Higgs-portal assisted Higgs inflation

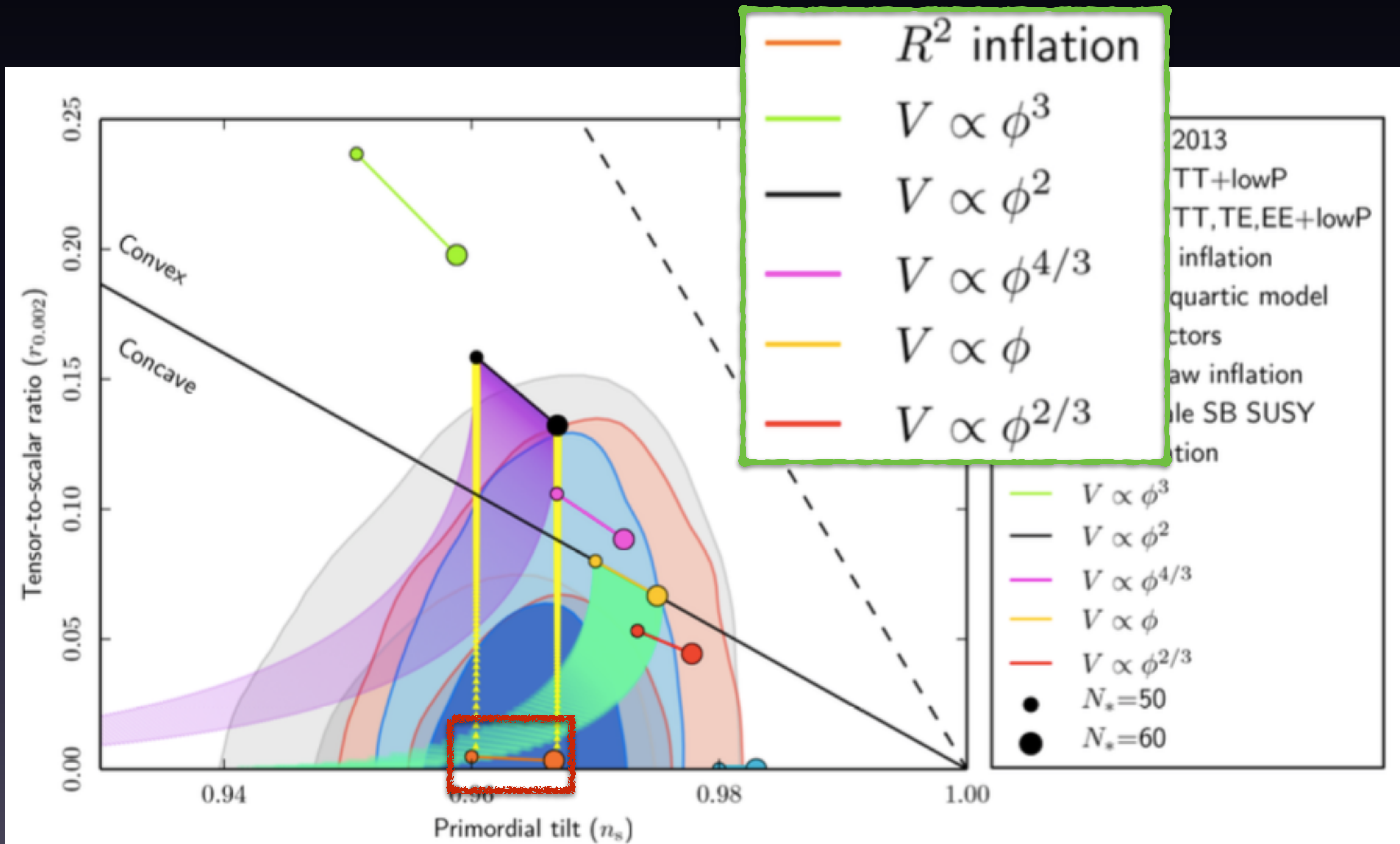
Jinsu Kim
in collaboration with
Wan-il Park and Pyungwon Ko

KIAS - Quantum Universe Center

Mar. 4, 2017 @ University of Toyama, Japan

JCAP02(2017)003

Non-minimal Coupling Model



Non-minimal Coupling Model

$$S_{\rm J} = \int d^4x \sqrt{-g_{\rm J}} \left[\frac{M_{\rm P}^2}{2} \Omega^2(\phi) R_{\rm J} - \frac{1}{2} g_{\rm J}^{\mu\nu} Z(\phi) \partial_\mu \phi \partial_\nu \phi - V_{\rm J}(\phi) \right]$$

Weyl rescaling (a.k.a. conformal transformation)

$$g_{\rm J}^{\mu\nu} \to g_{\rm E}^{\mu\nu} = \Omega^{-2} g_{\rm J}^{\mu\nu}$$

$$S_{\rm E} = \int d^4x \sqrt{-g_{\rm E}} \left[\frac{M_{\rm P}^2}{2} R_{\rm E} - \frac{1}{2} g_{\rm E}^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V_{\rm E}(\varphi) \right]$$

$$\left(\frac{d\varphi}{d\phi}\right)^2 = \frac{Z}{\Omega^2} + \frac{3M_{\rm P}^2}{2\Omega^4} \left(\frac{d\Omega^2}{d\phi}\right)^2$$

$$V_{\rm E} = \frac{V_{\rm J}}{\Omega^4}$$

Non-minimal Coupling Model

$$S_{\rm J} = \int d^4x \sqrt{-g_{\rm J}} \left[\frac{M_{\rm P}^2}{2} \Omega^2(\phi) R_{\rm J} - \frac{1}{2} g_{\rm J}^{\mu\nu} Z(\phi) \partial_\mu \phi \partial_\nu \phi - V_{\rm J}(\phi) \right]$$

Weyl rescaling (a.k.a. conformal transformation)

$$g_{\rm J}^{\mu\nu} \to g_{\rm E}^{\mu\nu} = \Omega^{-2} g_{\rm J}^{\mu\nu}$$

$$S_{\rm E} = \int d^4x \sqrt{-g_{\rm E}} \left[\frac{M_{\rm P}^2}{2} R_{\rm E} - \frac{1}{2} g_{\rm E}^{\mu\nu} \partial_\mu \varphi \partial_\nu \varphi - V_{\rm E}(\varphi) \right]$$

$$\left(\frac{d\varphi}{d\phi} \right)^2 = \frac{Z}{\Omega^2} + \frac{3M_{\rm P}^2}{2\Omega^4} \left(\frac{d\Omega^2}{d\phi} \right)^2$$

$$V_{\rm E} = \frac{V_{\rm J}}{\Omega^4}$$

Example : Higgs inflation

$$\Omega^2 = 1 + \xi_2 \frac{\phi^2}{M_{\rm P}^2}$$

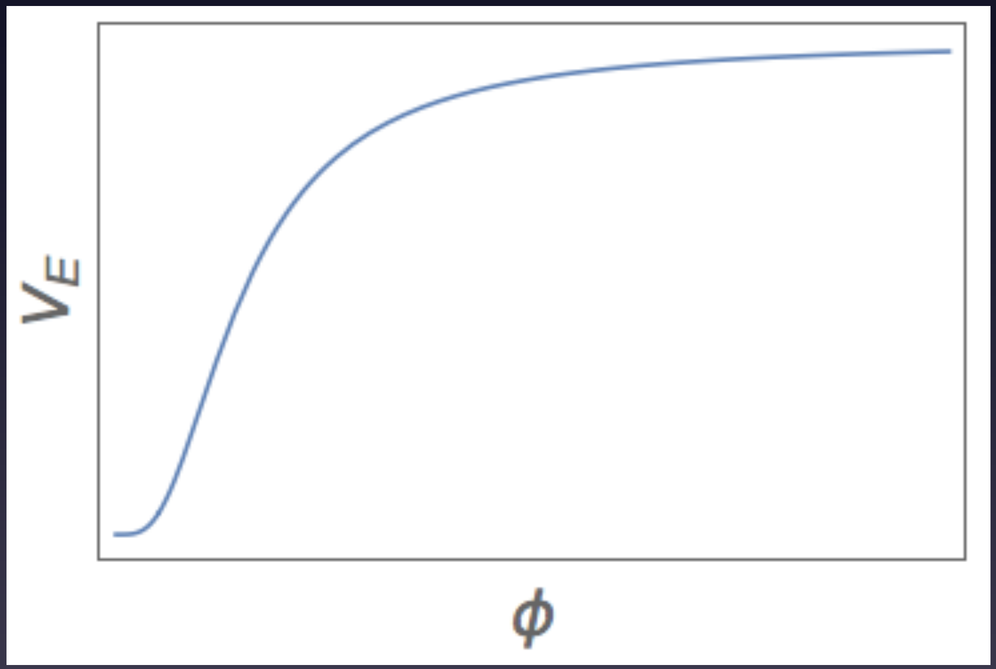
$$Z = 1$$

$$V_{\rm J} = \frac{\lambda}{4} \phi^4$$

Higgs Inflation

Einstein-frame potential

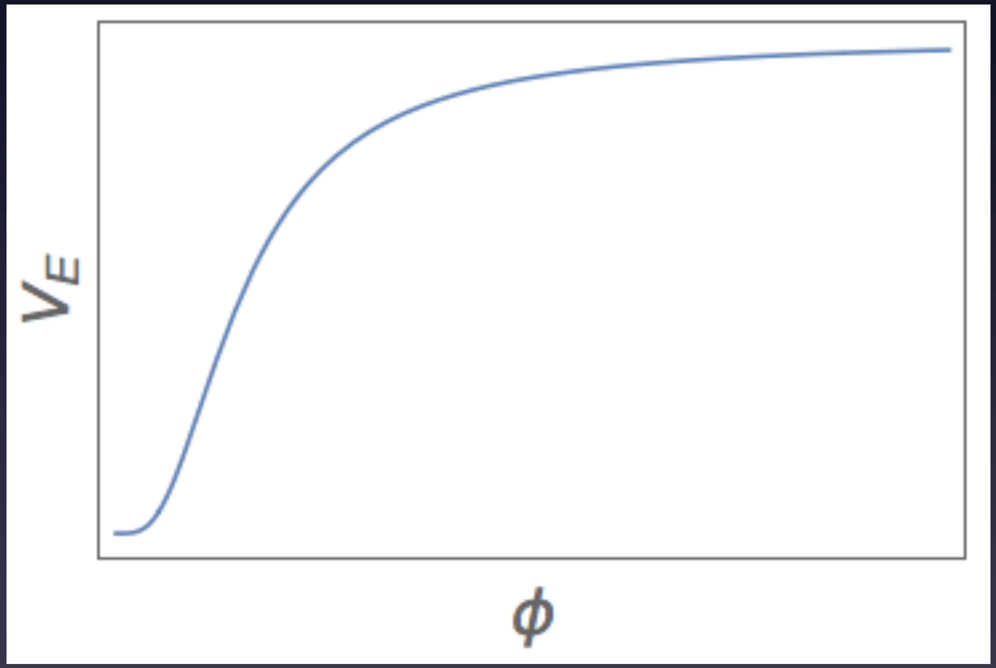
$$V_{\mathrm{E}} = \frac{\lambda\phi^4}{4(1+\xi_2\phi^2/M_{\mathrm{P}}^2)^2} \longrightarrow \left(\frac{\lambda}{4\xi_2^2}\right) M_{\mathrm{P}}^4$$



Higgs Inflation

Einstein-frame potential

$$V_{\mathrm{E}} = \frac{\lambda \phi^4}{4(1+\xi_2 \phi^2/M_{\mathrm{P}}^2)^2} \longrightarrow \left(\frac{\lambda}{4\xi_2^2}\right) M_{\mathrm{P}}^4$$



Planck normalization (or power spectrum)

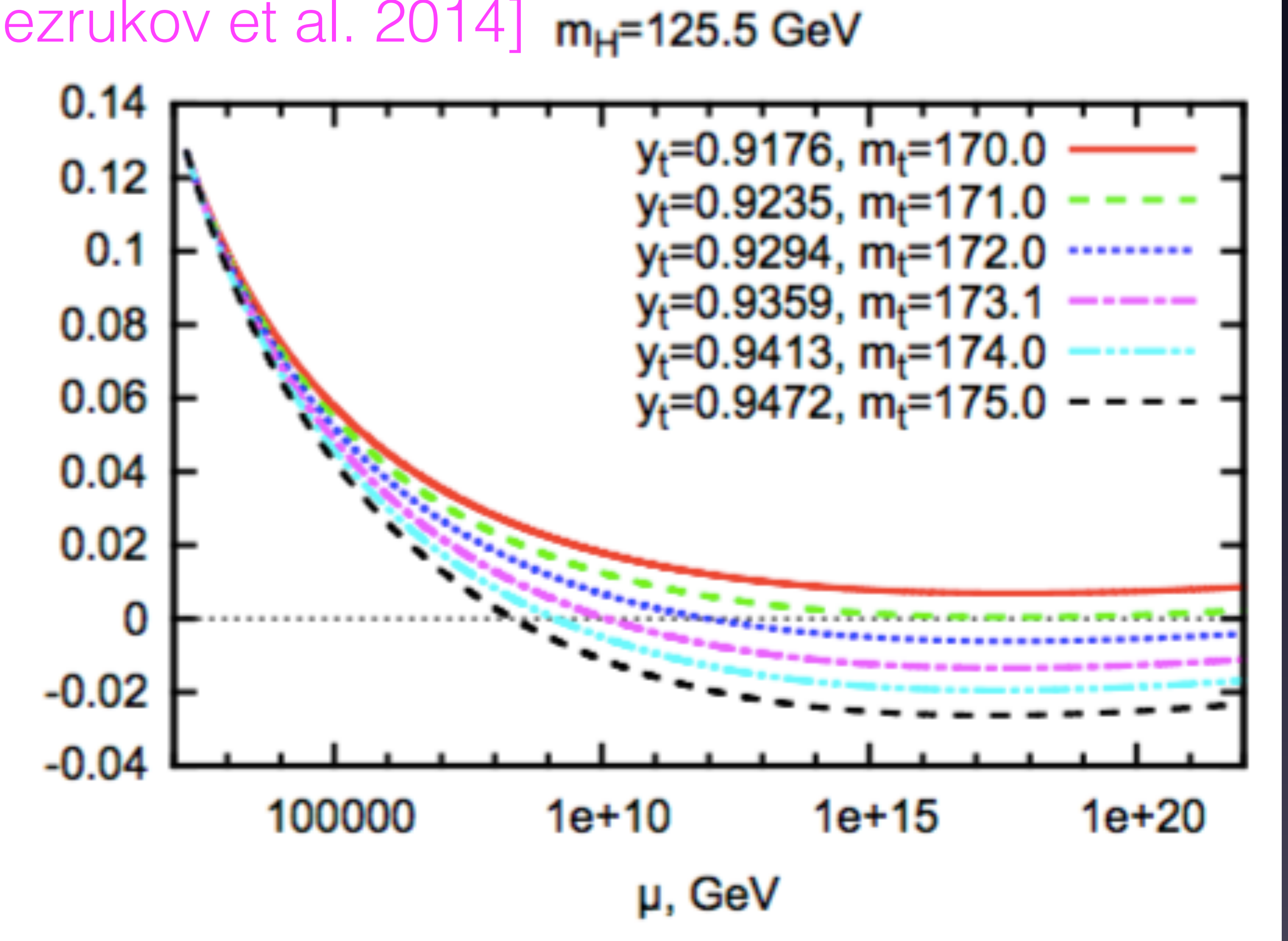
$$\frac{\lambda}{\xi_2^2} \sim 10^{-10}$$

$$\lambda \sim 0.1 \quad \& \quad \xi_2 \sim 10^4 - 10^5$$

Higgs Inflation

In the pure SM case, assuming that the SM is valid all the way up to the (nearly) Planck scale, the quartic coupling can be very small due to the RG effects.

[Bezrukov et al. 2014]



[Cook et al. 2014]

[Hamada et al. 2014]

[Allison 2014]

[Simone et al. 2009]

Higgs Inflation

The Einstein-frame potential is

$$V_{\mathrm{E}} = \frac{\lambda(t)\phi^4}{4(1+\xi_2\phi^2/M_{\mathrm{P}}^2)^2}$$

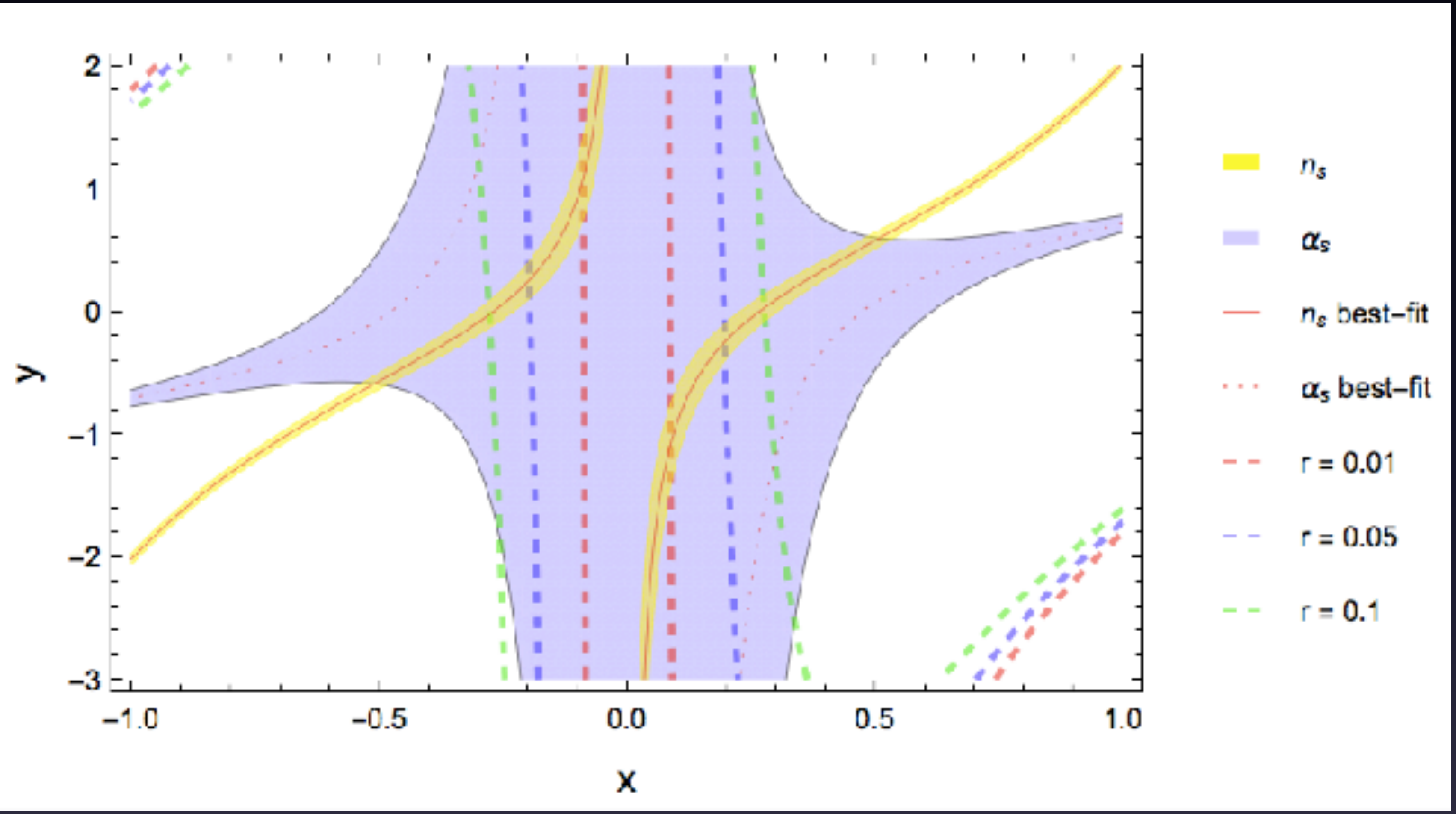
Tensor-to-scalar ratio, for example, is given by

$$r \approx \frac{64}{3\xi_2^2}\left(\frac{M_{\mathrm{P}}}{\phi}\right)^4\left[1 + x\frac{\xi_2\phi^2}{4M_{\mathrm{P}}^2}\right]^2$$

where

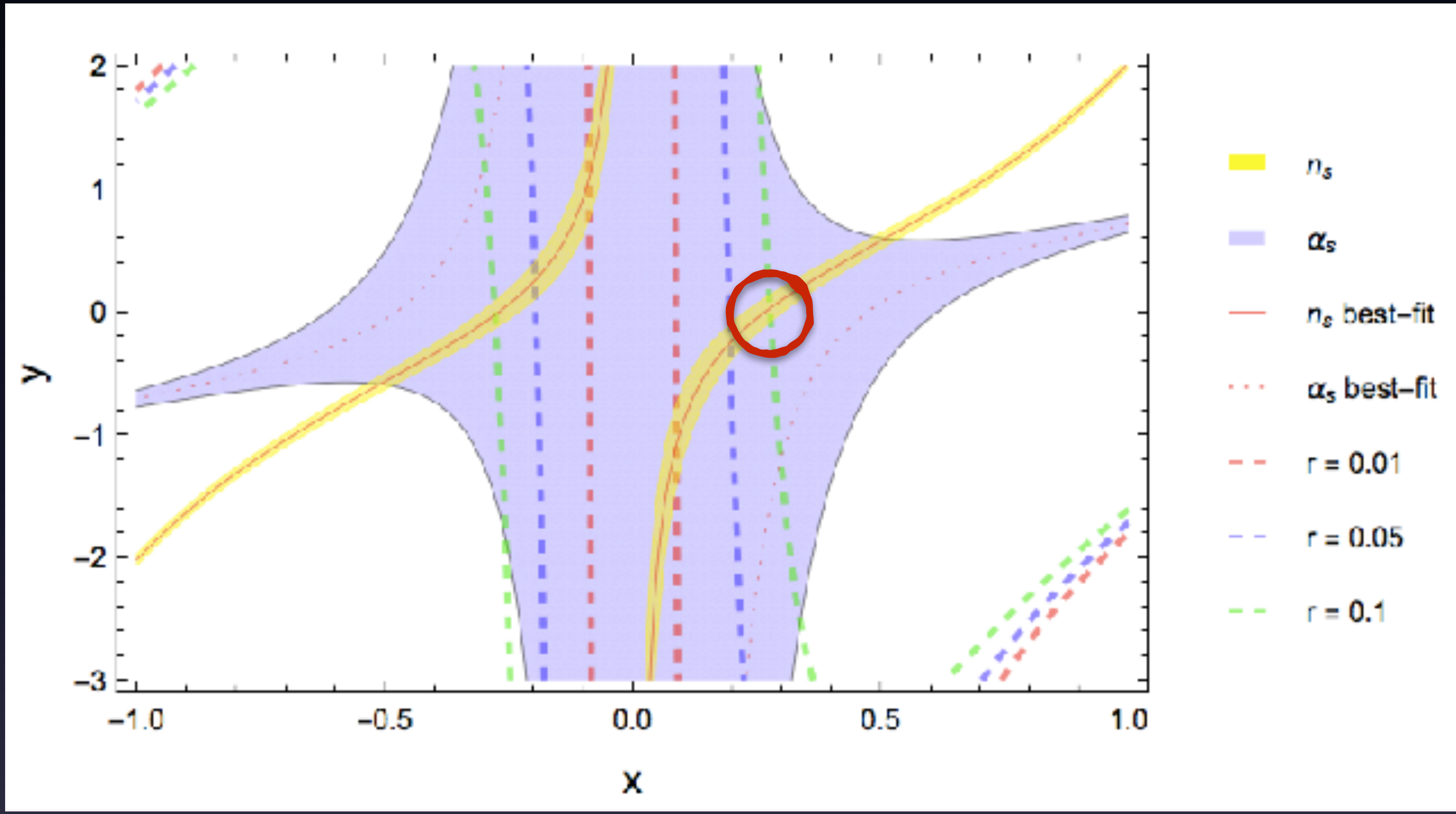
$$x \equiv \frac{1}{\lambda}\frac{d\lambda}{dt}$$

Higgs Inflation



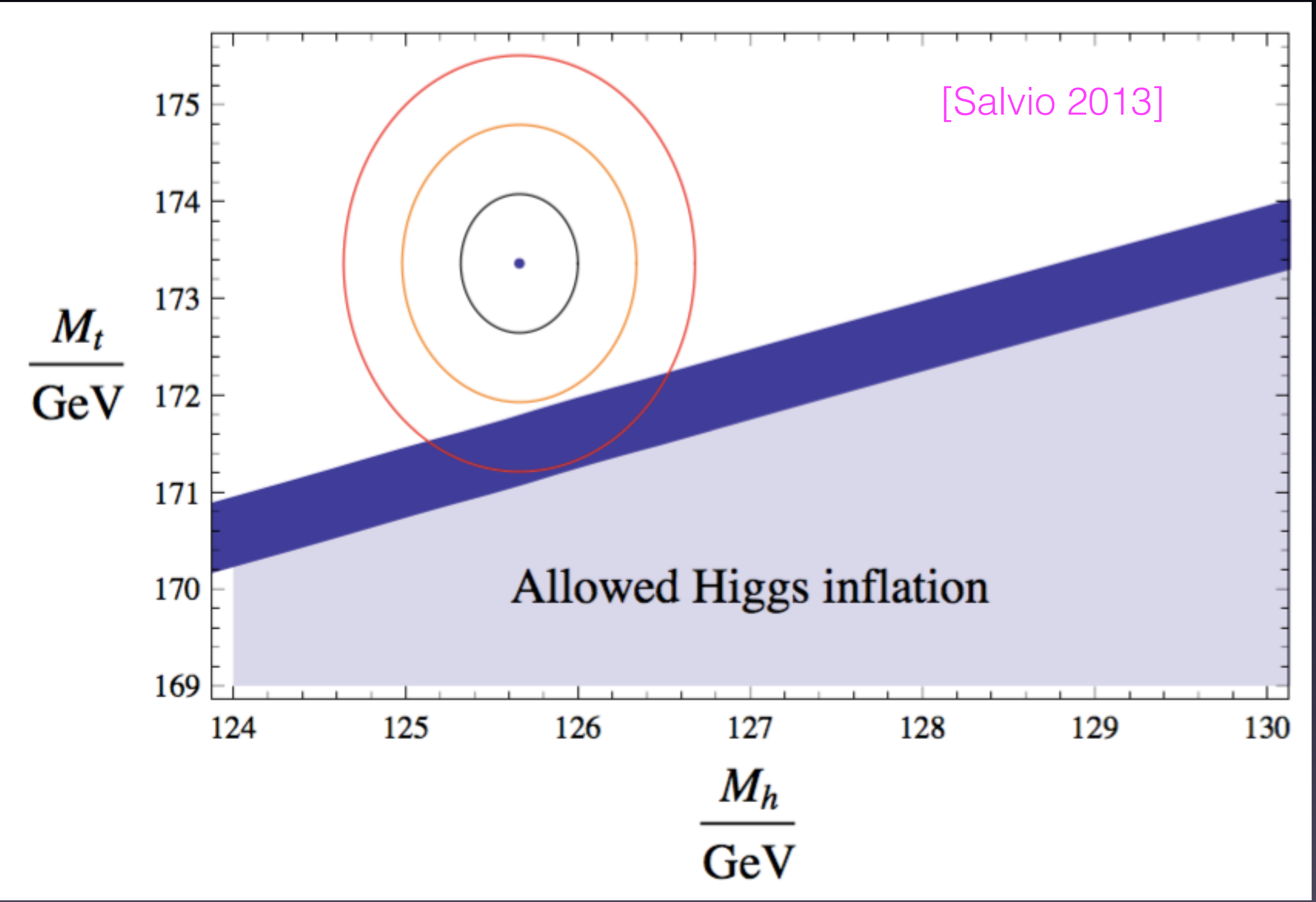
$$x \equiv \frac{1}{\lambda}\frac{d\lambda}{dt} \qquad \text{and} \qquad y \equiv \frac{1}{d\lambda/dt}\frac{d^2\lambda}{dt^2}$$

Higgs Inflation



$$x \equiv \frac{1}{\lambda}\frac{d\lambda}{dt} \qquad \text{and} \qquad y \equiv \frac{1}{d\lambda/dt}\frac{d^2\lambda}{dt^2}$$

Higgs Inflation



[Lerner et al. 2009] [Lerner et al. 2011] [Aravind et al. 2015]

Higgs Inflation with Higgs Portal

The SM needs to be extended in order to explain, at least, the existence of DM.

Higgs-portal interaction is generic in hidden-sector DM models.

In this work, we choose to work with the SFDM model, where the hidden sector consists of a singlet scalar field and a fermionic DM-candidate field.

The SM sector and the hidden sector communicate through the Higgs-portal interaction:

$$V_{\text{portal}} = \mu_{SH} S|H|^2 + \frac{1}{2}\lambda_{SH} S^2 |H|^2$$

Higgs Inflation with Higgs Portal

Relevant parameters:

λ_S : quartic coupling of S field

λ_ψ : coupling between S and ψ, $\lambda_\psi S\overline{\psi}\psi$

λ_{SH} : portal coupling

α : mixing angle between the dark Higgs and the SM Higgs

m_S : mass of S field

ξ_S : Non-minimal coupling of S to gravity

Note that ξ_2 is NOT a free parameter; determined by the Planck normalization

$$A_s \approx 2.2 \times 10^{-9}$$

Higgs Inflation with Higgs Portal

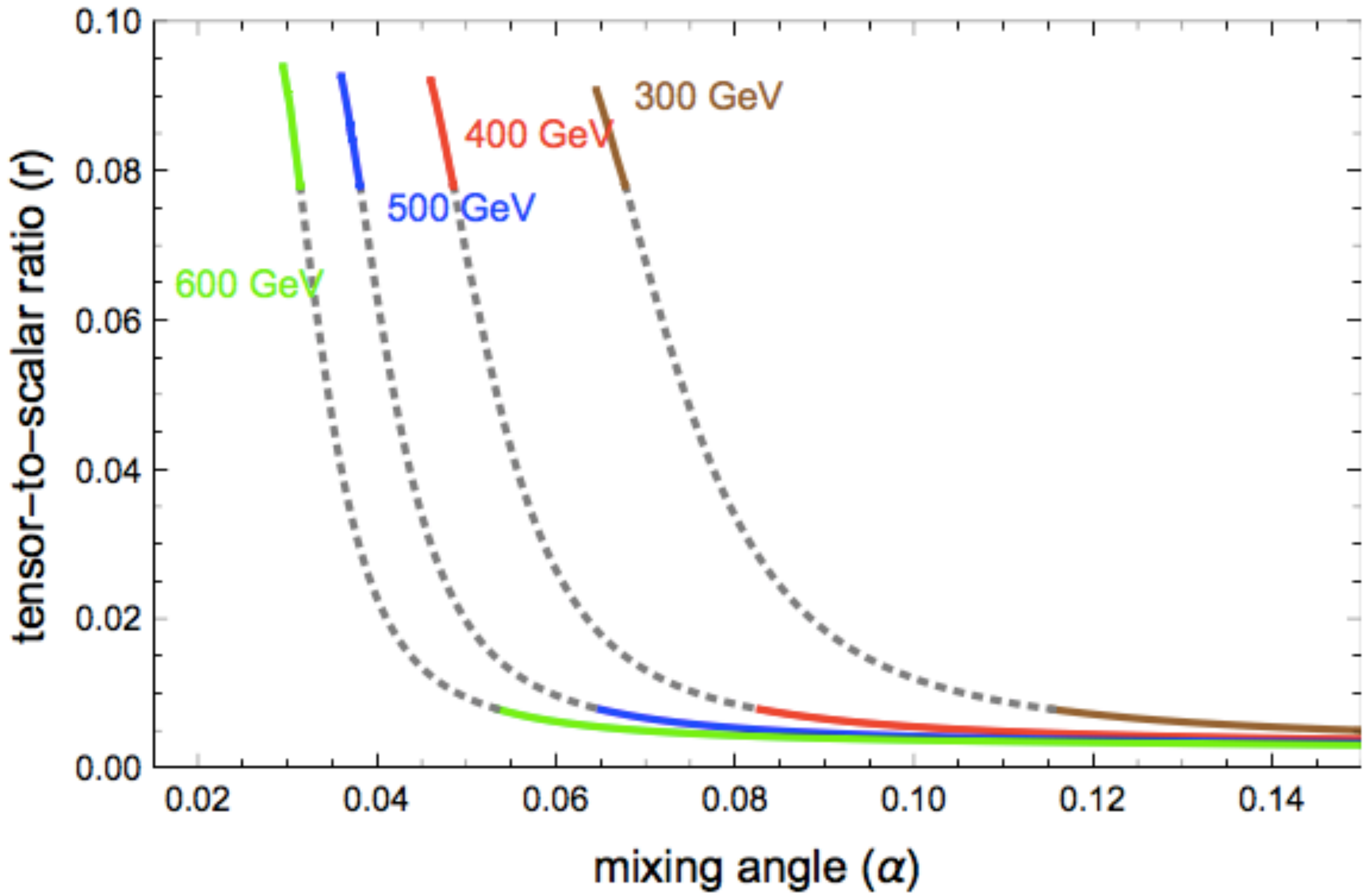
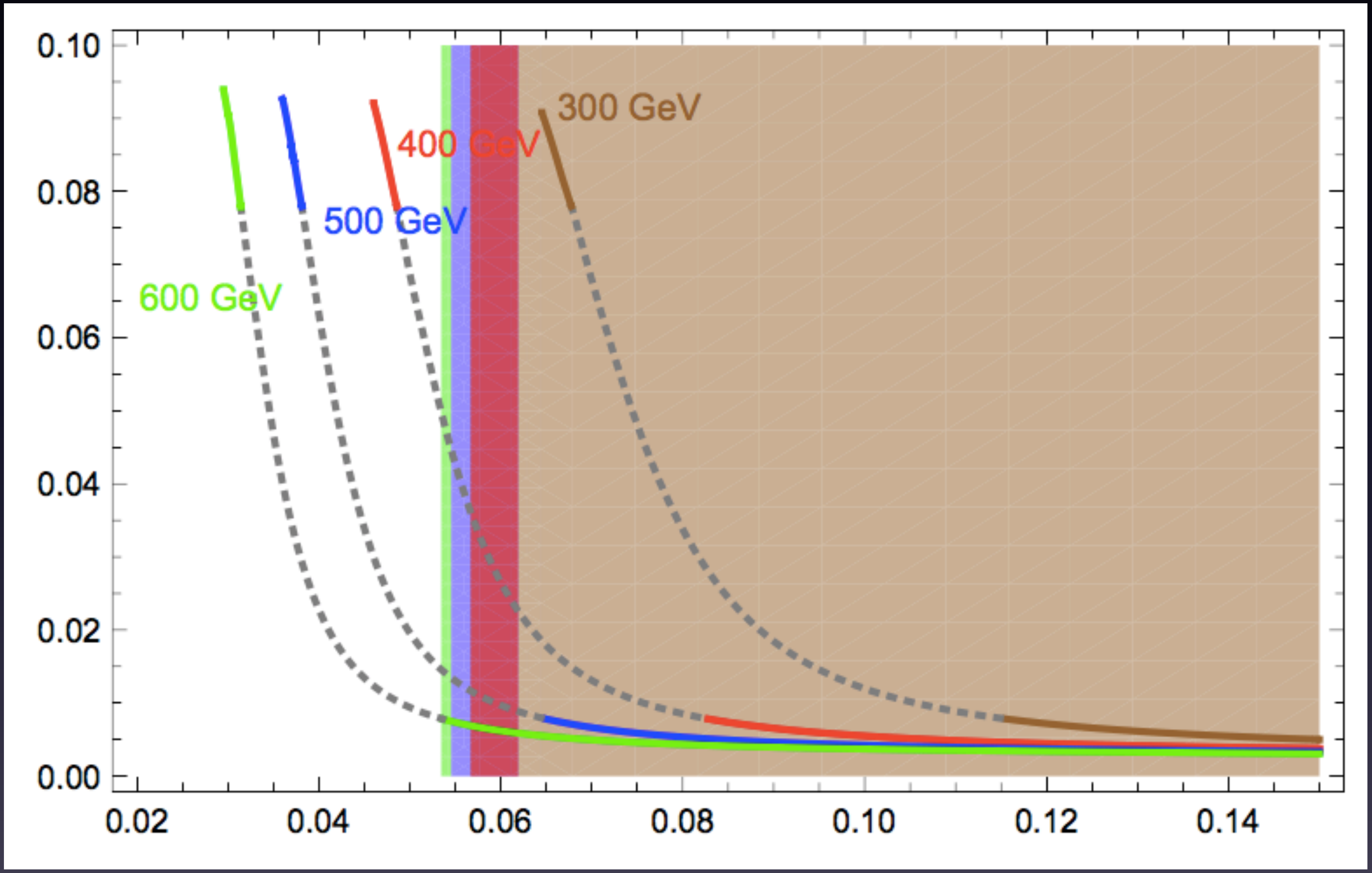


Figure 4. Tensor-to-scalar ratio as a function of the mixing angle α for $m_s = 300\,\mathrm{GeV}$, $400\,\mathrm{GeV}$, $500\,\mathrm{GeV}$ and $600\,\mathrm{GeV}$ at the pivot scale $k_* = 0.05\,\mathrm{Mpc}^{-1}$. Here $\xi_s = 0$, $\lambda_{SH} = 0.1$, $\lambda_S = 0.2$, and $\lambda_\psi = 0.3$ at M_t scale are used. The nonminimal coupling of the SM Higgs to gravity, ξ_h, is chosen in such a way that the Planck normalization (3.8) is satisfied. The grey-dotted lines indicate the parameter region where the spectral index n_s becomes larger than 2σ Planck bound, $n_s \gtrsim 0.98$. Similar behaviors are found for different sets of model parameters.

Higgs Inflation with Higgs Portal



[Baek et al. 2011] [Baek et al. 2012]

Summary

In this talk, we discussed

- Higgs inflation in the presence of Higgs-portal interaction
- and how a large tensor-to-scalar ratio can be achieved without resort to a strong dependence on M_t.

Especially, using the model of singlet fermion dark matter as a concrete model, we performed a numerical analysis and showed how it is realised.

We find it amusing that the dark Higgs guarantees the dark matter stability and improves the stability of electroweak vacuum as well as assisting the Higgs inflation at the same time.

Summary

In this talk, we discussed

- Higgs inflation in the presence of Higgs-portal interaction
- and how a large tensor-to-scalar ratio can be achieved without resort to a strong dependence on M_t.

Especially, using the model of singlet fermion dark matter as a concrete model, we performed a numerical analysis and showed how it is realised.

We find it amusing that the dark Higgs guarantees the dark matter stability and improves the stability of electroweak vacuum as well as assisting the Higgs inflation at the same time.

Thank you