Higgs and Inflation

Oleg Lebedev

DESY, Hamburg

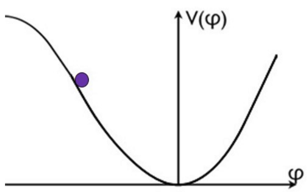
Plan :

- Higgs inflation
- stability of EW vacuum
- Higgs portal
- Higgs-inflaton interaction

Higgs inflation

Need a scalar field with a flat potential ⇨ **Higgs** ???

$$V \sim \lambda\ H^4$$



$$\varepsilon \sim (V'/V)^2\ M_{pl}^2 \gg 1$$

But the Higgs coupling to gravity is unknown ...

Bezrukov, Shaposhnikov '07

$$\Delta L = c\,|H|^2 R$$

$c \gg 1$

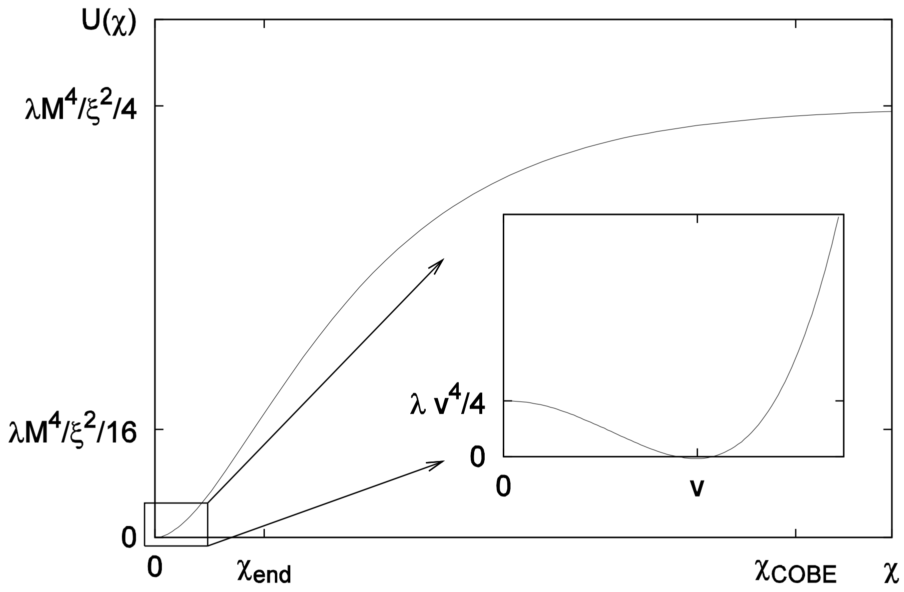
Conformal transformation to the Einstein frame :

$$g_{\mu\nu} \longrightarrow f(H)\, g_{\mu\nu} \quad , \quad f(H) = 1 + c|H|^2/M_{Pl}^2$$

Canonically normalized ``Higgs'' χ :

$$H = \text{const} \;\exp(\chi / M_{Pl})$$

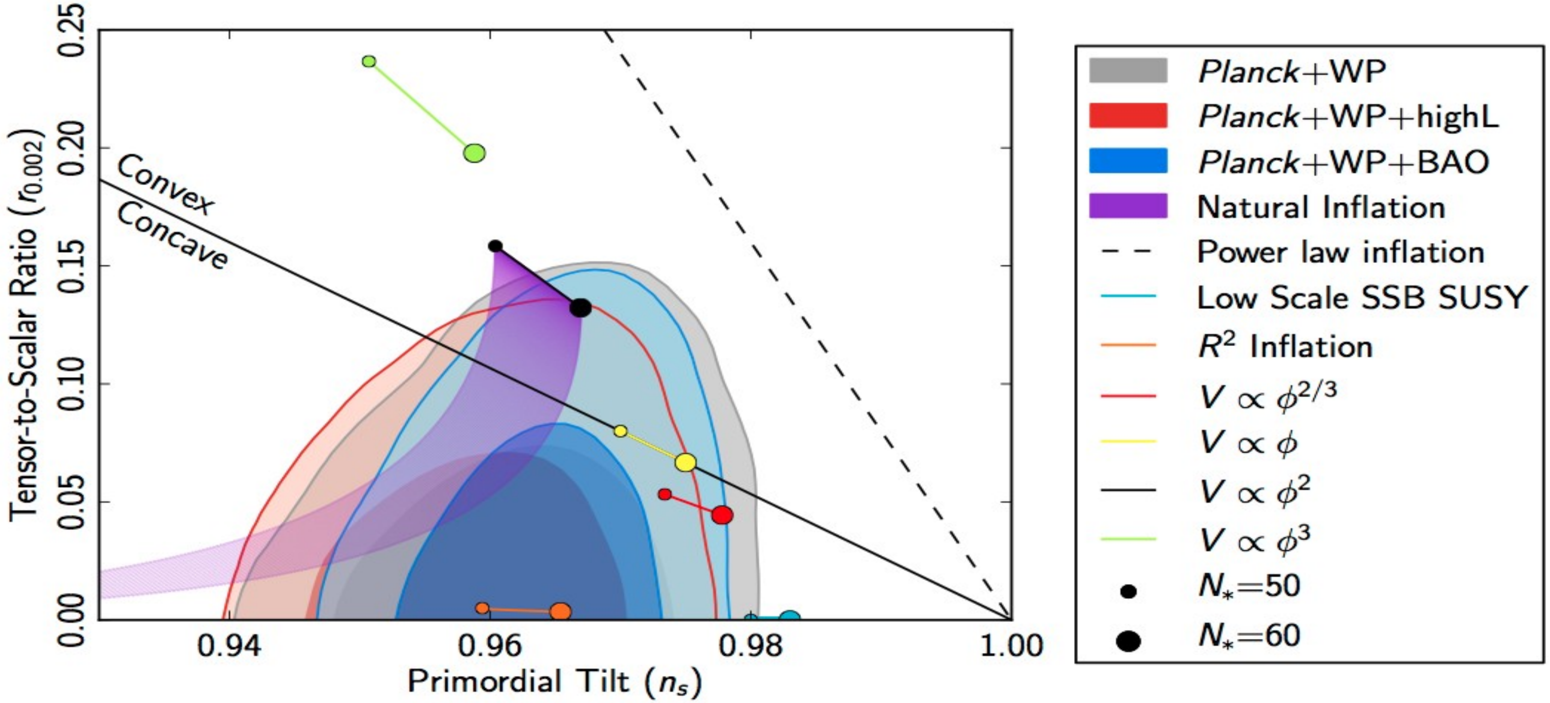
$$V = \text{const}\;[\,1 - 2\exp(-2\chi / M_{Pl})\,]$$



Inflation at $\chi \sim M_{Pl}$!

Preferred Higgs mass range 130 – 180 GeV

(problem ?)

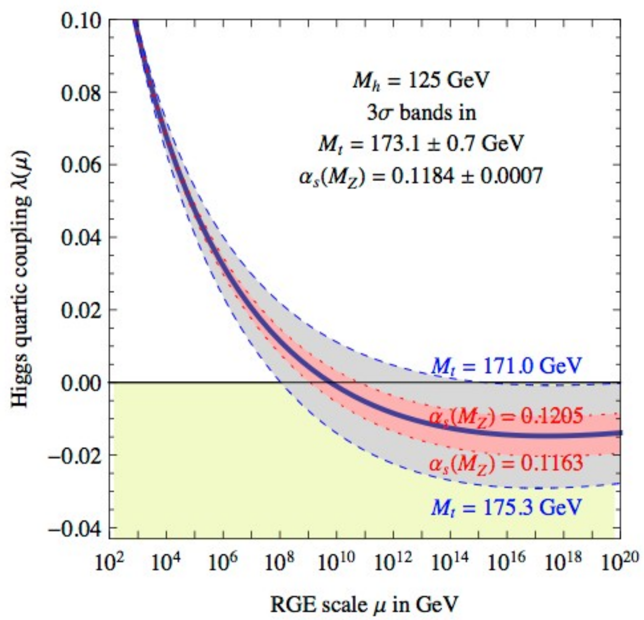


Tensor-to-Scalar Ratio ($r_{0.002}$)
Primordial Tilt (n_s)
0.00
0.05
0.10
0.15
0.20
0.25
0.94
0.96
0.98
1.00
Convex
Concave
Planck+WP
Planck+WP+highL
Planck+WP+BAO
Natural Inflation
Power law inflation
Low Scale SSB SUSY
R^2 Inflation
$V \propto \phi^{2/3}$
$V \propto \phi$
$V \propto \phi^2$
$V \propto \phi^3$
N_*=50
N_*=60

Stability of EW vacuum

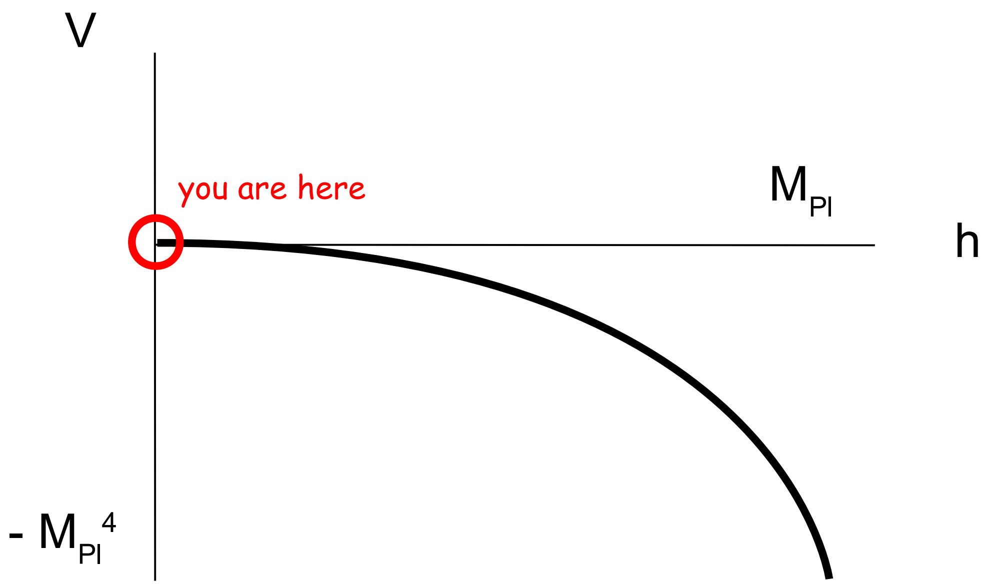
Degrassi et al.'12

SM stability bound: $m_h >$ 126 GeV at 98% CL



(not settled : Alekhin et al. '12
Bezrukov et al. '12)

$h >> \Lambda \sim 10^{10}$ GeV ⇨ $V \sim \frac{1}{4} \lambda(h)\, h^4$, $\lambda(h) < 0$



$\Lambda = 10^{-8}\, M_{Pl}$, barrier = $10^{-32}\, M_{Pl}^4$

⇒ Higgs inflation disfavored

OL, Westphal ' 12

NEW Problems:

- how did the Universe end up at $h \sim 0$?
- why did it stay there during inflation ?

Higgs portal

Key to the hidden sector :

- ✓ E_8 X E_8 strings

  observable   hidden

- ✓ dark matter , inflaton

- ✓ ...

Special role of the Higgs :

Silveira, Zee '85
Veltman, Ynduraín '89
...

$|H|^2$ = the only gauge and Lorentz-inv. dim-2 operator

$$L = a\,|H|^2 S^2 + b\,|H|^2 S$$

(S = "hidden" scalar)

b=0 (S has hidden charge):

$$\boxed{L = a\,|H|^2 S^2}$$

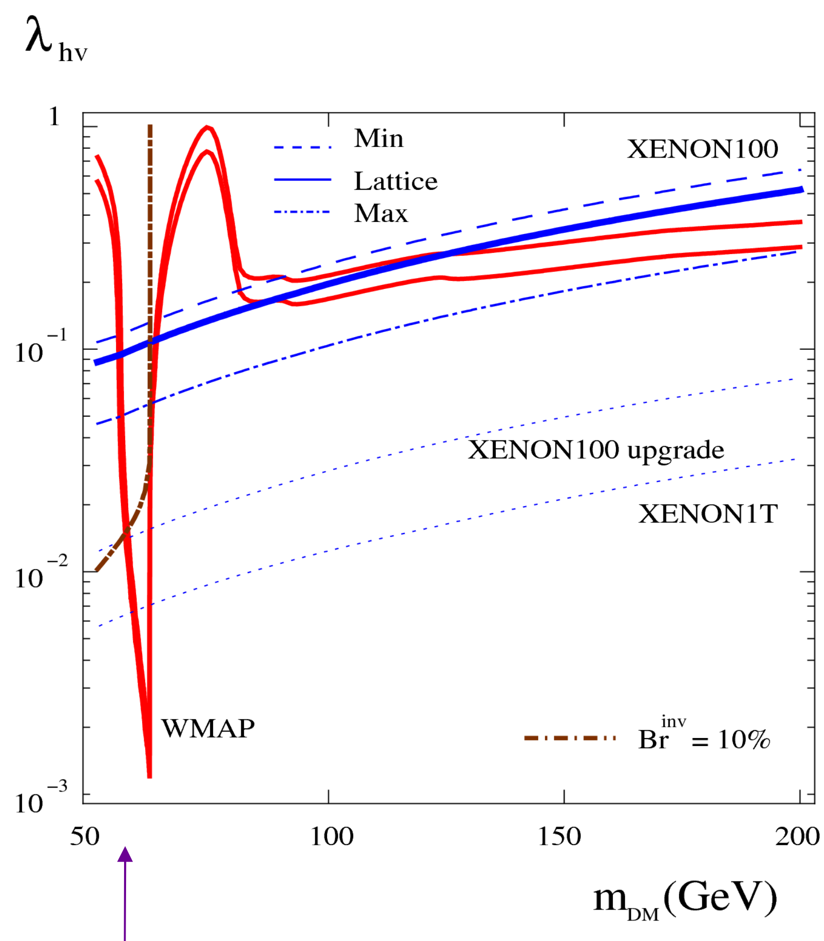
"S" is stable and couples weakly to SM --> DARK MATTER (?)

DM constraints :

WMAP: annihilation cross section
XENON : DM-nucleon interaction
LHC : invisible Higgs decay

Djouadi, OL, Mambrini, Quevillon '11
OL , Lee , Mambrini '11

Higgs-vector coupling



LHC: m_{DM} > 60 GeV

Stabilization through a coupling to a singlet:

Low energy states :

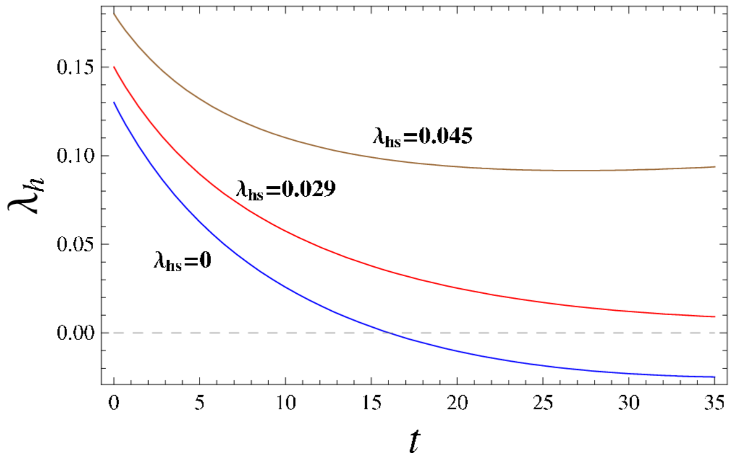
$$\begin{cases} H_1 = H\cos\theta + S\sin\theta \\ H_2 = H\sin\theta - S\cos\theta \end{cases}$$

OL '12
Elias-Miro et al. '12

If <S> >> 246 GeV ,

$$\begin{cases} \theta \to 0 \qquad \text{(SM—like Higgs)} \\ m_h^{\,2} = 2\,v^2\,[\,\lambda_h - \lambda^2_{hs}/(4\lambda_s\,)] \end{cases}$$

Stability :



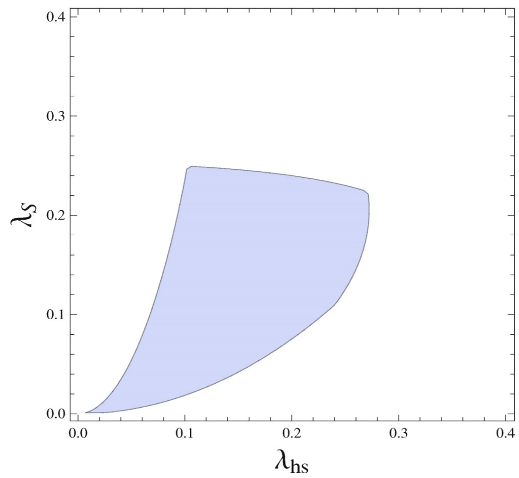
$\lambda_s = 0.01$
$t = \ln(\mu/m_t)$

⇨ *a (very) weakly coupled singlet can stabilize the EW scale*

Higgs inflation constraints:

$$\Delta L = \lambda_{hs} |H|^2 S^2 + \lambda_s S^4 + \xi |H|^2 R$$

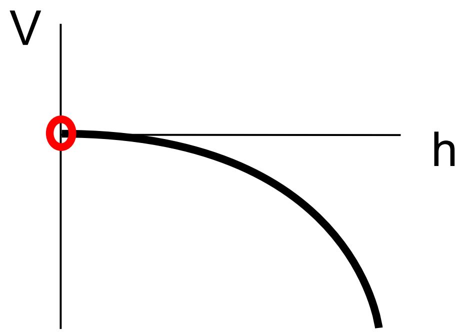
$$\begin{cases} \lambda_i (M_{INF}) > 0 \\ \lambda_i (M_{INF}) < O(1) \end{cases}$$



OL '12

Higgs-inflaton interaction

EW vacuum is metastable, what's a problem ?



In the Early Universe, the Higgs potential could be different :

always expect a coupling $\sim h^2 \phi^2$

OL, Westphal ' 12

$$\Delta V = \tfrac{1}{2}\, \xi\, h^2 \phi^2$$

$\Delta V_{1\text{-loop}} << V_{infl}$: $\xi \sim 10^{-6}$

$\Delta V + V_{Higgs} > 0$: $\phi_0 \sim 20\, M_{Pl}$

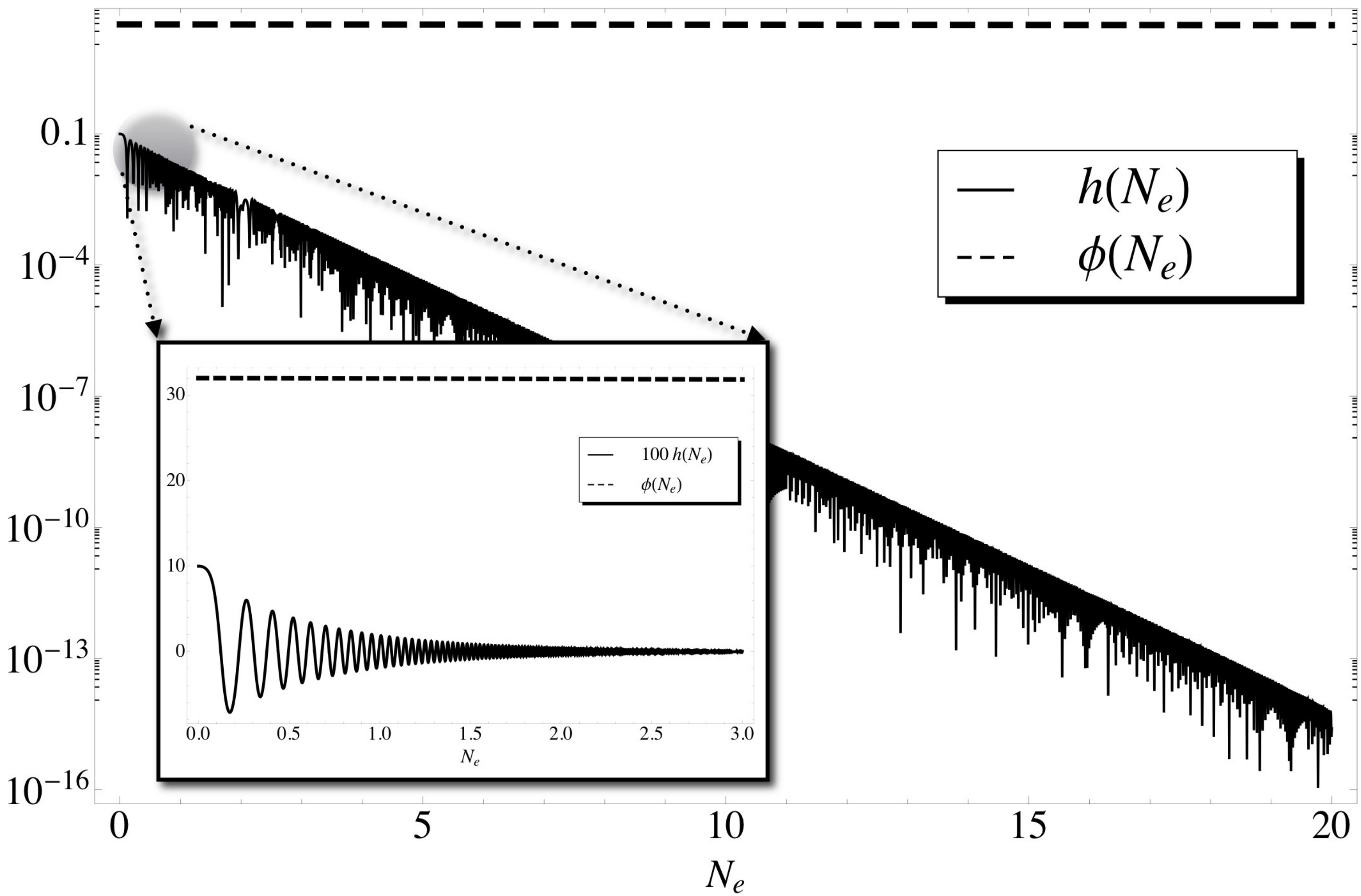
Large effective mass

⇩

$h(t) \sim h(0) \exp(-\, 3/2\, \mathbf{H} t)$

Higgs field is driven to zero during inflation !

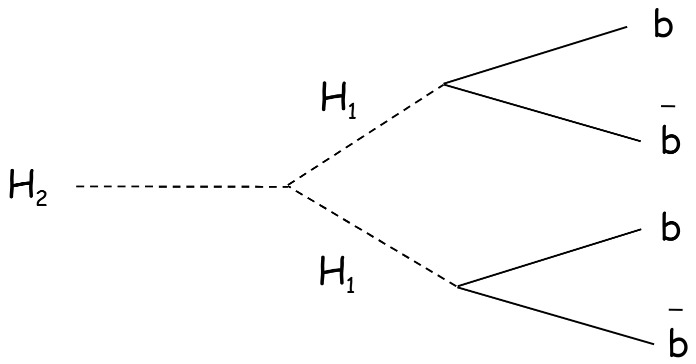
Higgs/inflaton evolution (in M_{Pl}):



⇨ *Higgs-portal coupling favored by cosmology*

Possible low-energy signatures :

- 2 Higgs-like states H_1 , H_2
- suppressed couplings
- cascades



Conclusion

- Higgs inflation possible, but ...

- EW vacuum likely metastable (or NP)

- Higgs initial conditions/stability problems

- Higgs-inflaton coupling is favored