Higgs inflation with singlet scalar dark matter and right-handed neutrino in the light of BICEP2

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Ryo Takahashi (Shimane University)

Reference

N. Haba and R. Takahashi,   arXiv:1404.4737
N. Haba, H. Ishida, and R. Takahashi, arXiv:1405.5738

Contents

1. Introduction

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- There are unsolved problems in the SM:
  - no DM candidate
  - BAU
  - vacuum instability
  - inflation
  - $\cdots$
  - non-vanishing active ν masses
  - gauge hierarchy problem
  - dark energy (DE)
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1. Introduction

Constraint on the tensor-to-scalar ratio (BICEP2 result)
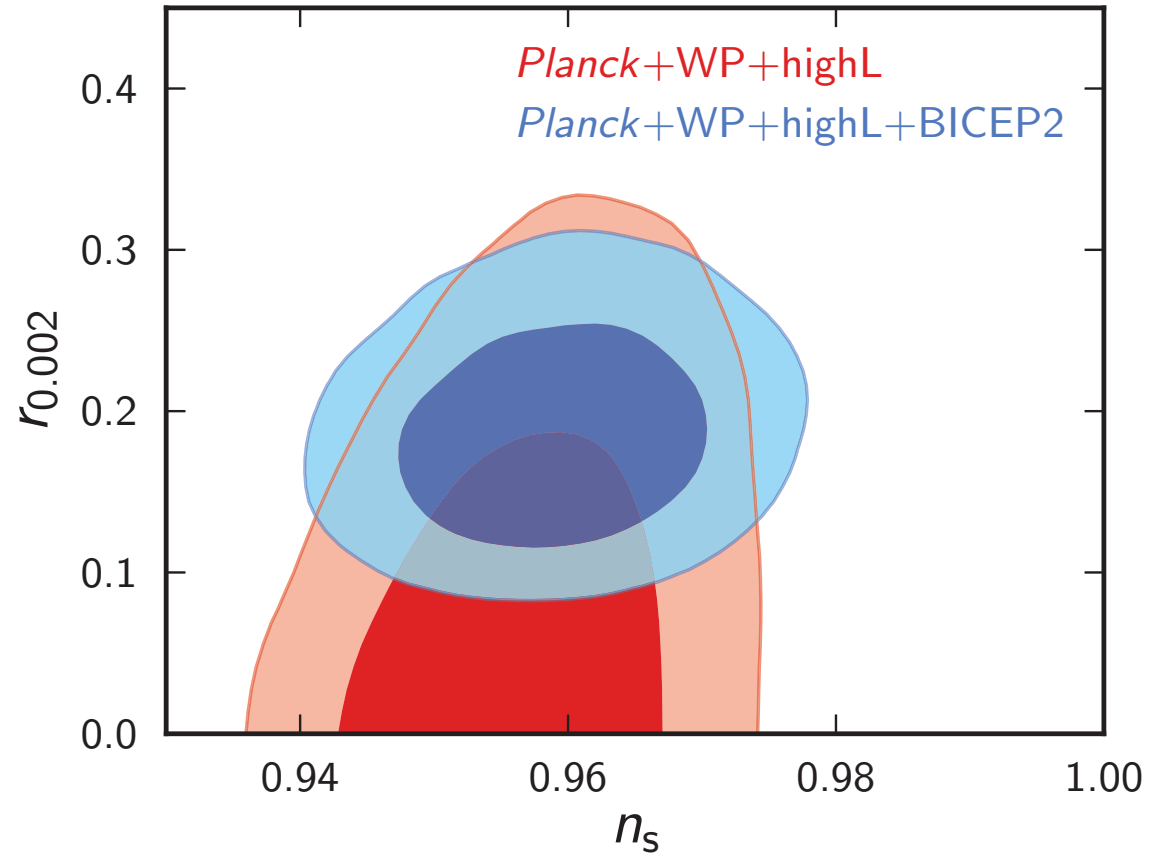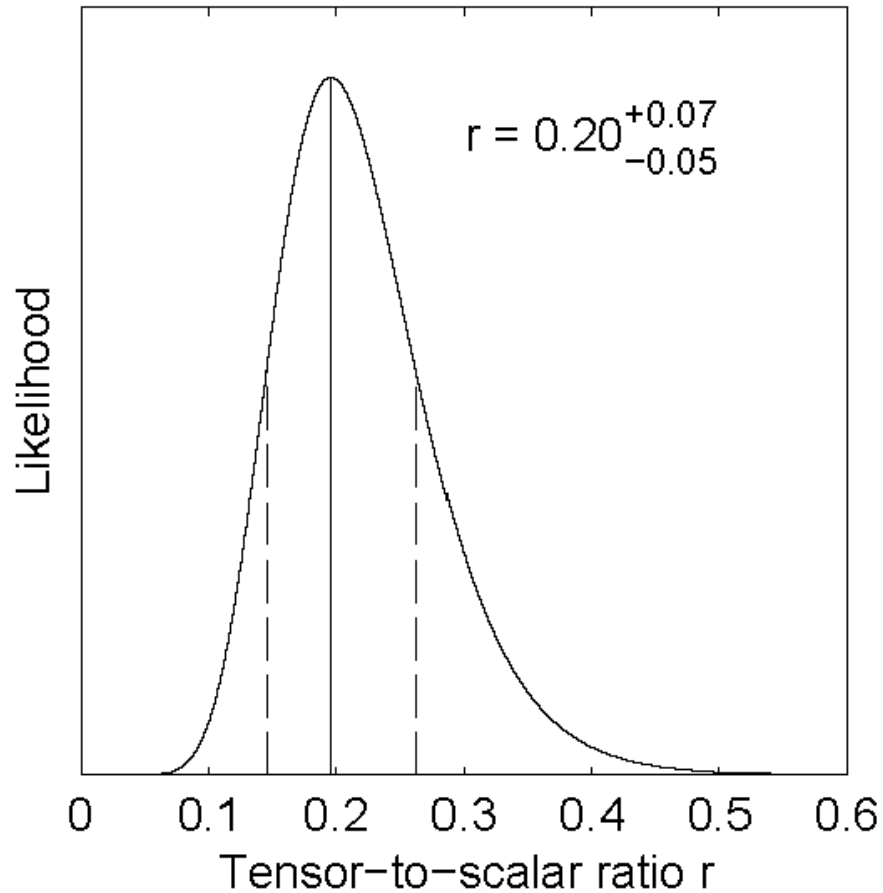
$$r = \frac{A_t}{A_s} = \frac{\dfrac{U}{24\pi^2 M_{\text{pl}}^4 \epsilon}}{\dfrac{2U}{3\pi^2 M_{\text{pl}}^4}} = 16\epsilon = 8M_{\text{pl}}^2 \left(\frac{dU/d\chi}{U}\right)^2 \simeq 0.2$$

1. Introduction

Higgs inflation

Action in the Jordan frame:

$$S_J \supset \int d^4x \sqrt{-g} \left(-\frac{M_{\rm pl}^2 + \xi h^2}{2} R - \frac{\lambda}{4} h^4 \right)$$

Conformal transformation:

$$\hat{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}, \quad \Omega^2 \equiv 1 + \frac{\xi h^2}{M_{\rm pl}^2}$$

$$\Downarrow$$

Action in the Einstein frame:

$$S_E \supset \int d^4x \sqrt{-\hat{g}} \left(-\frac{M_{\rm pl}^2}{2} \hat{R} + \frac{\partial_\mu \chi \partial^\mu \chi}{2} - \frac{\lambda}{4\Omega(\chi)^4} h(\chi)^4 \right)$$

with

$$\frac{d\chi}{dh} = \sqrt{\frac{\Omega^2 + 6\xi^2 h^2/M_{\rm pl}}{\Omega^4}}$$

1. Introduction

Potential in the Higgs inflation

Hamada, Kawai, Oda, Park, 1403.5043

$$m_H = 125.6 \text{ GeV}, \ M_t \simeq 171.1 \text{ GeV}, \ \xi = 7$$
$$\Rightarrow r = 0.19, \ n_s = 0.955$$

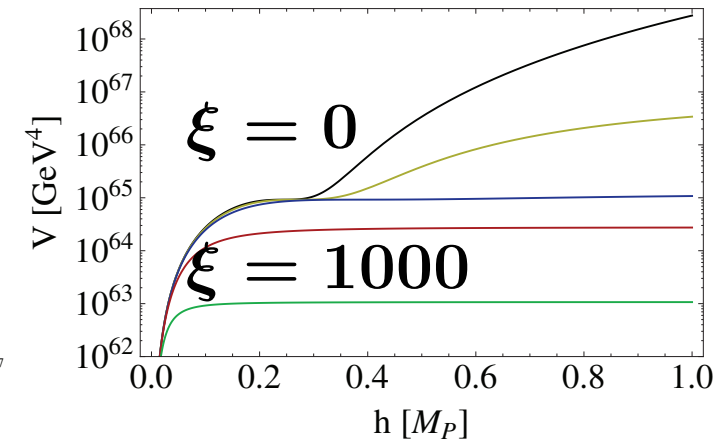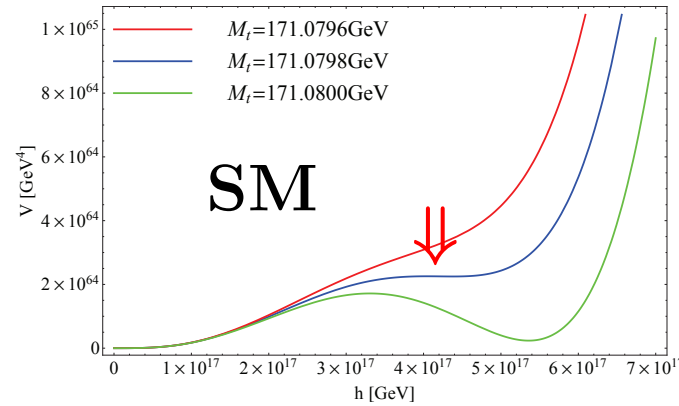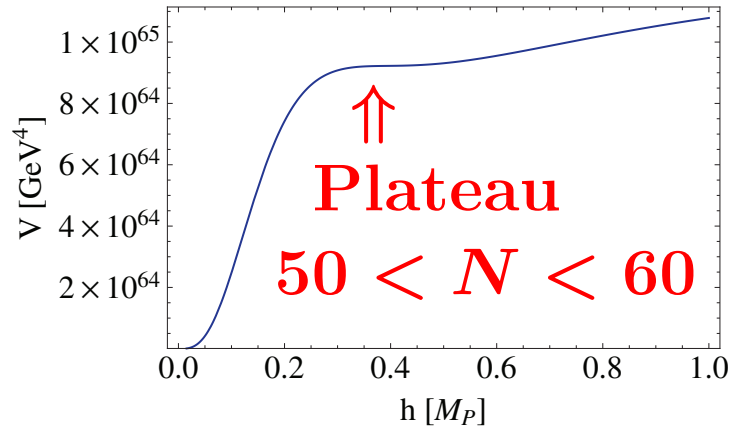Bezrukov and Shaposhnikov, 1403.6078

$$m_H \simeq 126.4 \text{ GeV}, \ M_t \simeq 171.6 \text{ GeV}, \ \xi \simeq 10$$
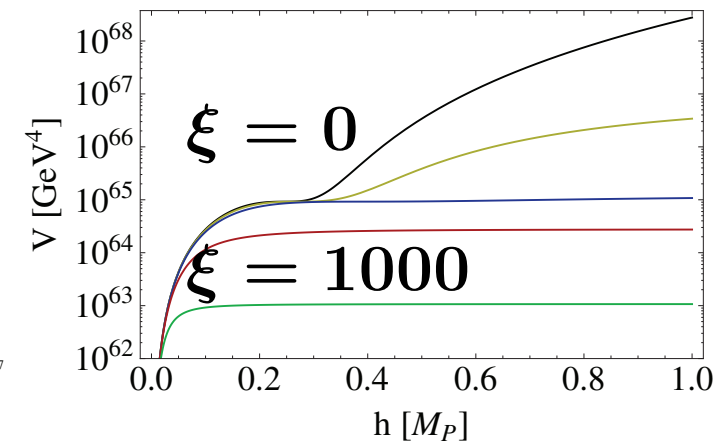$$\Rightarrow r = 0.1, \ n_s = 0.96$$

♠ We extend the (SM) Higgs inflation by adding gauge singlets to realize $r = 0.2$ with $M_t \simeq 173$ GeV.

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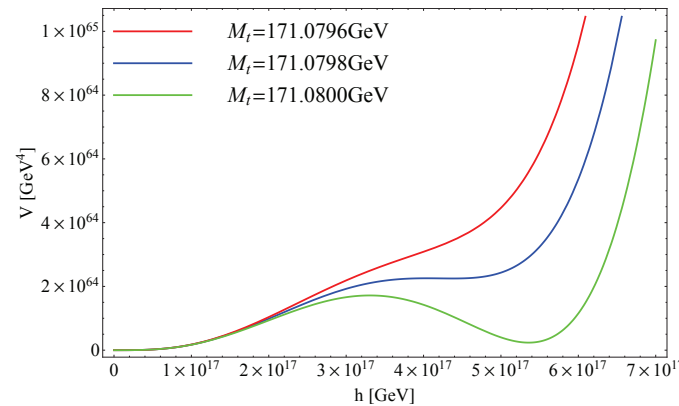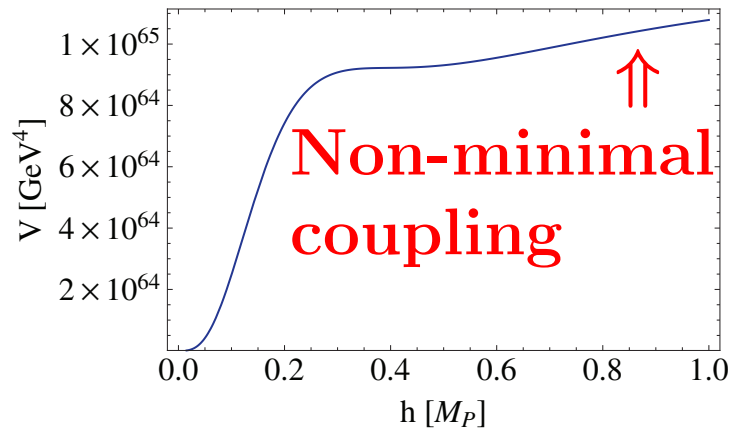$$\Rightarrow r = 0.1, \ n_s = 0.96$$

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Potential in the Higgs inflation

$$V = \frac{\lambda}{4(1+\frac{\xi h^2}{M_{\rm pl}^2})^2} h(\chi)^4$$

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Non-minimal coupling

$$m_H = 125.6 \text{ GeV}, \ M_t \simeq 171.1 \text{ GeV}, \ \xi = 7$$
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2. Higgs inflation in singlets extension of the SM

Lagrangian

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_S + \mathcal{L}_N$$

$$\mathcal{L}_{\text{SM}} \supset -\lambda \left(|H|^2 - \frac{v^2}{2} \right)^2$$

$$\mathcal{L}_S = -\frac{\bar{m}_S^2}{2} S^2 - \frac{k}{2} |H|^2 S^2 - \frac{\lambda_S}{4!} S^4 \quad (S : \text{DM}, \ Z_2\text{-odd})$$

$$\mathcal{L}_N = - \left(\frac{M_R}{2} \overline{N^c} N + y_N \overline{L} \tilde{H} N + c.c. \right) \quad (N : \text{Right-handed } \nu)$$

Goals of this model

$$r \simeq 0.2, \quad n_s \simeq 0.96, \quad 50 < N < 60, \quad \Omega_{\text{DM}} h^2 \simeq 0.119$$
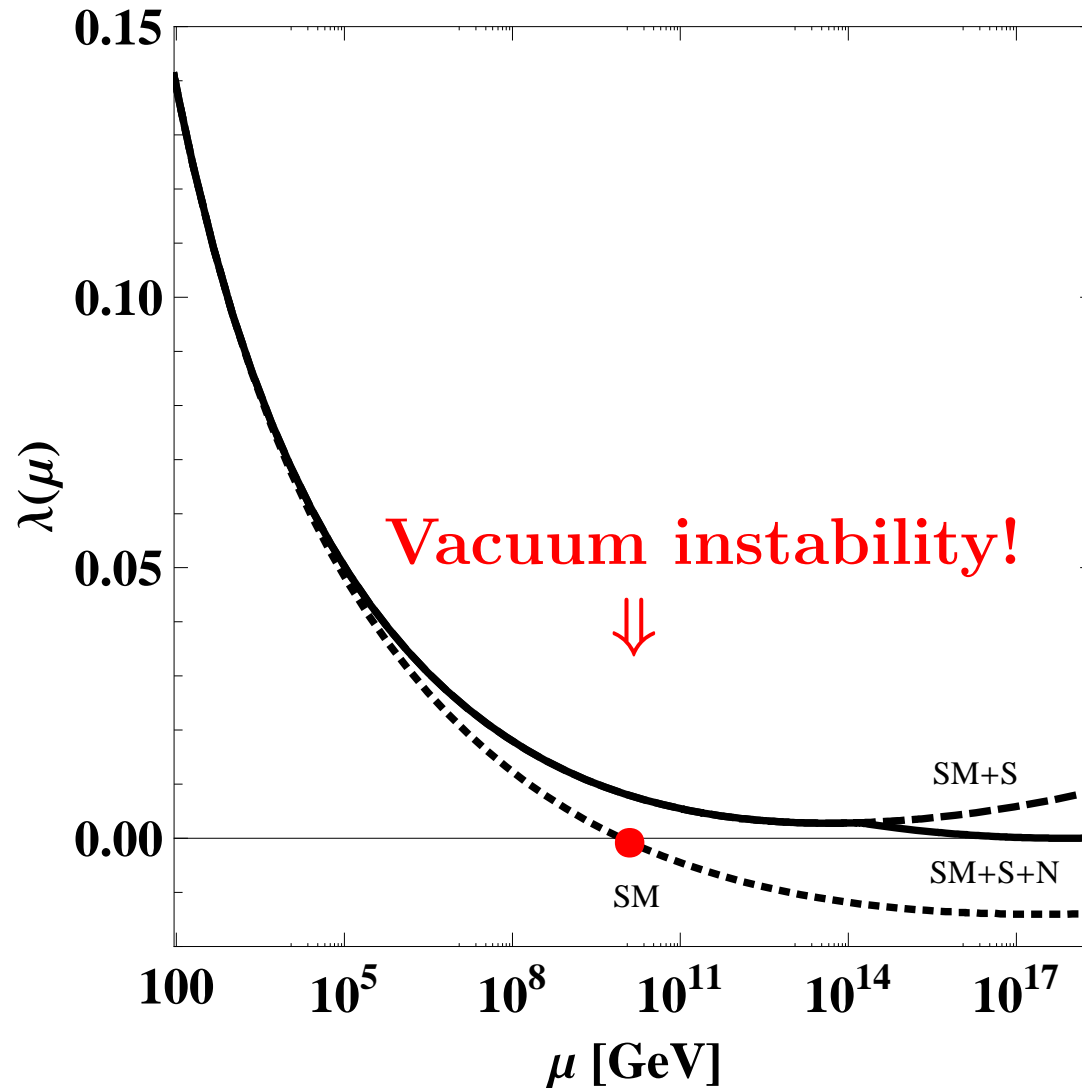
within

$$m_H = 125.6 \pm 0.35 \ \text{GeV}, \quad M_t = 173.34 \pm 0.76 \ \text{GeV}$$

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Realization of a suitable Higgs potential with $M_t \simeq 173$ GeV
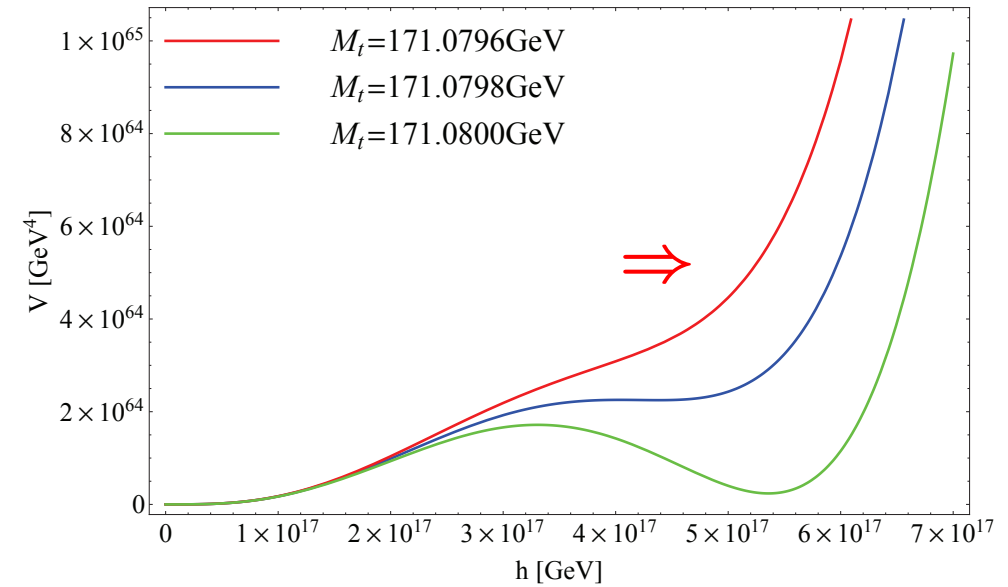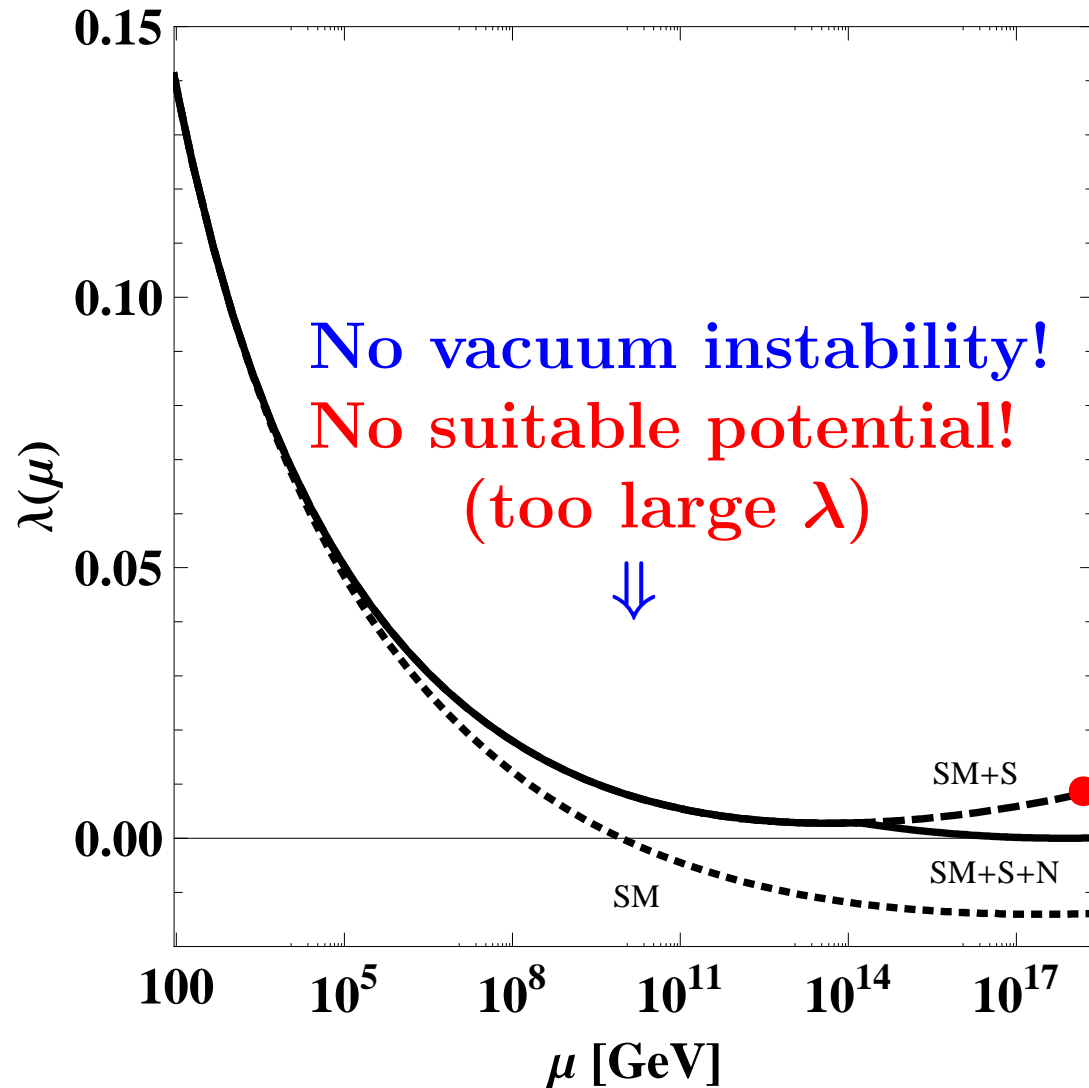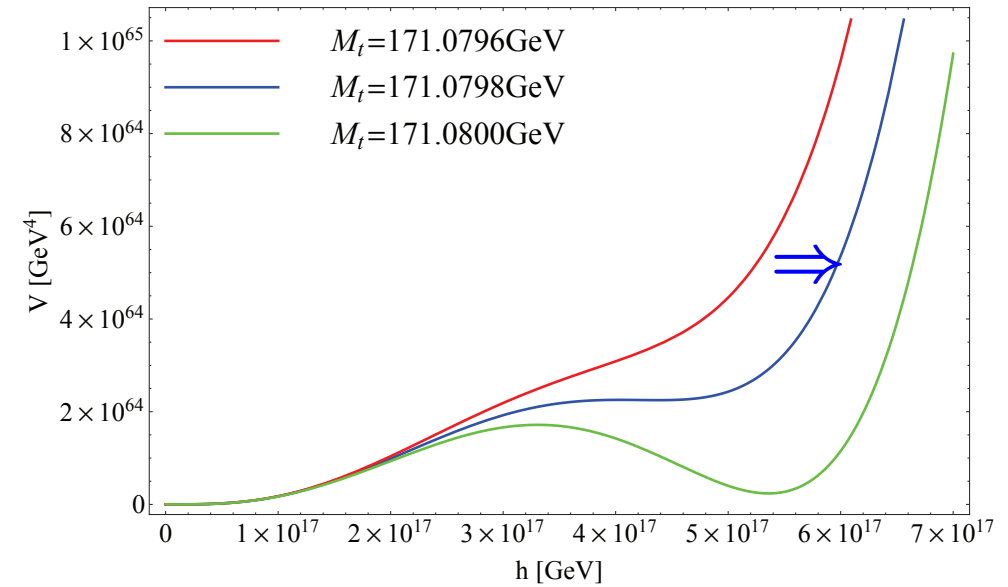
Haba and Takahashi, 1404.4737

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Haba and Takahashi, 1404.4737

No vacuum instability!
No suitable potential!
(too large λ)
$\Downarrow$

Hamada, Kawai, Oda, Park

$\Leftarrow$ SM+S ($M_t \simeq 173$ GeV and $m_H \simeq 125.6$ GeV):
$\mathcal{L} \supset k|H|^2 S^2/2$
$\beta_\lambda \supset +k^2/2$

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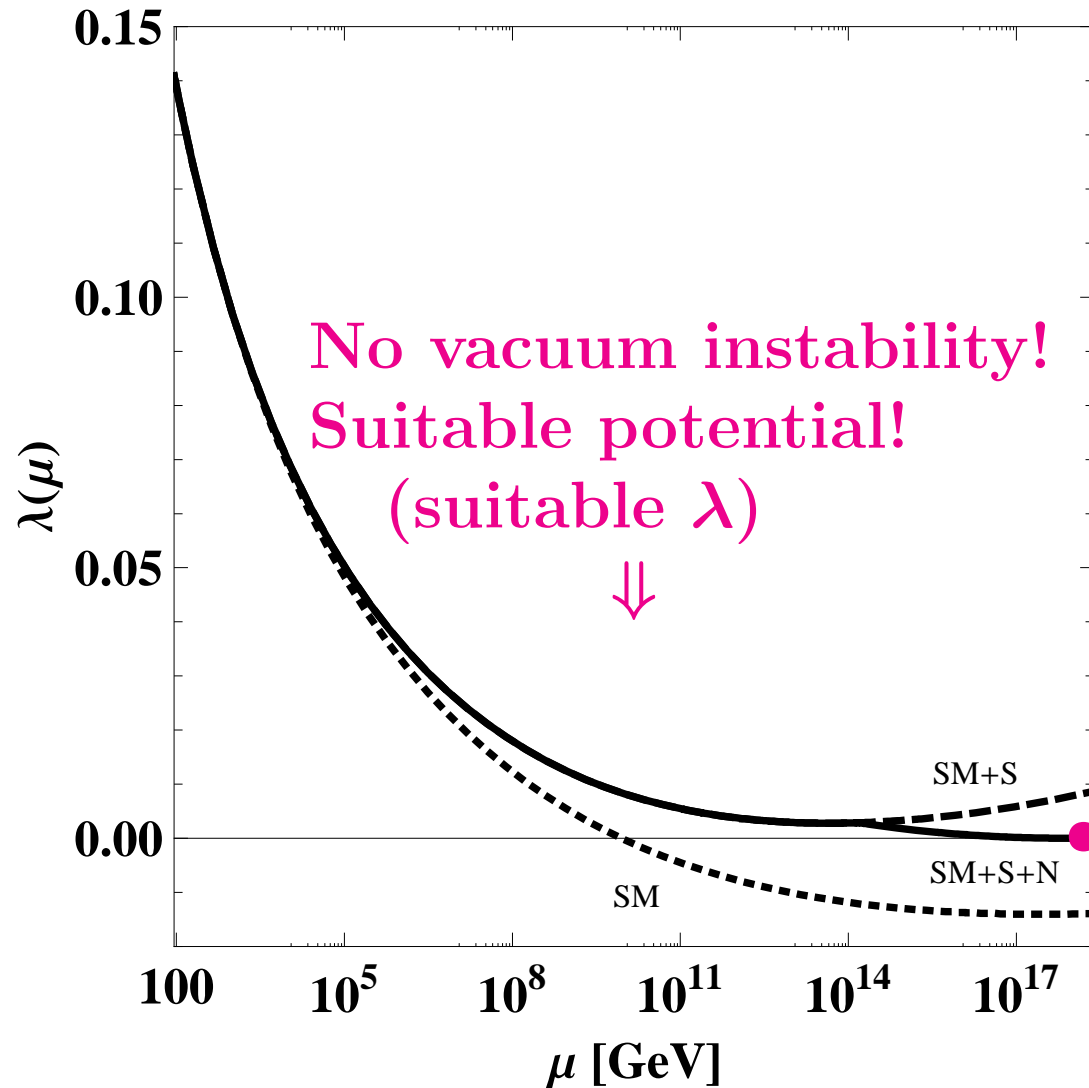
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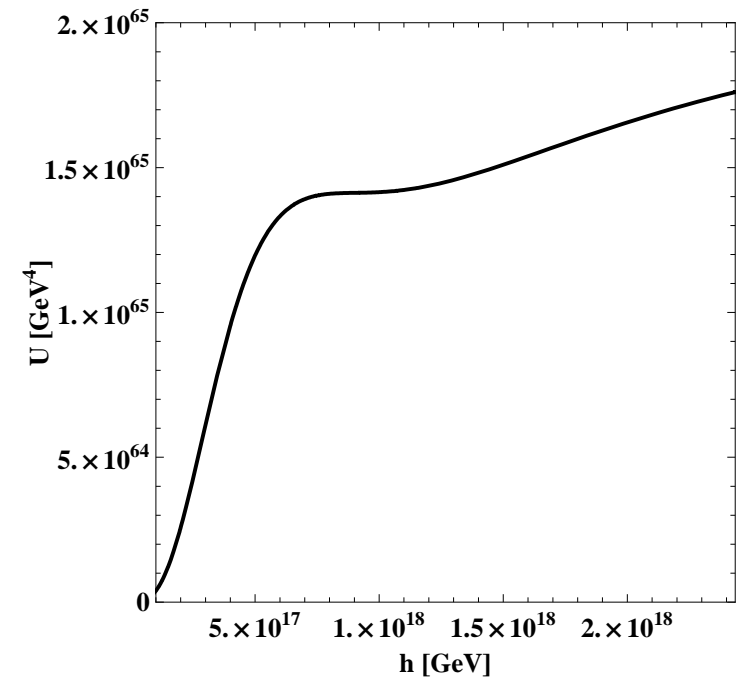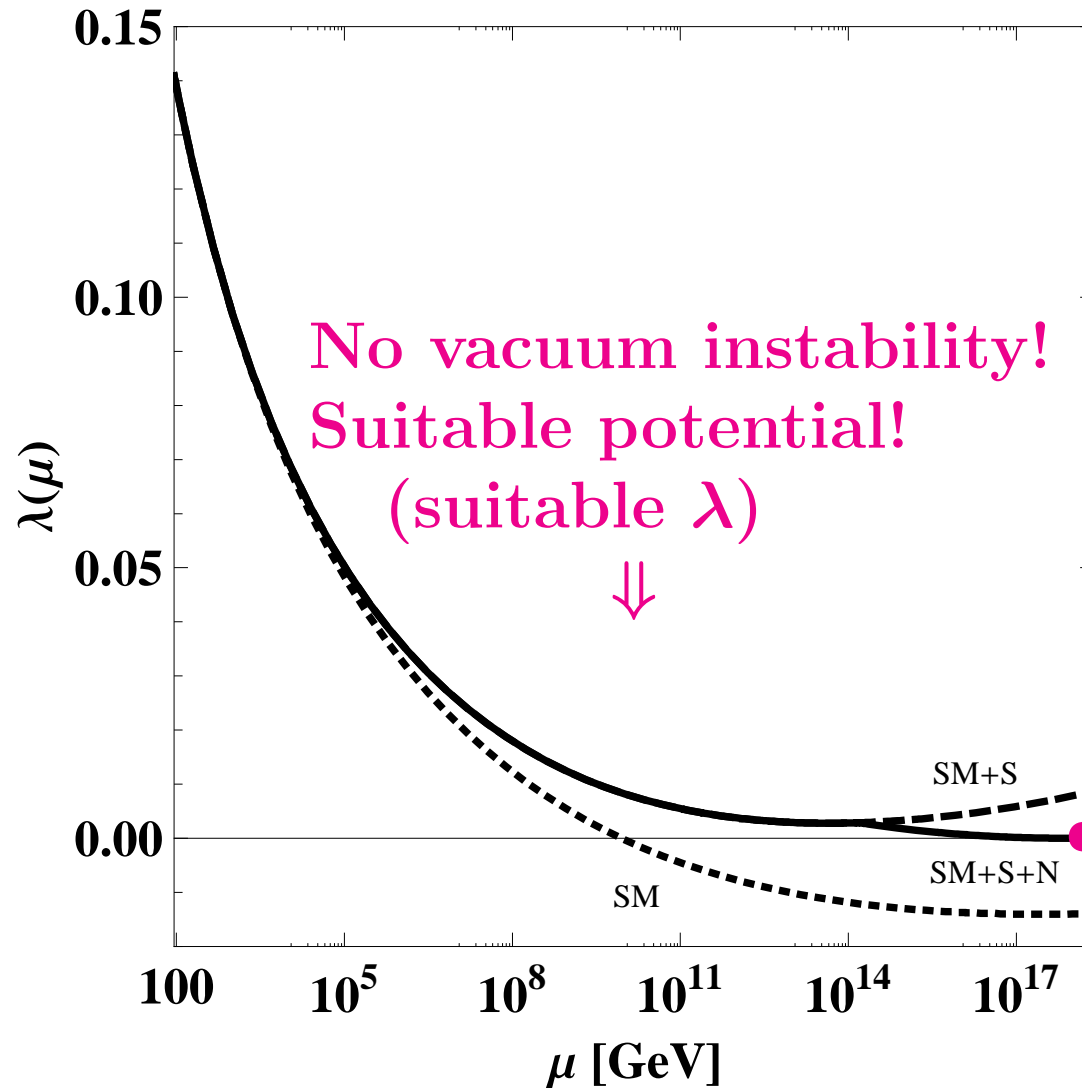$\mathcal{L} \supset k|H|^2 S^2/2 + y_N \overline{L}\tilde{H}N$
$\beta_\lambda \supset +k^2/2 - 2y_N^4$

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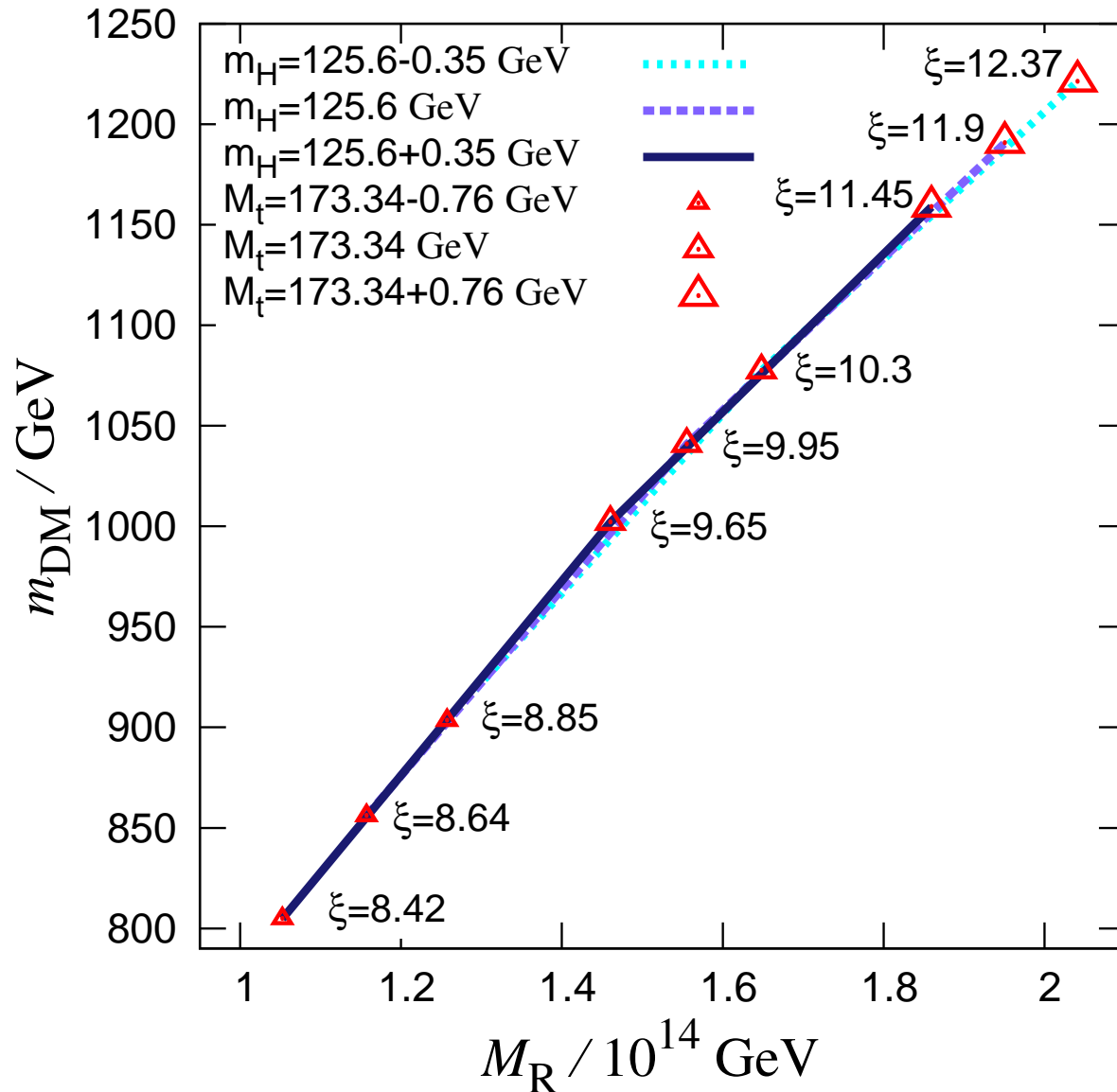
SM+S+N ($M_t \simeq 173$ GeV
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2. Higgs inflation in singlets extension of the SM

Numerical analysis at 2-loop level

$805 \text{ GeV} \lesssim m_{\text{DM}} \lesssim 1220 \text{ GeV}$
$1.05 \lesssim M_R/10^{14} \text{ GeV} \lesssim 2.04$
$8.42 \lesssim \xi \lesssim 12.4$
$\Downarrow$

$r \simeq 0.2, \ n_s \simeq 0.96$
$50 < N < 60$

within

$m_H = 125.6 \pm 0.35 \text{ GeV},$
$M_t = 173.34 \pm 0.76 \text{ GeV}.$

We also take
$\Omega_S h^2 = 0.12,$
$y_N = \sqrt{0.1 \text{ eV} \cdot M_R}/v,$
and decoupling effects of S
and N in $\mu < m_{\text{DM}}, \ M_R$.

3. Summary

- The BICEP2 detected B-modes from primordial gravitational waves at the level of tensor-to-scalar ratio,

$$r = 0.20^{+0.07}_{-0.05} \ .$$

- The Higgs inflation can explain

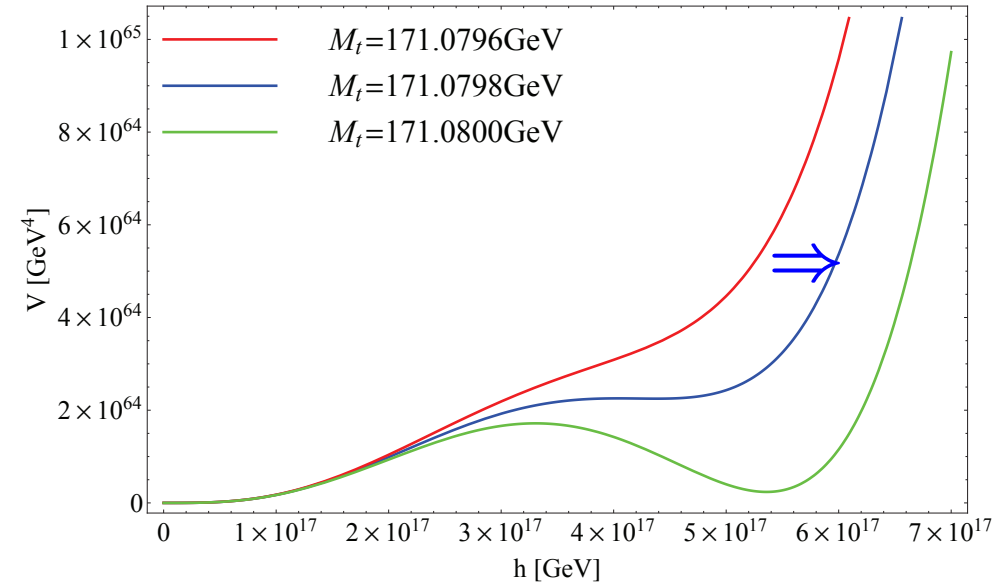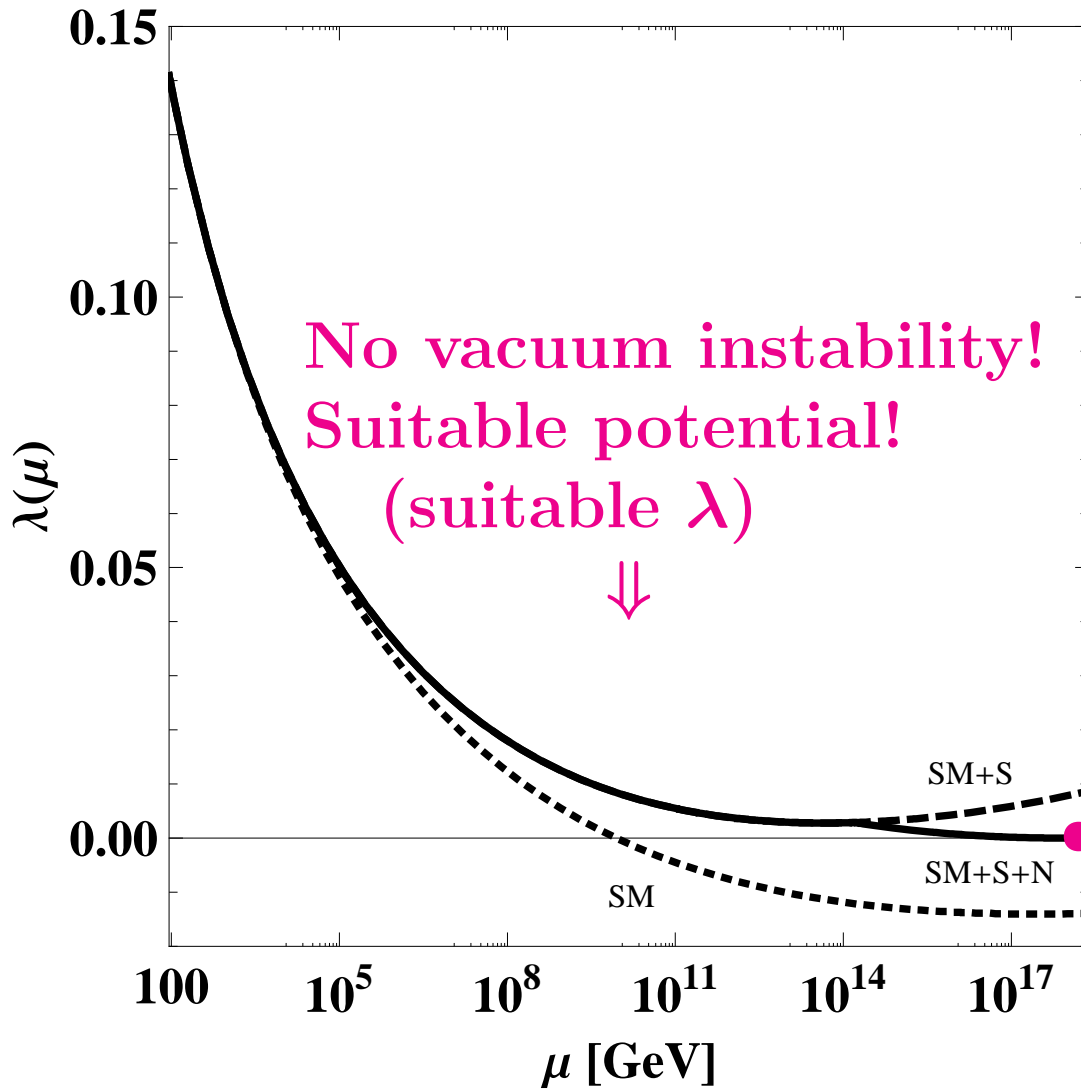Hamada, Kawai, Oda, Park

Bezrukov, Shaposhnikov

$$r \simeq (0.1 - 0.2), \quad n_s \simeq (0.955 - 0.96),$$

by taking $m_H \simeq 126$ GeV, $M_t \simeq (171.1 - 171.6)$ GeV, and $\xi \simeq (7 - 10)$.

♠ We extended the Higgs inflation by adding gauge singlets to realize $r = 0.2$ with $M_t \simeq 173$ GeV.

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SM+S

SM+S+N

SM

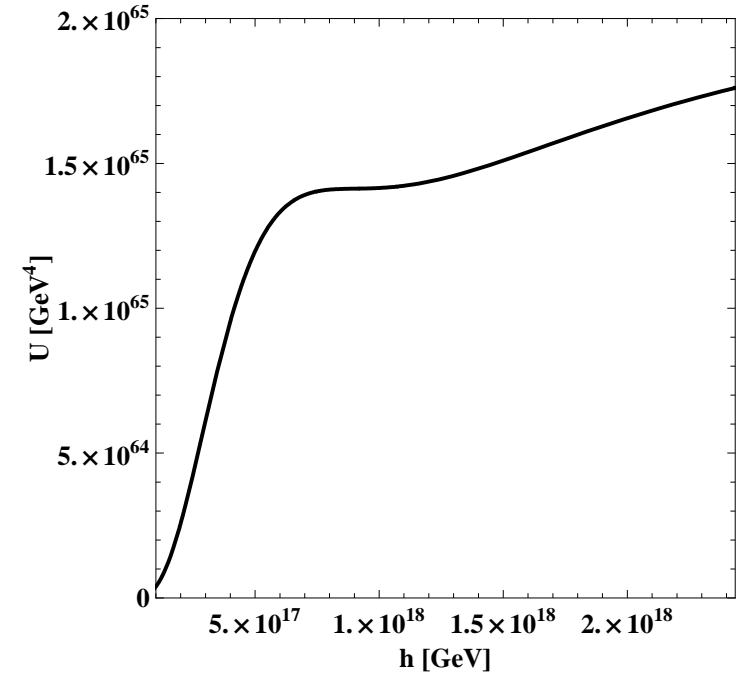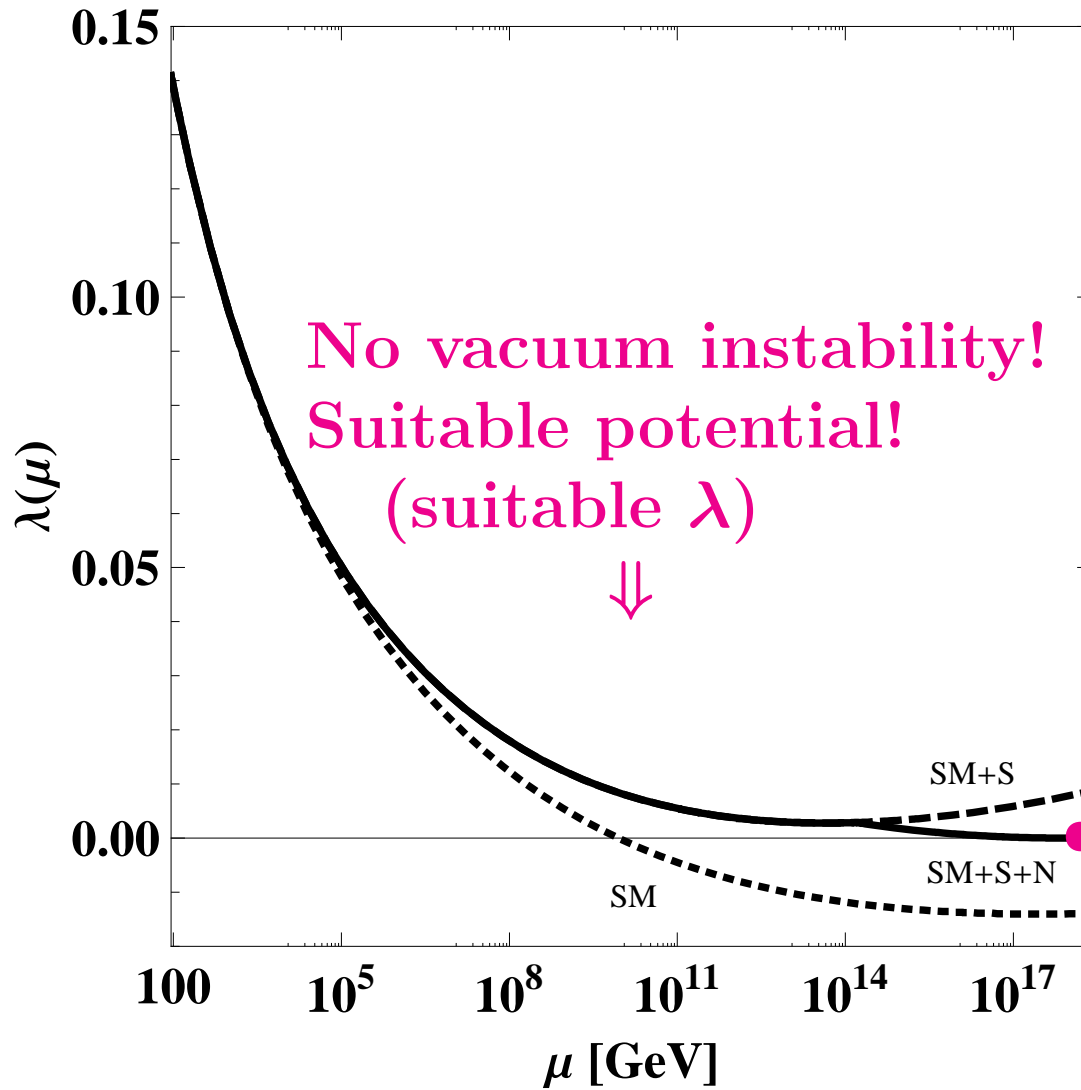$\Leftarrow$ SM+S+N ($M_t \simeq 173$ GeV and $m_H \simeq 125.6$ GeV):
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SM

$\lambda(\mu)$

μ [GeV]

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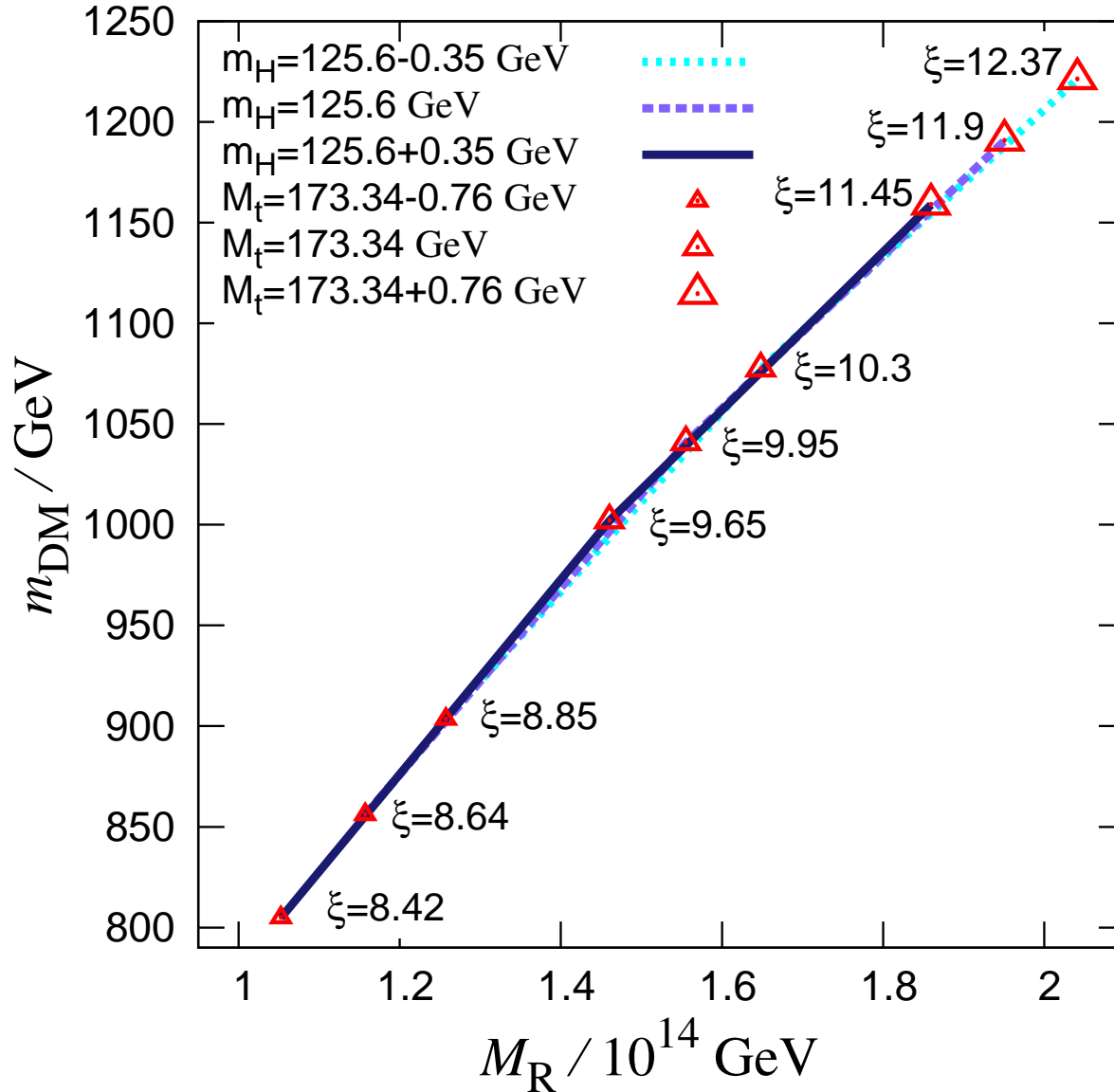$\mathcal{L} \supset k|H|^2 S^2/2 + y_N \overline{L}\tilde{H}N$
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