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

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Introduction

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

Hubble constant

scale factor

(zero curvature of space, homogeneity, …)

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

- Inflaton:

$$m \sim 10^{13}\ \text{GeV}, \qquad \lambda \le 10^{-13}, \qquad v \ge 10\ M_{Pl}$$

- Higgs boson:

$$114\ \text{ГэВ} < m_H < 185\ \text{GeV}, \qquad v \approx 246\ \text{GeV},$$

The Higgs boson is not successful for the generation of observed inflation

Question:

Why does the Higgs boson not generate the inflation?

(problem of the preference for the inflaton)

Answer: ***if the mass of Higgs boson exceeds a threshold value, the Higgs scalar is not able to cause the inflation***

Inflation (Higgs scalar)

- Potential $$V = \lambda(\phi^2 - \cancel{v}^2)^2/4$$

- Scaling variables $$\kappa^2 = 8\pi G$$

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

- 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 $N = \ln a_{\rm end} - \ln a$

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

- Parametric attractor *x'=y'=0* *x(z), y(z)*

- Driftage $z' = -\frac{3}{2}x^2 z$

- Criteria of stability (the end of inflation)

$$2\pi\, G\, H^2 = \lambda.$$

- $\lambda \sim 1 \implies H \sim M_{Pl}$ *(inflation is not possible)* ***Linde(1982)***

Quantum gravity fluctuations in cosmology

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

- *Action* $S = \frac{1}{6GH^2}$ $\delta S = 2\pi$

- *Number of waves* $\frac{S}{2\pi} = 1 \implies \lambda = \frac{1}{6}$

- *Confidence level* $\chi^2 = 2n$

Cosmological constraint: tree approximation

$$m^2 = 2\lambda v^2$$

$$m > \frac{v}{\sqrt{3}} = 142.3 \quad GeV$$

Renormalization group (2 loops)

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

3×10^{18} *GeV*

- *Initial data of evolution*

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

- 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***

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

loops

Conclusion

- *The Higgs scalar (min.SM)*

is not able to produce any inflation of Universe,

if it is heavier than

$$m_H^{\min} = 150 \pm 3 \text{ GeV}$$

- *Parametric attractor in the inflation*
- *Border of quantum gravity fluctuations in cosmology*
- *Renormalization group*