Higgs-portal assisted Higgs inflation

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in collaboration with

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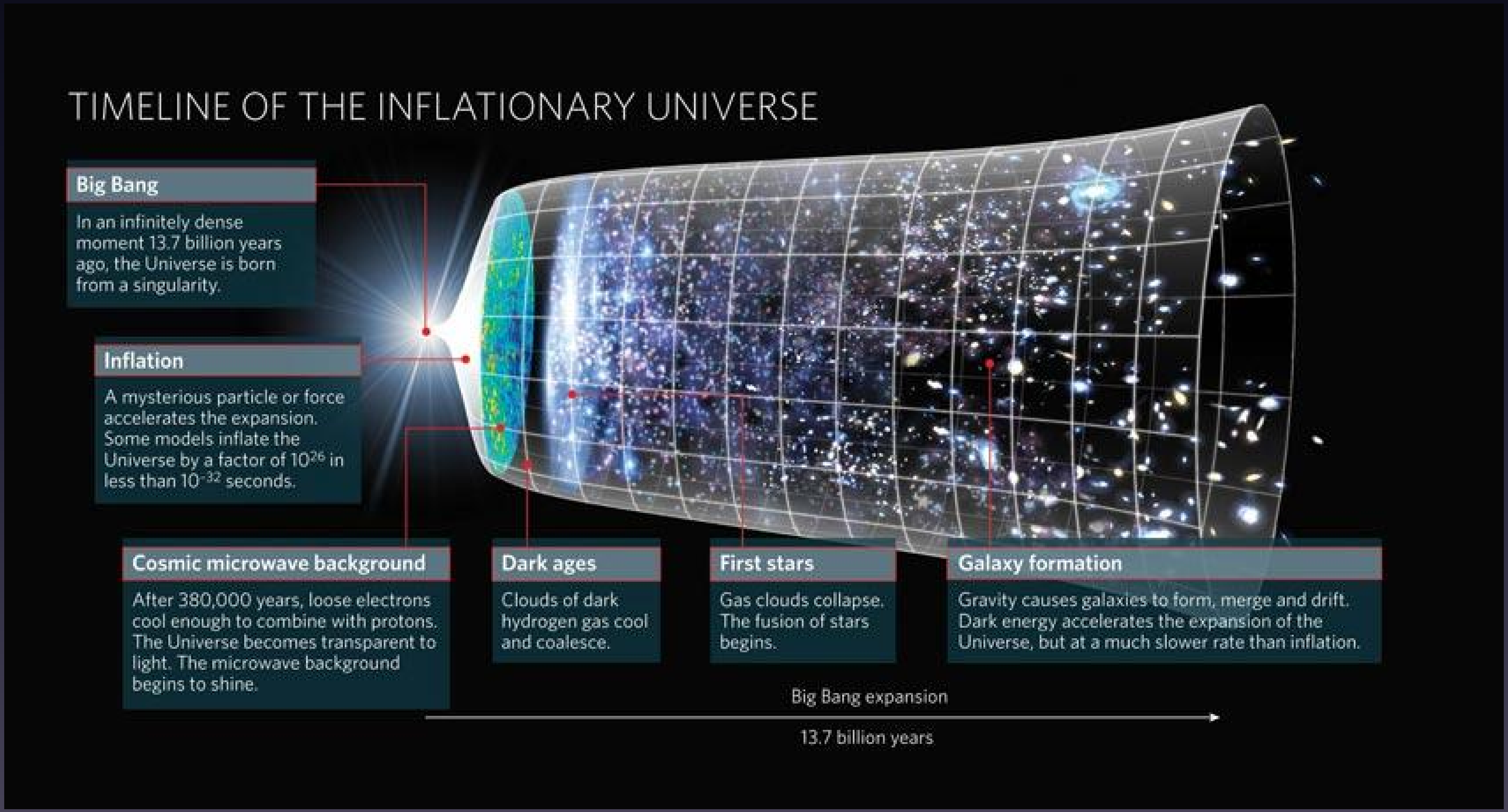
Our whole Universe was in a hot and dense state, then nearly 14 billion years ago (accelerating) expansion started, ..., That all started with the Big Bang!

– The Big Bang Theory



Can Higgs be the inflaton?

Higgs inflation

[Cervantes-Cota Dehnen 1995]
[Bezrukov Shaposhnikov 2008]

Minimal	Nonminimal

Higgs inflation

[Cervantes-Cota Dehnen 1995]
[Bezrukov Shaposhnikov 2008]

	Minimal	Nonminimal
Action	$\int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R-\frac{1}{2}g^{\mu\nu}\partial_\mu h\partial_\nu h-\frac{1}{4}\lambda_h h^4\right]$	$\int d^4x\sqrt{-g}\left[\frac{M_P^2}{2}R+\frac{1}{2}\xi_h h^2 R-\frac{1}{2}g^{\mu\nu}\partial_\mu h\partial_\nu h-\frac{1}{4}\lambda_h h^4\right]$

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Planck normalisation	$\lambda_h \sim 10^{-12}$	$\lambda_h / \xi_h^2 \sim 4 \times 10^{-10}$

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Higgs inflation

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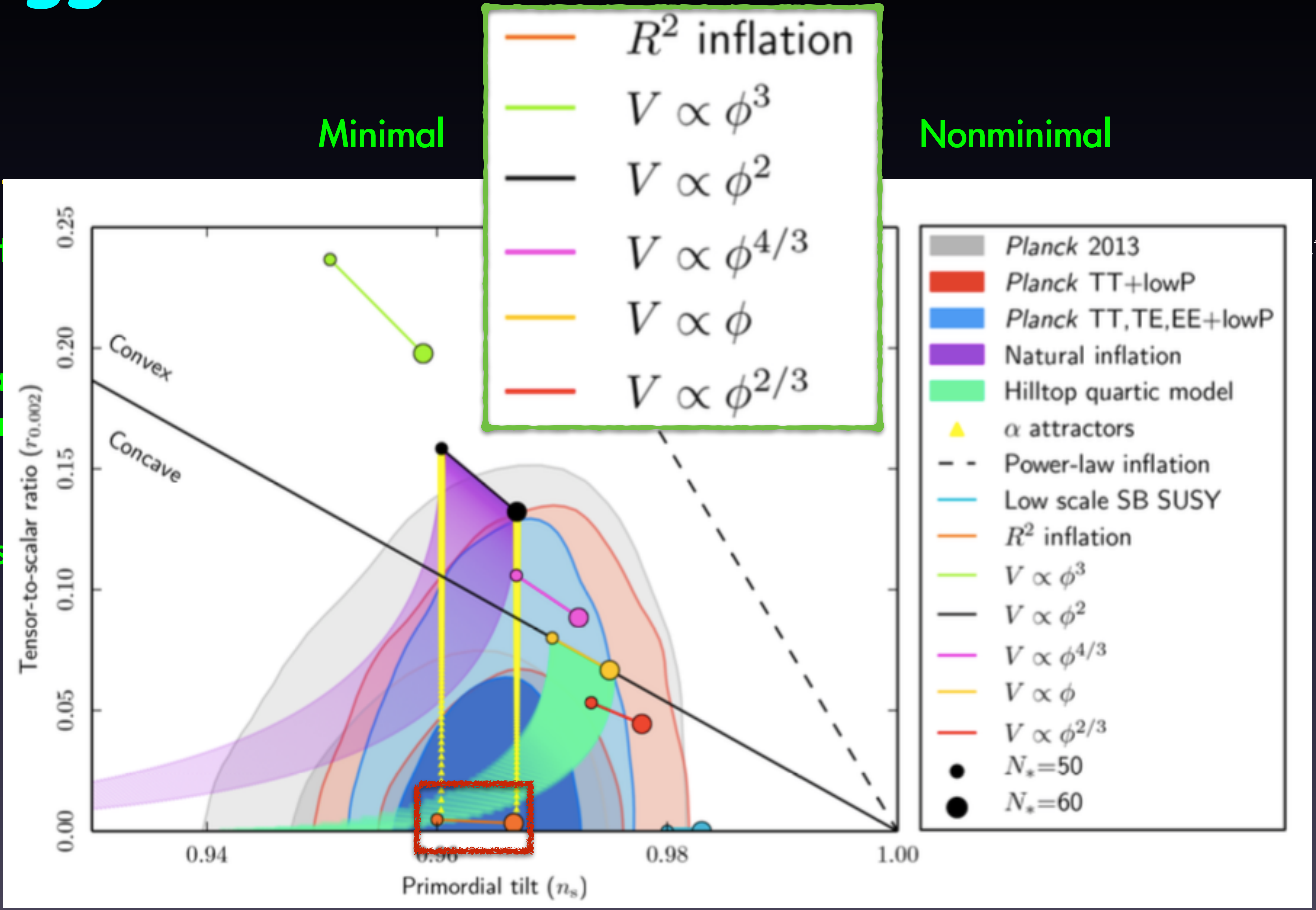

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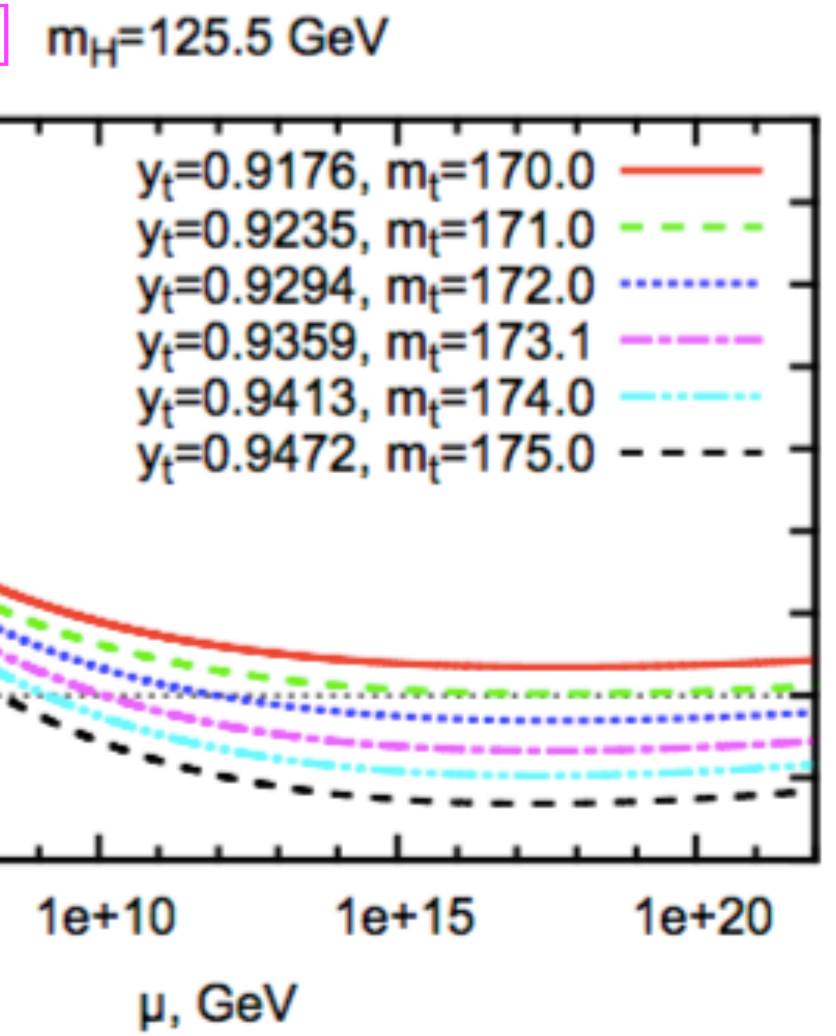
	Ruled out !	Favoured !

Wait!

Quantum Corrections?

In the pure SM case, assuming that the SM is valid all the way up to the (nearly) Planck scale, λ_h 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]

Sketch:

- The Einstein-frame potential is

$$U(h) = \frac{\lambda_h(t) h^4}{4(1+\xi_h h^2/M_{\rm P}^2)^2} \,.$$

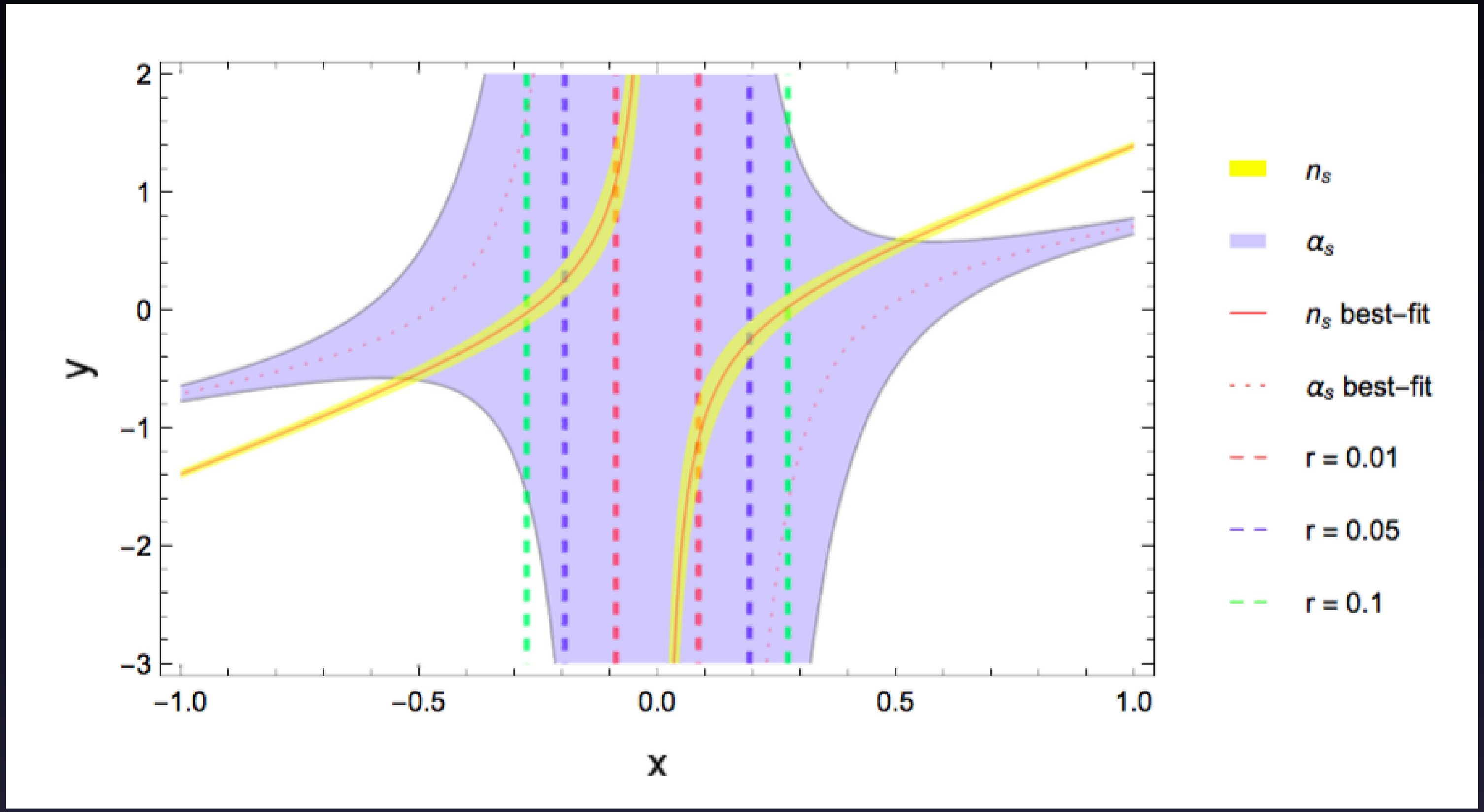
- Tensor-to-scalar ratio, for example, is given by

$$r \approx \frac{64}{3\xi_h^2}\left(\frac{M_{\rm P}^2}{h}\right)^4 \left[1 + x\frac{\xi_h h^2}{4M_{\rm P}^2}\right]^2 \,,$$

where

$$x \equiv \frac{1}{\lambda_h}\frac{d\lambda_h}{dt} \,.$$

Cosmological observables :



$$x \equiv \frac{1}{\lambda_h}\frac{d\lambda_h}{dt}\,, \qquad y \equiv \frac{1}{d\lambda_h/dt}\frac{d^2\lambda_h}{dt^2}$$

Higgs inflation

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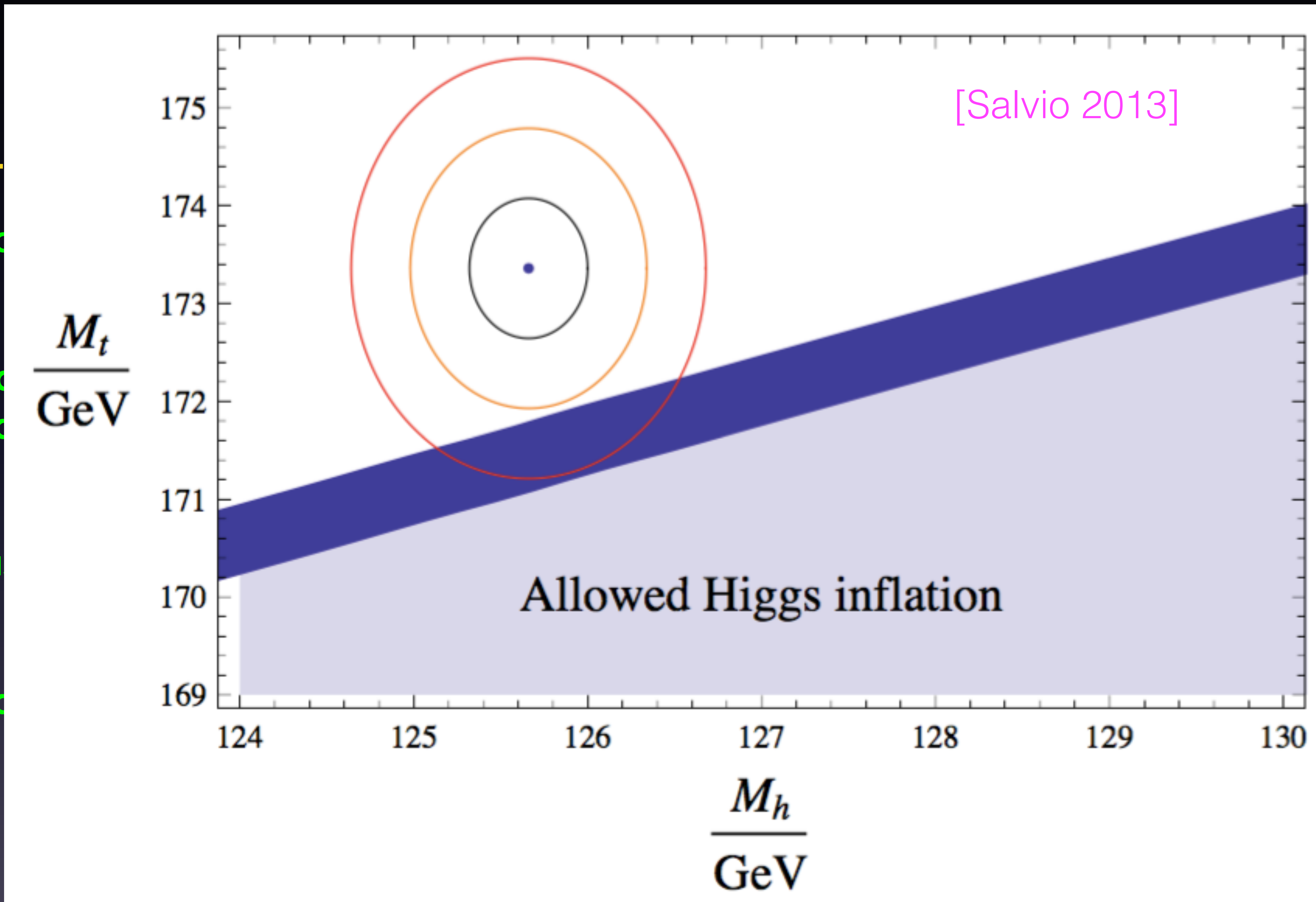
	Still ruled out !	Okay, but...

Higgs inflation



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$\frac{1}{4}\lambda_h h^4 \Big]$

$\mathcal{O}(0.1)$

Realisation
with Higgs portal

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

We shall see that Higgs-portal interaction, which is generic in hidden-sector DM models, revives the Higgs inflation by weakening the dependence on M_t.

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

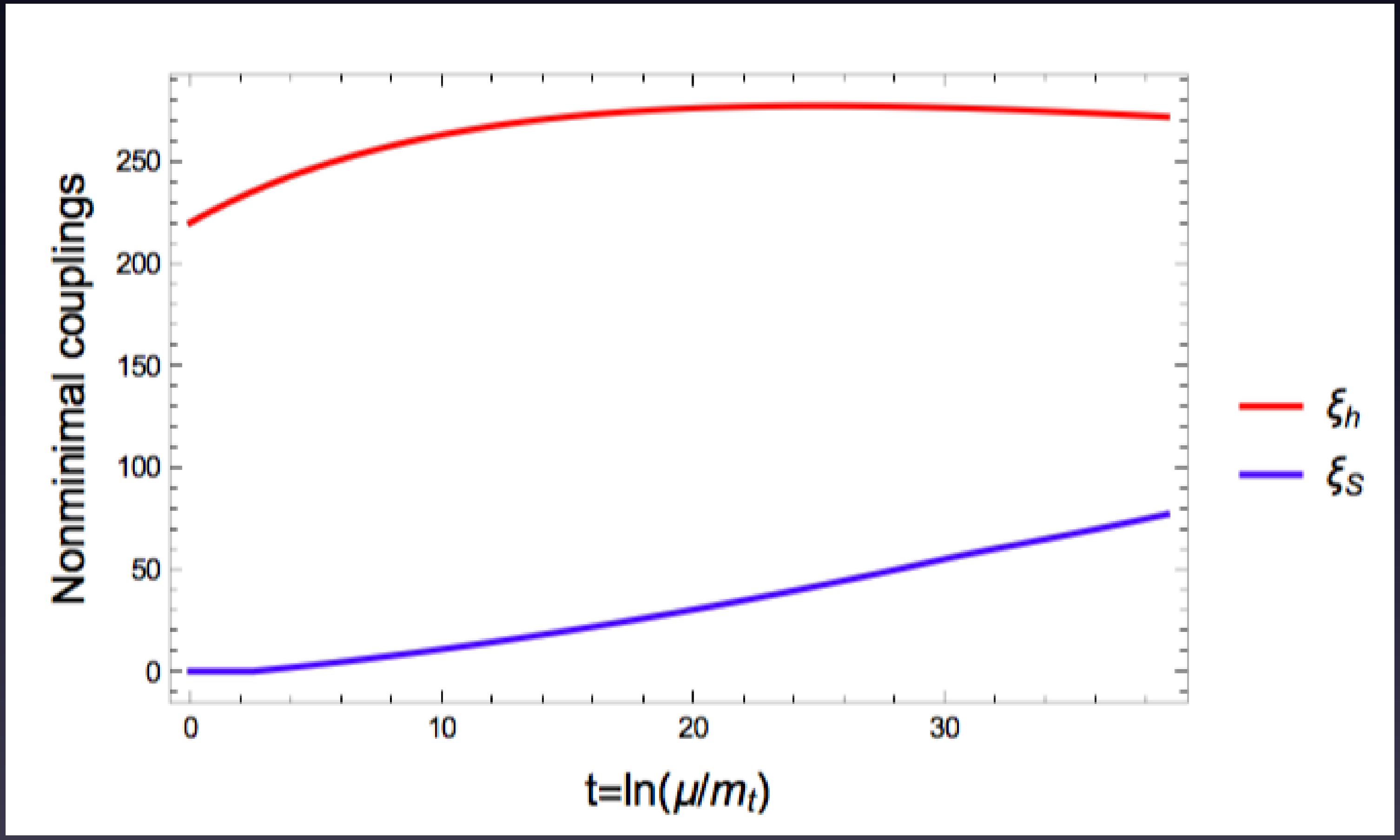
The SM sector and the hidden sector communicate through the Higgs-portal interaction:

$$V_{\rm portal} = \mu_{SH} S H^\dagger H + \frac{1}{2}\lambda_{SH} S^2 H^\dagger H \,.$$

Important point is to note that

$$\frac{1}{2}\xi_S S^2 R$$

is generated via RG runnings.



Numerical Analysis

Relevant parameter list:

- 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
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Note that ξ_h is NOT a free parameter; shall be determined by the Planck normalisation,

$$\mathcal{P}_S \approx 2.2 \times 10^{-9} \, .$$

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- LEP bound
- oblique parameters
- DM relic density
- DM direct detection

$$0 \leq |\lambda_\psi| \lesssim 0.6\,,$$
$$-0.2 \lesssim \lambda_{SH} \lesssim 0.4\,,$$
$$0 \leq \lambda_S \lesssim 0.2$$

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We are interested in the Higgs inflation !

$$\xi_S = 0$$

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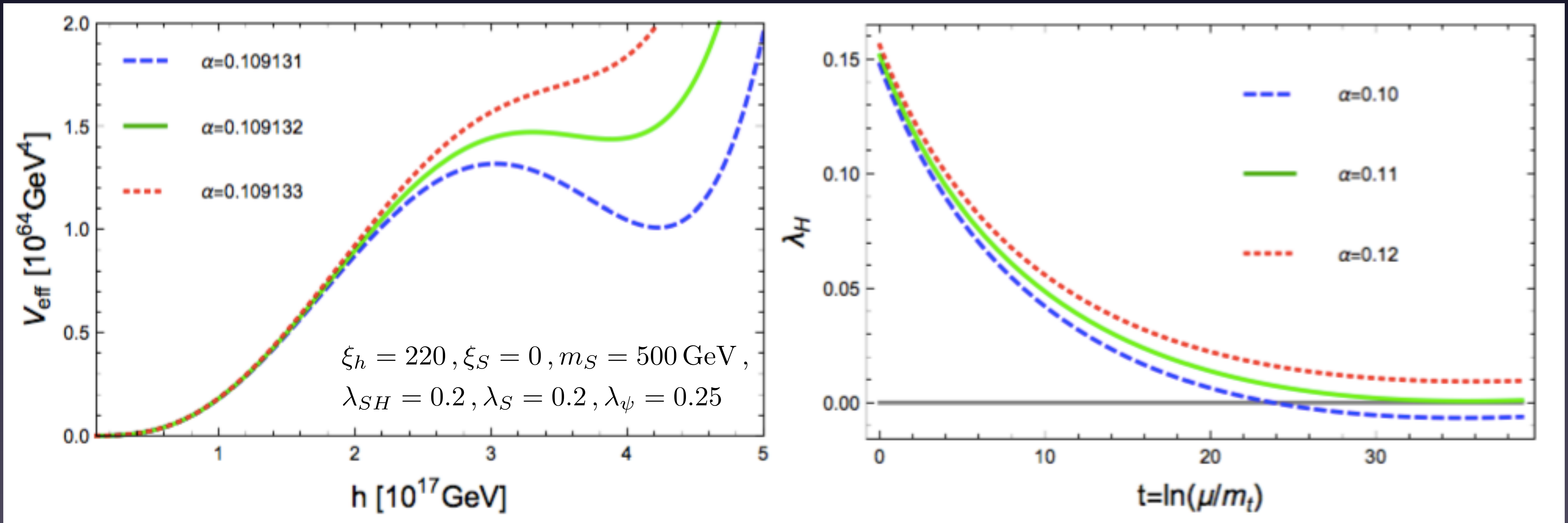
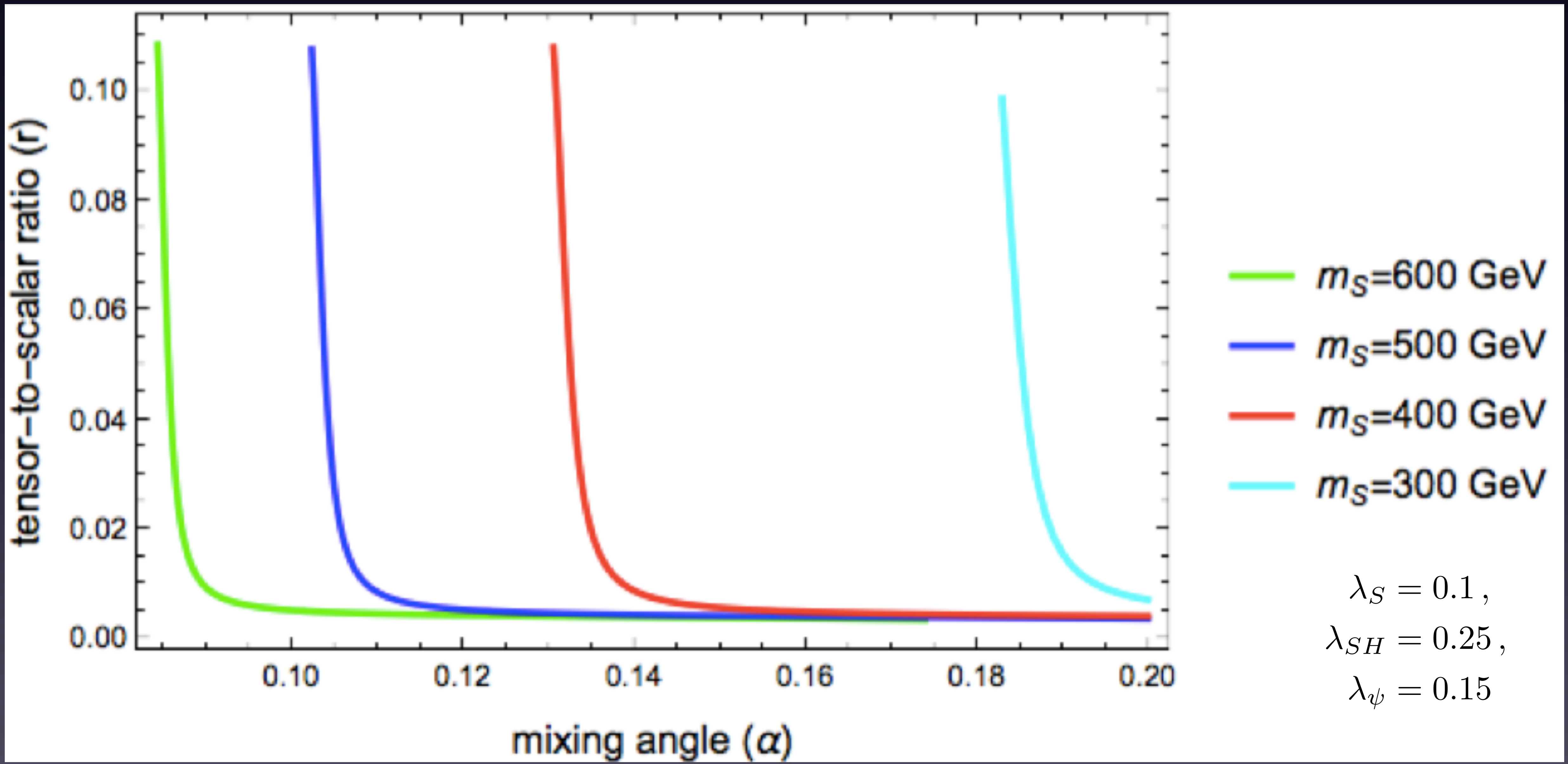


We performed a numerical analysis to find cosmological observables, by considering

- perturbativity
- vacuum stability
- Planck 2015 data



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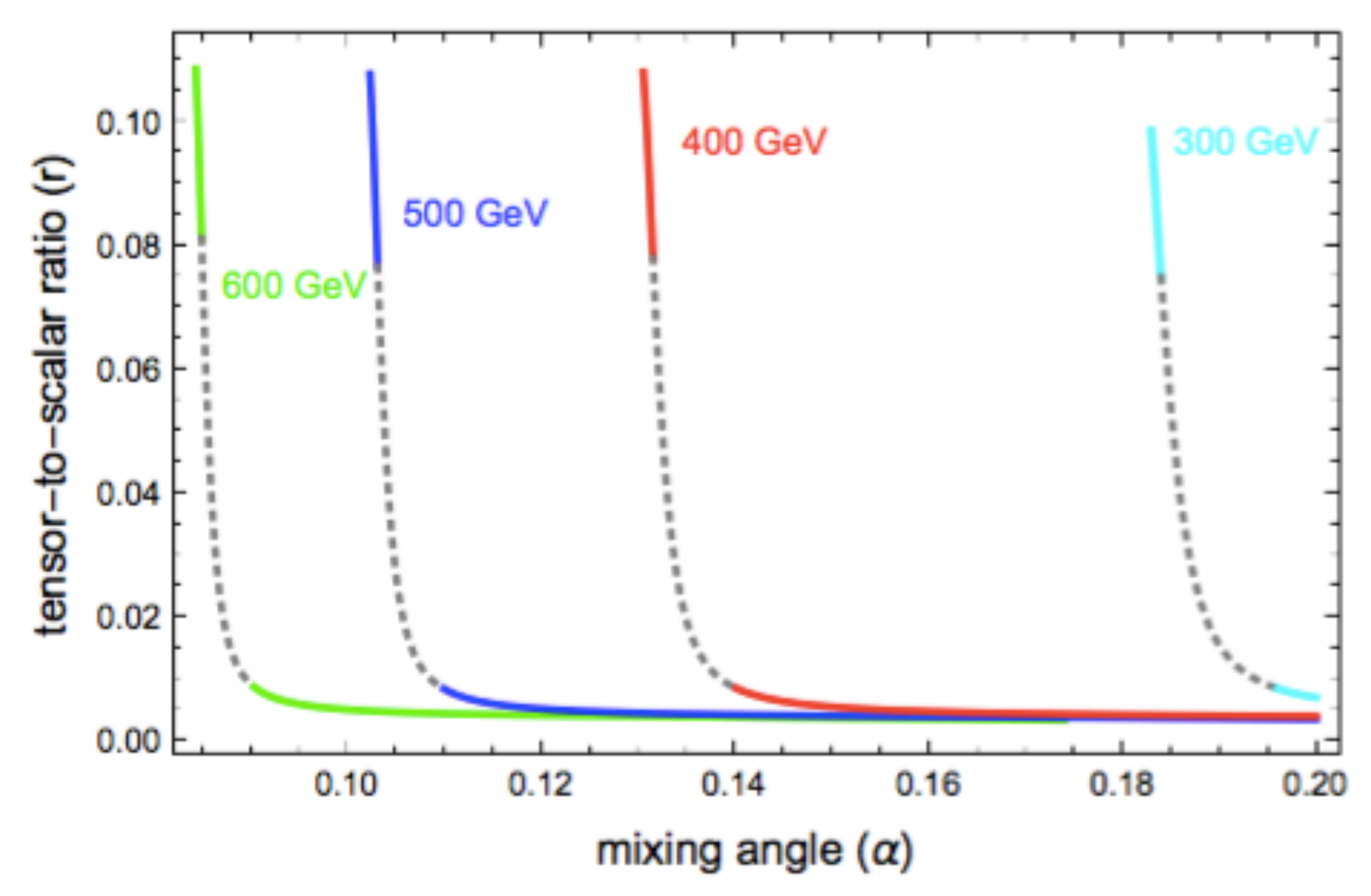


Summary

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

Backup

Weyl rescaling

[Cervantes-Cota Dehnen 1995][Bezrukov Shaposhnikov 2008]

$$S = \int d^4x \sqrt{-g} \left[\frac{M_P^2}{2} R + \xi \phi^2 R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right]$$

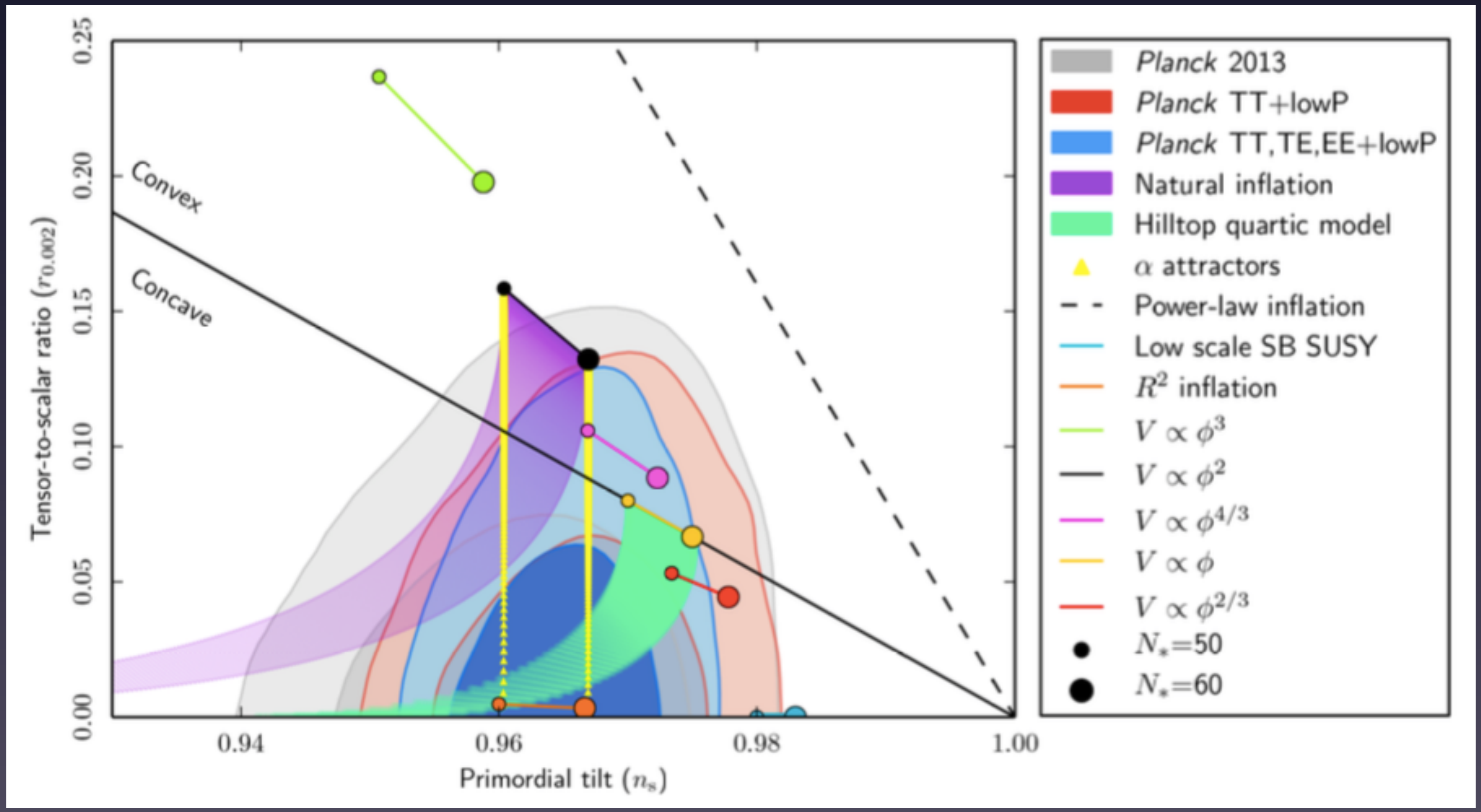
: Jordan frame

One can go to the Einstein frame via Weyl transformation:

$$g_{\mu\nu} \rightarrow g^{E}_{\mu\nu} = \Omega^2 \, g_{\mu\nu}$$

$$S = \int d^4x \sqrt{-g} \left[\frac{M_P^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \chi \partial_\nu \chi - U(\chi) \right]$$

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



$$\frac{d\chi}{d\phi} = \frac{1}{\Omega^2} \left[\Omega^2 + 6\xi^2 \left(\frac{\phi}{M_P} \right)^2 \right]^{1/2}$$

$$U(\chi) = \frac{V}{\Omega^4}$$

: Einstein frame potential

Higgs inflation

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Action

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$$\int d^4x \sqrt{-g}\left[\frac{M_{\rm P}^2}{2}R + \frac{1}{2}\xi_h h^2 R - \frac{1}{2}g^{\mu\nu}\partial_\mu h \partial_\nu h - \frac{1}{4}\lambda_h h^4\right]$$

$$16\pi^2\beta_{\lambda_H} = 6(1+3s_h^2)\lambda_H^2 + 12\lambda_H\lambda_t^2 - 6\lambda_t^4 - 3\lambda_H(3g_2^2+g_1^2) + \frac{3}{8}\left(2g_2^4 + (g_2^2+g_1^2)^2\right) + \frac{1}{2}s_s^2\lambda_{HS}^2$$

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