SUSY-phenomenology-based models of Higgs inflation

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Based on [1512.05861] [1411.5188] [1404.1450] [1212.6828] [1107.4767] [1112.2391]
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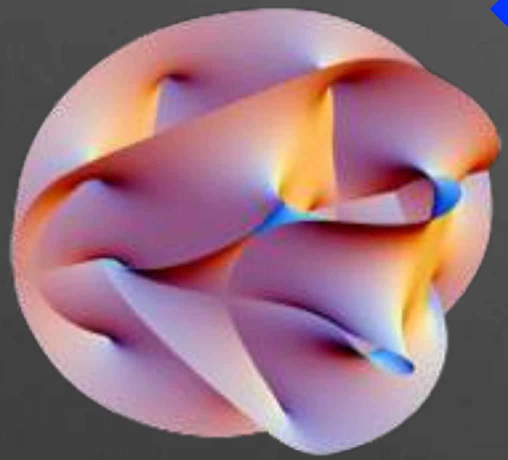
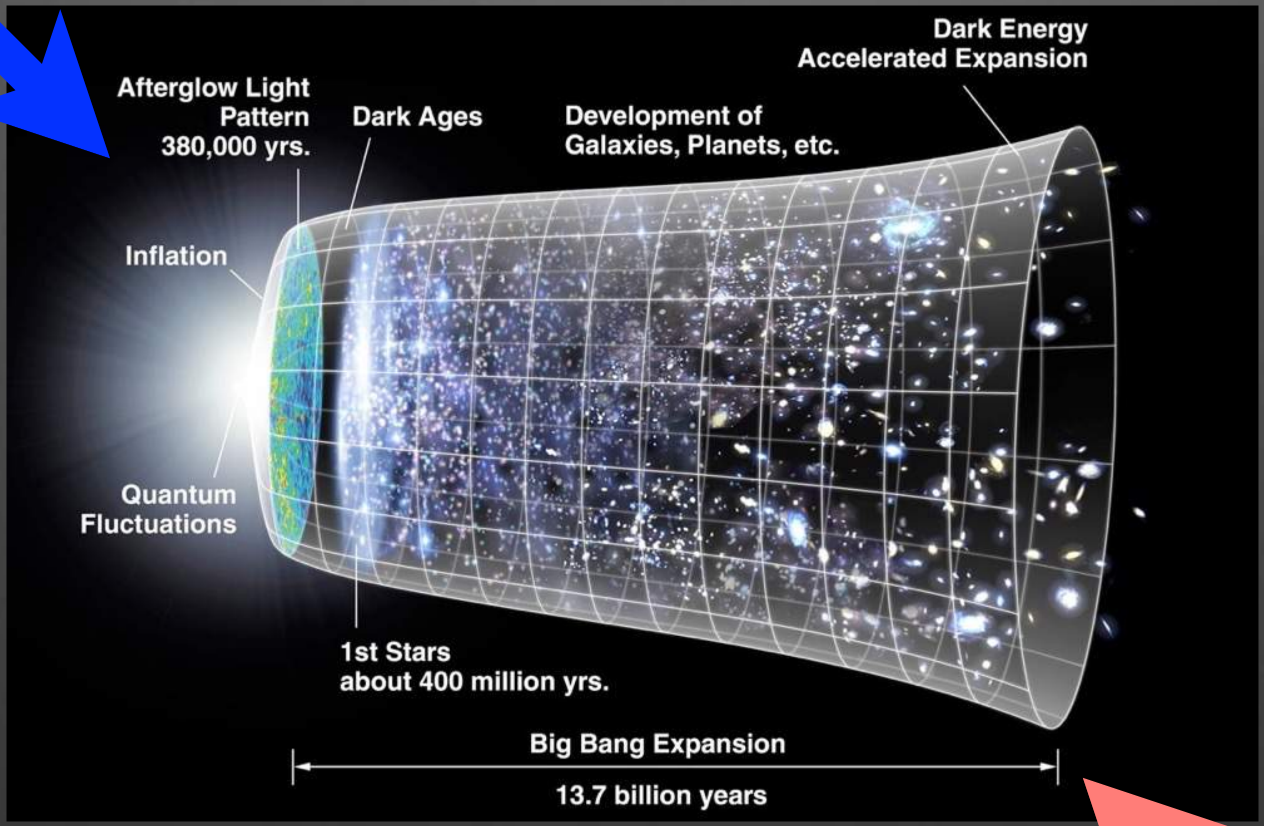
Masato Arai (Yamagata)

18 Feb 2016 @HIP

What is the particle physics behind inflation?

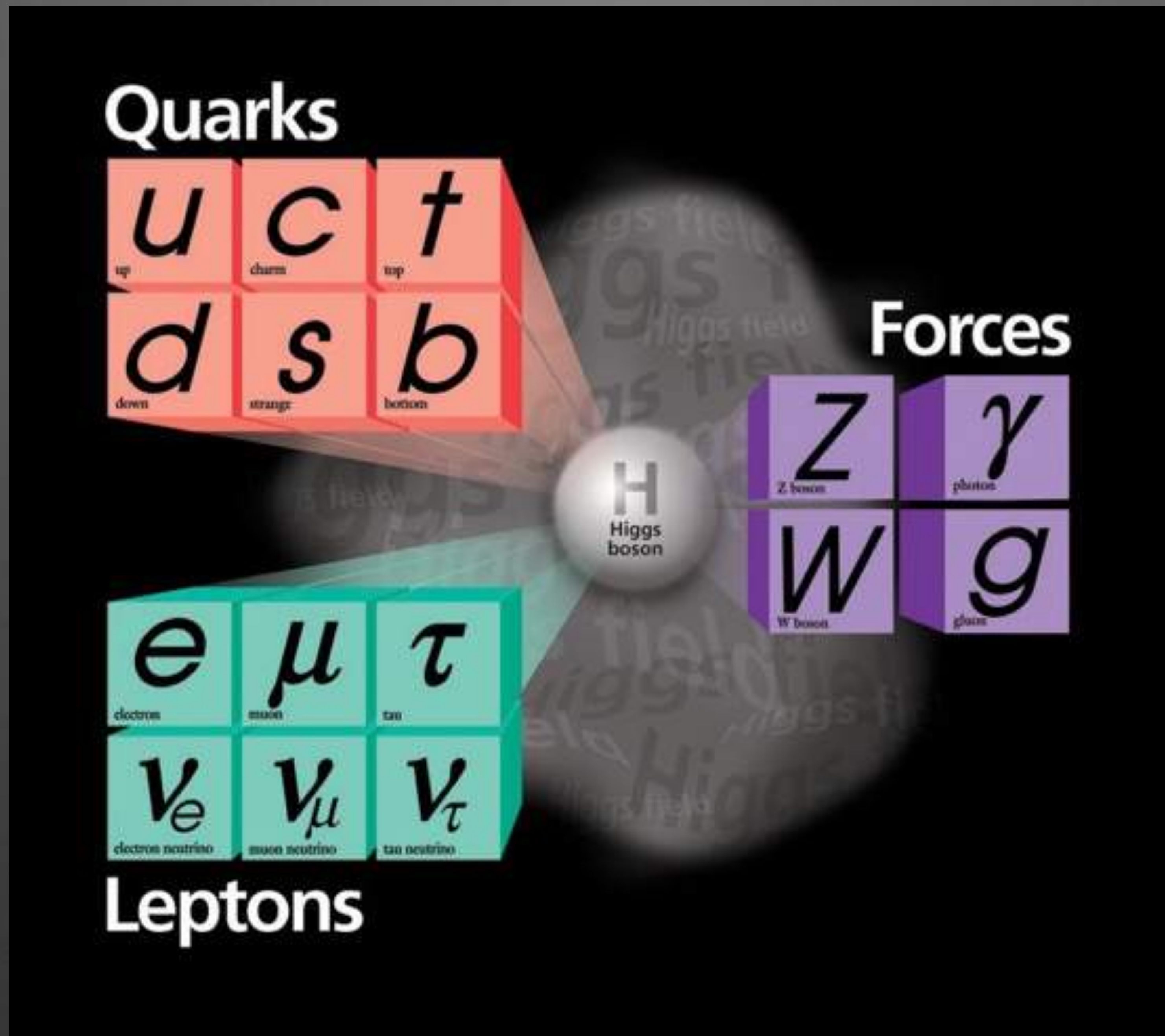
String theory





Particle phenomenology

Standard Model of particle physics



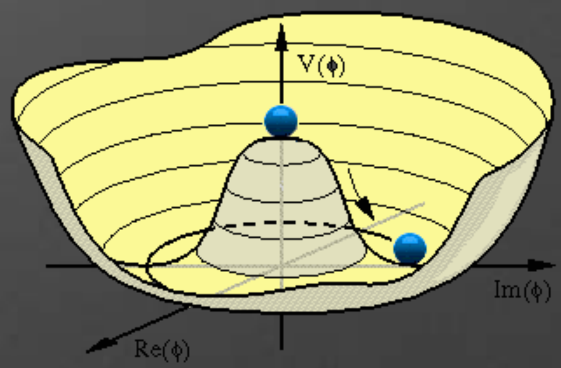
or, *beyond* the Standard Model (+singlets, SUSY, etc.)

Inflaton: origin of everything

- A scalar field — where is it from?

- Right handed scalar neutrino?

  m ≃10^{13} GeV chaotic inflation
  [Murayama Suzuki Yanagida Yokoyama 1992]

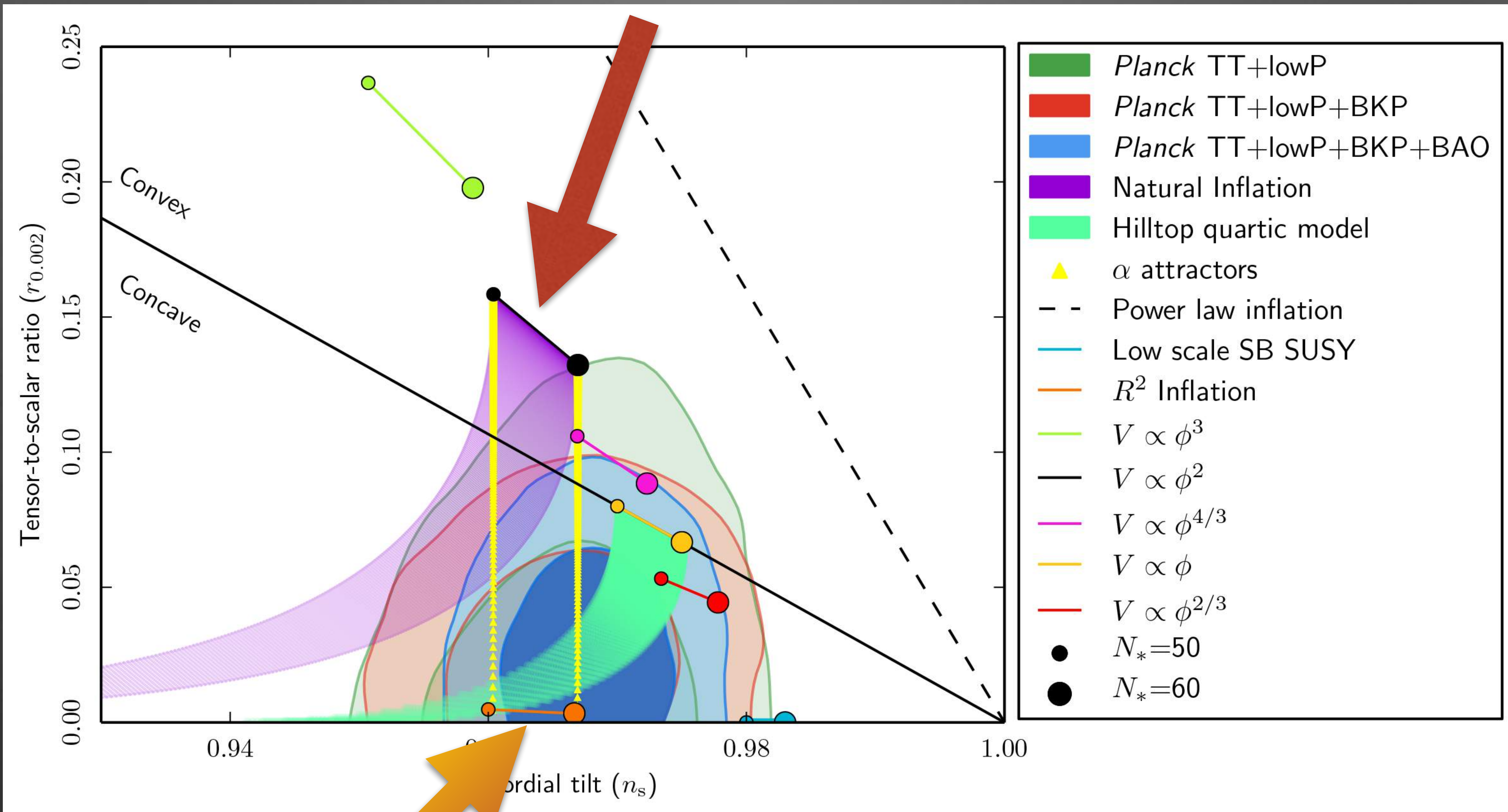


- Higgs field?

  SM Higgs boson: mass ≈ 125 GeV, λ ≈ O(1)
  Chaotic inflation: m ≈ 10^{13} GeV or λ ≈ 10^{-12}

— Nonminimal coupling to gravity [Cervantes-Cota, Dehnen 1995] [Bezrukov Shaposhnikov 2008]
— Non canonical kinetic term [Nakayama Takahashi] [Germani Kehagias] [others]
— Curvaton scenario [Langlois Vernizzi] [others]
— RG criticality, ad-hoc modification beyond cutoff [Hamada et al.]

$m^2\phi^2$ chaotic inflation (RHN)



Planck 2015 [1502.02114v1]

Nonminimal Higgs inflation

Confidence level (CL)

1σ: 68%
2σ: 95%
3σ: 99.7%
4σ: 99.994%
5σ: 99.99994%

in collider physics

$5\sigma \simeq 50\%$

in cosmology

Overview

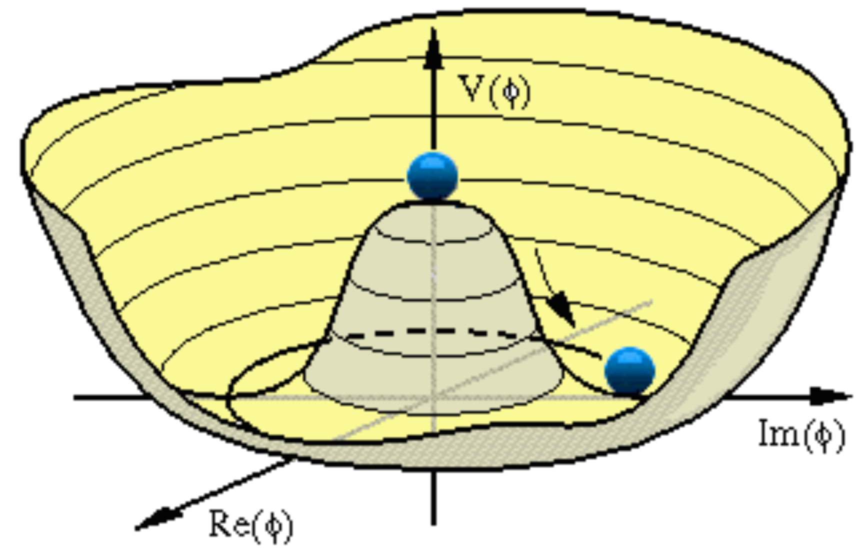
- Particle phenomenology-based approach to cosmic inflation: Higgs inflation
- Supersymmetric Higgs inflation
  - Supersymmetric Higgs-lepton inflation
  - Supersymmetric SU(5) GUT inflation
- Summary

Higgs inflation

[Bezrukov Shaposhnikov, PLB 659 (2008) 703]

- Higgs potential: $V = \frac{\lambda}{4}(\phi^2 - v^2)^2$

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{M_P^2}{2} R - \xi H^\dagger H R$$



- During inflation $\langle\phi\rangle \gg v$

$$S = \int d^4x \sqrt{-g}\Big(- \frac{M_P^2 + \xi\phi^2}{2} R + \frac{1}{2}(\partial_\mu \phi)^2 - \frac{\lambda}{4}\phi^4 \Big)$$

- This is in the Jordan frame. Go to the Einstein frame:

$$\hat{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}, \qquad \Omega^2 = 1 + \frac{\xi\phi^2}{M_{\rm P}^2}$$

- In the Einstein frame,

$$S_E = \int dx^4 \sqrt{-\hat{g}} \Big(-\frac{M_{\rm P}^2}{2} \hat{R} + \frac{1}{2} (\partial_\mu \hat{\phi})^2 - U(\hat{\phi}) \Big)$$

$$\frac{d\hat{\phi}}{d\phi} = \Omega^{-2} \sqrt{\Omega^2 + 6\xi^2 \phi^2 M_{\rm P}^{-2}}$$

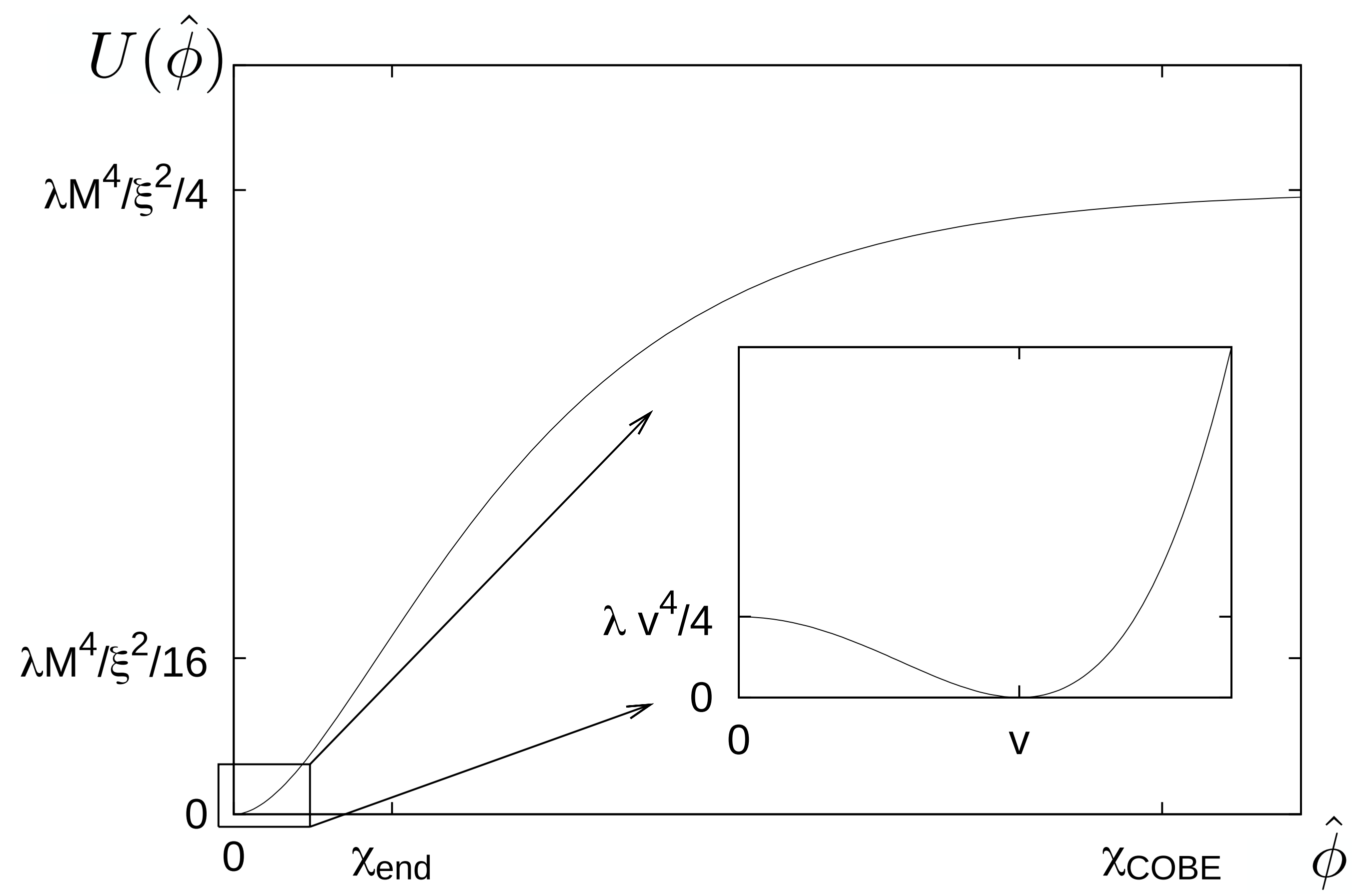
$$U(\hat{\phi}) = \frac{\lambda}{4} \frac{(\phi^2 - v^2)^2}{\Omega^4}$$

- Inflaton potential

$$\phi \ll M/\xi \Longrightarrow \hat{\phi} \approx \phi$$

$$M/\xi \ll \phi \ll M/\sqrt{\xi} \Longrightarrow \hat{\phi} \approx \sqrt{3/2}\xi\phi^2$$

$$\phi \gg M/\sqrt{\xi} \Longrightarrow \hat{\phi} \approx \sqrt{6} \ln \phi$$



- Inflation at $\phi \gg M/\sqrt{\xi}$

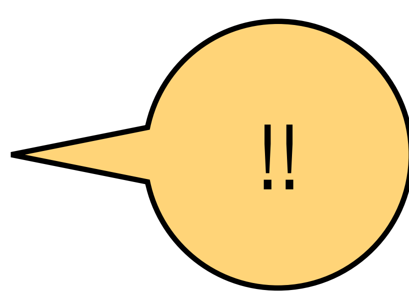
$$\epsilon \equiv \frac{1}{2}\left(\frac{\partial_{\hat{\phi}} U}{U}\right)^2 \approx \frac{4}{3}\frac{M^4}{\xi^2\phi^4}$$

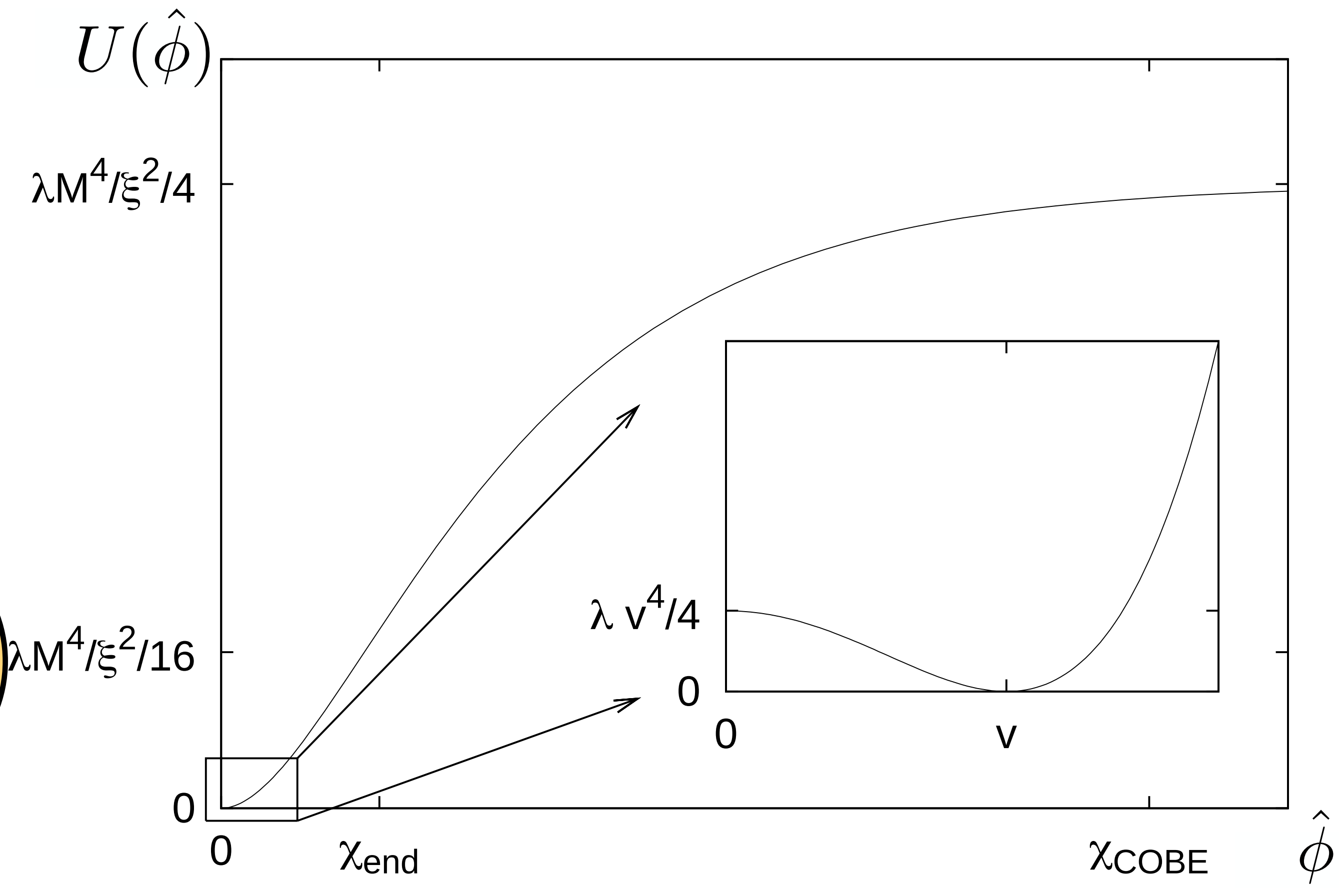
$$\eta \equiv \frac{\partial^2_{\hat{\phi}} U}{U} \approx -\frac{4}{3}\frac{M^2}{\xi\phi^2}$$

- Curvature perturbation

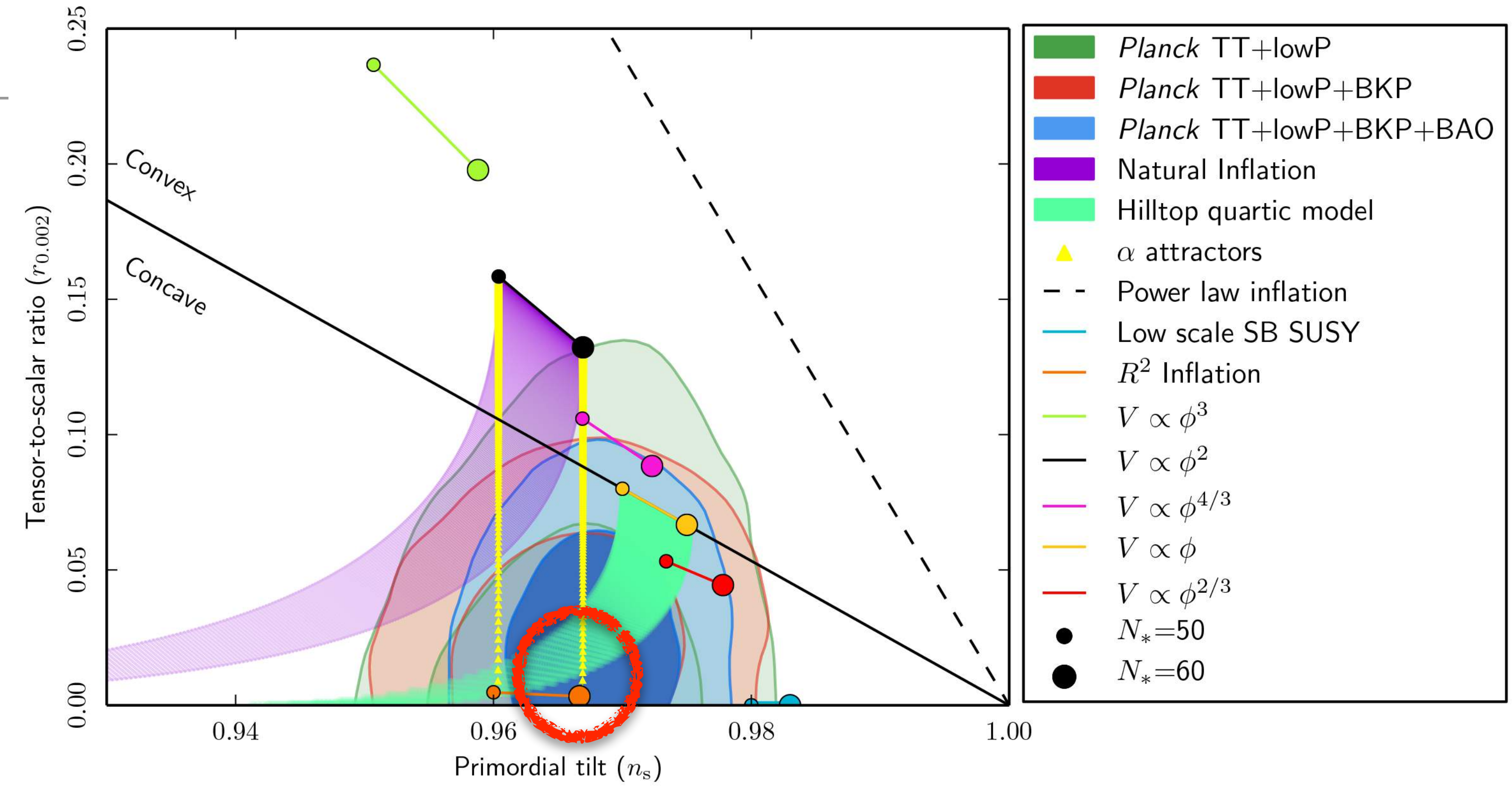
$$P_R = \frac{1}{12\pi^2 M_{\rm P}^6}\frac{U^3}{(\partial_{\hat{\phi}} U)^2} \sim 10^{-9}$$

$$\Longrightarrow \xi \sim 10^4$$





Summary: Higgs inflation



- Inflaton identified with a known particle field
- Predicted CMB spectrum fits well with the present data
- Higgs potential unstable against radiative corrections

GO SUSY!

- Nonminimal coupling ξ ~ 10000. This is insanely large

Supersymmetric extension

- SM is good, but not perfect
  - No good candidate of DM
  - Difficulty in baryogenesis
  - Hierarchy problem
- Supersymmetric extension of the SM
  - Gauge coupling unification favours SUSY
  - UV completion, e.g. string theory
  - *SUSY Higgs inflation?*

The η-problem

Supergravity with

- ☞ **Canonical Kähler potential**
- ☞ **Generic superpotential W**
- ☞ **F-term SUSY breaking**

gives slow-roll parameter $\eta \sim O(1)$

- Slow roll inflation in supergravity is known to be difficult.

The η-problem

To circumvent the η-problem?

— non-canonical Kähler potential

or

— special form of W

or

— D-term SUSY breaking

“Compensator formalism” in the Jordan frame

e.g. [Ferrara Kallosh Linde Marrani Van Proeyen 2010, 2011]

K, W, f_{ab} and Φ

logically redundant, but useful in practice

Constructing Supersymmetric Higgs inflation

W Superpotential (MSSM + extra),

K Kähler potential (canonical + extra)

Supergravity Lagrangian (Jordan frame) $L_J = R\Phi + \cdots$

Einstein frame Lagrangian

$$\mathcal{L} = \sqrt{-g}\left[\frac{1}{2}\mathcal{R} - \frac{1}{2}G_{IJ}g^{\mu\nu}\partial_\mu\phi^I\partial_\nu\phi^J - V(\phi^I)\right],$$

Multi-field inflation with nontrivial field space

$G_{IJ}, V(\phi^I):$ complicated

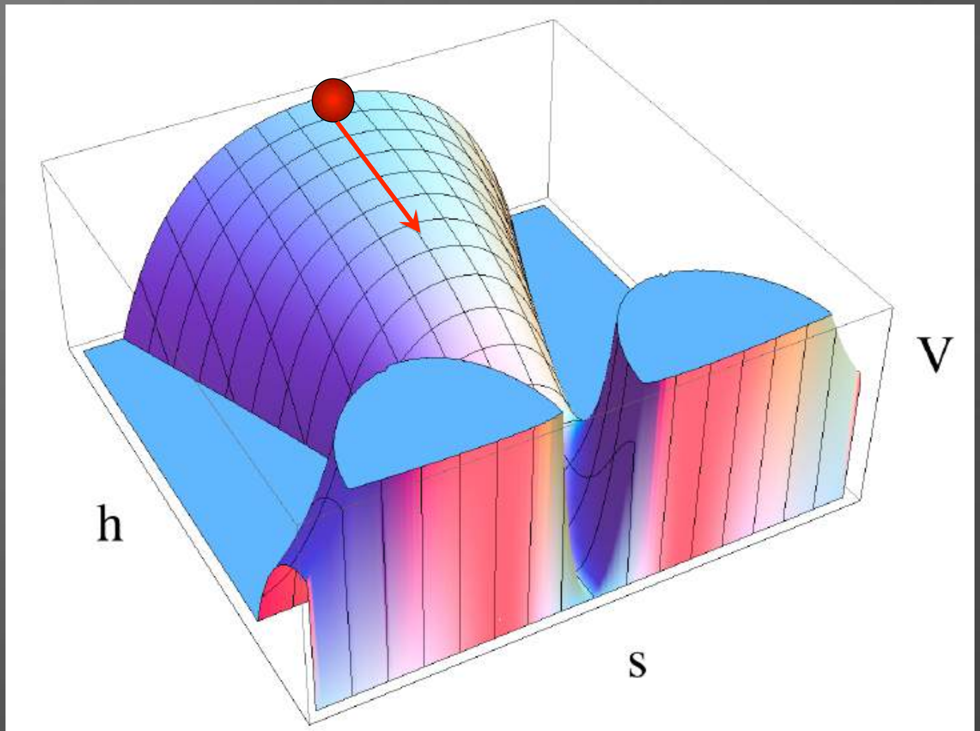
Models of SUSY Higgs inflation

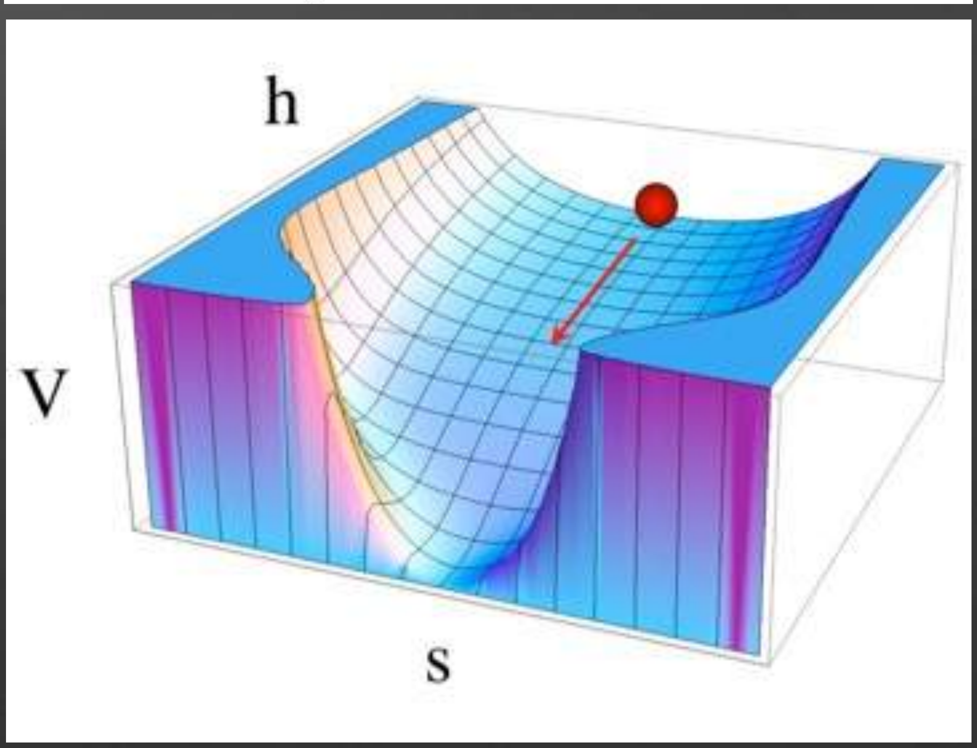
- Nonminimally coupled Higgs inflation not possible in MSSM
- NMSSM [Einhorn Jones 2009] [Ferrara Kallosh Linde Marrani Van Proeyen 2010]
- Pati-Salam [Pallis Toumbas 2011]
- SUSY seesaw [Arai SK Odaka 2011]
- SUSY GUT [Arai SK Odaka 2011]

⬅ focus on these example

SUSY Higgs inflation: generic features

- Noncanonical Kähler potential ➜ nonminimal coupling (unlike A-term MSSM inflation or F-term hybrid inflation)
- Nonminimal coupling not necessarily large
- Tachyonic instability in the singlet direction, removed by further modification of Kähler [Ferrara Kallosh Linde Marrani Van Proeyen]
- Multifield dynamics not studied so far





Single field vs. multi field

	SINGLE FIELD INFLATION	MULTI FIELD INFLATION
BACKGROUND EVOLUTION	Straight trajectory	Curved trajectory in n-dimensional space
DOF OF FLUCTUATIONS	Scalar 1(=2+1-2) Vector 2 Tensor 2	Scalar n (=2+n-2) Vector 2 Tensor 2
EVOLUTION OF FLUCTUATIONS	Adiabatic, freeze outside the Hubble horizon	Adiabatic (curvature) and entropy (isocurvature)
NON-GAUSSIANITY OF SCALAR FLUCTUATIONS	Small	Can be large

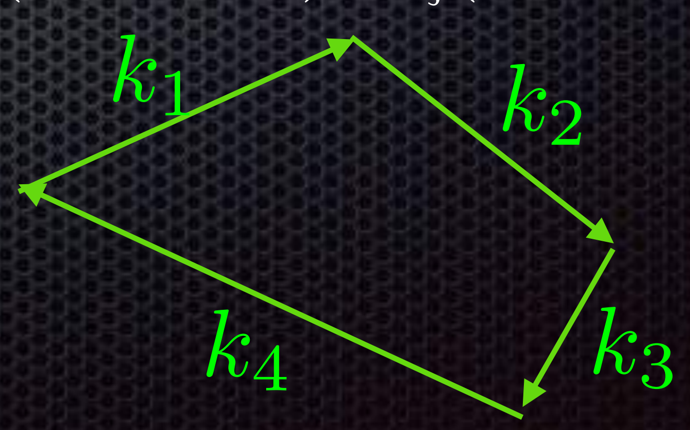
source

Primordial density fluctuations

- Power spectrum $\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \rangle = (2\pi)^3 \delta^3(\vec{k}_1 + \vec{k}_2) P_\zeta(k_1)$
- Bispectrum $\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \zeta_{\vec{k}_3} \rangle = (2\pi)^3 \delta^3(\vec{k}_1 + \vec{k}_2 + \vec{k}_3) B_\zeta(k_1, k_2, k_3)$
- Trispectrum $\langle \zeta_{\vec{k}_1} \zeta_{\vec{k}_2} \zeta_{\vec{k}_3} \zeta_{\vec{k}_4} \rangle$

$$= (2\pi)^3 \delta^3(\vec{k}_1 + \vec{k}_2 + \vec{k}_3 + \vec{k}_4) T_\zeta(k_1, k_2, k_3, k_4)$$

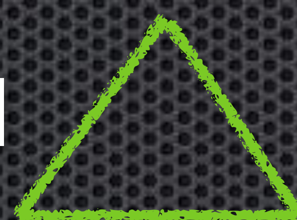
  - Translational invariance ➔ $\delta^3(\sum \vec{k}_i)$
  - Rotational invariance ➔ $P_\zeta(k_1), B_\zeta(k_1, k_2, k_3), B_\zeta(k_1, k_2, k_3, k_4), \mathrm{etc.}$
  - ‘Shape’ of non-Gaussianities



Non-Gaussianities (bispectrum)

- Different profiles corresponding to different shapes
  - Local: 

    $$B_\zeta^{\rm local}(k_1,k_2,k_3)=\frac{6}{5}f_{\rm NL}^{\rm local}\Big[P_\zeta(k_1)P_\zeta(k_2)+P_\zeta(k_2)P_\zeta(k_3)+P_\zeta(k_3)P_\zeta(k_1)\Big]$$

    generated at superhorizon in multifield inflation models
  - Equilateral 
  - Orthogonal
  - Other types (warm, flat, etc.)

$$f_{\rm NL}^{\rm local}=0.8\pm5.0,\quad f_{\rm NL}^{\rm equil}=-4\pm43,\quad f_{\rm NL}^{\rm ortho}=-26\pm21$$

[Planck (2015)]

Constructing SUSY Higgs inflation

(example in SUSY seesaw [Arai, SK, Okada, arXiv:1112.2391, 1212.6828])

Superpotential

Right-handed neutrinos

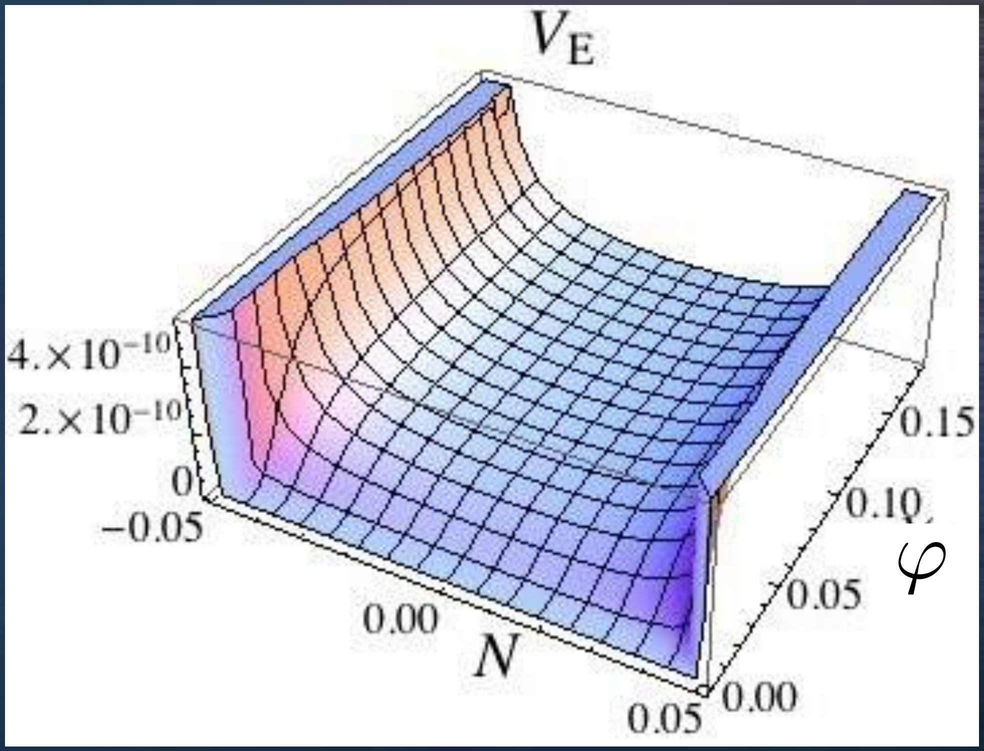
$$W = \mu H_u H_d + y_u u^c Q H_u + y_d d^c Q H_d + y_e e^c L H_d + y_D N_R^c L H_u + M N_R^c N_R^c$$

MSSM

D-flat direction

y_D can be naturally small

$$L = \frac{1}{\sqrt{2}} \begin{pmatrix} \varphi \\ 0 \end{pmatrix}, H_u = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \varphi \end{pmatrix}.$$



Kähler potential

$$K = -3 \ln \Phi,$$

nonminimal coupling $\xi R \varphi^2$, $\xi = \gamma/4 - 1/6$

$$\Phi = 1 - \frac{1}{3}(|N_R^c|^2 + |\varphi|^2) + \frac{1}{4}\gamma(\varphi^2 + c.c.) + \frac{1}{3}\upsilon |N_R^c|^4$$

controls tachyonic instability

Seesaw relation

$$m_\nu = \frac{y_D^2 \langle H_u \rangle^2}{M}$$

$$m_\nu^2 \approx \Delta_{32}^2 = 2.43 \times 10^{-3} \mathrm{eV}^2 \quad \langle H_u \rangle \approx 174 GeV$$

Large enough υ ⟹ single field inflation

Constructing Supersymmetric Higgs inflation

W Superpotential (MSSM + extra),

K Kähler potential (canonical + extra)

Supergravity Lagrangian (Jordan frame) $L_J = R\Phi + \cdots$

Einstein frame Lagrangian

$$\mathcal{L} = \sqrt{-g}\left[\frac{1}{2}\mathcal{R} - \frac{1}{2}G_{IJ}g^{\mu\nu}\partial_\mu\phi^I\partial_\nu\phi^J - V(\phi^I)\right],$$

Multi-field inflation with nontrivial field space $(\varphi \to h, N_R^c \to s)$

$$G_{ss} = \frac{\frac{1}{12}\upsilon s^4 + (1 - 2\upsilon s^2)(1 + \xi h^2)}{\Phi^2},$$

$$G_{sh} = G_{hs} = -\frac{\xi h s(1 - \upsilon s^2)}{\Phi^2},$$

$$G_{hh} = \frac{6\xi^2 h^2 + \Phi}{\Phi^2},$$

$$V(\phi^I) = V_J/\Phi^2,$$

$$V_J = \frac{1}{4}y_D^2 s^2 h^2 + \frac{(2\sqrt{2}Ms + y_D h^2)^2}{16(1 - 2\upsilon s^2)} - \frac{1}{8}\frac{s^2\left(\sqrt{2}Ms + 3\gamma y_D h^2 - \frac{\upsilon s^2(y_D h^2 + 2\sqrt{2}Ms)}{1 - 2\upsilon s^2}\right)^2}{12 + \frac{\upsilon s^4}{1 - 2\upsilon s^2} + 3\gamma h^2(\frac{3}{2}\gamma - 1)}.$$

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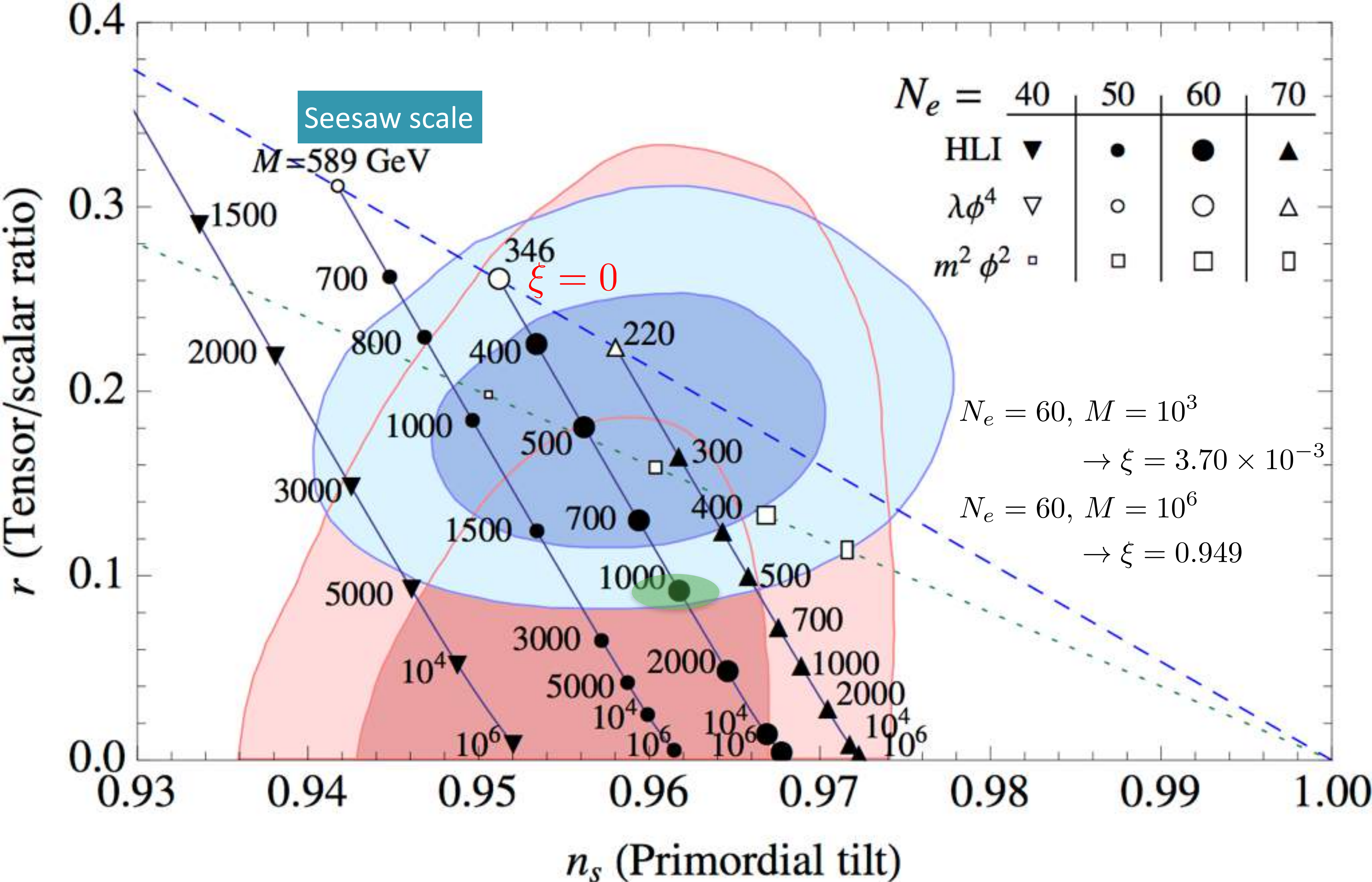
Prediction in the single-field limit & Planck/BICEP2 (2014)



Noncanonical (quartic) term in Kähler

$\Longrightarrow$ NR =0

$\Longrightarrow$ Single-field inflation

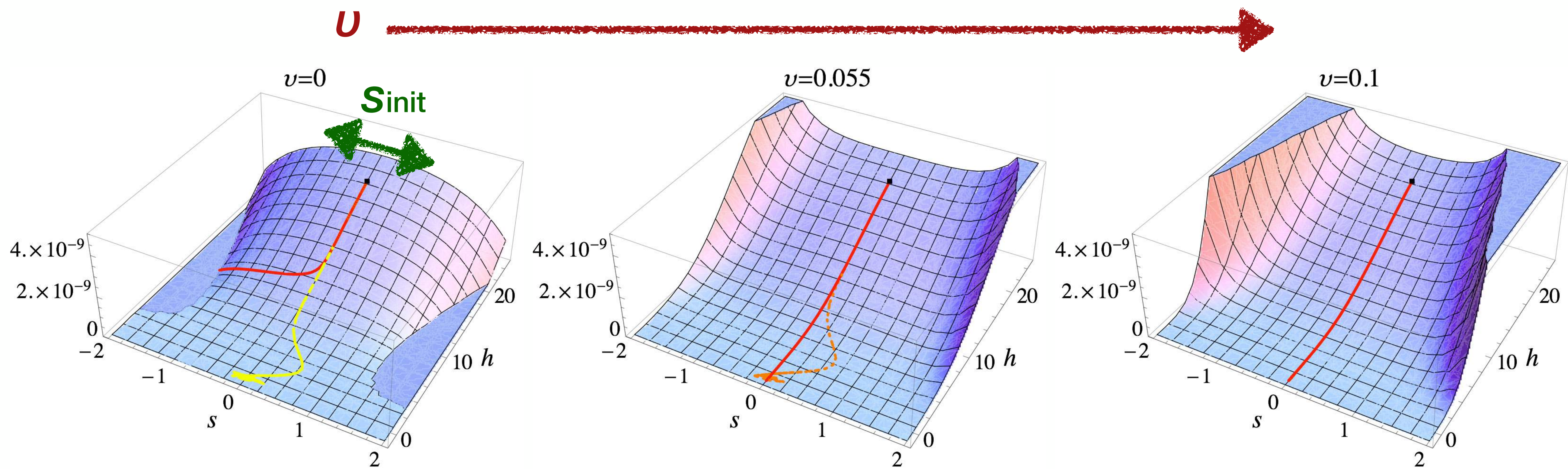
Purpose:

investigate how the multi-field effects (e.g. non-Gaussianity) restricts Kähler potential of the underlying supergravity theory

$$\Phi = 1 - \frac{1}{3}(|N_R^c|^2 + |\varphi|^2) + \frac{1}{4}\gamma(\varphi^2 + c.c.) + \frac{1}{3}\upsilon|N_R^c|^4$$

Inflaton trajectories

(2-field SUSY Higgs inflation in SUSY seesaw)



red: s_{init} =0, yellow: s_{init} = 1.617×10^{-11}, orange: s_{init} = 10^{-5}

$\dot{s}_{init}$ =0 in all cases

quantum fluctuations

$$\langle (\Delta s)^2 \rangle \approx \frac{H^2}{(2\pi)^2}$$

- Seesaw mass M =1TeV, e-folding number N =60
- h_{init} set by N =60 in the single field limit
- Trajectory dep on the parameter υ and the init cond (s_{init}, $\dot{s}_{init}$)
- Once trajectory is fixed, observables can be computed

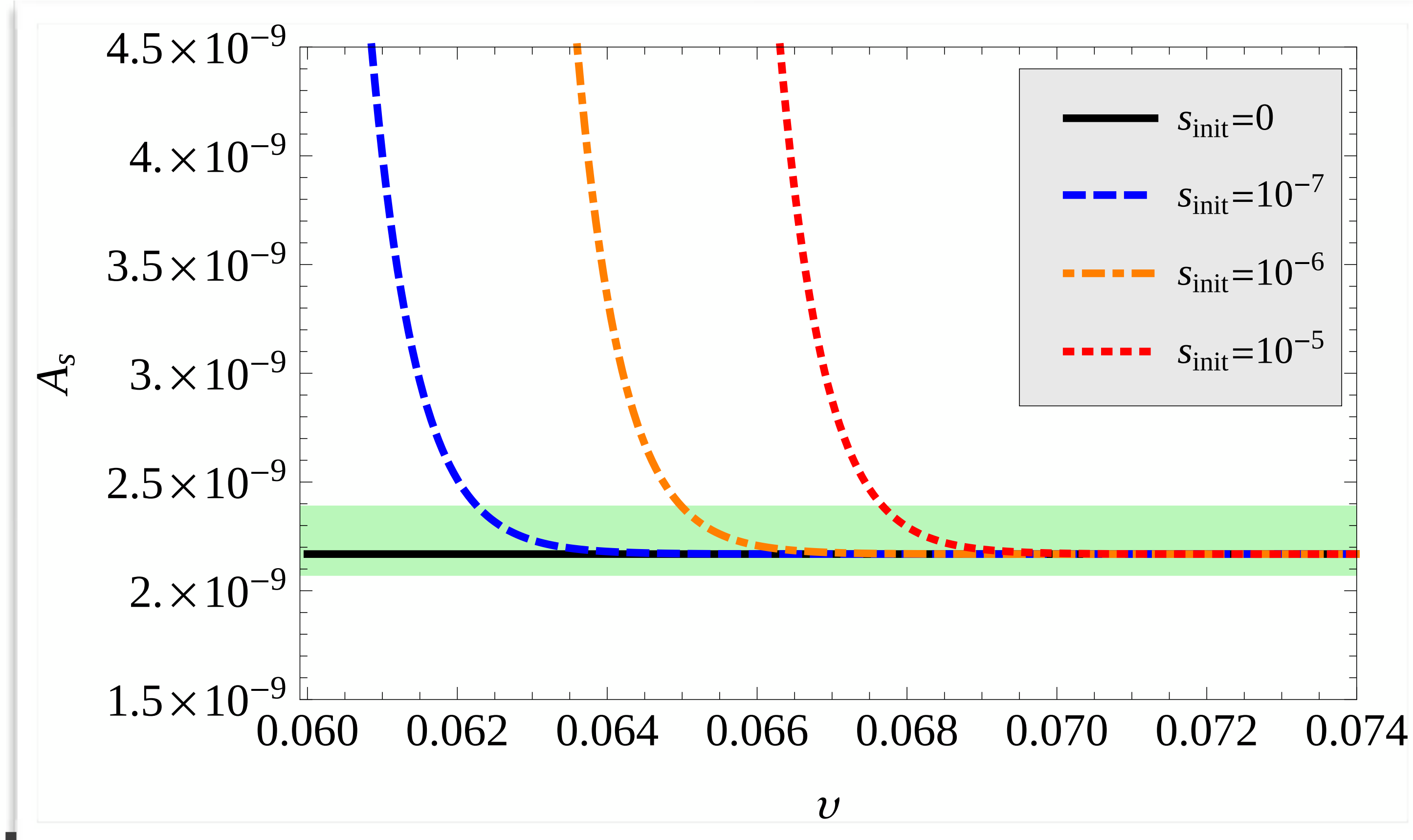
(we used the backward δN [Yokoyama Suyama Tanaka])

Scalar power spectrum A_s

$$\mathcal{P}_S = \frac{k^3}{2\pi^2} P_\zeta(k),$$

$$\langle \zeta_{\boldsymbol{k}_1} \zeta_{\boldsymbol{k}_2} \rangle = (2\pi)^3 \delta^3 (\boldsymbol{k}_1 + \boldsymbol{k}_2) P_\zeta(k).$$

$$\mathcal{P}_S = A_s \left(\frac{k}{k_0}\right)^{n_s - 1 + \frac{1}{2}\frac{dn_s}{d\ln k}\ln\frac{k}{k_0} + \cdots}$$



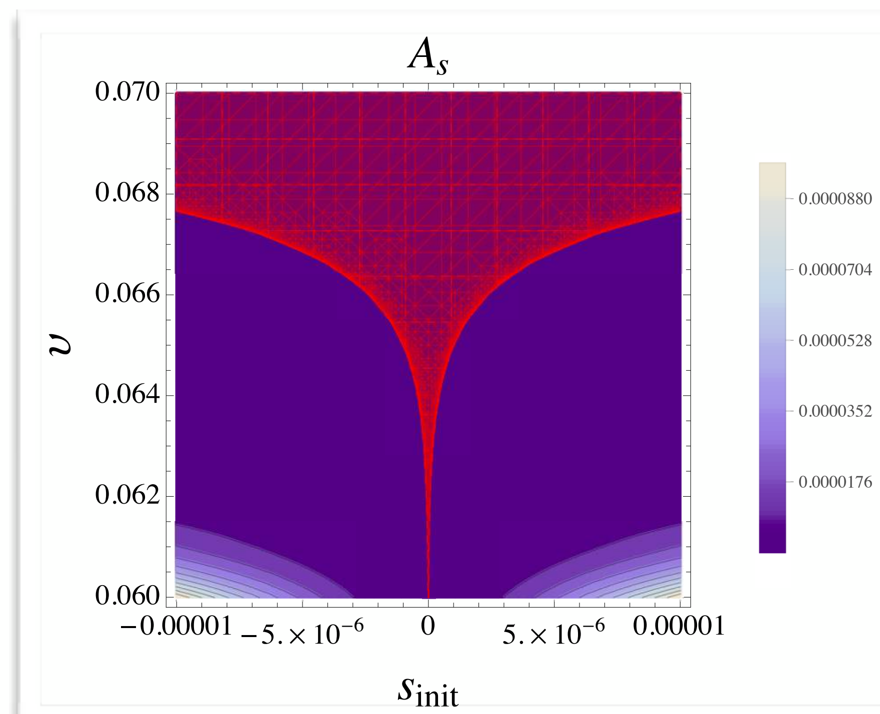
- Observation (Planck 2013):

$$A_s \times 10^9 = 2.23 \pm 0.16 \qquad \text{(Planck)}$$

$$k_0 = 0.05\,\mathrm{Mpc}^{-1}$$

Quantum fluctuations give $\langle \Delta s \rangle \approx \frac{H}{2\pi} \sim 10^{-5} M_{\mathrm{Pl}}$

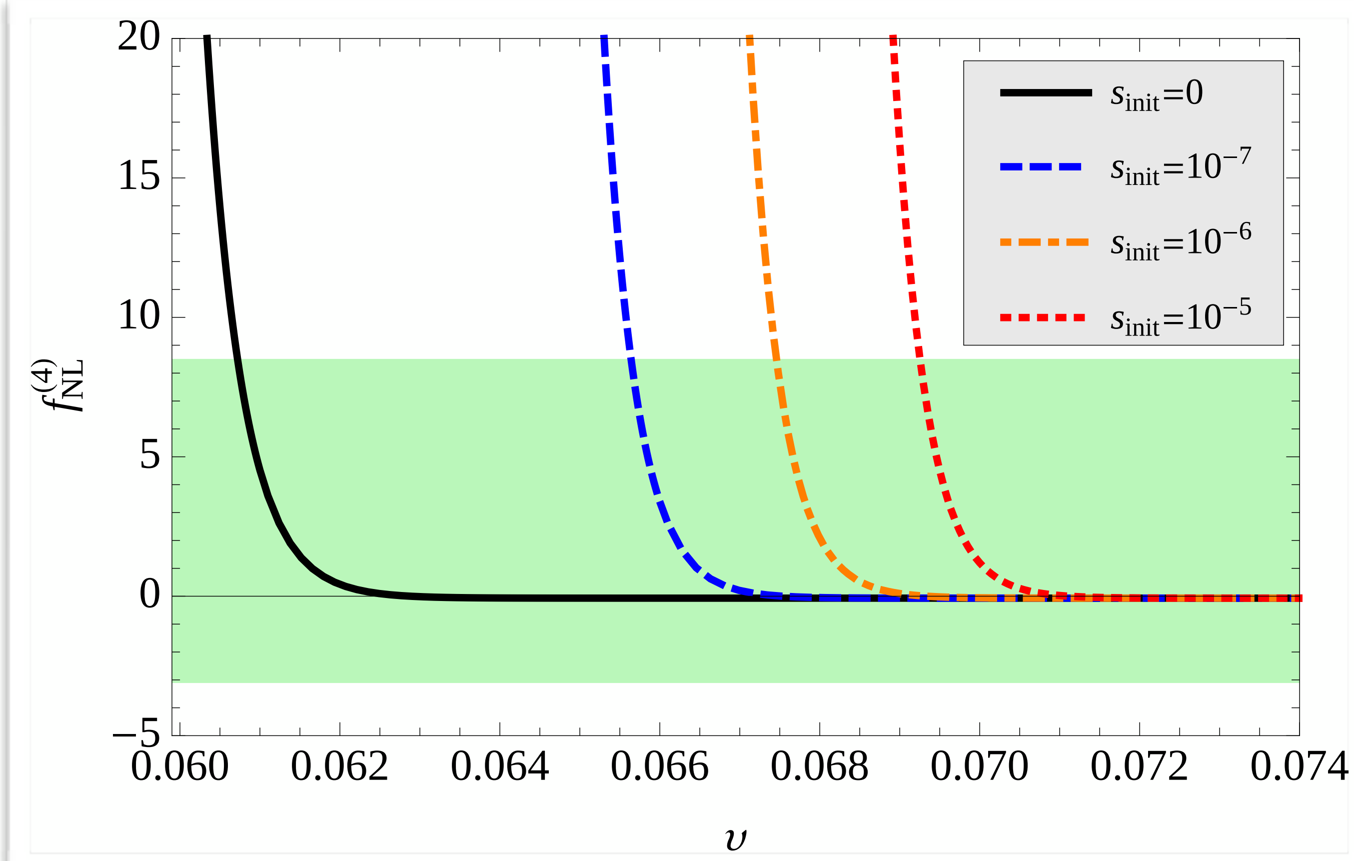
for the seesaw mass M =1TeV, e-folding number N =60



Non-Gaussianity (nonlinearity) f_{NL}

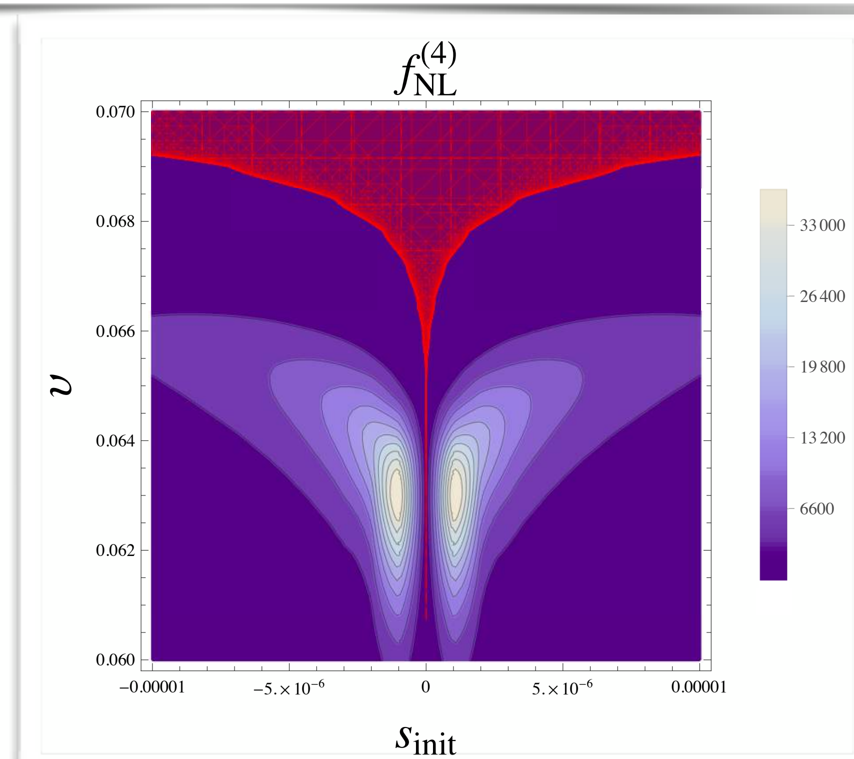
$$\langle \zeta_{\boldsymbol{k}_1} \zeta_{\boldsymbol{k}_2} \zeta_{\boldsymbol{k}_3} \rangle = (2\pi)^3 \delta^3 \left(\boldsymbol{k}_1 + \boldsymbol{k}_2 + \boldsymbol{k}_3 \right) B_\zeta(k_1, k_2, k_3)$$

$$B_\zeta(k_1, k_2, k_3) = \frac{6}{5} f_{NL}^{\text{local}} \left\{ P_\zeta(k_1) P_\zeta(k_2) + 2 \text{ perms} \right\}$$



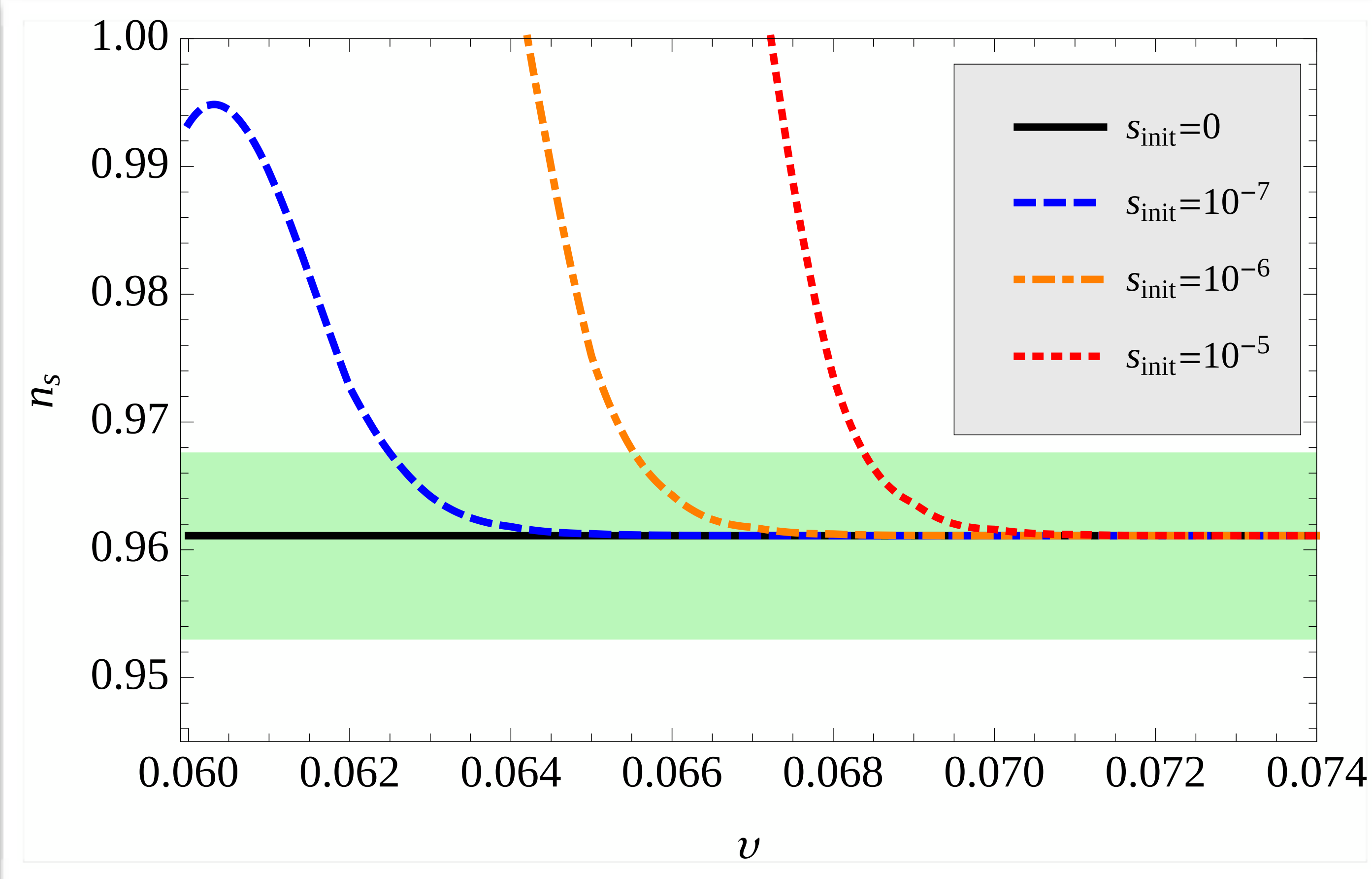
- Observation (Planck 2013):

$$f_{\text{NL}}^{\text{local}} = 2.7 \pm 5.8 \qquad\qquad (68\% \text{ C.L.})$$



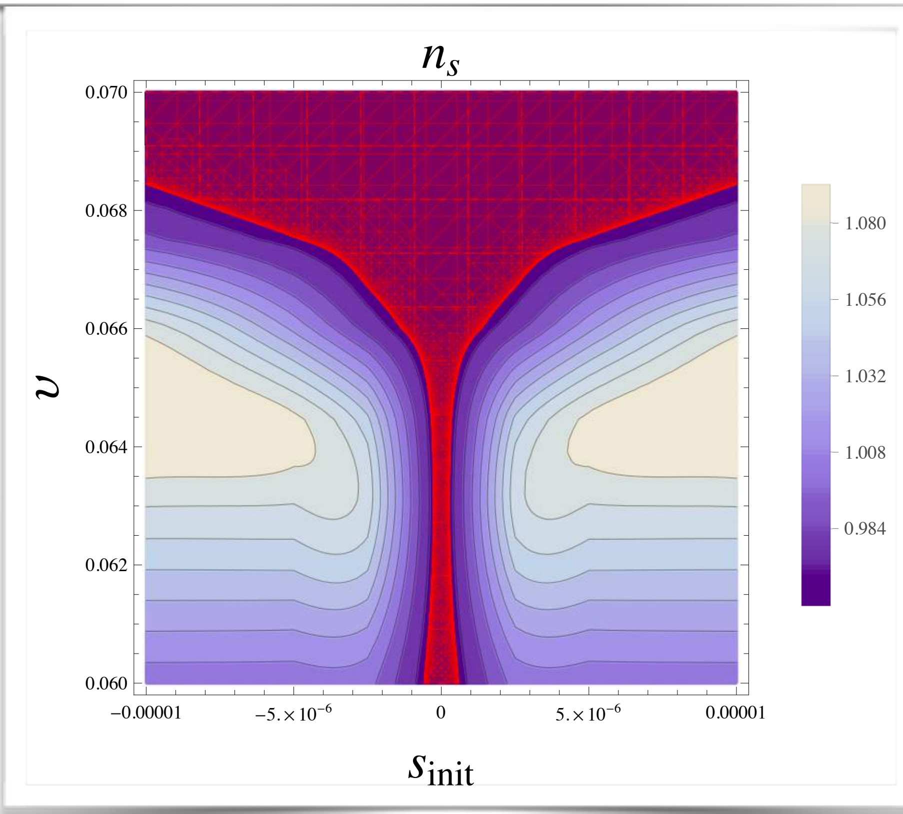
Scalar spectral index n_s

$$\mathcal{P}_S = A_s \left(\frac{k}{k_0}\right)^{n_s - 1 + \frac{1}{2}\frac{d n_s}{d \ln k}\ln\frac{k}{k_0} + \cdots}$$



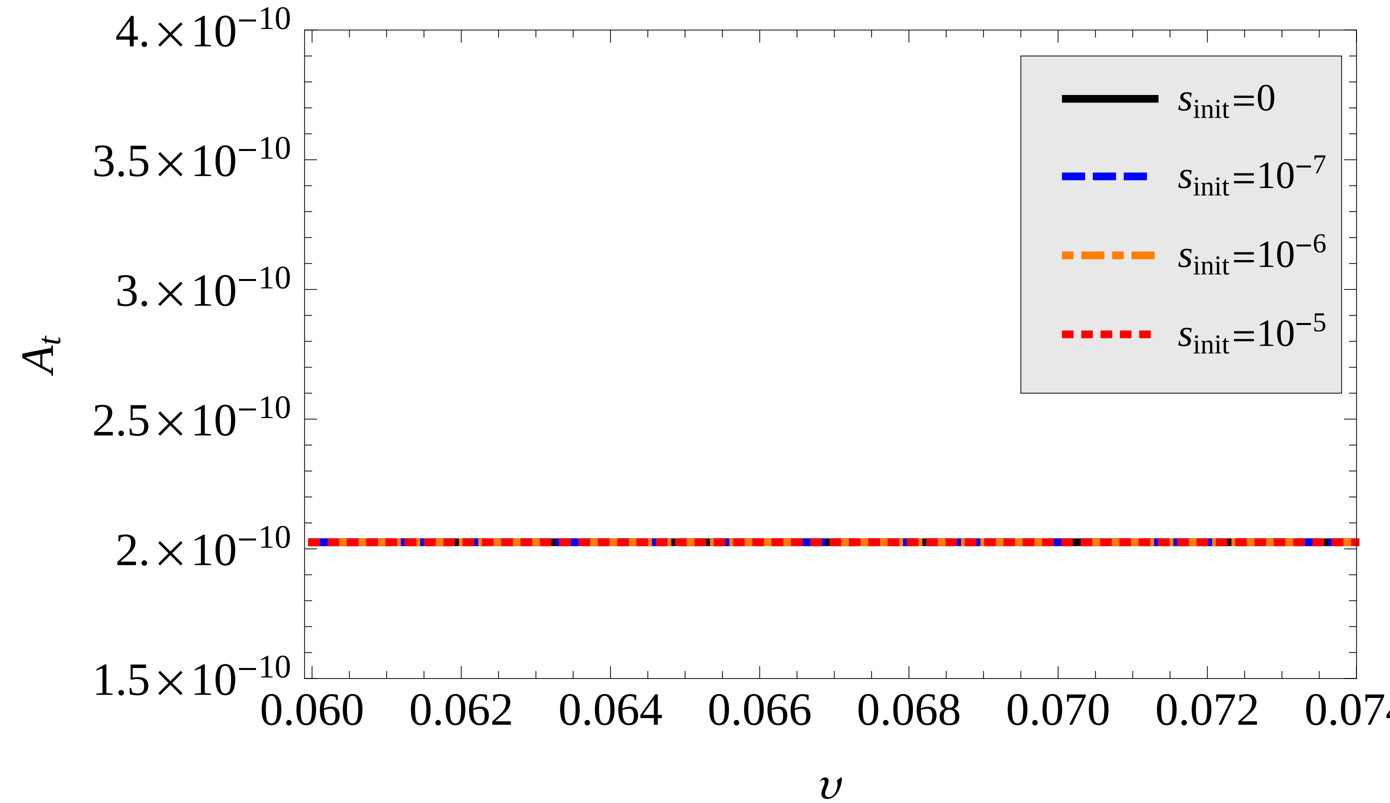
- **Observation (Planck 2013):**

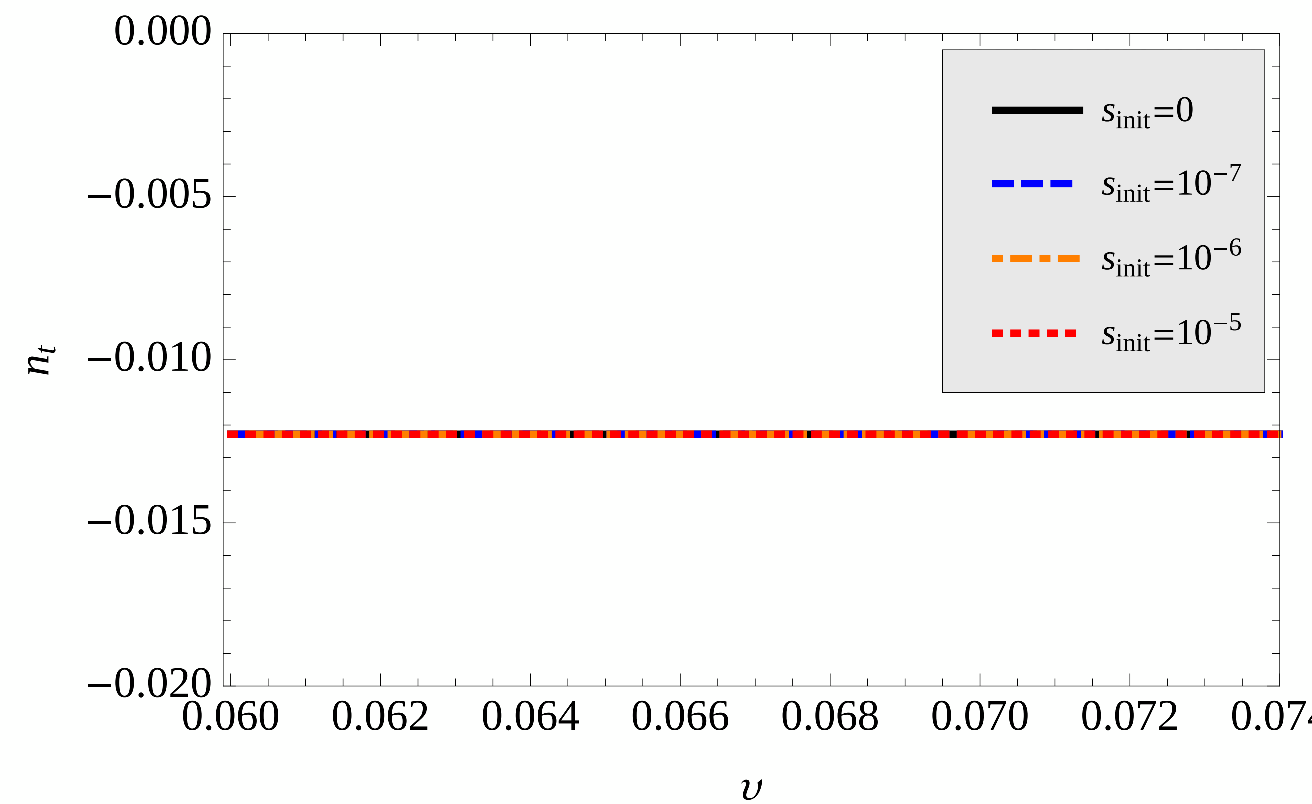
$$n_s = 0.9603 \pm 0.0073 \qquad (68\%\ \text{C.L.})$$



Tensor amplitude A_t and tilt n_t

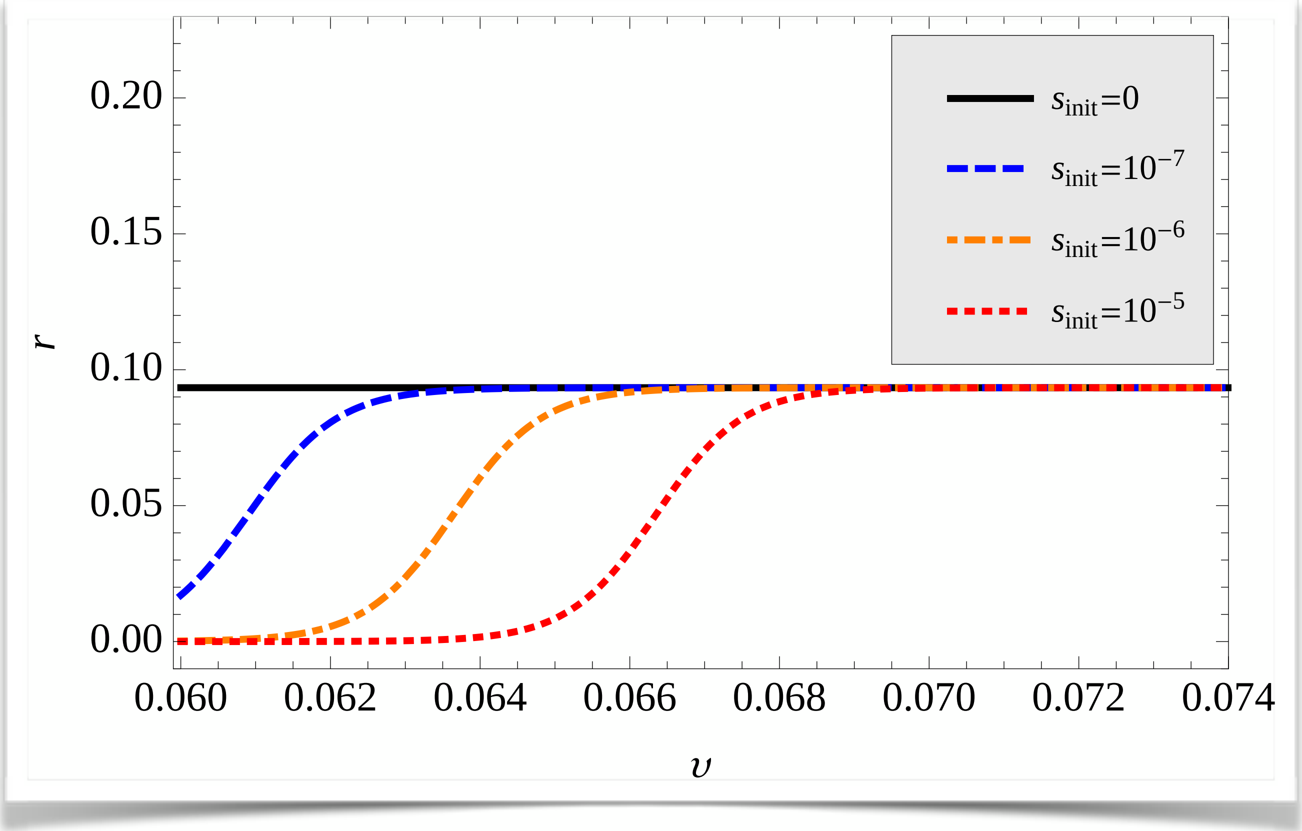
- No effects of multi-field on the tensor mode
- This is expected: tensor mode generated quantum mechanically at subhorizon, decouple from scalar mode
- Gravitational waves are same as in the single-field case

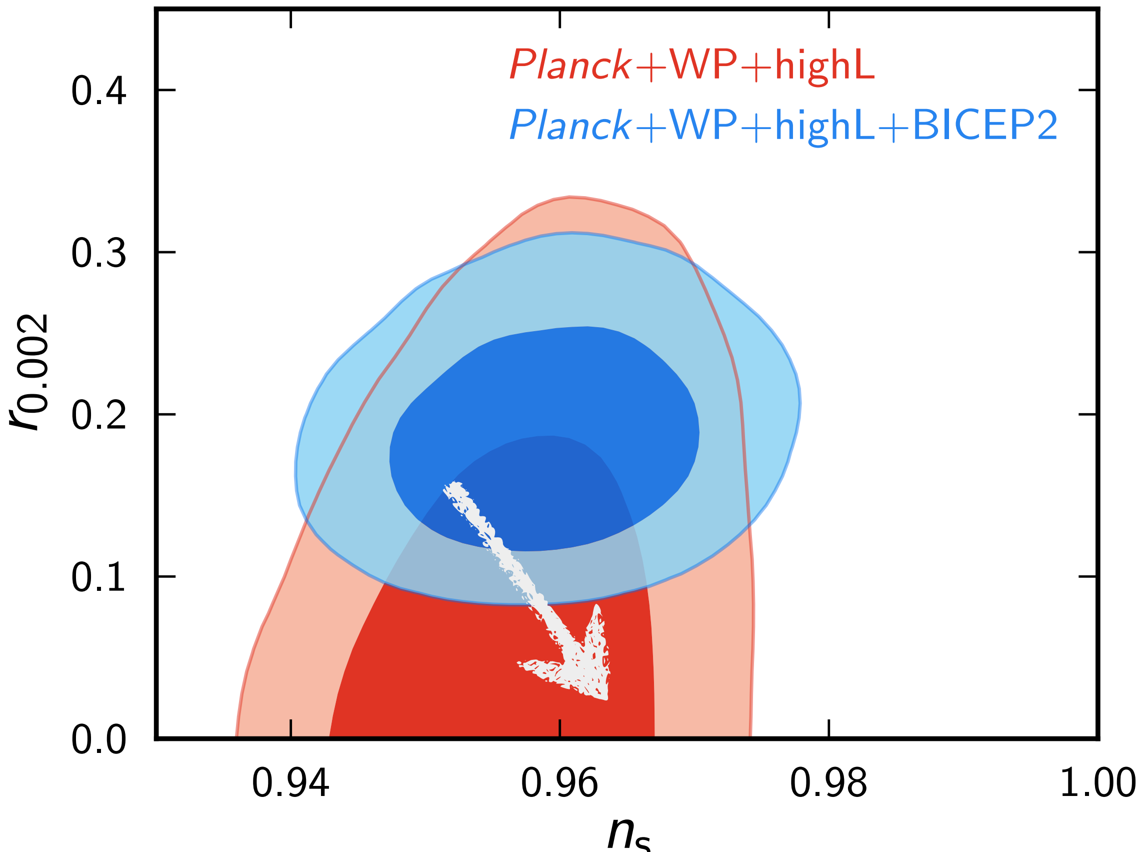


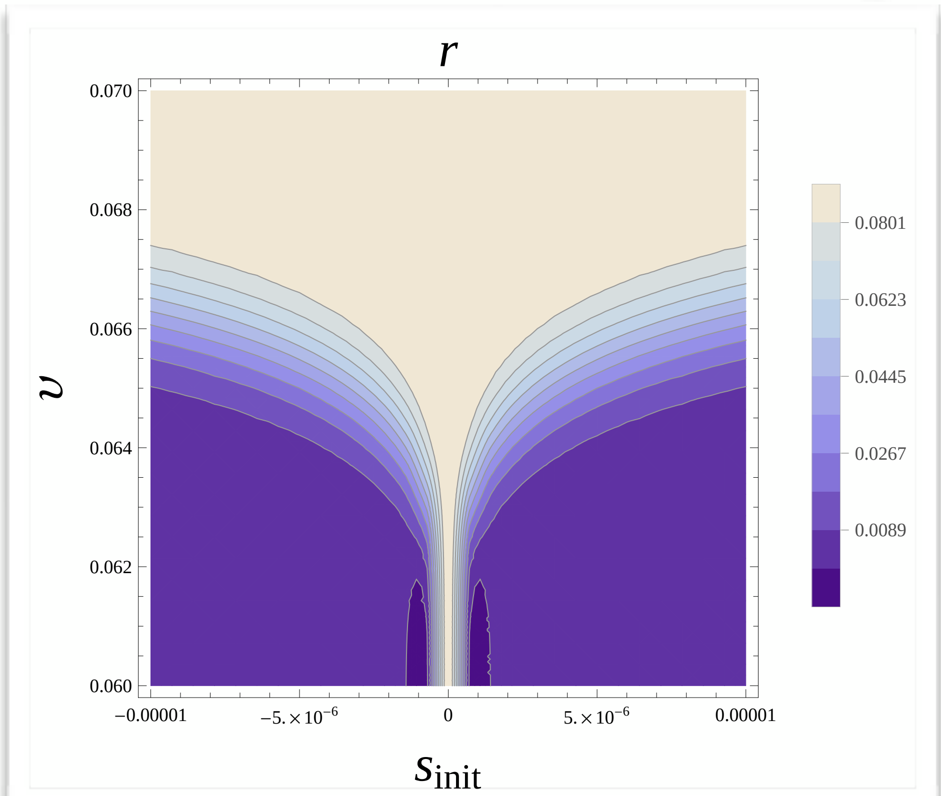


Tensor/scalar ratio $r = A_t / A_s$

- Multi-field: A_s enhanced, whereas A_t stays constant
- The ratio $r = A_t / A_s$ suppressed by the multi-field effects







A_s, f_{NL} and n_s

- **Planck (2013):**

$$
\begin{aligned}
A_s &= (2.23 \pm 0.16) \times 10^{-9} \quad &(68\%\ \text{C.L.}),\\
n_s &= 0.9603 \pm 0.0073 \quad &(68\%\ \text{C.L.}),\\
r &< 0.12 \quad &(95\%\ \text{C.L.}),\\
f_{\rm NL}^{\rm local} &= 2.7 \pm 5.8 \quad &(68\%\ \text{C.L.}).
\end{aligned}
$$

- **Recall: quantum fluctuation gives $\Delta s \sim 10^{-5}$**

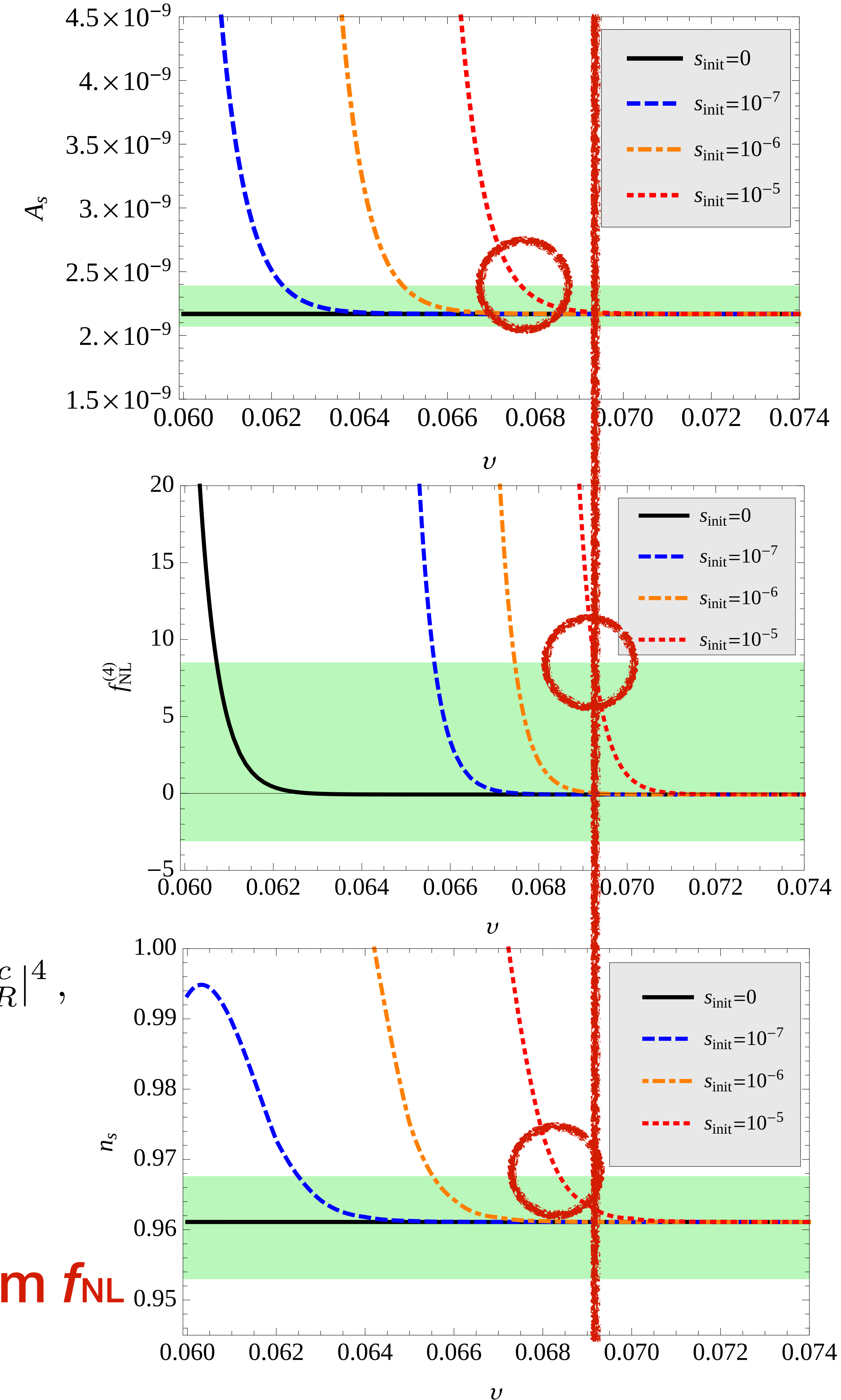
- **Kähler potential was**

$$\Phi = 1 - \frac{1}{3}\left(|N_R^c|^2 + |\varphi|^2\right) + \frac{1}{4}\gamma\left(\varphi^2 + \text{c.c.}\right) + \frac{1}{3}\upsilon|N_R^c|^4\,,$$

canonical terms

fixed by A_s

$\upsilon > 0.069$ from $f_{\rm NL}$



Inflation in SUSY-seesaw

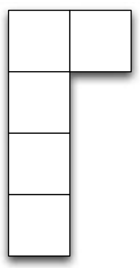
- Multi-field dynamics potentially important
- Planck constraints on non-Gaussianities restricts Kähler potential of supergravity
- NMSSM inflation model is similar

Higgs inflation in GUT

- Inflation ~ GUT scale ≫ SM (EW) scale
- Hierarchy problem, gauge coupling unification ⇒ super GUT
- Simplest: SU(5)
- This is a revival of inflation models in the 80s, now with nonminimal coupling
- Enough e-folding number? Spectral index? Scalar-tensor ratio?
- SM after the inflation? Phenomenological consistency (DM, baryogenesis, gravitino problem...)?

SU(5) grand unification

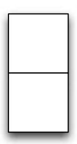
- Gauge field



$$\mathbf{24} = (\mathbf{8},\mathbf{1},0) + (\mathbf{1},\mathbf{3},0) + (\mathbf{1},\mathbf{1},0) + (\mathbf{3},\mathbf{2},\frac{5}{3}) + (\bar{\mathbf{3}},\mathbf{2},-\frac{5}{3})$$

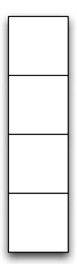
$$g \qquad A^a_\mu \to W^a_\mu \qquad B_\mu \qquad X_{\alpha\mu},\, Y_{\alpha\mu} \qquad \overline{X}_{\alpha\mu},\, \overline{Y}_{\alpha\mu}$$

- Fermion fields



$$\mathbf{10} = (\mathbf{1},\mathbf{1}) + (\bar{\mathbf{3}},\mathbf{1}) + (\mathbf{3},\mathbf{2})$$

$$\bar{e} \qquad \bar{u} \qquad Q = (u_L, d_L)$$

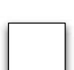


$$\bar{\mathbf{5}} = (\bar{\mathbf{3}},\mathbf{1}) + (\mathbf{1},\mathbf{2})$$

$$\bar{d} \qquad L = (e, \nu_e)$$

- Scalar fields

$\mathbf{24}$ GUT Higgs $SU(5) \to SU(3) \times SU(2) \times U(1)$



$$\mathbf{5} = (\mathbf{3},\mathbf{1},-\frac{2}{3}) + (\mathbf{1},\mathbf{2},1)$$

Colour Higgs + SM Higgs

Minimal SUSY SU(5) model

- Vector multiplet

$\mathbf{24}$ of SU(5)

- Chiral multiplets

$\bar{\mathbf{5}} \quad (\bar{d}, L) \times N_F$

$\mathbf{10} \quad (\bar{e}, \bar{u}, Q) \times N_F$

$\mathbf{24}$	Σ	GUT Higgs
$\mathbf{5}$	H	including H_u
$\bar{\mathbf{5}}$	$\overline{H}$	including H_d

} Inflatons

$$H = \begin{pmatrix} H_c \\ H_u \end{pmatrix}$$

$$\overline{H} = \begin{pmatrix} \overline{H}_c \\ H_d \end{pmatrix}$$

Higgs inflation of minimal SUSY SU(5) GUT

- The superpotential

$$W = \overline{H}\left(\mu + \rho\Sigma\right)H + \frac{m}{2}\mathrm{Tr}(\Sigma^2) + \frac{\lambda}{3}\mathrm{Tr}(\Sigma^3)$$

- The Kähler potential

$$\Phi = 1 - \frac{1}{3}\left(\mathrm{Tr}\Sigma^\dagger\Sigma + |H|^2 + |\overline{H}|^2\right) - \frac{\gamma}{2}\left(\overline{H}H + H^\dagger\overline{H}^\dagger\right)$$
$$+ \frac{\tilde{\omega}}{3}\left(\mathrm{Tr}\Sigma^\dagger\Sigma^2 + \mathrm{Tr}\Sigma^{\dagger 2}\Sigma\right) + \frac{\zeta}{3}\left(\mathrm{Tr}\Sigma^\dagger\Sigma\right)^2$$

Phenomenological constraints

- Gauge symmetry broken to SU(3) x SU(2) x U(1)

$$\Sigma = \sqrt{\frac{2}{15}} S \ \mathrm{diag}\left(1, 1, 1, -\frac{3}{2}, -\frac{3}{2}\right)$$

- The superpotential is

$$M_{H_u}, M_{H_d} \ll M_{\mathrm{GUT}} \Rightarrow \mu = \sqrt{\frac{3}{10}} \rho \langle S \rangle$$

$$\text{Colour unbroken} \ \Rightarrow \langle H_c \rangle = \langle \overline{H}_c \rangle = 0$$

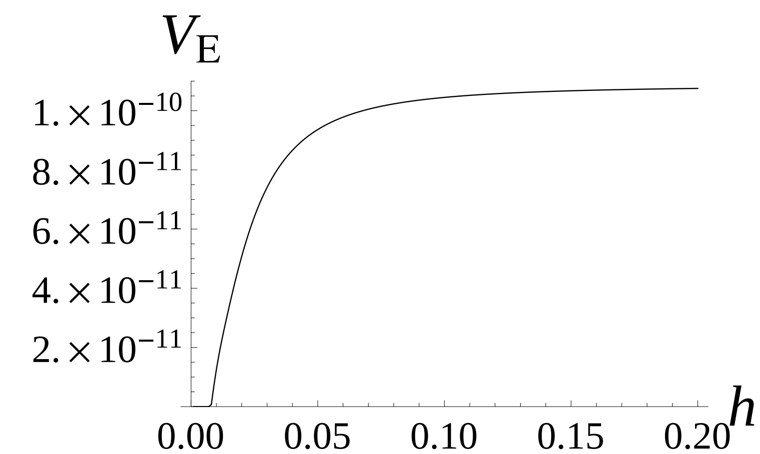
$$W = \left(\mu + \sqrt{\frac{2}{15}} \rho S\right) \overline{H}_c H_c + \left(\mu - \sqrt{\frac{3}{10}} \rho S\right) H_u H_d + \frac{m}{2} S^2 - \frac{\lambda}{3\sqrt{30}} S^3 .$$

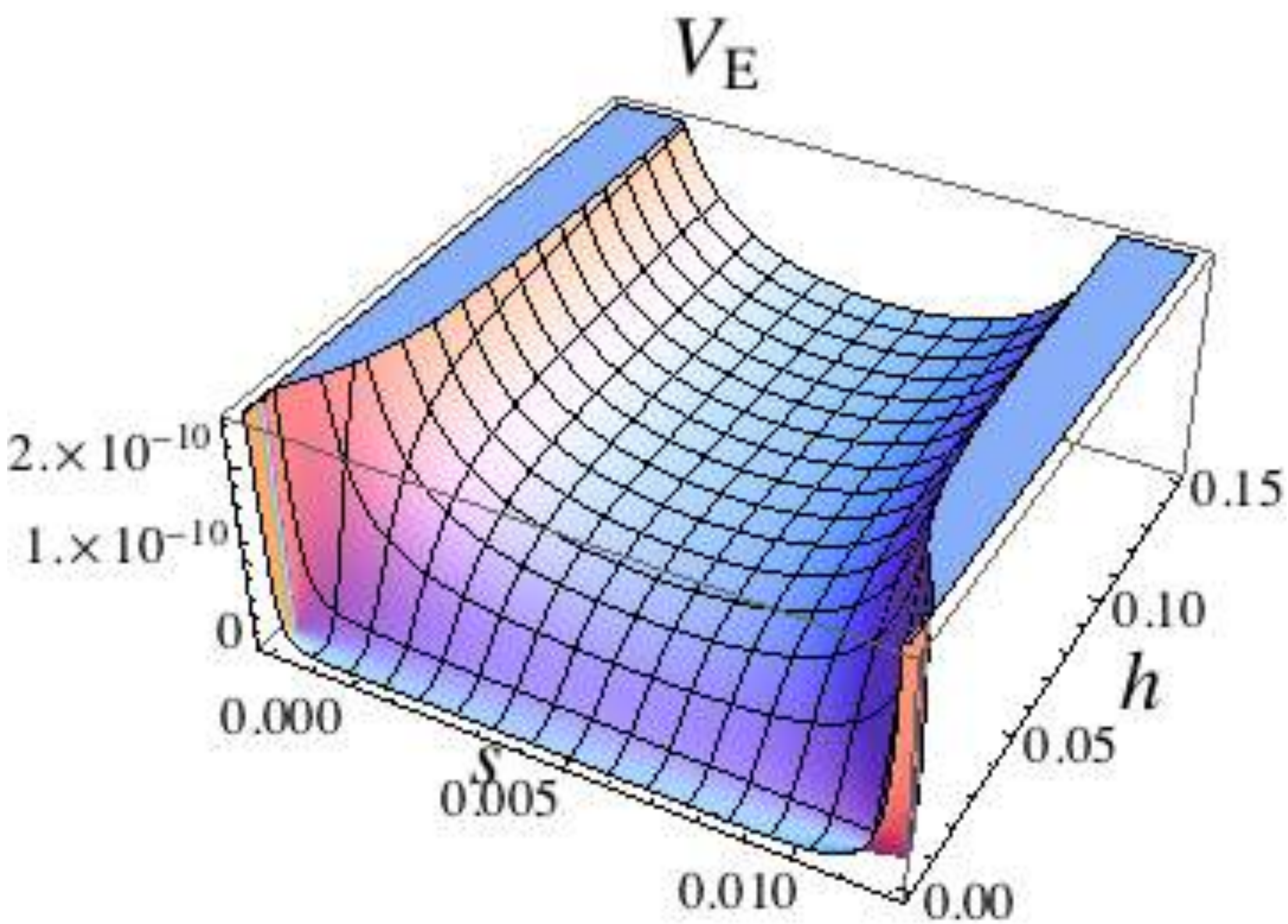
$$SU(5) \text{ broken} \ \Rightarrow \langle S \rangle \equiv v = 2 \times 10^{16} \ \mathrm{GeV}$$

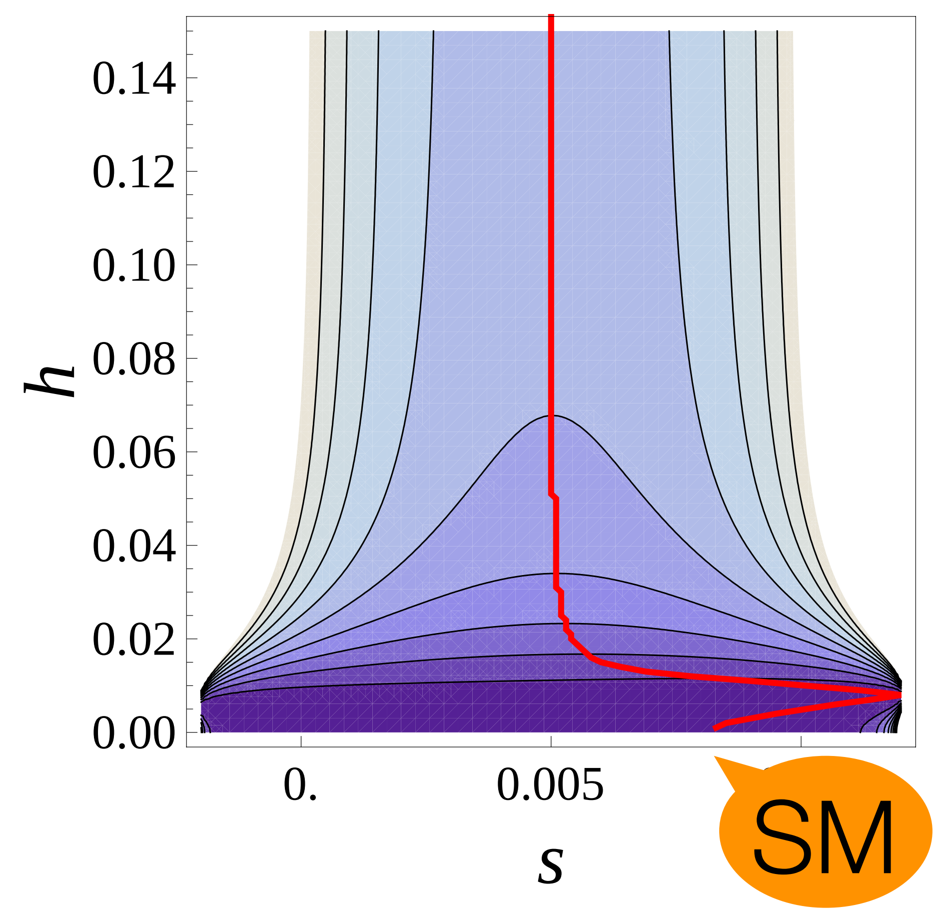
$$\frac{\delta W}{\delta S} = 0 \Rightarrow m = \frac{\lambda}{\sqrt{30}} v$$

The SU(5) super GUT model [M.Arai, S.K. N.Okada 2011]

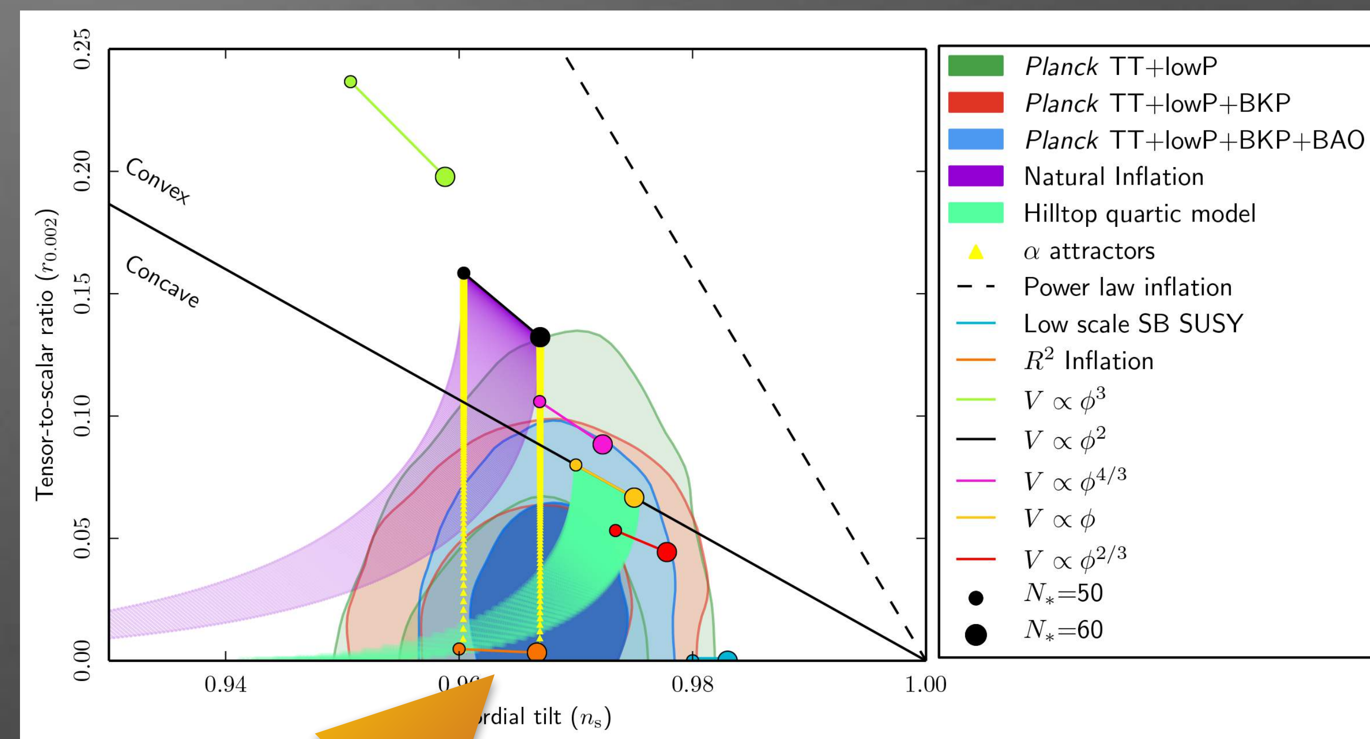
- Cubic + quartic terms in Kähler necessary
- Stable trajectory, SM vacuum
- No cosmological constant problem







Prediction of the SU(5) GUT Higgs inflation



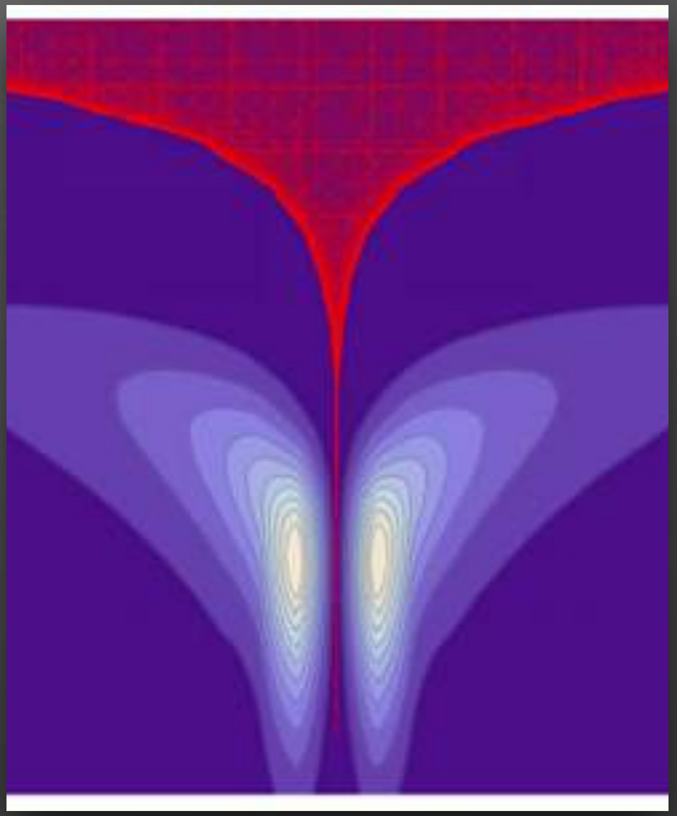
SU(5) GUT Higgs inflation

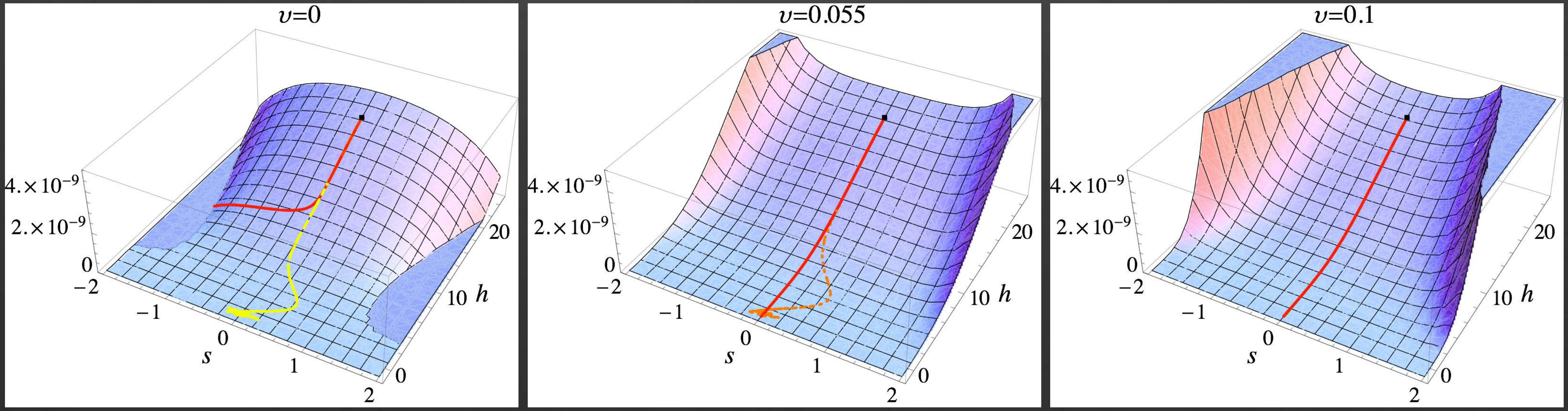
…is identical to the single-field case.

No large non-Gaussianities

Why the SU(5) case different?

- Multifield effects (non-Gaussianity, isocurvature modes) arise from nontrivial nonlinear dynamics outside the horizon
- This is possible only when the inflaton trajectory stays on a ridge for long enough e-folds and then swerve off
- The potential of the SU(5) model needs to be asymmetric and such a trajectory is unlikely, even with fine-tuned initial conditions





Summary

- It’s good time to think about the origin of the inflaton within “beyond the Standard Model” physics.
- Higgs inflation interesting. SUSY Higgs inflation perhaps more interesting.
- Avoid the η problem: non-canonical Kähler potential
- Multi-field signatures (e.g. non-Gaussianities) may be a clue to understand supergravity embedding of BSM.
- Analysed a concrete model based on SUSY seesaw & SU(5) GUT

Summary

- It seems that that symmetries of the inflaton potential are crucial for the multifield effects

- In generic multifield inflation (e.g. in string landscape), no particular symmetries are expected, thus a single-field analysis is likely to be sufficient.

Thank you for your attention.