Cosmological constraint on the mass of Higgs boson in the Standard Model minimally coupled to the gravity

V.V.Kiselev, *S.A.Timofeev*

Institute for High Energy Physics (Protvino)   Russia   Moscow Institute of Physics and Technology

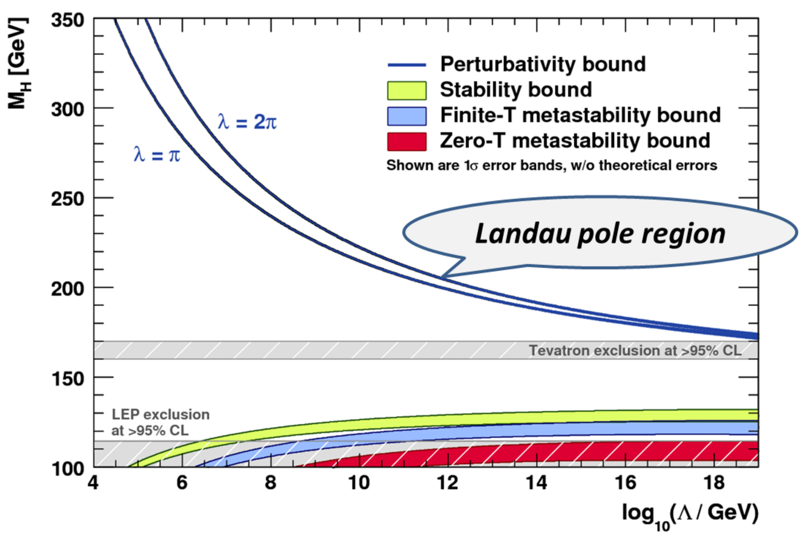
Known high-virtuality bounds on the mass of Higgs boson in SM

(figures taken from arXiv:0906.0954v1 [hep-ph], J.Ellis et al.*)*

$\boldsymbol{129 \le m_H \le 175\ GeV}$

Uncertainty = 1 GeV

Reaching the Landau pole involves ***arbitrary amplitudes*** *of processes!*



Inflation

- Scalar fields: inflation $H - H_c \sim \ln a(t)$

  Hubble constant   scale factor

  (zero curvature of space, homogeneity, …)

- Fluctuations of scalar field:
  1. Inhomogeneity of matter, Large scale structure of Universe (LSS)
  2. Anisotropy of cosmic microwave background radiation (CMBR)

Quantum gravity fluctuations in cosmology

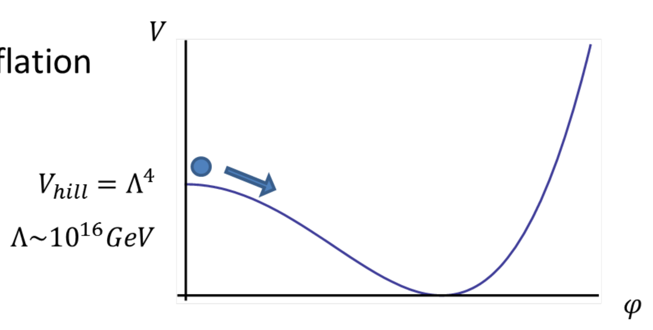
What is the curvature of de Sitter space, when quantum effects of gravity become essential?

- *Action:* $S = \frac{1}{6GH^2}$ $\Rightarrow$ *Quantum amplitude* $\Psi \sim e^{iS/\hbar}$
- *Number of waves* $\delta S = 2\pi$

  $\frac{S}{2\pi} = 1 \Rightarrow \boxed{\lambda = \frac{1}{6}}$
- *Confidence level* $\chi^2 = 2n \Rightarrow \chi^2 = 2$

New scenario of inflation & Higgs boson

- Hilltop inflation



- Energy density greater than $V_{hill} = \Lambda^4$ is due to the excited Higgs field:
  - sub-critical Higgs field produces its own inflation,
  - Inhomogeneity is definite before the inflation,
  - Super-critical field involves *arbitrary* spectrum of inhomogeneity

Inflation by the Higgs scalar

- Potential $V = \lambda(\phi^2 - \cancel{v}^2)^2/4$
- Scaling variables (**kinetic & potential**) $\kappa^2 = 8\pi G$

$$x = \frac{\kappa}{\sqrt{6}}\frac{\dot{\phi}}{H}, \qquad y = \sqrt[4]{\frac{\lambda}{12}}\frac{\kappa\,\phi}{\sqrt{\kappa H}},$$

- Parameter $z = \frac{\sqrt[4]{3\lambda}}{\sqrt{\kappa H}},$

Method:
L. A. Urena-Lopez and M. J. Reyes-Ibarra, Int. J. Mod. Phys. D **18**, 621 (2009) [arXiv:0709.3996 [astro-ph]]

- Equations of motion $N = \ln a_{\text{end}} - \ln a$

$$x' = -3x^3 + 3x + 2y^3 z, \qquad y' = -\frac{3}{2}x^2 y - xz,$$

- **Parametric attractor** *x′=y′=0*   *x(z), y(z)*
- **Driftage** $z' = -\frac{3}{2}x^2 z$
- Criteria of stability (the end of inflation)

  $\boxed{2\pi\, G\, H^2 = \lambda}$
- $\lambda \sim 1 \Rightarrow H \sim M_{Pl}$ *(inflation is not possible)* ***Linde(1982)***

Renormalization group (2 loops)

- Scale $\lambda(\mu)$, $\mu = ?$
  1. Field $\mu = \varphi$
  2. Energy density $\rho = \mu^4$
  3. Virtuality $\mu^2 = m^2 - p^2$

  $\Rightarrow 3 \times 10^{18}$ *GeV*

- *Initial data of evolution*

$$\begin{aligned} m_Z &= 91.1873 \pm 0.0021 \text{ GeV}, \\ m_t &= 170.9 \pm 1.9 \text{ GeV}, \\ \alpha_{\text{em}}^{-1}(m_Z) &= 127.906 \pm 0.019, \\ \alpha_s(m_Z) &= 0.1187 \pm 0.0020, \\ \sin^2\theta_W &= 0.2312 \pm 0.002, \end{aligned}$$

- mass

$$\lambda(m_t) = \frac{m_H^2}{2v^2}(1 + \Delta_H),$$

$$h_t(m_t) = \frac{\sqrt{2}}{v} m_t (1 + \Delta_t),$$

corrections

- ***Result***

$$m_H = 150 + 0.28 \cdot \ln\frac{10^{18}}{\mu} - 0.19 \cdot \frac{\alpha_s - 0.1187}{0.002} + 2 \cdot \frac{m_t - 171}{2} \pm 2 \text{ GeV}$$

loops

Decoupling mass interpretation

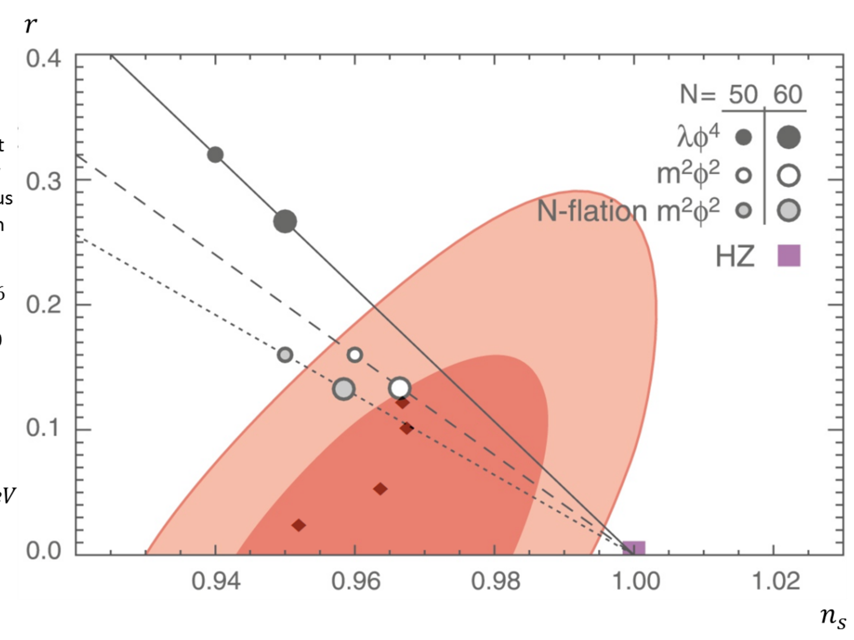
- *Super-critical field: no inflation, inhomogeneity is* ***arbitrary (not predictable)***
- *Sub-critical field: higgsian inflation generates the definite inhomogeneity, but inconsistent with observations* $\Rightarrow$ *inflaton field is necessary*

Fraction of tensor-spectrum of inhomogeneity $\boldsymbol{r}$ **versus the spectral index** $\boldsymbol{n_s}$

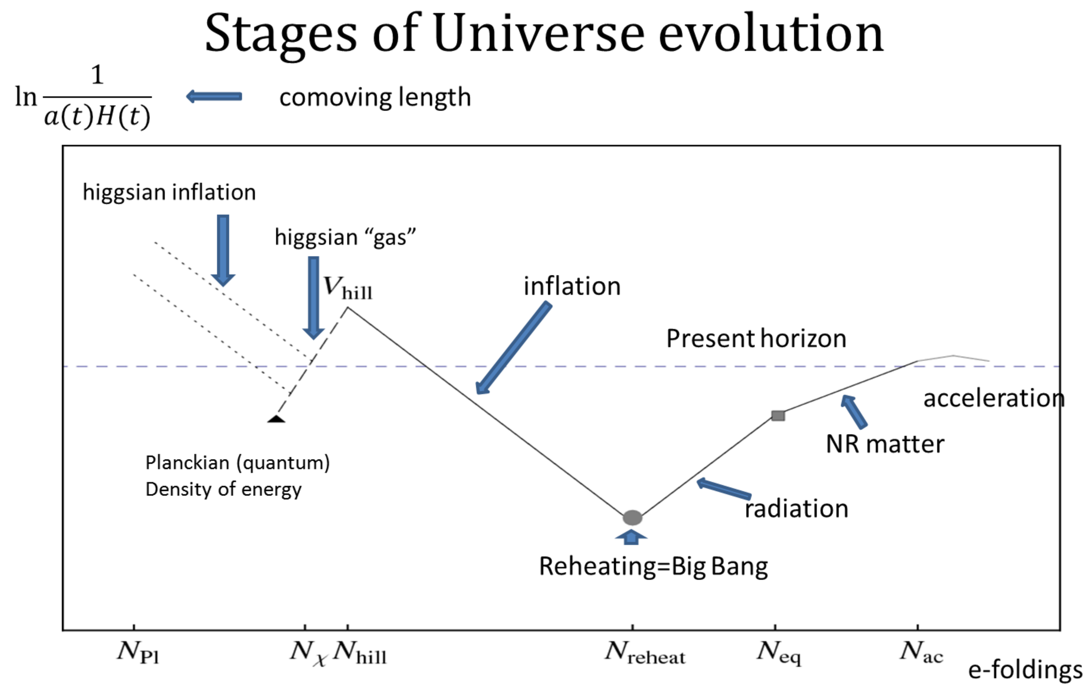
WMAP data in comparison with models
(from arXiv:1001.4538v2 [astro-ph.CO], E.Komatsu et al.*)*

Diamonds represent the scenario of new inflation with various vacuum expectation values of inflaton:
$\frac{v}{m_{Pl}}$ =2.8, 4, 7.4, 24.6 (to larger r) at N=60

Inflaton mass
$m \approx 1.4 \cdot 10^{13}\ GeV$



Stages of Universe evolution



Constraint excluding the super-critical mass

$$\boldsymbol{129 \le m_H \le 153\ GeV}$$

- Cosmological role of Higgs scalar is *predictable*
- *Arbitrary* spectrum of inhomogeneity produced by the Higgs boson is excluded
- The Landau-pole constraint is strengthened by the bound of decoupling

  $\lambda(\mu_{\text{pole}}) = \infty \ \mapsto\ \lambda_c(m_{Pl}) = \frac{1}{6}$