HIGGS-DILATON COSMOLOGY

Universality vs. Criticality

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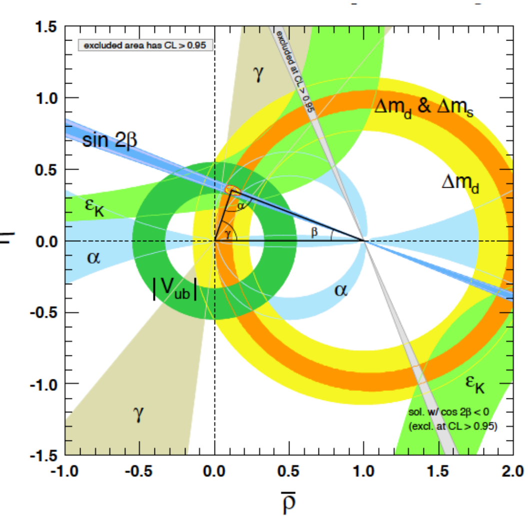
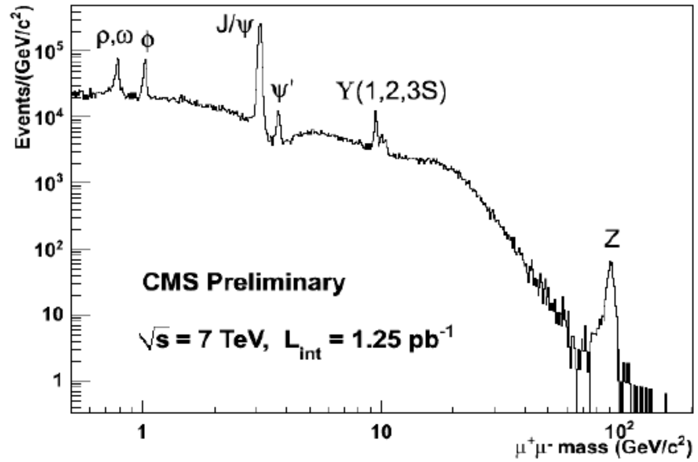
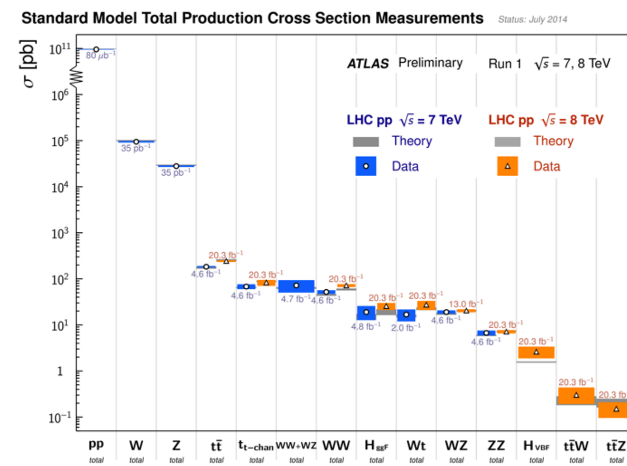
SM

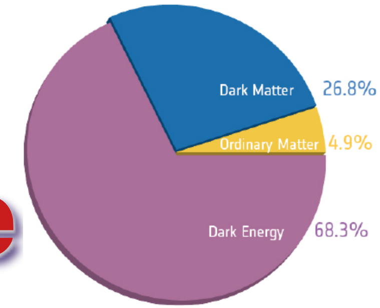
"SMs" are nicely compatible with Nature

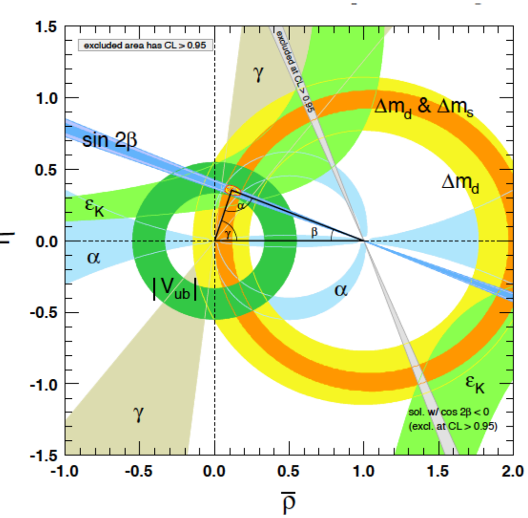


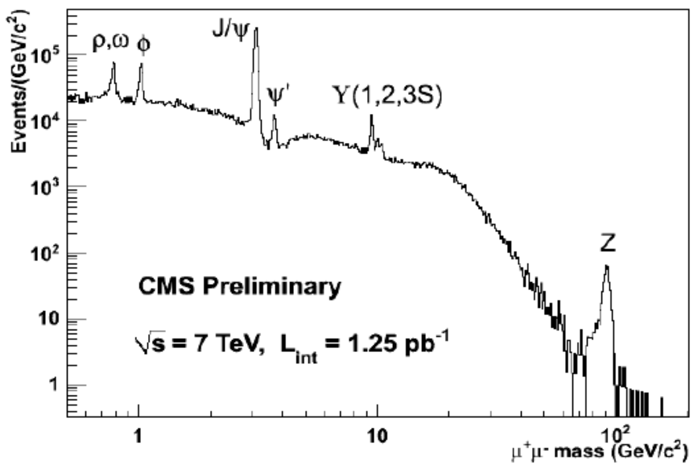


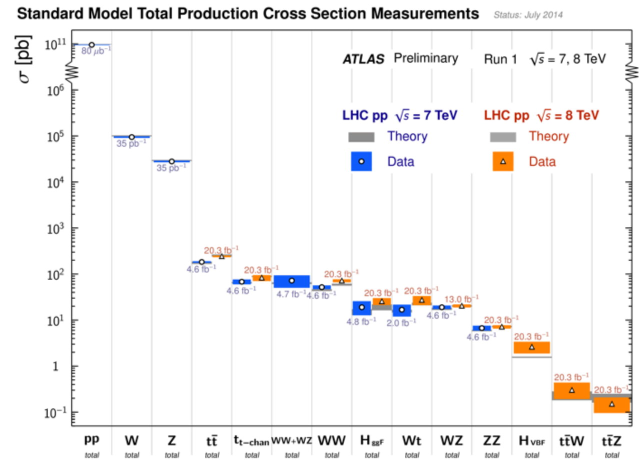


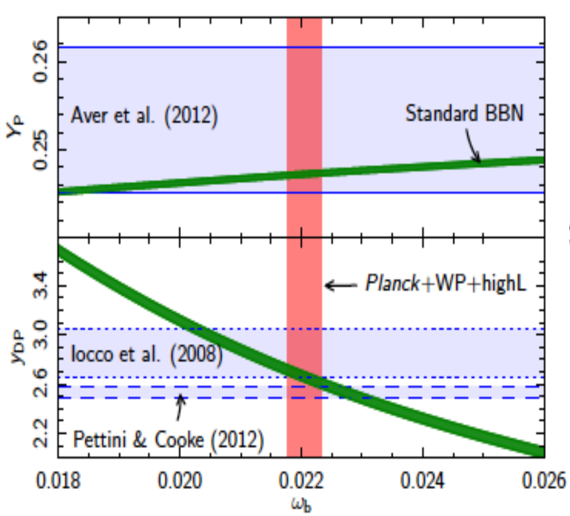
“SMs” are nicely compatible with Nature

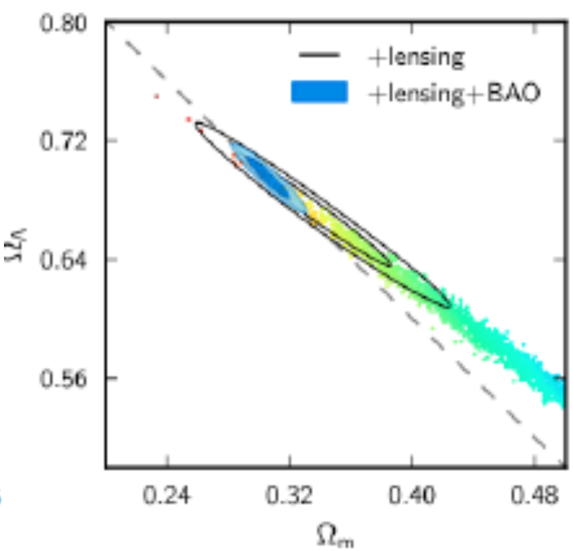


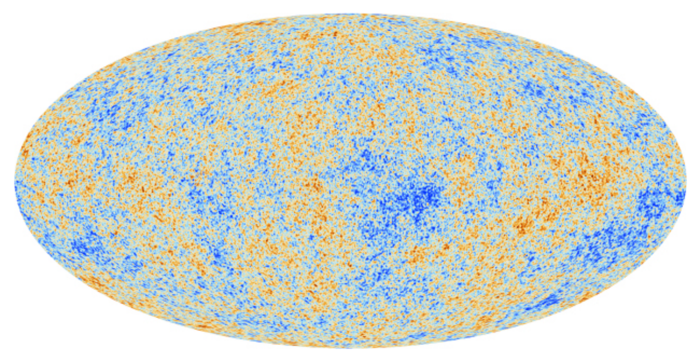






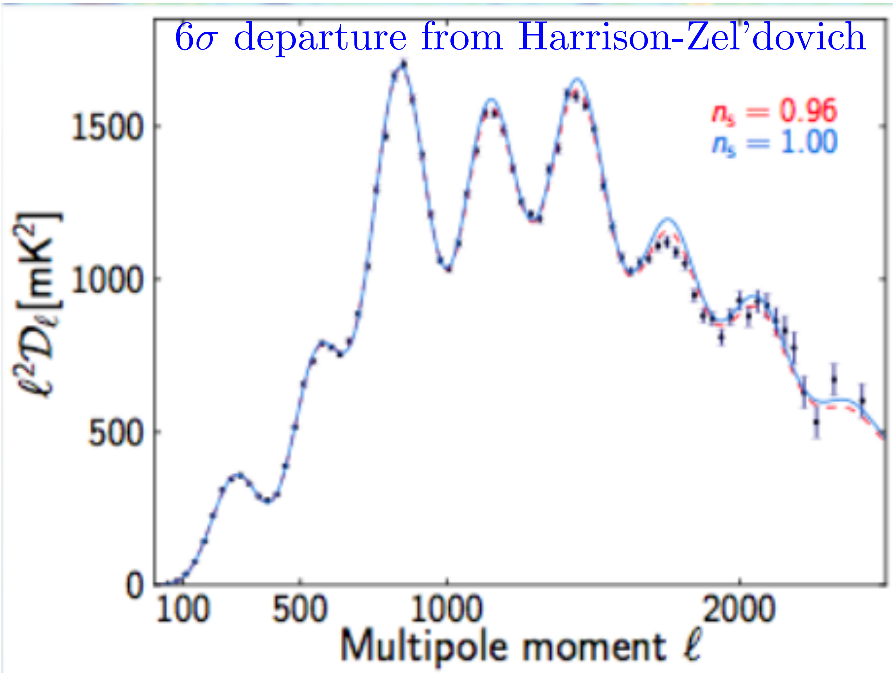






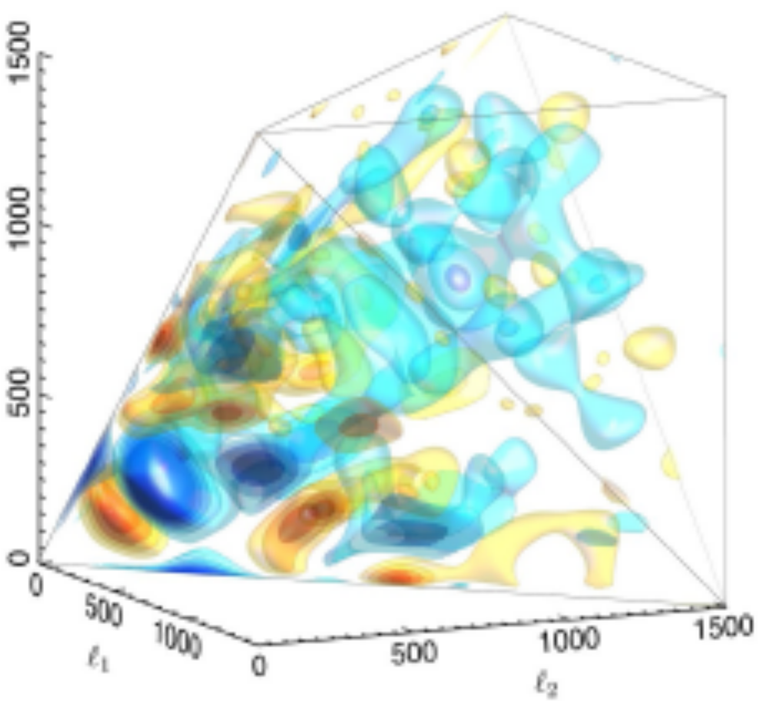
Our overall conclusion is that the *Planck* data are remarkably consistent with the predictions of the base ΛCDM cosmology.

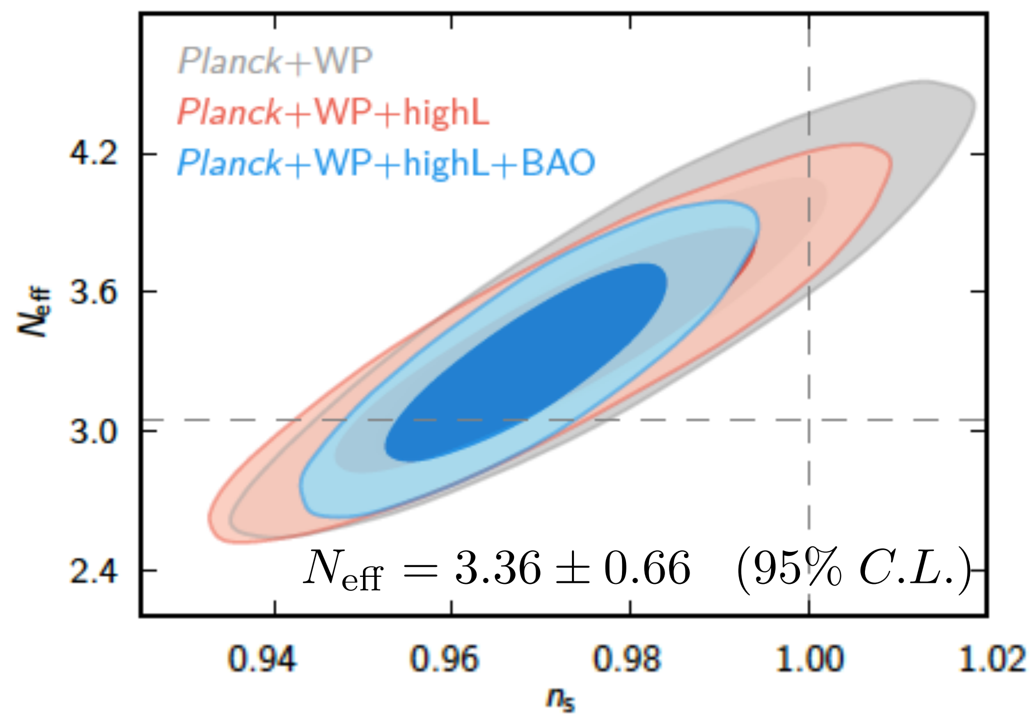
... and wants to remain
“SIMPLE”

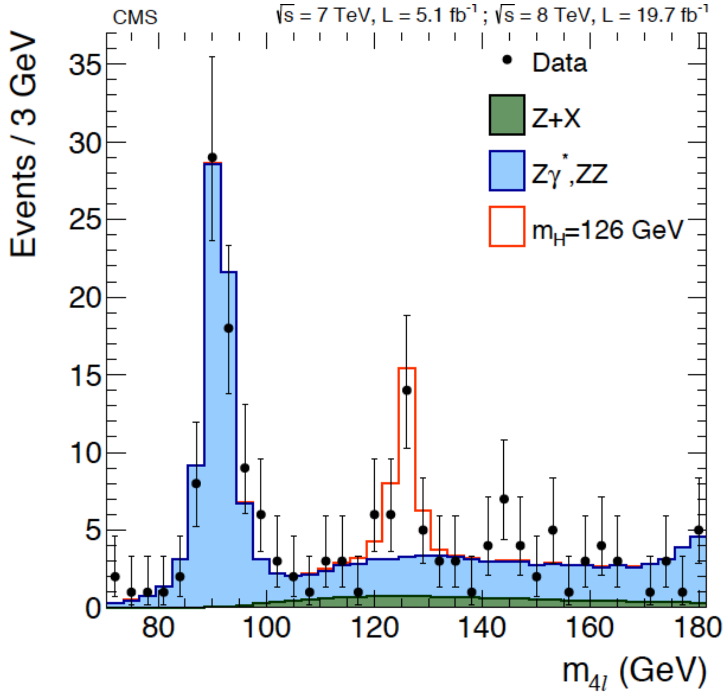


PLANCK

- "Single field SR inflation has survived its most stringent tests"
- "Small isocurvature contribution"
- "No evidence for primordial NG"
- "No evidence for additional relativistic particles"

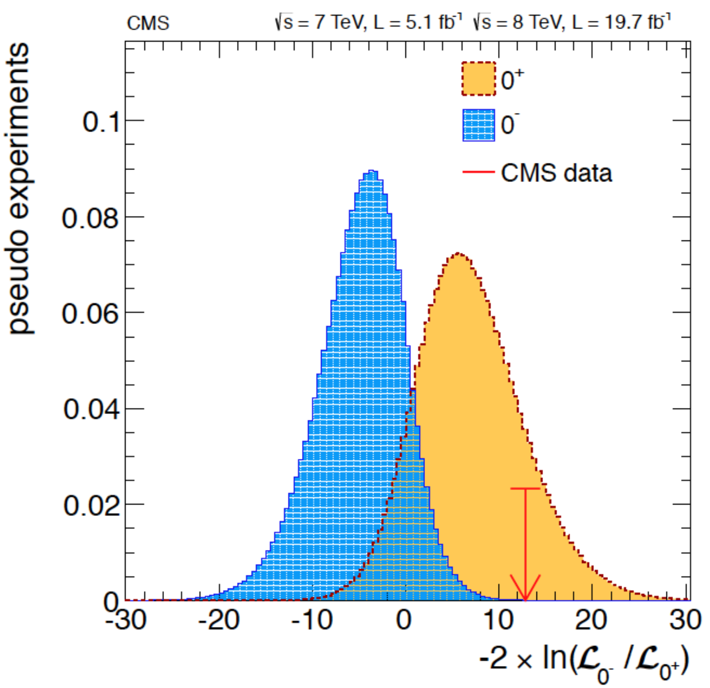


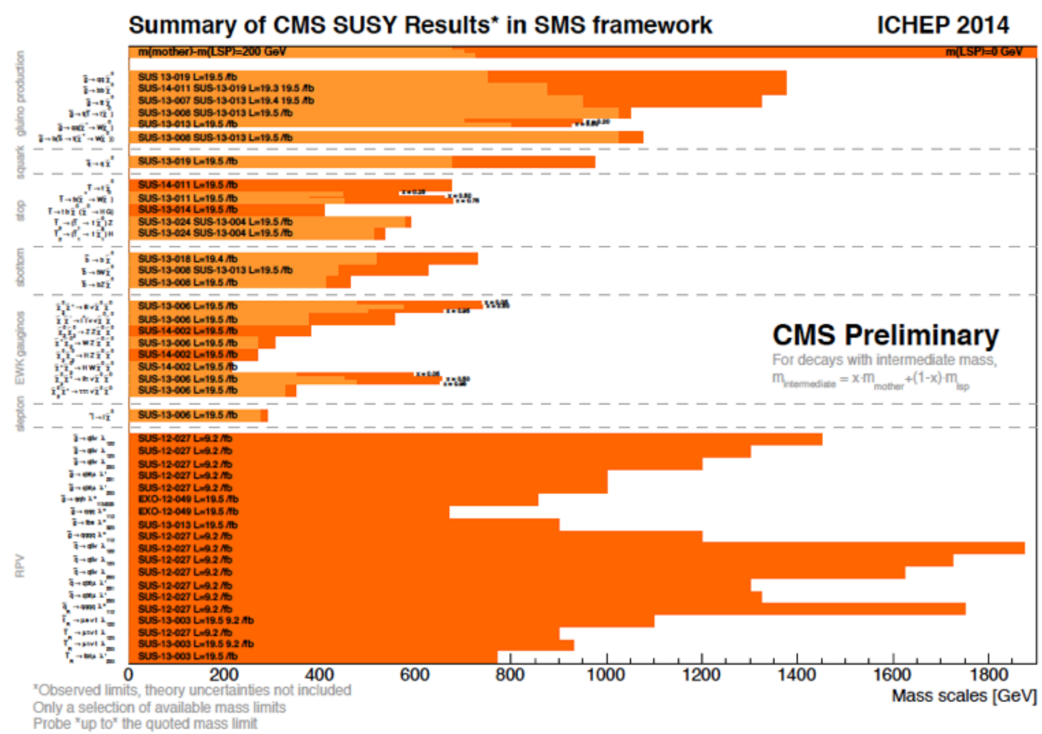




LHC

- "Clear evidence for a neutral boson with a mass of 126 GeV"
- "Extensive search without any significant deviations from the SM so far"





The resistance of the SM

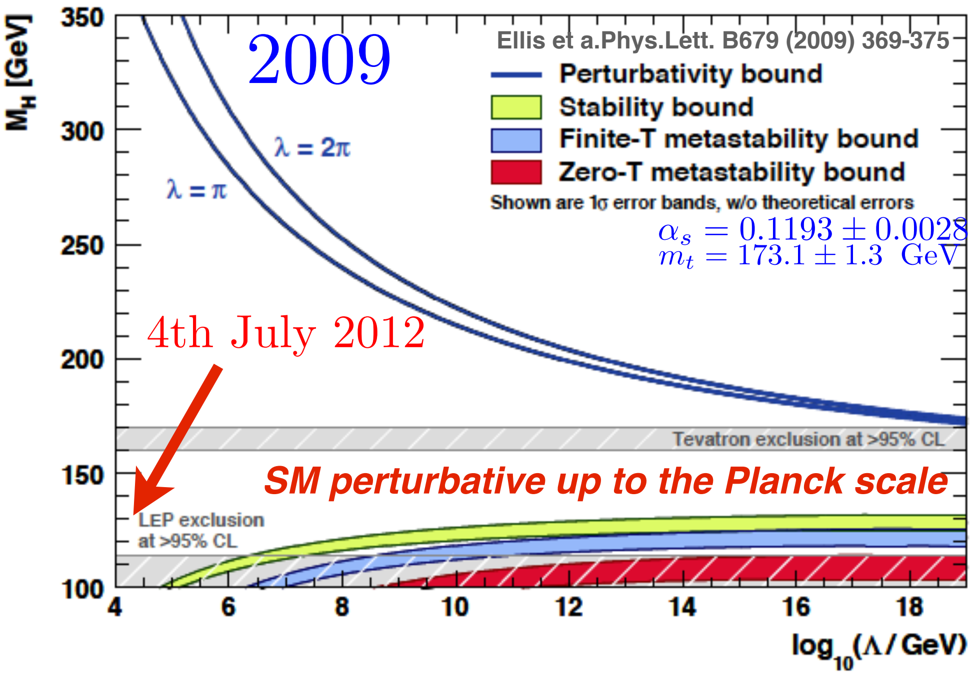
re·sis·tance (rĭ-zĭs'təns)

5. *Biology*

a. The capacity of an organism to defend itself against a disease.

b. The capacity of an organism or a tissue to withstand the effects of a harmful environmental agent.

..like Odysseus between Scylla and Charybdis



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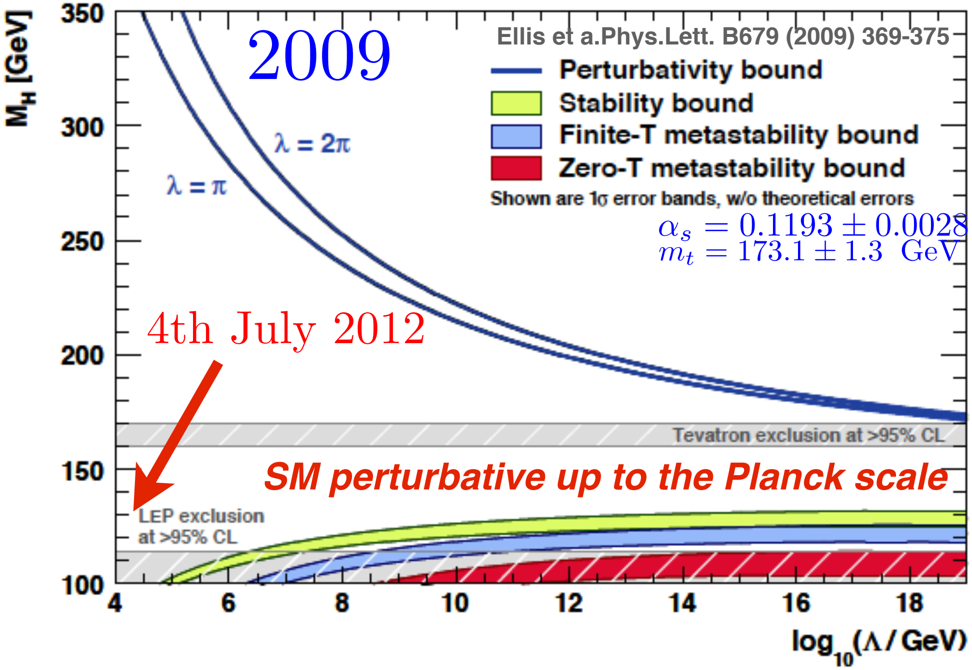
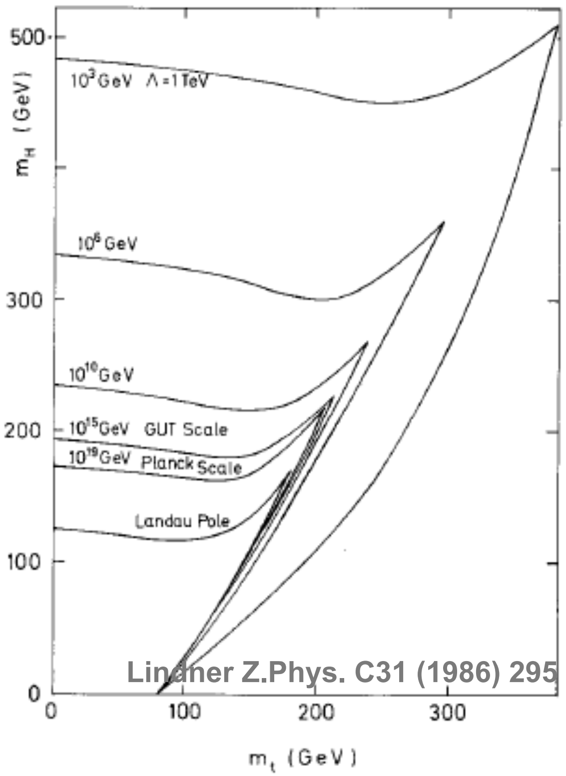
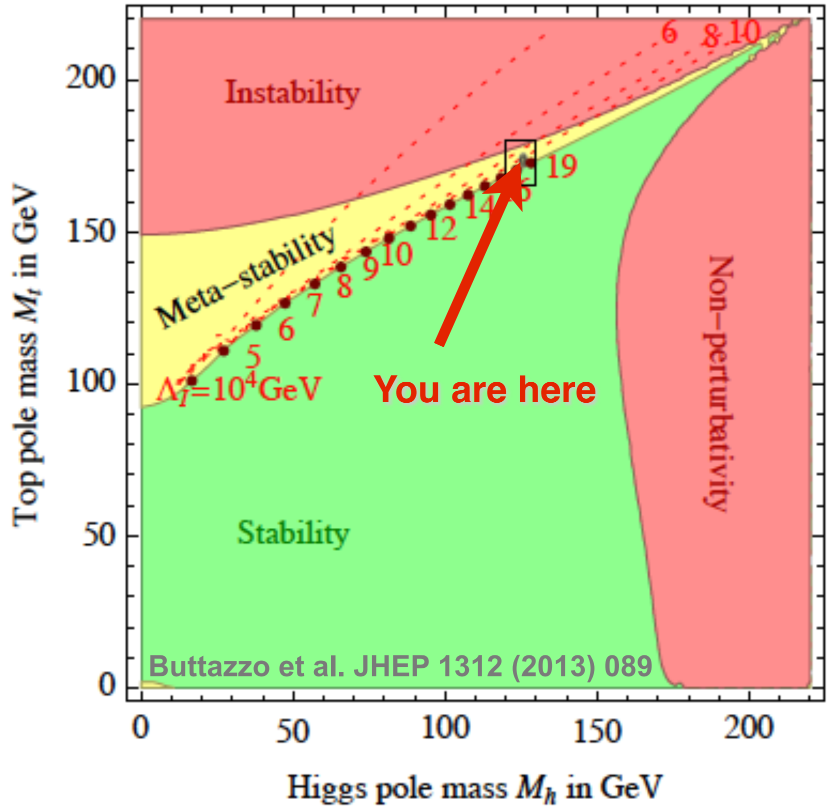


"incidit in scyllam cupiens vitare charybdim"

"he runs on Scylla, wishing to avoid Charybdis"

On the edge of stability





Non trivial interplay between top Yukawa and Higgs self-coupling....evil *Scylla* hidden in error bars

Stable or metaestable? An experimental rather than theoretical issue ...

Is there a reason for that? M. Lindner, M. Sher, and H. W. Zaglauer, Phys.Lett., B228, 139 (1989), C. Froggatt and H. B. Nielsen, Phys.Lett., B368,96 (1996), M. Shaposhnikov and C. Wetterich, Phys.Lett., B683, 196 (2010), M. Veltman, Acta Phys.Polon., B12, 437 (1981), B683, 196 (2010), M. Holthausen, K.S.Lim, M.Lindner and references therein....

Gravitational corrections? Lalak,Lewicki, Olszewki arXiv 14.02.3826, Branchina, Massina Phys.Rev.Lett. 111 (2013) 241801 etc...

Messages from sky and Earth

1. The era of scalars has begun

2. No hints of NP in the vicinity of SM

   SM could be valid till the Planck scale

3. Hierarchy problem should be reconsidered

Main assumptions of HDM

1. One field to rule them "all"

Identify the Higgs with the inflaton

"Frustra fit per plura quod potest fieri per pauciora". William of Ockham, Summa Totius Logicae

2. Physicists' Nightmare Scenario

No new intermediate scales till "Planck" scale

3. Where these scales come from???

Scale invariance

~~Exact SI~~

~~*Zero Higgs mass*~~

~~*Zero Newton constant*~~

~~*Zero Cosmological Constant*~~

SB SI

Non-zero Higgs mass

Non-zero Newton constant

Cosmological Constant???

For similar ideas see for instance Lindner Z.Phys. C31 (1986) 29, T. Asaka, S. Blanchet, M. Shaposhnikov, Phys.Lett. B631 (2005) 151, K.A. Meissner, H. Nicolai, Phys.Lett. B648 (2007) 312, M. Holthausen, K.S.Lim, M.Lindner and references therein.

The Higgs-Dilaton model (JF)

All the scales are generated by SSB of global scale invariance

$$\frac{\mathcal{L}_{SI}}{\sqrt{-g}} = \frac{1}{2}\left(\xi_\chi \chi^2 + \xi_h h^2\right) R - \frac{1}{2}(\partial h)^2 - \frac{1}{2}(\partial \chi)^2 - U(h,\chi)$$

Dimensionless parameters

Fine tuning

$$U(h,\chi) = \frac{\lambda}{4}\left(h^2 - \frac{\vartheta}{\lambda}\chi^2\right)^2$$

$$\vartheta \sim \frac{m_H^2}{M_P^2} \sim 10^{-35}$$

The dilaton is the new mass donor
It gives mass to the Higgs and defines the Planck scale

$$m_H \sim m_G \sim m_f \propto \chi_0 \qquad M_P \propto \chi_0$$

A singlet under the SM group
No couplings with SM particles

The question "*Who* gives mass to whom?" becomes irrelevant
The dilaton is massless

Cosmological consequences

1. Tree level results

- Inflation
- Dark energy

} Consistency relations ↓

2. Radiative Corrections

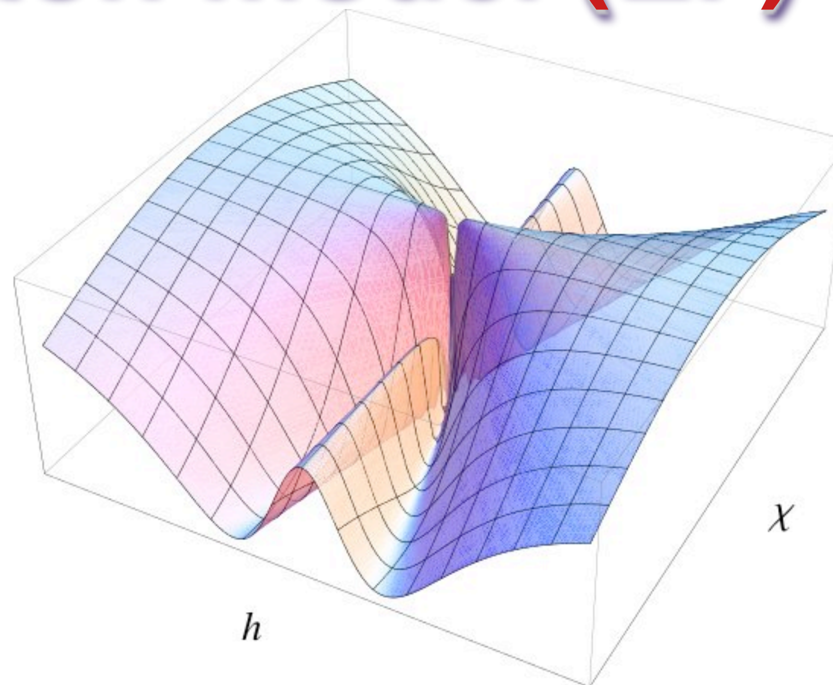
- Subtleties ⟷ UV completion
- Universality regime
- Critical regime

Inflation

The Higgs-Dilaton model (EF)

Conformal transformation

$$\tilde{g}_{\mu\nu} = M_P^{-2}(\xi_\chi \chi^2 + \xi_h h^2) g_{\mu\nu}$$



Vacuum is infinitely degenerate

Physics does not depend on the particular value of the dilaton

$$\frac{\tilde{\mathcal{L}}}{\sqrt{-\tilde{g}}} = \frac{M_P^2}{2}\tilde{R} - \frac{1}{2}\gamma_{ab}(\Omega)\tilde{g}^{\mu\nu}\partial_\mu \varphi^a \partial_\nu \varphi^b - V(\varphi)$$

$$\gamma_{ab}(\Omega) = \frac{1}{\Omega^2}\left(\delta_{ab} + \frac{3}{2}M_P^2 \frac{\Omega^2_{,a}\Omega^2_{,b}}{\Omega^2}\right)$$

Canonical fields?

$R_{\gamma_{ab}} \neq 0$ ***unless*** $\xi_h = \xi_\chi$

... non-canonical kin. terms??

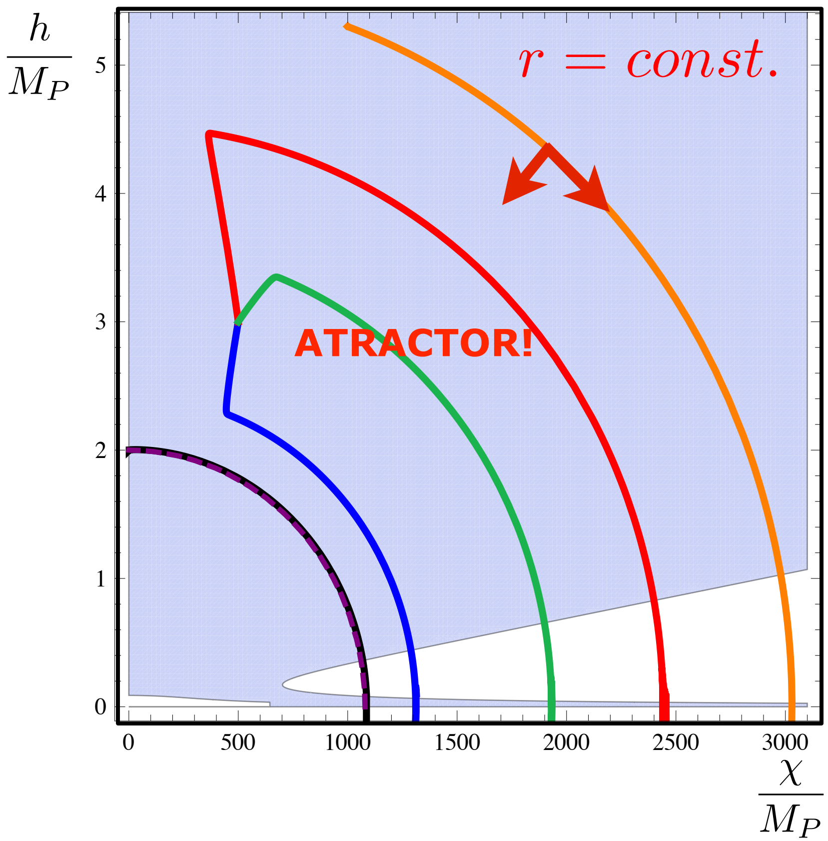
...multifield inflation ???

Isocurvature ??

Non-gaussianities ??

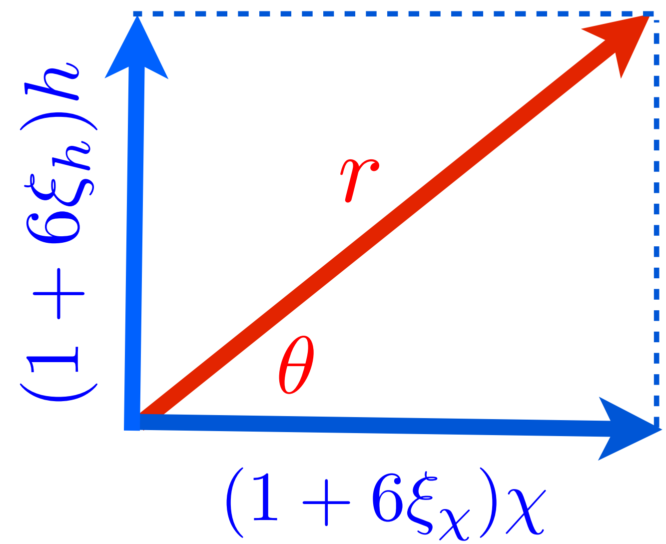
SI to the rescue

A dynamical constraint between Higgs and Dilaton



$$D_\mu J^\mu = 0 \longrightarrow \Box\, r^2 = 0$$

Normal modes



$$\rho = \frac{M_P}{\gamma} \ln\left(\frac{r}{M_P}\right) \qquad \tanh\left[\bar{\alpha}\kappa\left(\phi_0 - |\phi|\right)\right] = \sqrt{1-\sigma}\cos\theta$$

with $\sigma, \gamma^2 \sim \xi_\chi$

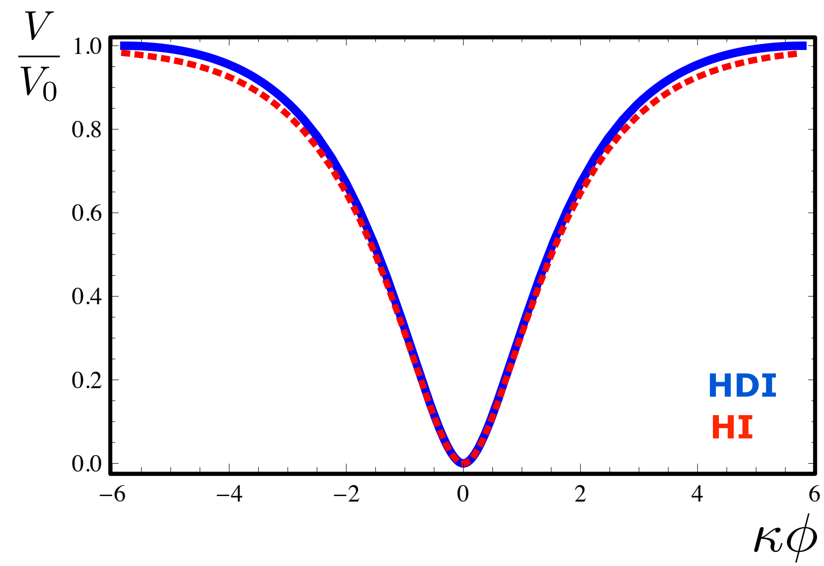
A simple lagrangian density

$$\frac{\tilde{\mathcal{L}}}{\sqrt{-\tilde{g}}} = \frac{M_P^2}{2}R - \frac{e^{2b(\phi)}}{2}(\partial\rho)^2 - \frac{1}{2}(\partial\phi)^2 - \tilde{U}(\phi)$$

$$e^{2b(\phi)} \equiv \sigma \cosh^2\left[\alpha\kappa\left(\phi_0 - |\phi|\right)\right] \qquad \tilde{U}(\phi) = U_0\left(1 - e^{2b(\phi)}\right)^2$$

A single field model!

- **Similar to Higgs inflation/ R2 inflation**
- **Curvature perturbation is conserved**
- **Reconstruction of the potential is almost independent of the preheating details**



$$\dot{\zeta} = \frac{k^2}{a^2}\frac{H}{\dot{H}}\Phi - 2H\frac{V_\phi \dot{\phi}\dot{\rho}^2 e^{2b}}{(e^{2b}\dot{\rho}^2 + \dot{\phi}^2)^2}\left(\frac{\delta\phi}{\dot{\phi}} - \frac{\delta\rho}{\dot{\rho}}\right)$$

F. Di Marco, F. Finelli, R. Brandenberger Phys.Rev. D67 (2003) 063512

The primordial spectra

Scalar pert. $$\mathcal{P}_S(k) = \mathcal{A}_s \left(\frac{k}{k^*}\right)^{n_s - 1 + \frac{1}{2}\alpha_s \ln(k/k^*) + \frac{1}{6}\beta_s (\ln(k/k^*))^2 + \ldots}$$

Tensor pert. $$\mathcal{P}_T(k) = \mathcal{A}_t \left(\frac{k}{k^*}\right)^{n_t + \frac{1}{2}\alpha_t \ln(k/k^*) + \ldots}$$

$$n_\mathrm{s} \equiv 1 + \frac{\mathrm{d}\ln \mathcal{P}_\mathrm{s}}{\mathrm{d}\ln k} \qquad r(k) \equiv \frac{\mathcal{P}_\mathrm{T}(k)}{\mathcal{P}_\mathrm{s}(k)} \qquad \alpha_\mathrm{s} \equiv \frac{\mathrm{d}\, n_\mathrm{s}}{\mathrm{d}\ln k} \qquad \beta_s \equiv \frac{d^2 n_s}{d \ln k^2}$$

The primordial spectra

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Tensor pert. $$\mathcal{P}_T(k) = \mathcal{A}_t \left(\frac{k}{k^*}\right)^{n_t + \frac{1}{2}\alpha_t \ln(k/k^*) + \ldots}$$

$$n_s \equiv 1 + \frac{d \ln \mathcal{P}_s}{d \ln k} \qquad r(k) \equiv \frac{\mathcal{P}_T(k)}{\mathcal{P}_s(k)} \qquad \alpha_s \equiv \frac{d n_s}{d \ln k}, \qquad \beta_s \equiv \frac{d^2 n_s}{d \ln k^2}$$

In Higgs-Dilaton inflation

Scalar spectral tilt

$$n_s(k^*) \simeq 1 - 8\xi_\chi \coth(4\xi_\chi N^*)$$

Amplitude

$$\mathcal{A}_s(k^*) \simeq \frac{\lambda \sinh^2(4\xi_\chi N^*)}{1152\pi^2 \xi_\chi^2 \xi_h^2}$$

Running of the tilt

$$\alpha_s(k^*) \simeq -32\xi_\chi^2 \sinh^{-2}(4\xi_\chi N^*)$$

Tensor-to-scalar ratio

$$r(k^*) \simeq 192\xi_\chi^2 \sinh^{-2}(4\xi_\chi N^*)$$

Inflationary Observables

$$n_s\left(k^*\right) \simeq 1 - 8\xi_\chi \coth\left(4\xi_\chi N^*\right)$$

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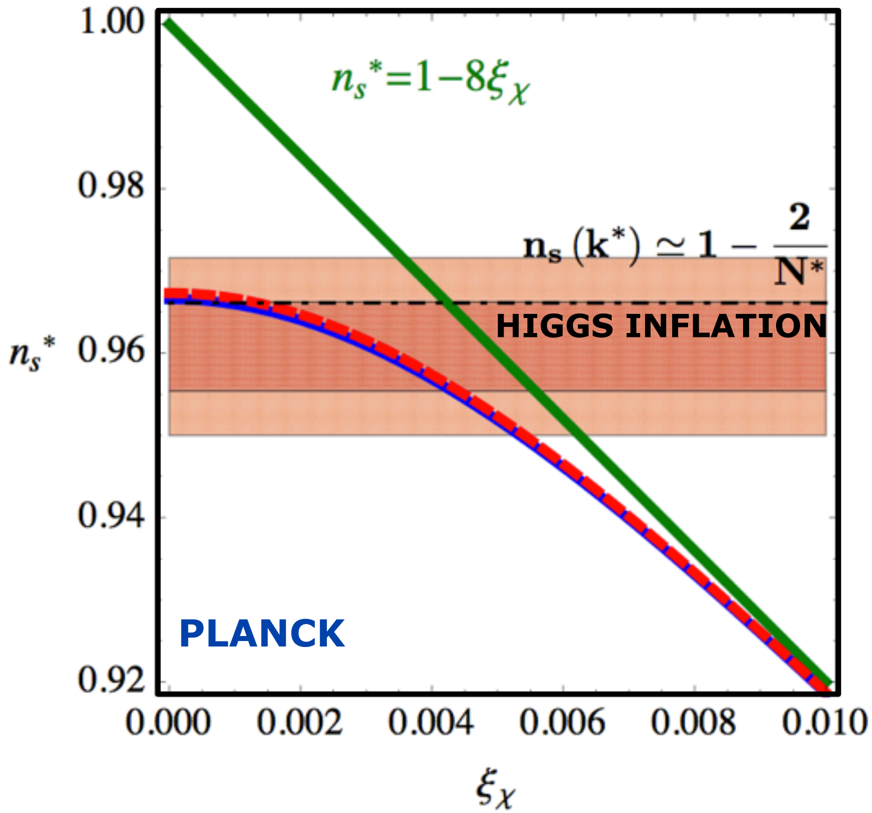
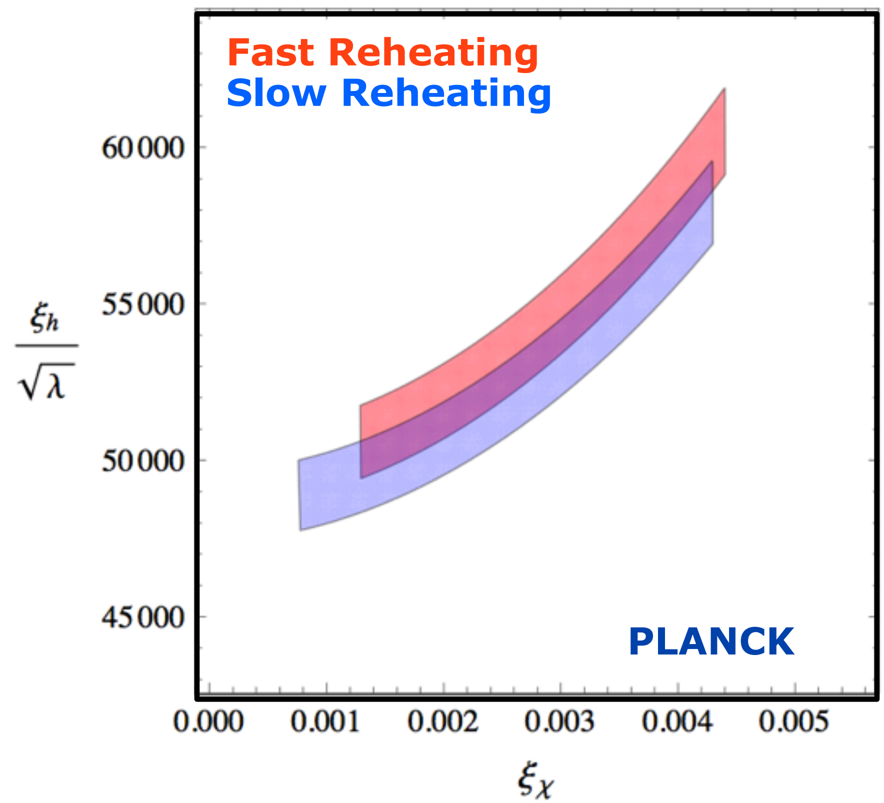
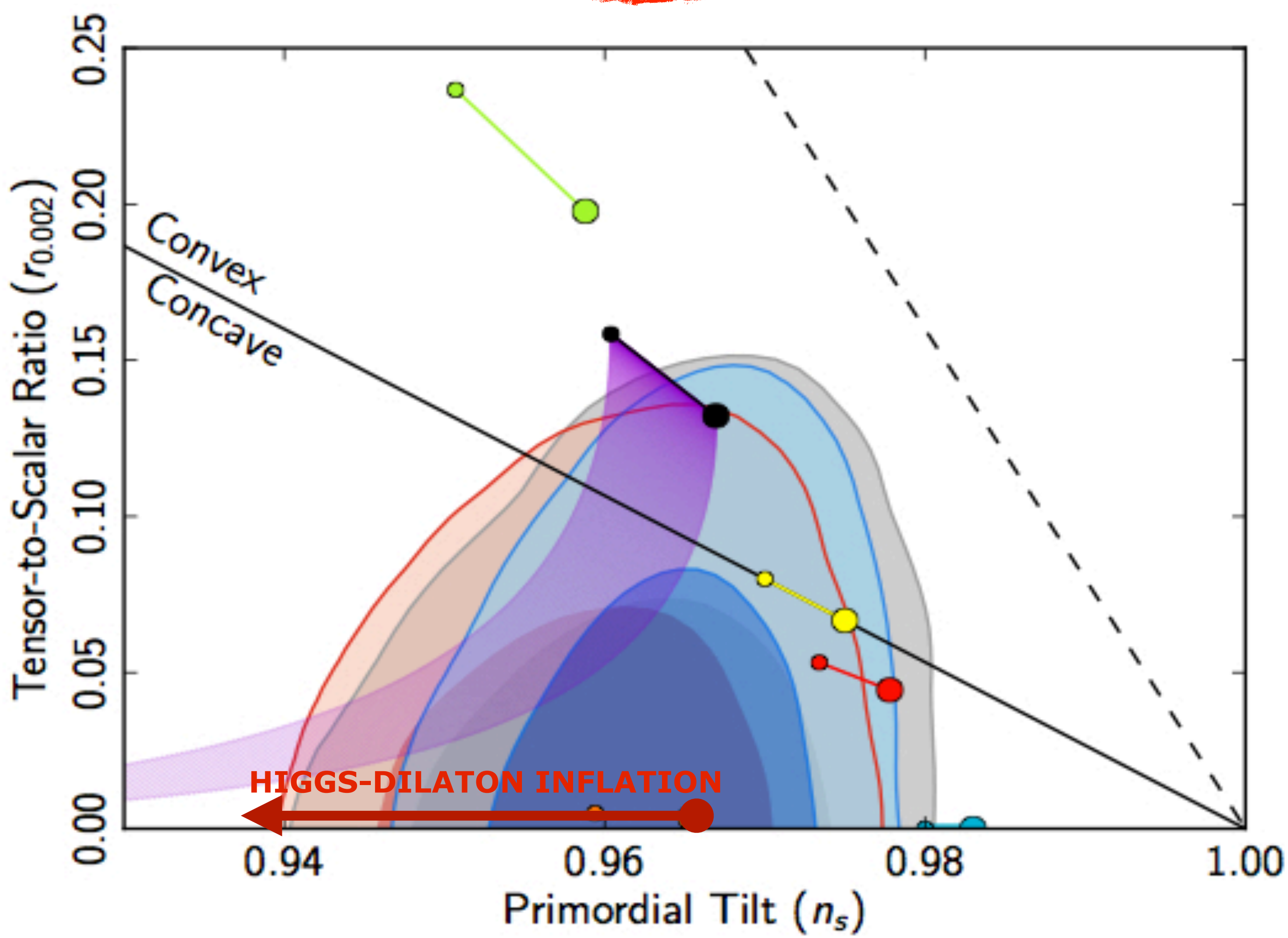




No free parameters left

Primordial GWs

$$r(k^*) \simeq 192\xi_\chi^2 \sinh^{-2}(4\xi_\chi N^*)$$



Dark Energy

Scale invariance vs Λ ???

General Relativity -> Unimodular Gravity

No CC at the level of the action

$$S = \int d^4x \mathcal{L}\left(g_{\mu\nu}, \partial g_{\mu\nu}, \Phi, \partial \Phi\right)$$

Restricted metric determinant

$$|g| = 1$$

Variation of the action with a lagrange multiplier

$$\partial_\mu \lambda(x) = 0 \Longleftrightarrow \lambda(x) = \Lambda_0$$

Same equations of motion as in GR

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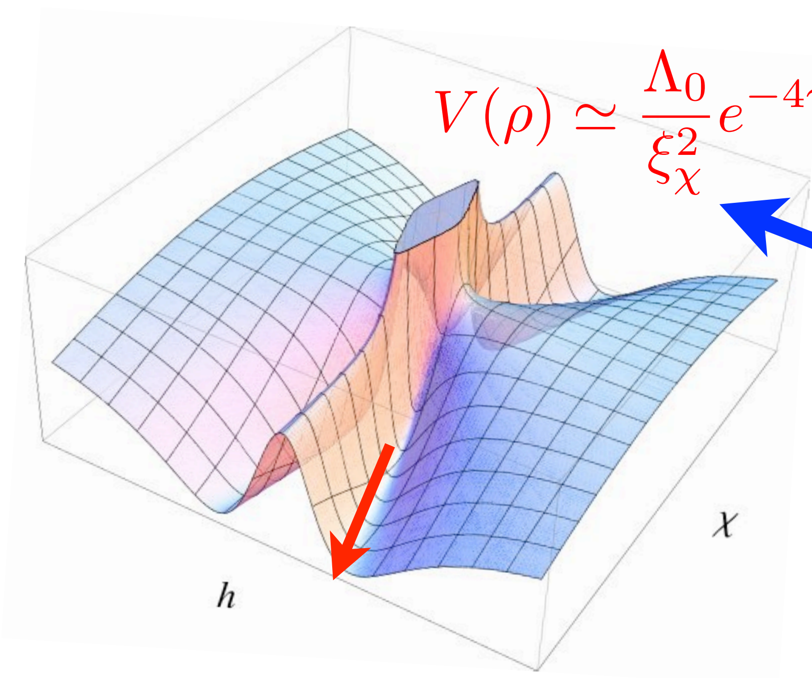
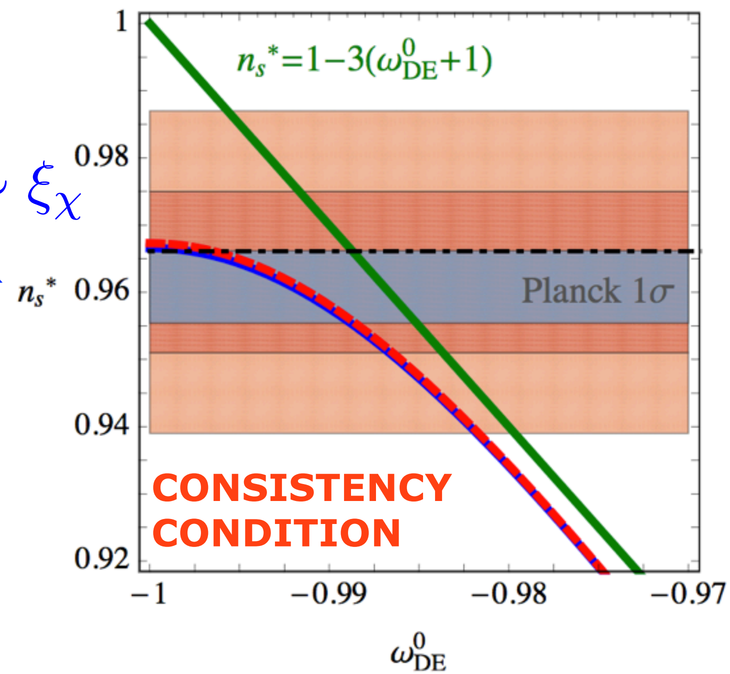


$$V(\rho) \simeq \frac{\Lambda_0}{\xi_\chi^2} e^{-4\gamma\kappa\rho}$$

$$\gamma^2 \sim \xi_\chi$$



Consistency

Cutoffs in a background

$$\Phi(\mathbf{x},t) = \bar{\Phi}(t) + \delta\Phi(\mathbf{x},t) \quad \Rightarrow \quad c_n \frac{\mathcal{O}_n(\delta\Phi)}{[\Lambda(\bar{\Phi})]^{n-4}}$$

⚠ **Background dependent!**

Cutoffs in a background

1. Compute the quadratic lagrangian (Jordan F.)

$$\mathscr{K}_2^{\mathrm{G+S}} = \frac{\xi_\chi \bar{\chi}^2 + \xi_h \bar{h}^2}{8} \left(\delta g^{\mu\nu} \Box \delta g_{\mu\nu} + 2\partial_\nu \delta g^{\mu\nu} \partial^\rho \delta g_{\mu\rho} - 2\partial_\nu \delta g^{\mu\nu} \partial_\mu \delta g - \delta g \Box \delta g\right)$$

$$- \frac{1}{2}(\partial \delta\chi)^2 - \frac{1}{2}(\partial \delta h)^2 + (\xi_\chi \bar{\chi}\delta\chi + \xi_h \bar{h}\delta h)(\partial_\lambda \partial_\rho \delta g^{\lambda\rho} - \Box \delta g) \ .$$

Cutoffs in a background

1. Compute the quadratic lagrangian (Jordan F.)

$$\mathcal{K}_2^{\rm G+S} = \frac{\xi_\chi \bar\chi^2 + \xi_h \bar h^2}{8}\left(\delta g^{\mu\nu}\Box\delta g_{\mu\nu} + 2\partial_\nu\delta g^{\mu\nu}\partial^\rho\delta g_{\mu\rho} - 2\partial_\nu\delta g^{\mu\nu}\partial_\mu\delta g - \delta g\Box\delta g\right)$$
$$-\frac{1}{2}(\partial\delta\chi)^2 - \frac{1}{2}(\partial\delta h)^2 + (\xi_\chi\bar\chi\delta\chi + \xi_h\bar h\delta h)(\partial_\lambda\partial_\rho\delta g^{\lambda\rho} - \Box\delta g)\ .$$

2. Get rid of the mixings in the quadratic action

Non-canonical kinetic terms for perturbations

$$\delta\hat h = \frac{1}{\sqrt{\xi_\chi^2\bar\chi^2 + \xi_h^2\bar h^2}}\left(-\xi_h\bar h\delta\chi + \xi_\chi\bar\chi\delta h\right)$$

$$\delta\hat\chi = \sqrt{\frac{\xi_\chi\bar\chi^2(1+6\xi_\chi) + \xi_h\bar h^2(1+6\xi_h)}{(\xi_\chi^2\bar\chi^2 + \xi_h^2\bar h^2)(\xi_\chi\bar\chi^2 + \xi_h\bar h^2)}}\left(\xi_\chi\bar\chi\delta\chi + \xi_h\bar h\delta h\right)$$

$$\delta\hat g_{\mu\nu} = \frac{1}{\sqrt{\xi_\chi\bar\chi^2 + \xi_h\bar h^2}}\left[(\xi_\chi\bar\chi^2 + \xi_h\bar h^2)\delta g_{\mu\nu} + 2\bar g_{\mu\nu}(\xi_\chi\bar\chi\delta\chi + \xi_h\bar h\delta h)\right]$$

A consistent EFT

3. Read out the cutoff from higher order operators

$$\frac{1}{\Lambda_1(h,\chi)}(\delta\hat{h})^2\Box\delta\hat{g} \quad , \quad \frac{1}{\Lambda_2(h,\chi)}(\delta\hat{\chi})^2\Box\delta\hat{g} \quad , \quad \frac{1}{\Lambda_3(h,\chi)}(\delta\hat{h})(\delta\hat{\chi})\Box\delta\hat{g} \quad , \quad \text{etc ...}$$

A consistent EFT

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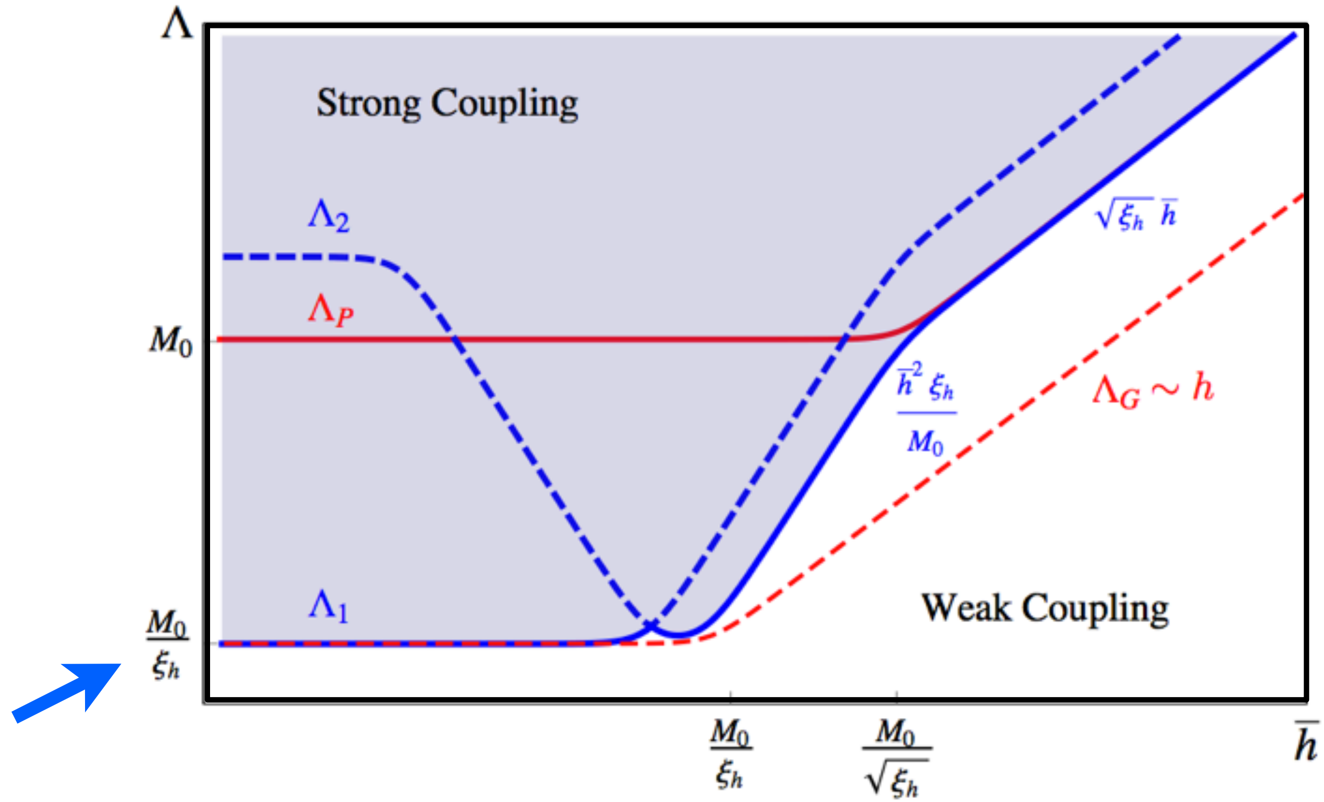
$$\frac{1}{\Lambda_1(h,\chi)}(\delta\hat{h})^2\Box\delta\hat{g} \quad , \quad \frac{1}{\Lambda_2(h,\chi)}(\delta\hat{\chi})^2\Box\delta\hat{g} \quad , \quad \frac{1}{\Lambda_3(h,\chi)}(\delta\hat{h})(\delta\hat{\chi})\Box\delta\hat{g} \quad , \quad \text{etc ...}$$



A consistent EFT : Cutoffs are parametrically larger than all the energy scales involved in the history of the Universe

The meaning of the cutoff

Two different definitions

- ◉ The energy at which perturbative unitarity in high-energy scattering processes is violated
- ◉ ~~The onset of new physics~~

Breaking of tree level unitarity $\neq$ new physics

Ufuk Aydemir, Mohamed M. Anber, John F. Donoghue, Phys.Rev. D86 (2012) 014025

◉ We will assume that the SM is valid for all momenta up to the Planck scale (self-healing ?)

Radiative Corrections

Respect scale invariance -> Dimensional regularization

SM vs. Chiral SM

Gauge bosons/fermions action invariant under conformal transformations

$$\Omega^2 = \frac{\xi_\chi \chi^2 + \xi_h^2 h^2}{M_P^2}$$

SM vs. Chiral SM

Gauge bosons/fermions action invariant under conformal transformations

$$\Omega^2 = \frac{\xi_\chi \chi^2 + \xi_h^2 h^2}{M_P^2}$$

except for mass terms

$$\mathcal{L}_F = \frac{y_f}{\sqrt{2}} h \bar{\psi}\psi \quad \longrightarrow \quad \tilde{\mathcal{L}}_F = \frac{y_f}{\sqrt{2}} \frac{h}{\Omega} \bar{\psi}\psi \equiv \frac{y_f}{\sqrt{2}} F(\phi) \bar{\psi}\psi$$

Low energies

$$F = h$$

$$F'(0) = 1$$

$$\tilde{m}_{A,f} = m_{A,f}$$

USUAL SM

During inflation

$$F = \frac{M_P}{\sqrt{\xi(1-\sigma)}} \left(1 - e^{2b(\phi)}\right)^{1/2}$$

$$F'(\phi_0) = 0$$

$$\tilde{m}_{A,f} = \text{const.}$$

CHIRAL SM

RGE Effective potential

1. Run SM RGE until the chiral SM

2. The obtained values are used as the input of the chiral phase, whose RG equations are run until a given scale.

3. This scale is chosen to minimize higher order corrections

4. RGE effective potential at inflation is computed

$$\tilde{U}_{RGE}(\phi) = \frac{\lambda(\mu(\phi))}{4} \frac{M_P^4}{\xi_h^2(\mu(\phi))(1-\sigma)^2} \left(1 - \sigma \cosh^2 \frac{\alpha\phi}{M_P}\right)^2$$

7. Inflationary observables are computed

Subtlety : Relation between Inflationary / physical masses

$$\mathcal{L}_F = \frac{y_f}{\sqrt{2}} h \bar{\psi}\psi \quad \longrightarrow \quad \tilde{\mathcal{L}}_F = \frac{y_f}{\sqrt{2}} \frac{h}{\Omega} \bar{\psi}\psi \equiv \frac{y_f}{\sqrt{2}} F(\phi) \bar{\psi}\psi$$

Subtlety : Relation between Inflationary / physical masses

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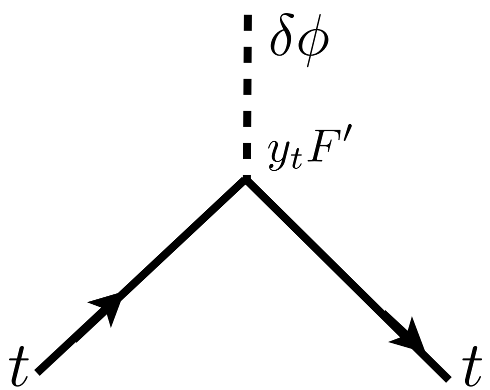
$$= \frac{y_t}{\sqrt{2}} F(\phi) \bar{\psi}_t \psi_t + \frac{y_t}{\sqrt{2}} \frac{dF(\phi)}{d\phi} \delta\phi \bar{\psi}_t \psi_t + \ldots$$

In a background field the coupling of the top to the Higgs pert. is proportional to F'.



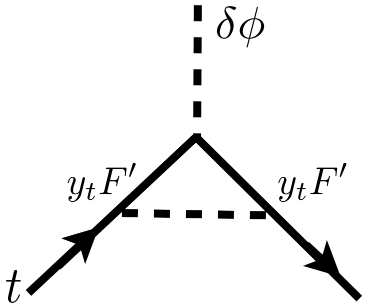
$F = h$	$F'(0) = 1$
$F = const.$	$F'(\phi_0) = 0$

Top quark contributions

To remove the divergencies, we must add counter terms to the action

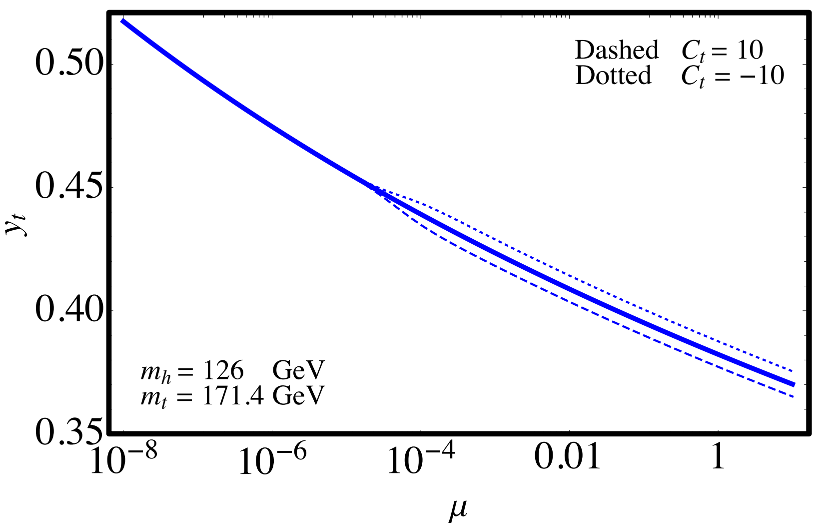
$F'(0) = 1$

$F'(\phi_0) = 0$



$$y_t \to y_t + \frac{y_t^3}{16\pi^2}\left(\frac{9}{4\epsilon} + C_t\right) F'^2$$

$$y_t^{\rm phys} = y_t + \frac{y_t^3}{16\pi^2} C_t \longrightarrow y_t$$



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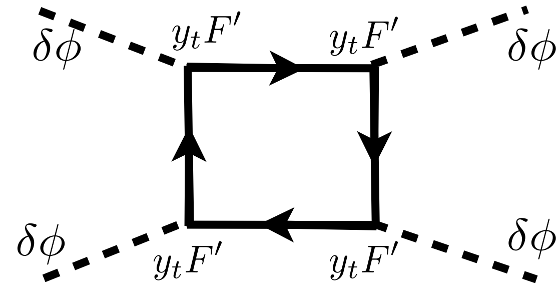
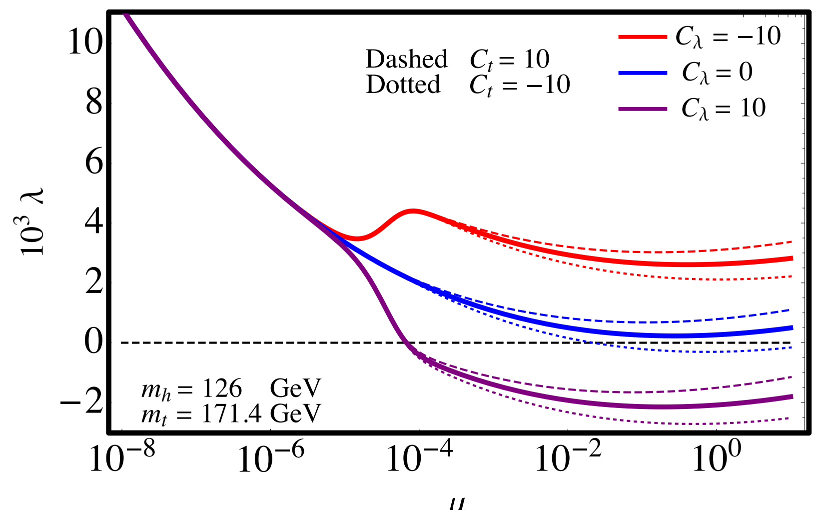
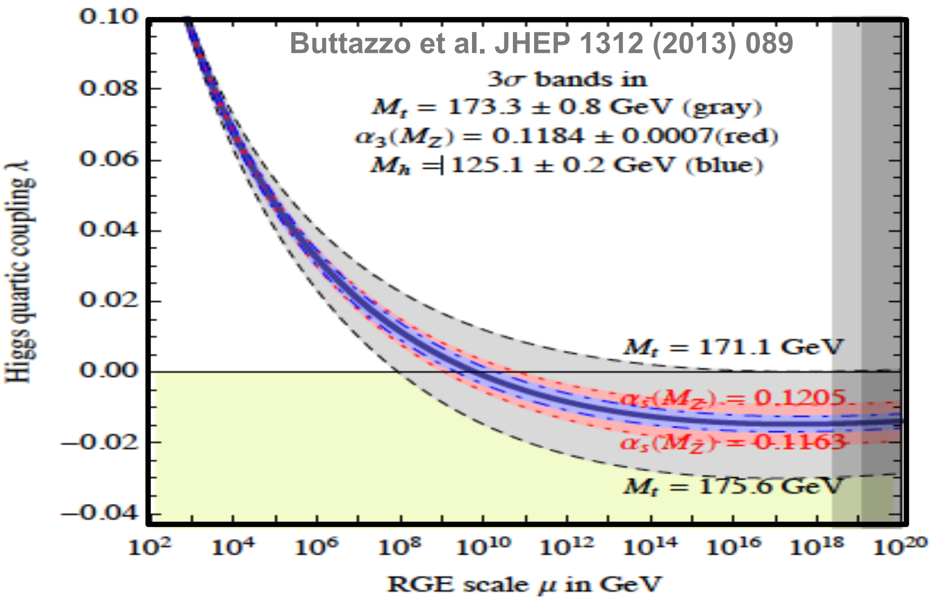


$$\lambda \to \lambda - \frac{y_t^4}{16\pi^2}\left(\frac{3}{\epsilon} - C_\lambda\right) F'^4$$

$$\lambda^{\rm phys} = \lambda - \frac{y_t^4}{16\pi^2} C_\lambda \longrightarrow \lambda$$



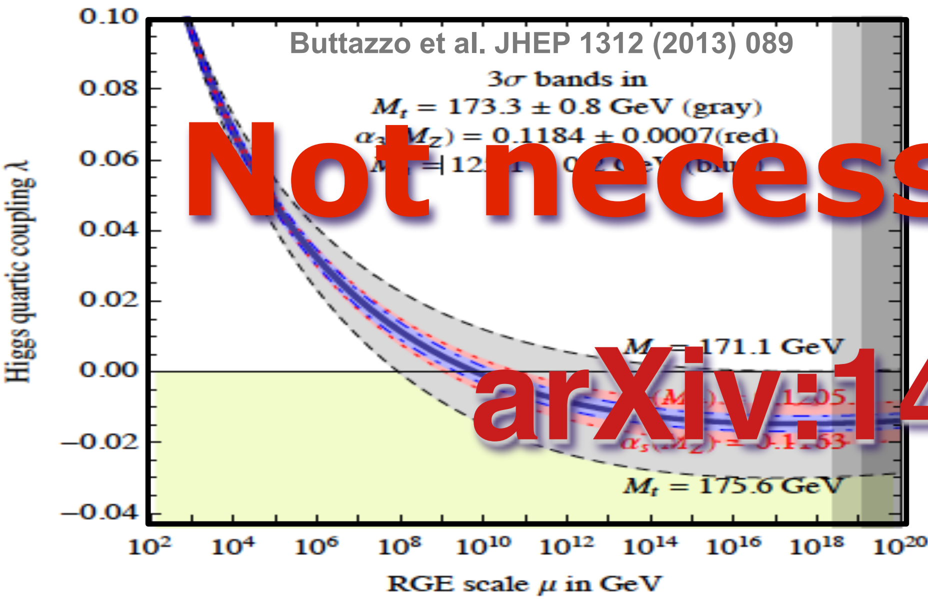
Vacuum stability vs inflation ?



It is often said that

"If m_h and m_t are close to the measured central value, Higgs inflation is not possible and V_{eff} becomes negative much before M_P"

Vacuum stability vs inflation ?

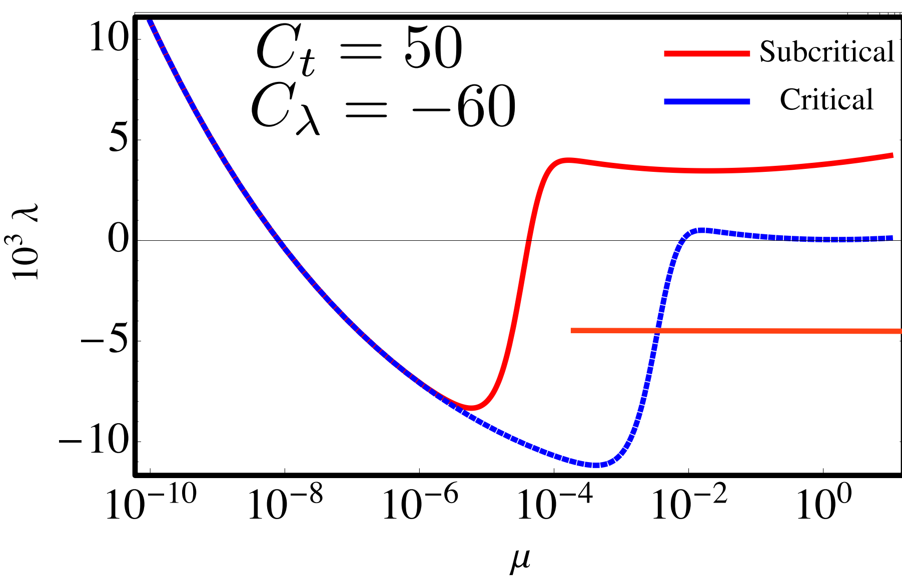


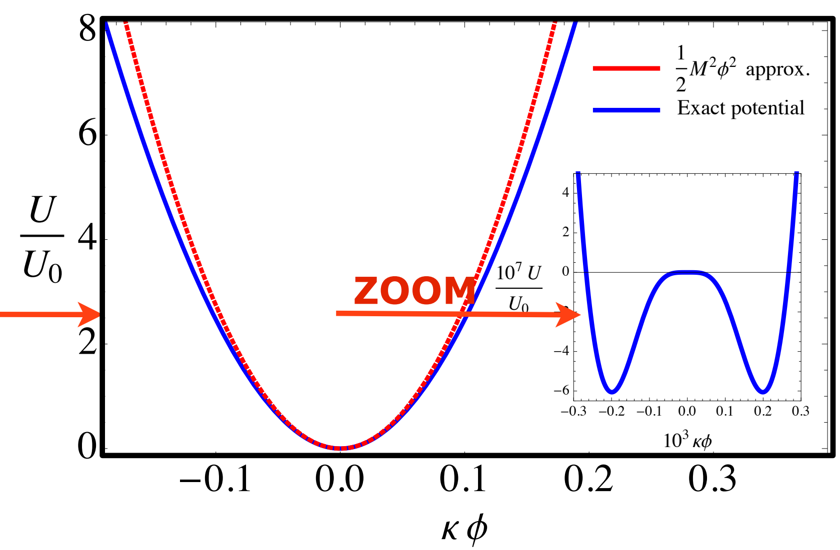
It is often said that

"If m_h and m_t are close to the measured central value, Higgs inflation is not possible and V_{eff} becomes negative much before M_P"

Not necessarily true!!!

arXiv:1410.XXXX





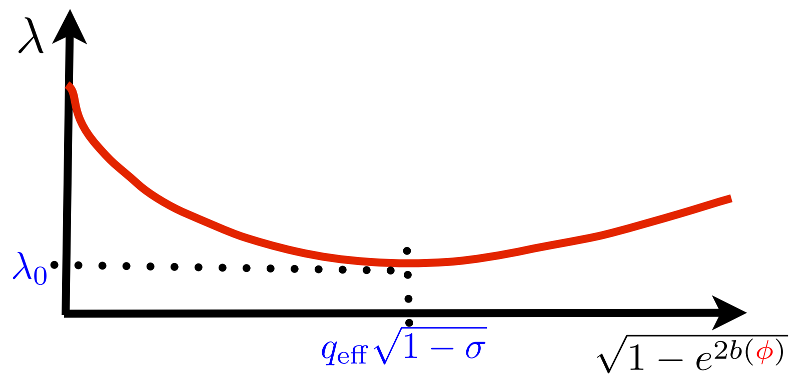
3 possibilities

$$\lambda(\mu(\phi)) = \lambda_0 + b\log^2\left(\frac{\sqrt{1-e^{2b(\phi)}}}{q_{\rm eff}\sqrt{1-\sigma}}\right)$$

$$\sigma \sim \xi_\chi \qquad b \simeq 2.3\times 10^{-5}$$

$$\lambda_0 = \lambda_0(m_h^*, m_t^*) \ll 1$$

$$q_{\rm eff} = q_{\rm eff}(m_h^*, m_t^*) \sim \mathcal{O}(1)$$



$$m^* - m \sim \text{few GeV} \quad \text{for} \quad C \sim 1$$

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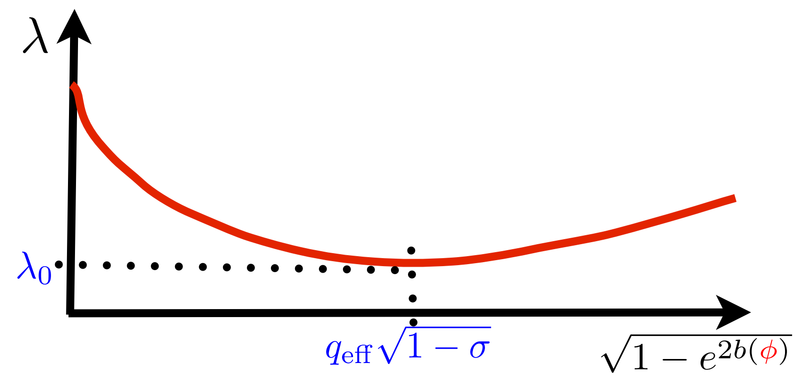

$m^* - m \sim$ few GeV for $C \sim 1$

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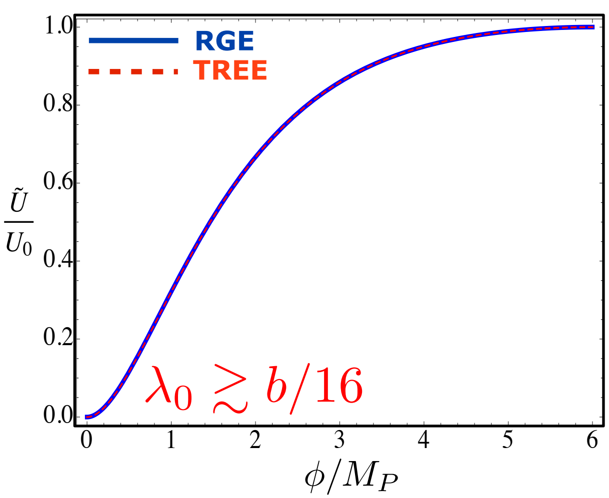

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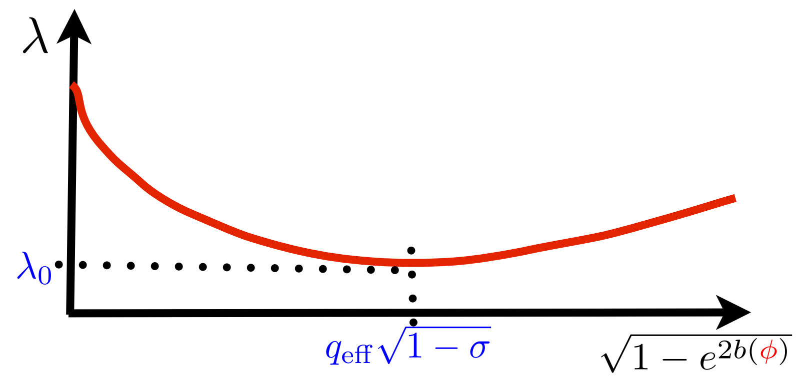

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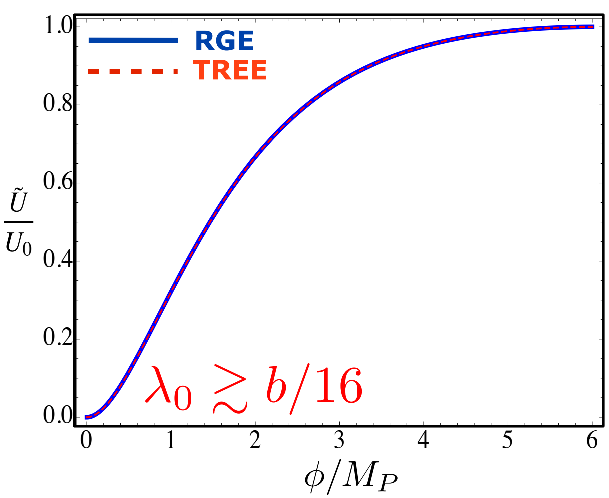
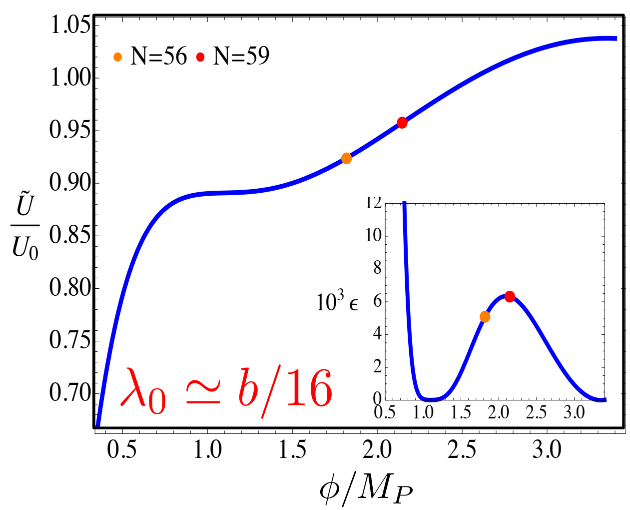


CRITICALITY



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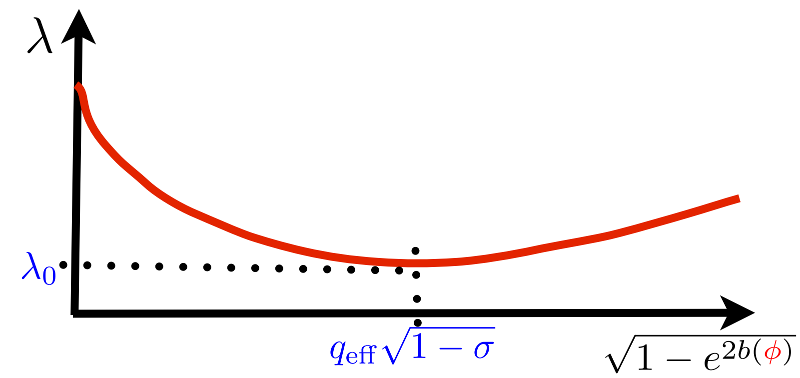

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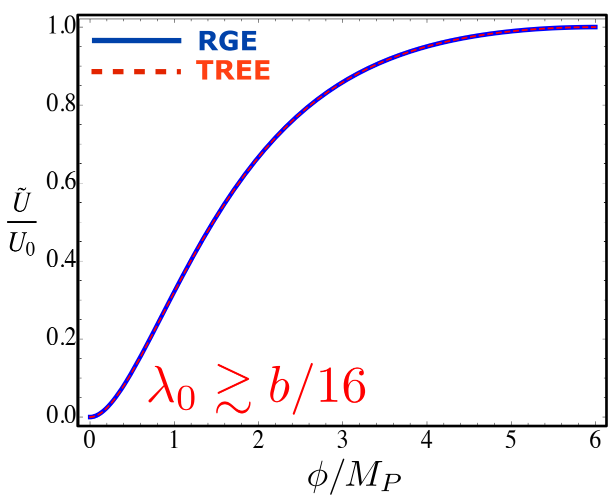

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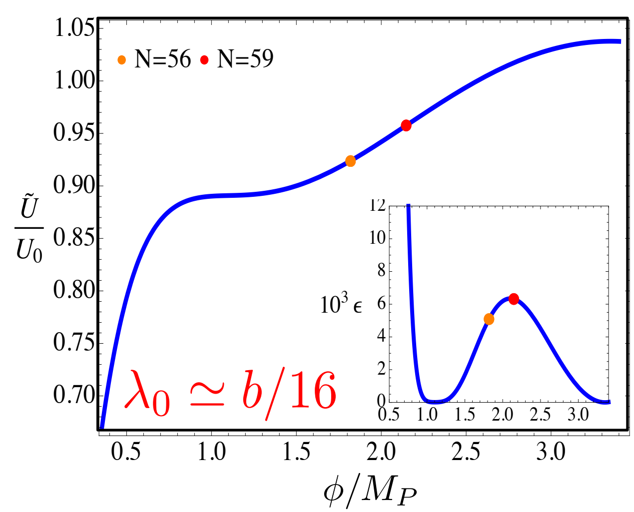
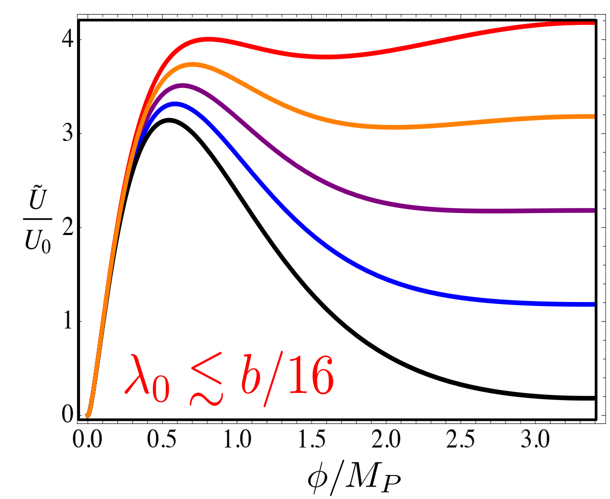


NO INFLATION



Universal HDI

$\lambda_0 \gtrsim b/16$ $\quad$ Only λ_0/ξ_h^2 is important

For masses slightly above the critical Higgs mass *

$$m_h^* > m_{\rm crit} - 0.1 \log \frac{\xi}{1000} GeV$$

$$m_{\rm crit} = [129.1 + \frac{y_t(173.2 \text{ GeV}) - 0.9361}{0.0058} \times 2.0] \text{ GeV}$$

Bezrukov et al. JHEP 1210 (2012) 140, Buttazzo et al. JHEP 1312 (2013) 089,

the predictions of the model are universal

$$n_s \leq 0.97 \qquad 0.0021 \leq r \leq 0.0034$$

$$-0.00057 \leq \frac{dn_s}{d\ln k} \leq -0.00034 \qquad 0 \leq 1 + w_{DE} \leq 0.014$$

* We take $\alpha_s(M_z) = 0.1184$

Critical HDI

$$\lambda(\mu(\phi)) = \lambda_0 + b\log^2\left(\frac{\sqrt{1-e^{2b(\phi)}}}{q_{\rm eff}\sqrt{1-\sigma}}\right)$$

4 restrictive observational inputs for 4 unknown parameters

$\lambda_0 \longleftrightarrow \mathcal{A}_s$

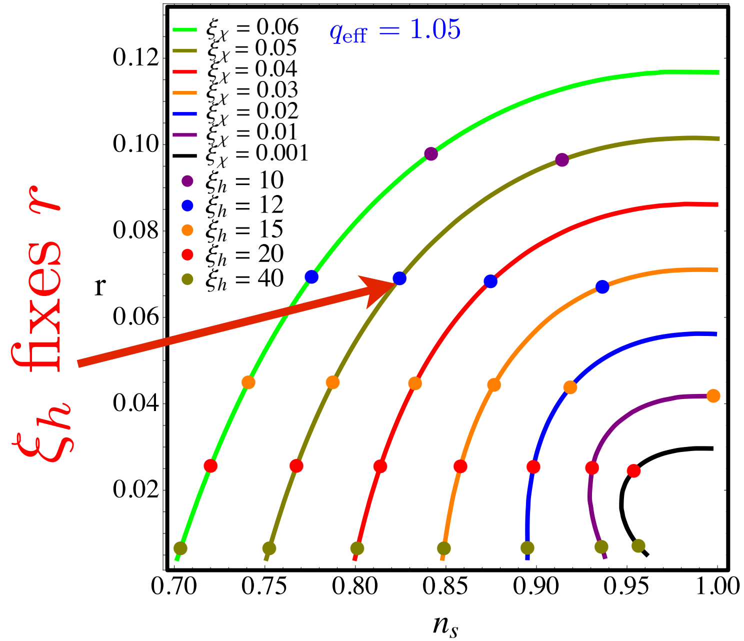
$\xi_h \longleftrightarrow r$

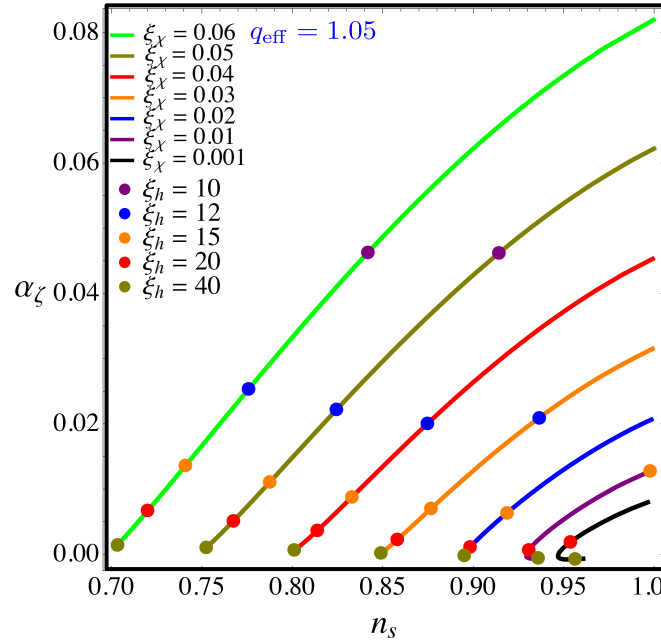
$\mathrm{DE} \longleftrightarrow \xi_\chi$

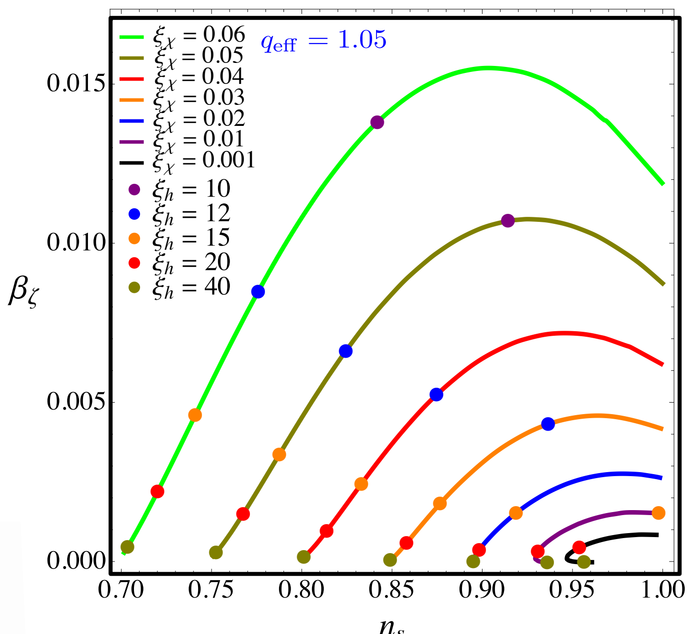
$m_h^*, m_t^* \longleftrightarrow q_{\rm eff}$

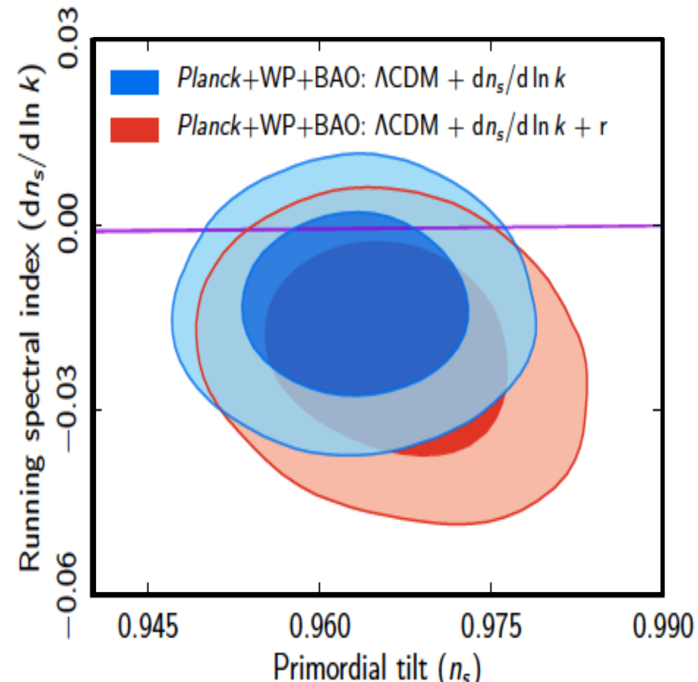
$\xi_\chi, q_{\rm eff} \longleftrightarrow n_s$

Critical HDI





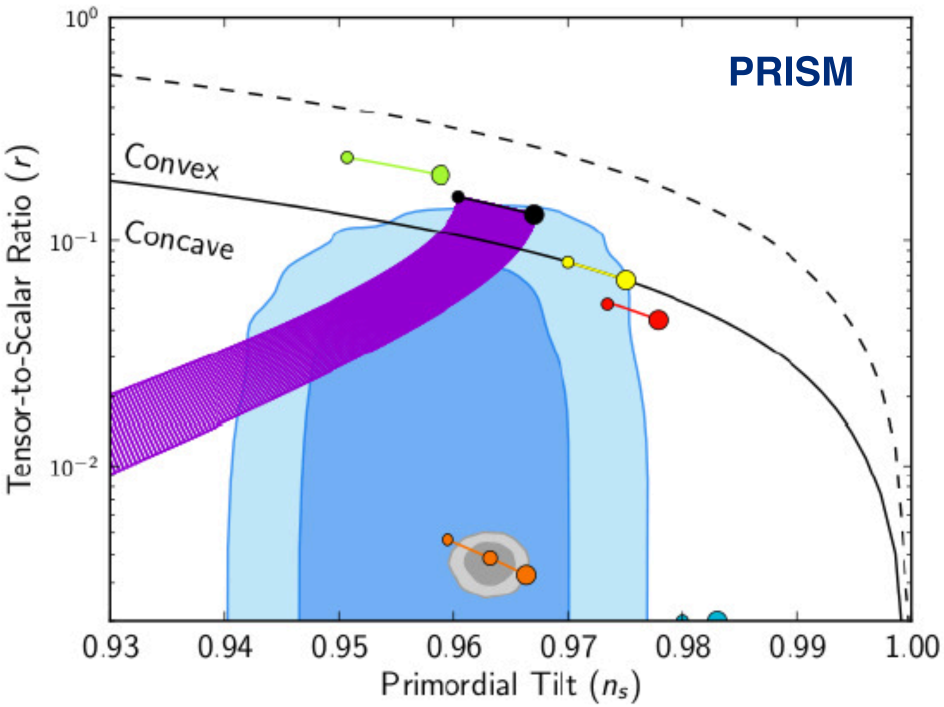




Comparison with observations requires further analysis

Is all this true?

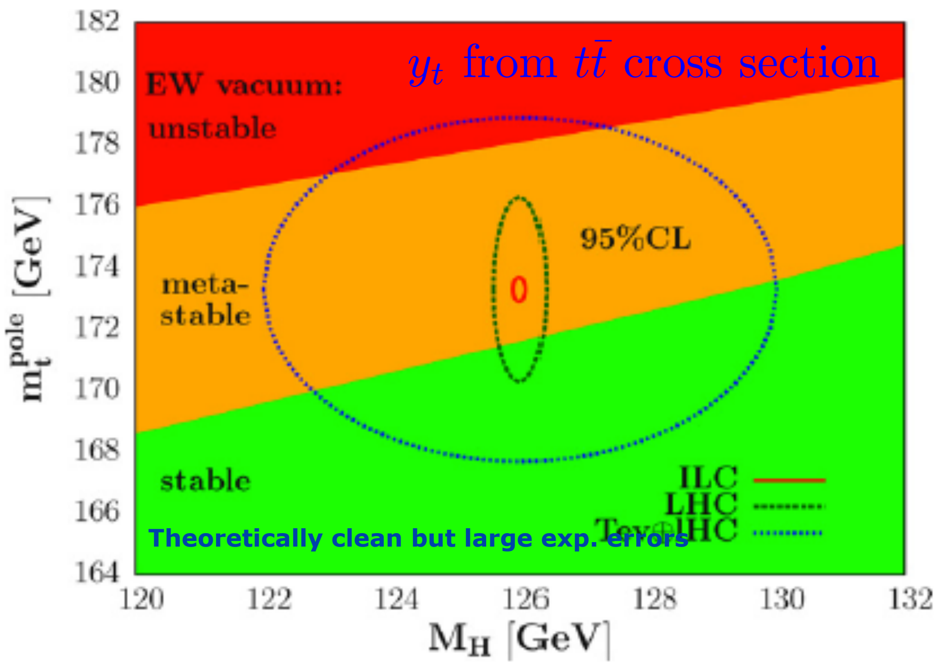
1. Determine the MS y_t
2. Determine the value of r
3. Determine ω_{DE}^{0}



- **Position in the phase diagram depends on the top mass**
- **The mass used (Tevatron + LHC average) is a "Pythia mass" extracted with template methods from decay products**
- **Yukawa is extracted from pole mass**

$\mathcal{O}(\Lambda_{\mathrm{QCD}})$ uncert.

$m_t^{\mathrm{pole}} = m_t^{\mathrm{MC}}$??



Some numbers

$w_{\rm DE}^0 \simeq -0.95$	$r \simeq 0.05$	$10^9 \mathcal{A}_s \simeq 2.2$	$n_s \simeq 0.96$
$\xi_\chi \simeq 0.02$	$\xi_h \simeq 13.2$	$10^6 \lambda_0 \simeq 1.46$	$q_{\rm eff} = 1.05$

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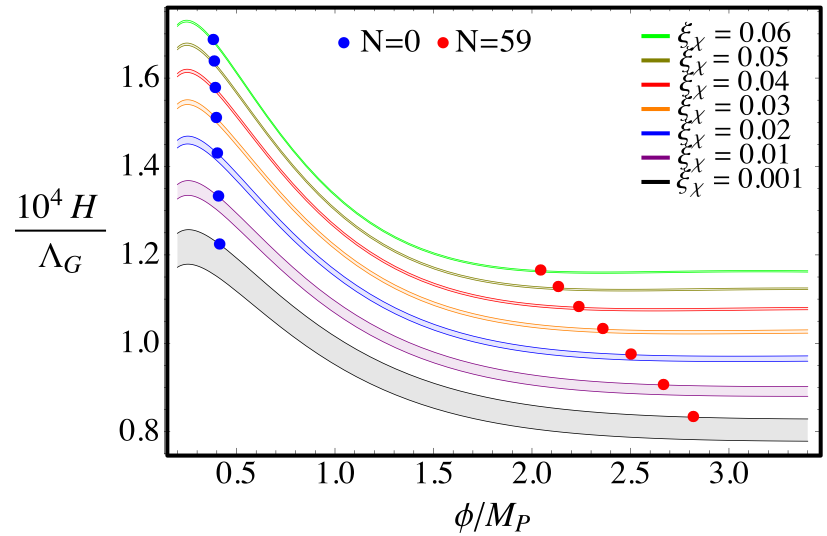
No additional scales

$$\frac{M_P}{\xi} \sim \frac{M_P}{\sqrt{\xi}} \sim M_P$$



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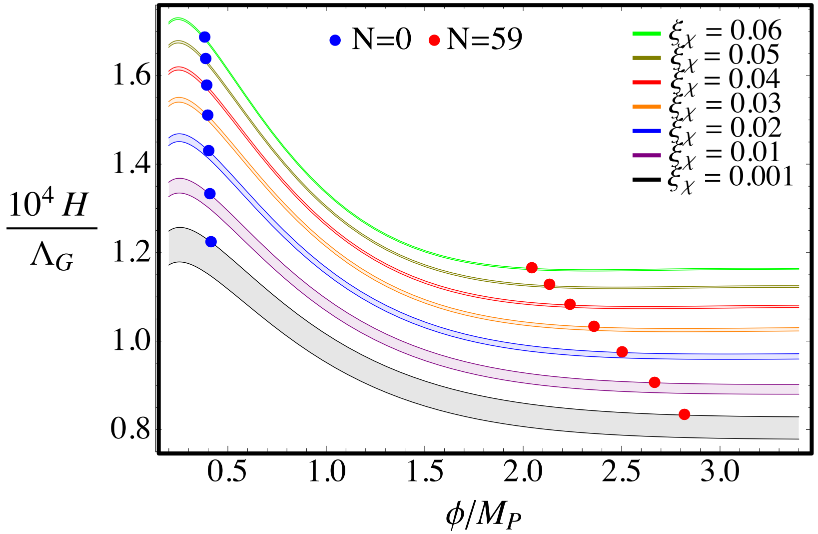

Remember that $\lambda_0 = \lambda_0(m_h^*, m_t^*)$ $q_{\mathrm{eff}} = q_{\mathrm{eff}}(m_h^*, m_t^*)$

$m_h^* \simeq 122.9$ GeV	$m_h \simeq 125.6$ GeV	$C_t \simeq 2C_\lambda \simeq 1.6$
$m_t^* \simeq 169.9$ GeV	$m_t \simeq 171.5$ GeV	

Conclusions

Higgs-Dilaton Cosmology: A scale-invariant extension of SM

- ✓ Massless dilaton: unique source for SM particle masses / scales
- ✓ Naturally gives single field inflation with a graceful exit
- ✓ Dark energy without a cosmological constant
- ✓ A consistent EFT if the UV completion respects scale invariance

UNIVERSALITY

$$0.0021 \leq r \leq 0.0034$$

$$-0.00057 \leq \frac{dn_s}{d\ln k} \leq -0.00034$$

$$0 \leq 1 + w_{DE} \leq 0.014$$

✓ Non-trivial relations between inflationary and DE observables

CRITICALITY

$$r \sim \mathcal{O}(0.1)$$

$$\frac{dn_s}{d\ln k} \sim \mathcal{O}(0.01)$$

$$1 + w_{DE} \sim \mathcal{O}(0.1)$$

✓ Higg & top masses close to the vacuum instability values