

$$r = \frac{P_t}{P_s} = \frac{1}{N^I N_I}$$

Non-Gaussianity :

$$f_{NL} = \frac{5}{6}\frac{N^I N^J \mathcal{D}_I \mathcal{D}_J N}{(N^K N_K)^2}$$