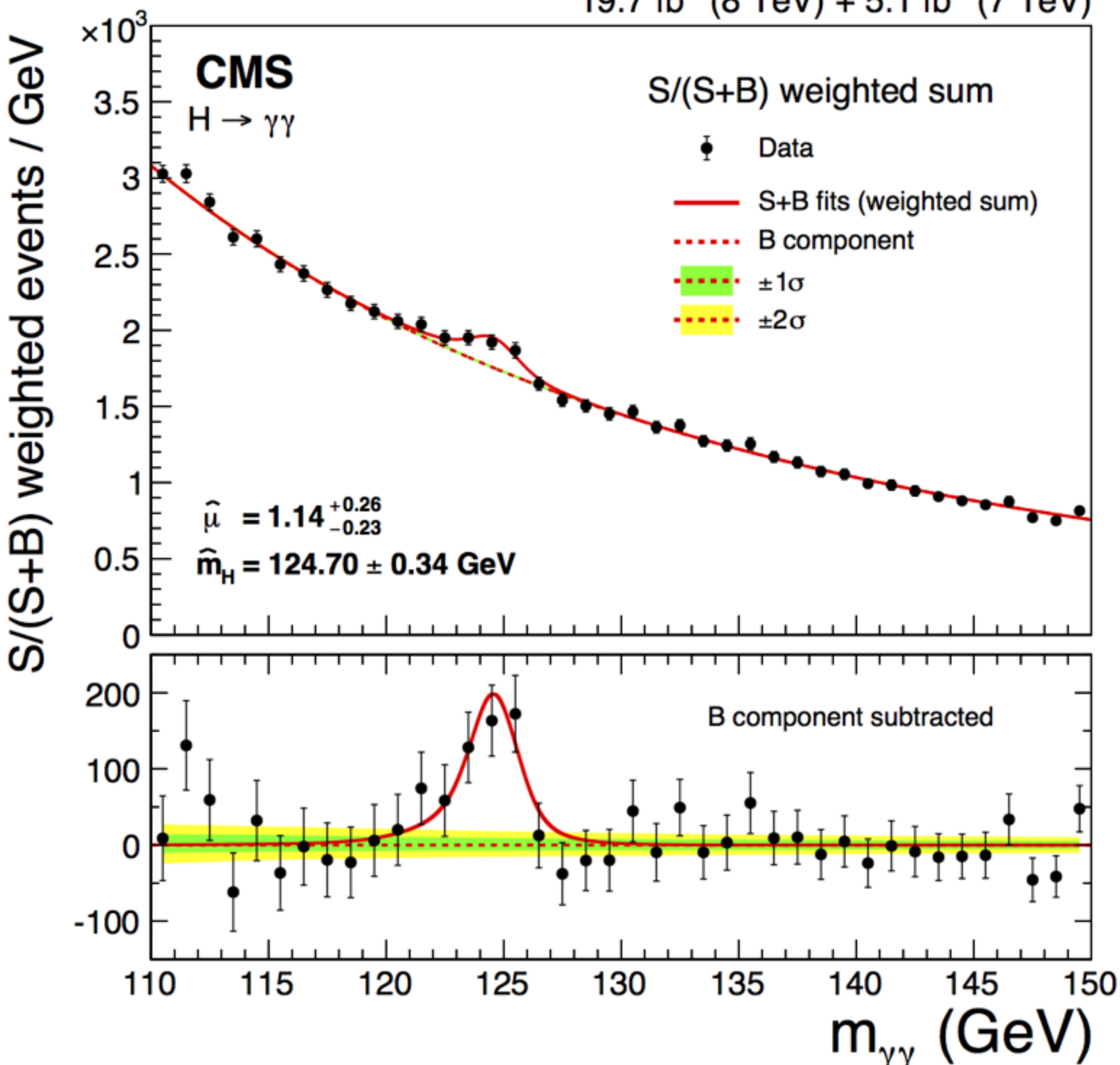
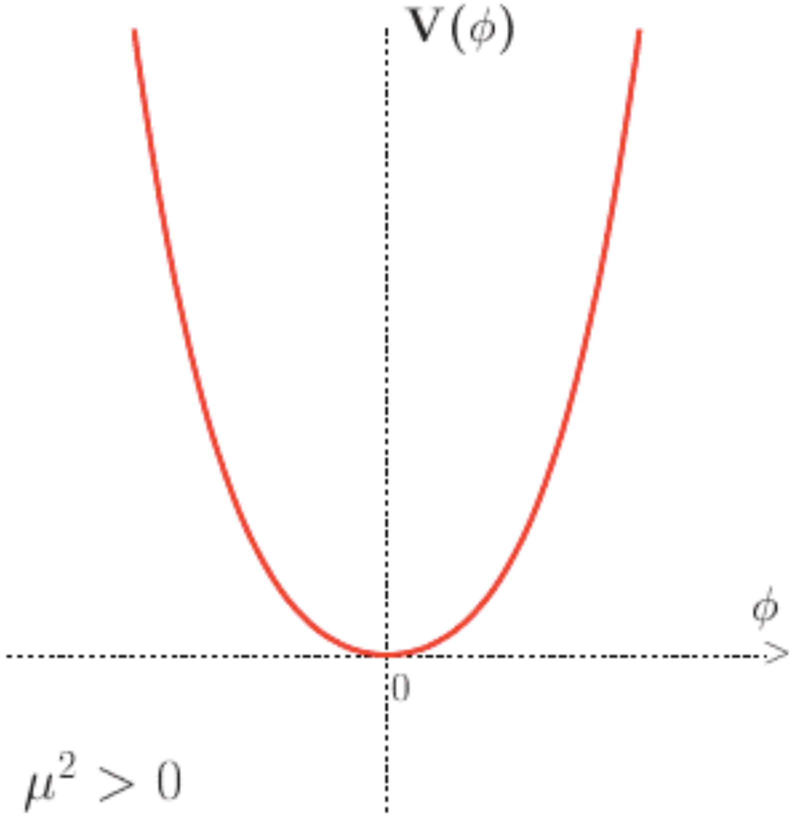
How does the Higgs potential survive Inflation

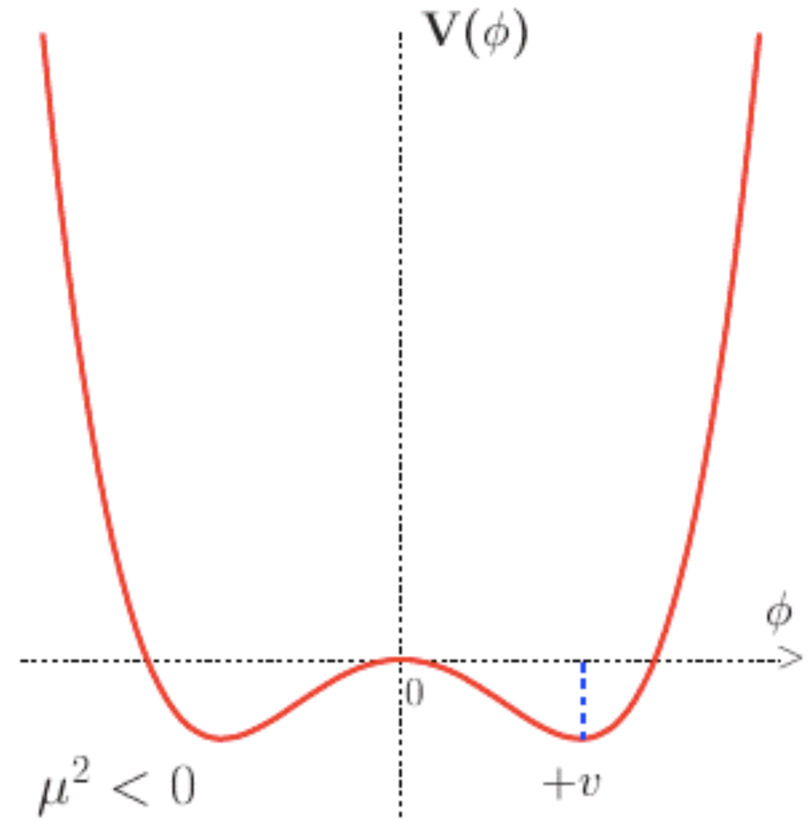
Subhendra Mohanty
Physical Research Laboratory, Ahmedabad, India


19.7 fb⁻¹ (8 TeV) + 5.1 fb⁻¹ (7 TeV)
CMS
H → γγ
S/(S+B) weighted sum
Data
S+B fits (weighted sum)
B component
±1σ
±2σ
$\hat{\mu}$ = 1.14 $^{+0.26}_{-0.23}$
$\hat{m}_H$ = 124.70 ± 0.34 GeV
B component subtracted
S/(S+B) weighted events / GeV
×10³
$m_{\gamma\gamma}$ (GeV)

Higgs Potential

$$V(\phi) = \frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$





$$\langle 0|\phi^2|0\rangle \equiv \phi_0^2 = -\frac{\mu^2}{\lambda} \equiv v^2$$

Higgs Mass depends on the quartic coupling

$$M = \sqrt{2\lambda} v$$

$$M = 125 \text{ GeV} \implies \lambda(M_z) = 0.13$$

Renormalization of couplings in the standard model

$$\beta_\lambda^{(1)} = \lambda(-9g_2^2 - 3g_1^2 + 12\lambda_t^2) + 24\lambda^2 + \frac{3}{4}g_2^4 + \frac{3}{8}(g_1^2 + g_2^2)^2 - 6\lambda_t^4,$$

$$\beta_{\lambda_t}^{(1)} = \frac{9}{2}\lambda_t^3 + \lambda_t\left(-\frac{17}{12}g_1^2 - \frac{9}{4}g_2^2 - 8g_3^2\right),$$

$$\beta_{g_1}^{(1)} = \frac{41}{6}g_1^3, \quad \beta_{g_2}^{(1)} = -\frac{19}{6}g_2^3, \quad \beta_{g_3}^{(1)} = -7g_3^3,$$

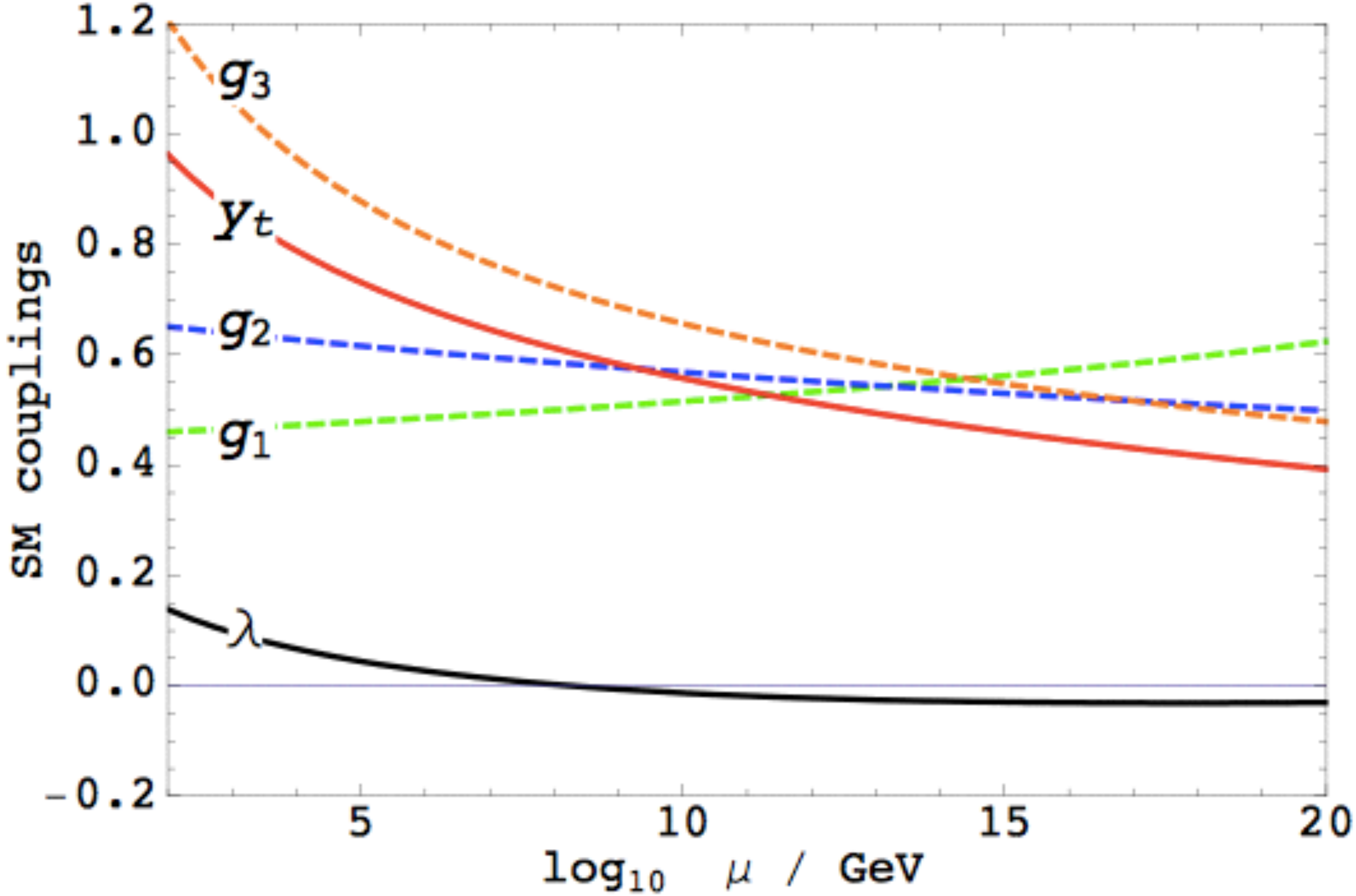
$$\begin{aligned}\beta_\lambda^{(2)} =& -312\lambda^3 - 144\lambda^2\lambda_t^2 + 36\lambda^2(3g_2^2 + g_1^2) - 3\lambda\lambda_t^4 + \lambda\lambda_t^2\left(80g_3^2 + \frac{45}{2}g_2^2 + \frac{85}{6}g_1^2\right)\\ &- \frac{73}{8}\lambda g_2^4 + \frac{39}{4}\lambda g_2^2 g_1^2 + \frac{629}{24}\lambda g_1^4 + 30\lambda_t^6 - 32\lambda_t^4 g_3^2 - \frac{8}{3}\lambda_t^4 g_1^2 - \frac{9}{4}\lambda_t^2 g_2^4\\ &+ \frac{21}{2}\lambda_t^2 g_2^2 g_1^2 - \frac{19}{4}\lambda_t^2 g_1^4 + \frac{305}{16}g_2^6 - \frac{289}{48}g_2^4 g_1^2 - \frac{559}{48}g_2^2 g_1^4 - \frac{379}{48}g_1^6\end{aligned}$$

$$\begin{aligned}\beta_{\lambda_t}^{(2)} =& \lambda_t\left(-12\lambda_t^4 + \lambda_t^2\left(\frac{131}{16}g_1^2 + \frac{225}{16}g_2^2 + 36g_3^2 - 12\lambda\right) + \frac{1187}{216}g_1^4\right.\\ &\left.-\frac{3}{4}g_2^2 g_1^2 + \frac{19}{9}g_1^2 g_3^2 - \frac{23}{4}g_2^4 + 9g_2^2 g_3^2 - 108g_3^4 + 6\lambda^2\right)\end{aligned}$$

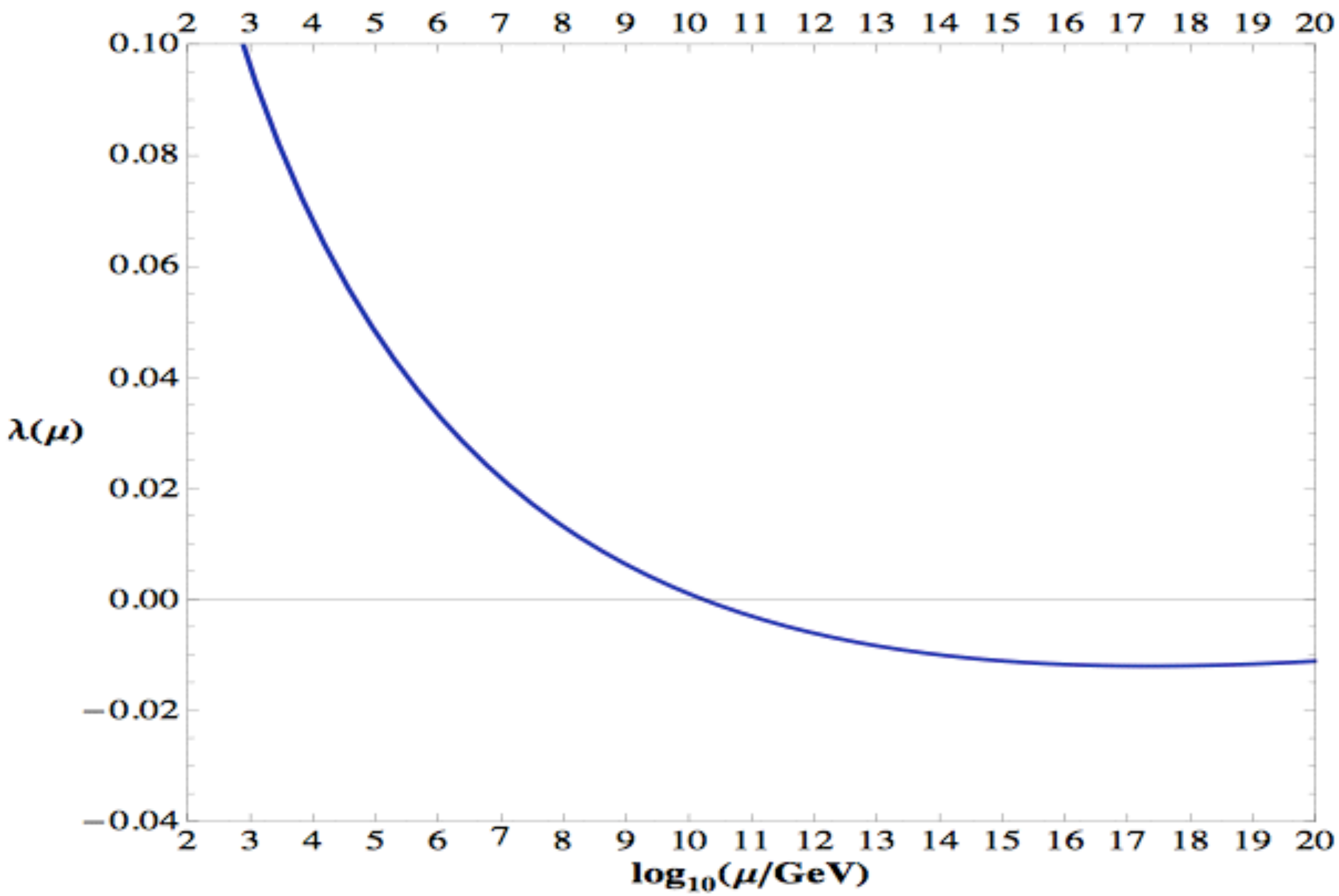
$$\beta_{g_1}^{(2)} = g_1^3\left(\frac{199}{18}g_1^2 + \frac{9}{2}g_2^2 + \frac{44}{3}g_3^2 - \frac{17}{6}\lambda_t^2\right)$$

$$\beta_{g_2}^{(2)} = g_2^3\left(\frac{3}{2}g_1^2 + \frac{35}{6}g_2^2 + 12g_3^2 - \frac{3}{2}\lambda_t^2\right)$$

$$\beta_{g_3}^{(2)} = g_3^3\left(\frac{11}{6}g_1^2 + \frac{9}{2}g_2^2 - 26g_3^2 - 2\lambda_t^2\right),$$

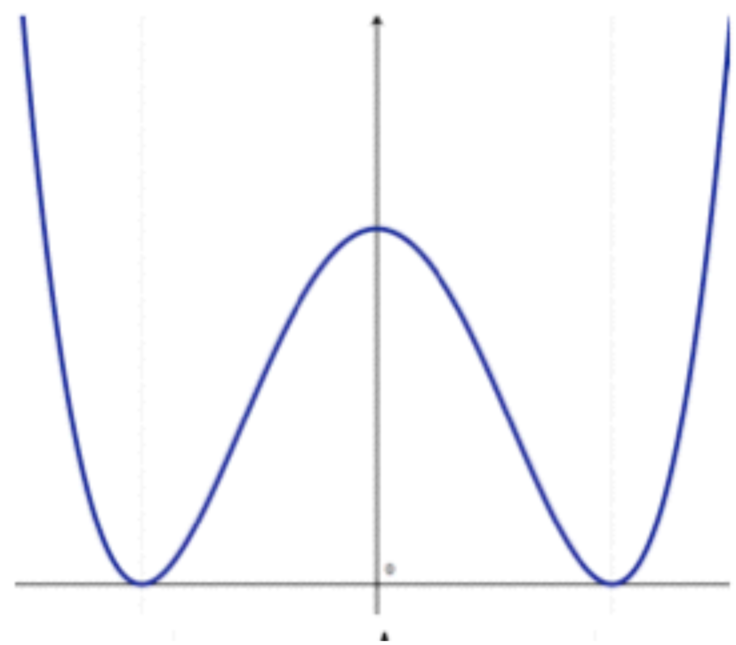


1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
5
10
15
20
SM couplings
log10 μ / GeV
g3
yt
g2
g1
λ



0.10
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
λ(μ)
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
log10(μ/GeV)

$$V_{\mathrm{H}}^{(0)}(h) = \frac{\lambda}{8}\left(h^2 - v_{EW}\right)^2$$

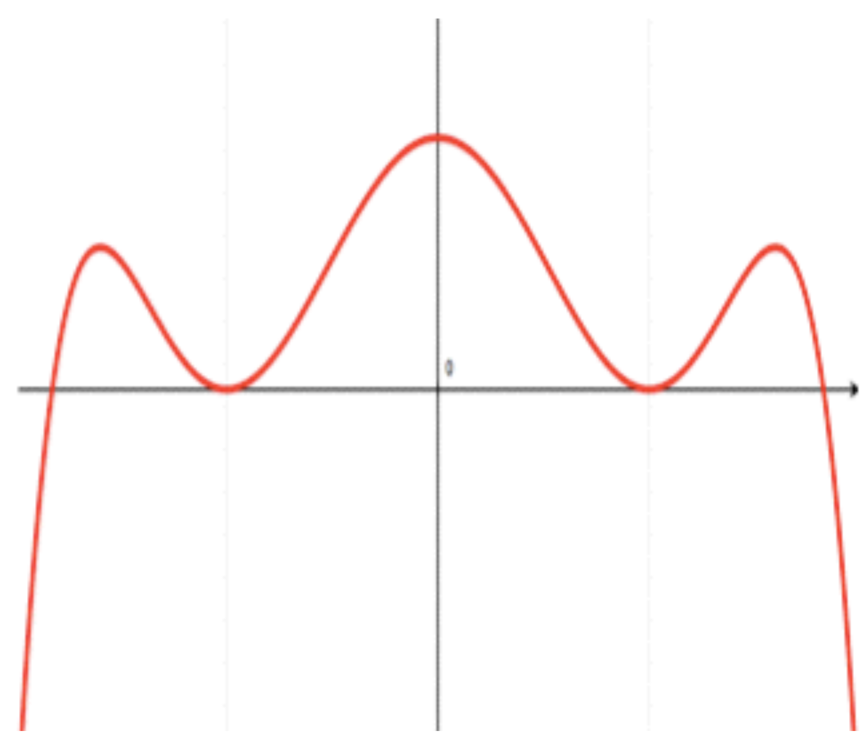


$$V_{\mathrm{H}}^{(1-\mathrm{loop})}(h) = \frac{\lambda(h)}{8}\left(h^2 - v_{EW}\right)^2$$

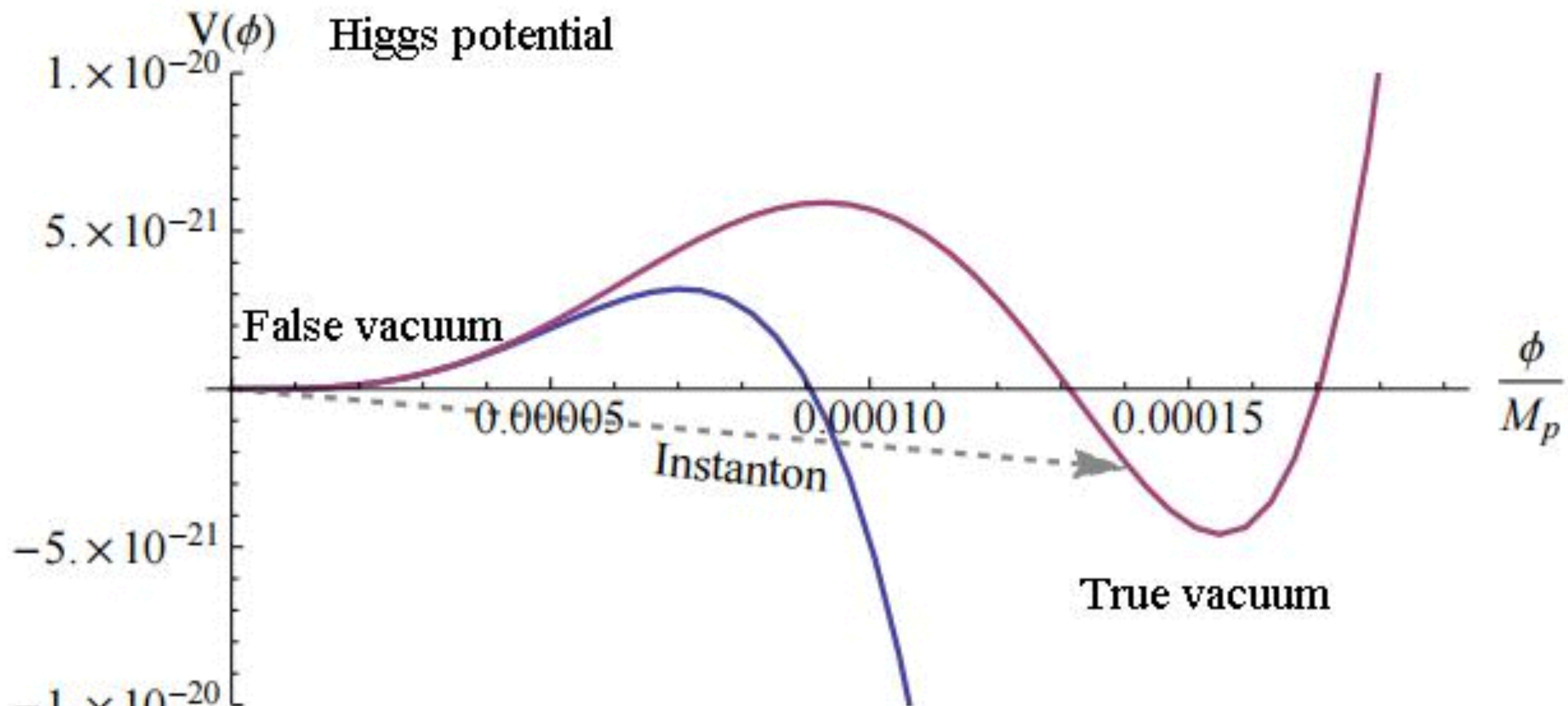
$$\lambda(h) = \lambda(\mu) + \beta_\lambda \ln(h/\mu)$$

$$(4\pi)^2 \beta_\lambda = -6y_t^4 + 24\lambda^2 + \dots$$

$$y_t(m_t) \approx 1\ ,\ \ \lambda(m_h) \approx 0.13$$

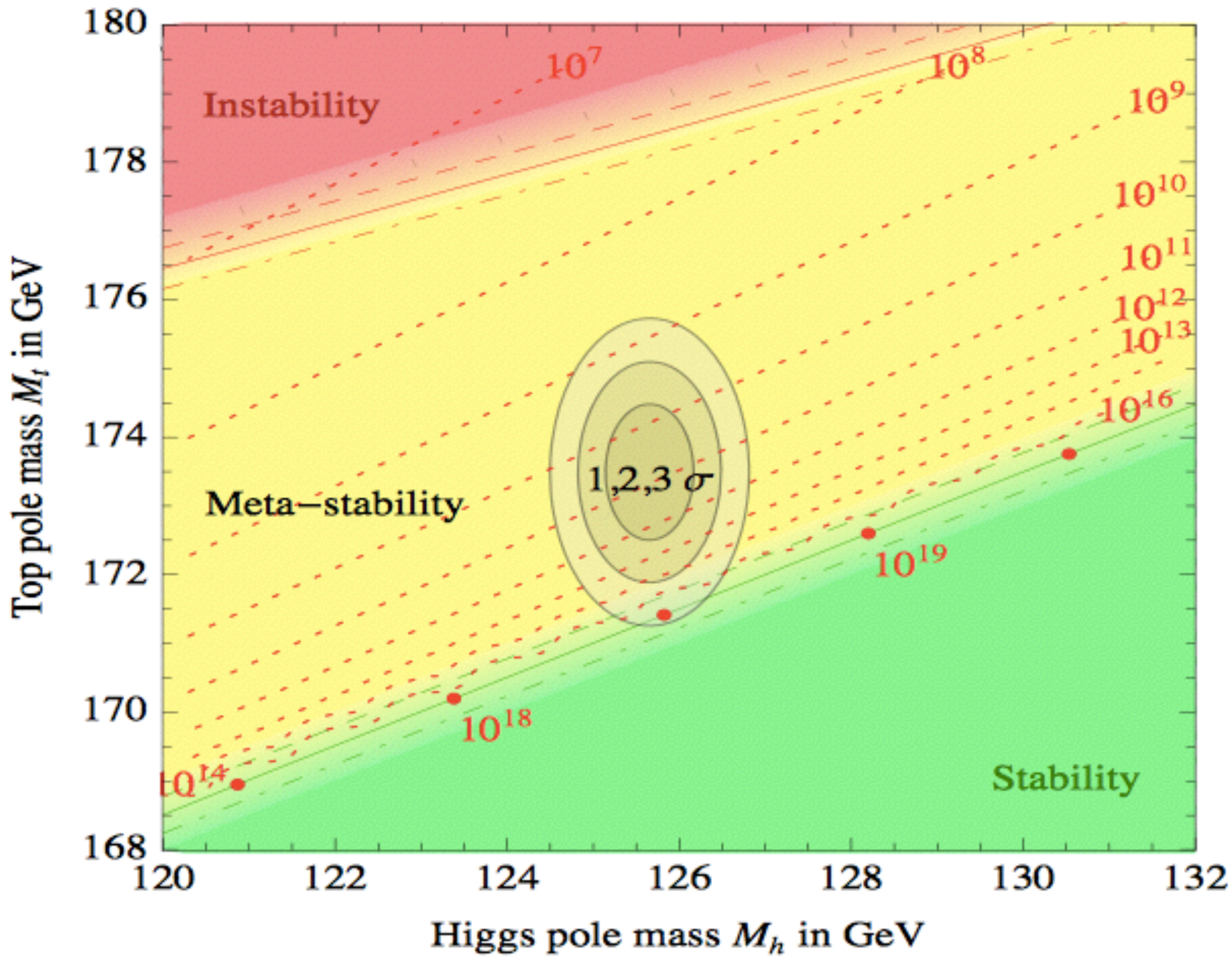


$$V_{eff}(\phi) \sim \frac{\lambda_{eff}(\phi)}{24}\phi^4$$



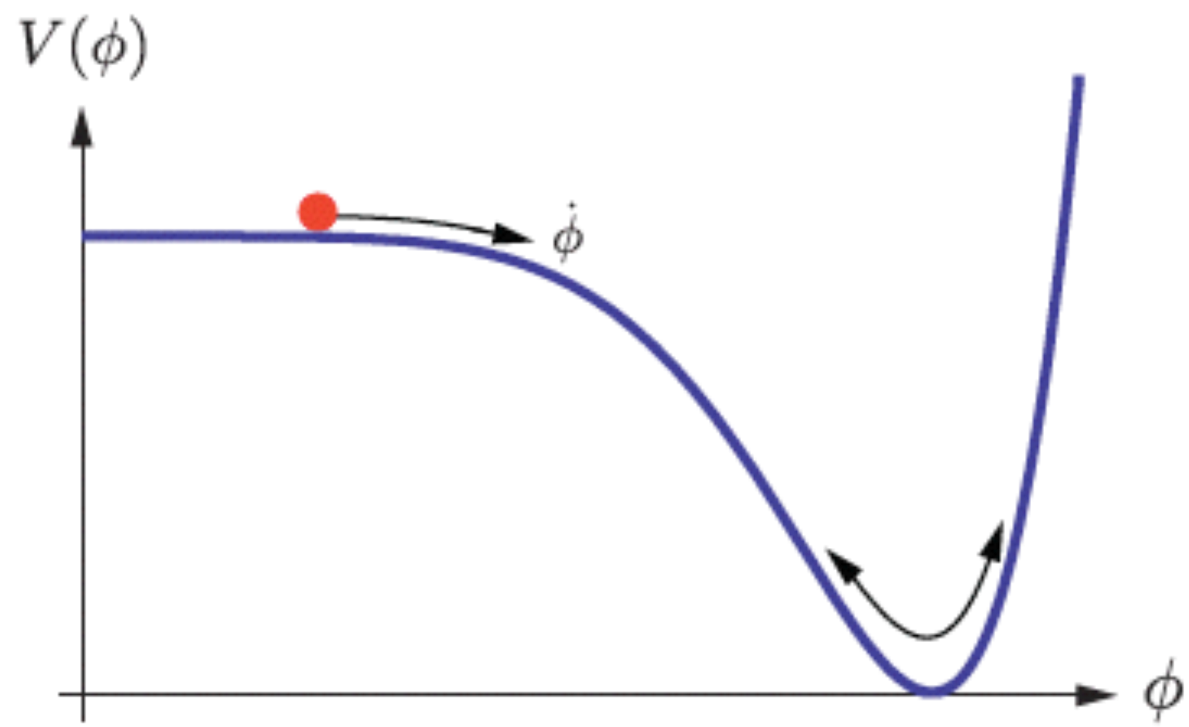
V(ϕ) Higgs potential

We live in a metastable vacuum



Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia, (2013)

Inflation



Inflaton potential

Is Higgs instability inconsistent with Inflation?

The cosmological Higgstory of the vacuum instability

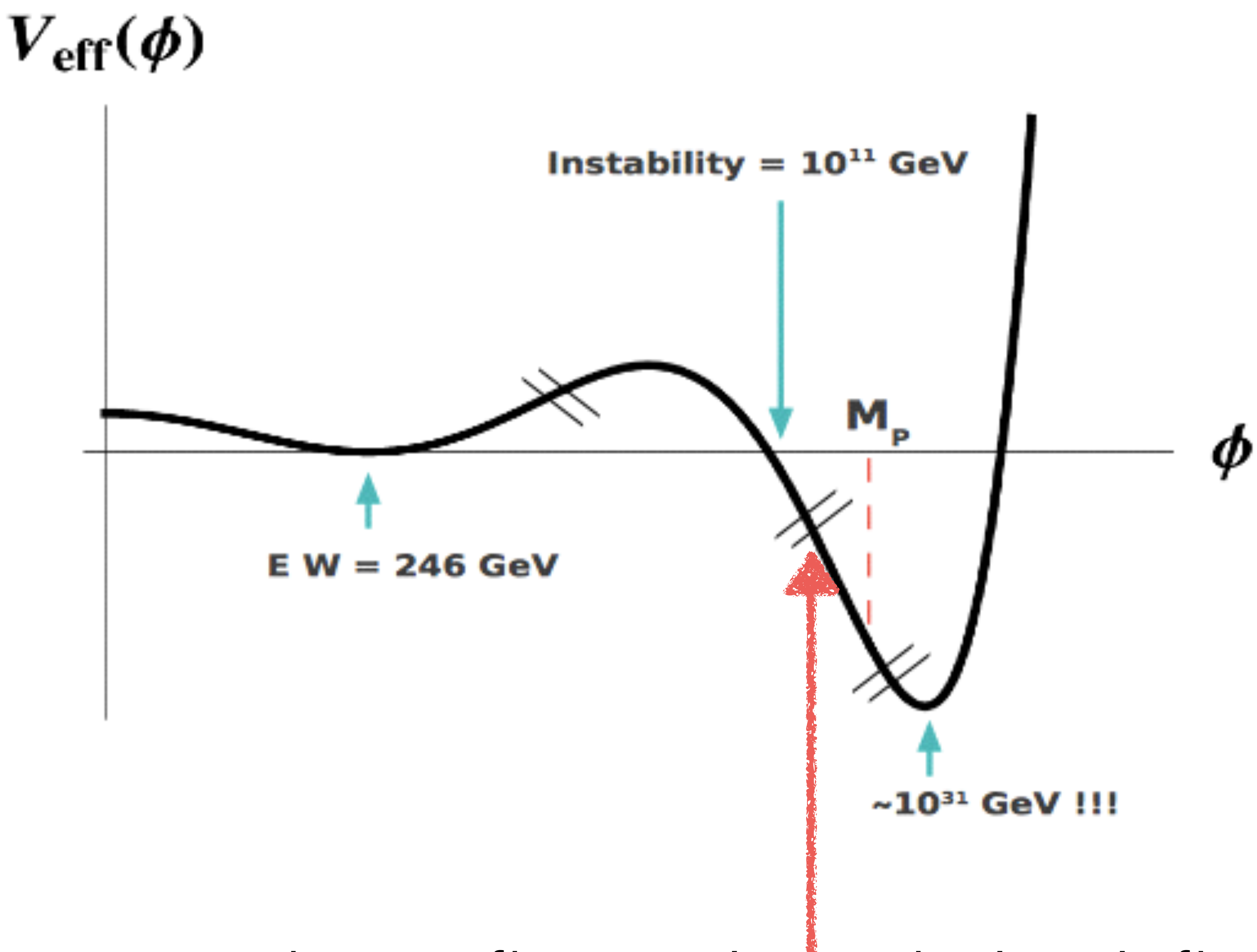
Jose R. Espinosa, Gian F. Giudice, Enrico Morgante, Antonio Riotto, Leonardo Senatore, Alessandro Strumia, Nikolaos Tetradis

Arxiv: 1505.04825

During Inflation all light fields have a quantum fluctuation with value

$$\langle \phi^2 \rangle = \frac{H^2}{2\pi}$$

$$H = 10^{14} \;\; \mathrm{GeV}$$



Higgs vev due to fluctuations during inflation

Higgs field is driven to the unstable regime during inflation

During inflation the static observer measures the Higgs potential at a finite temperature

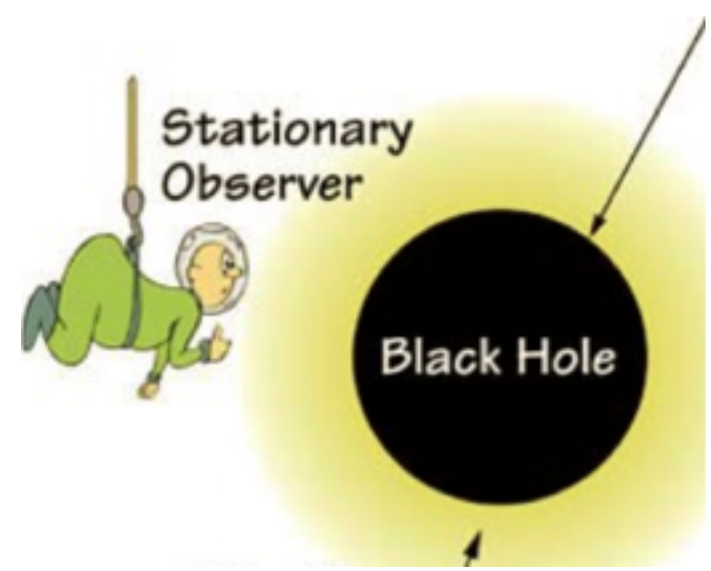
$$T = \frac{H}{2\pi}$$

Higgs instability and de-Sitter radiation - Gaurav Goswami and SM arxiv 1406.5644 , Phys Lett B (2015).

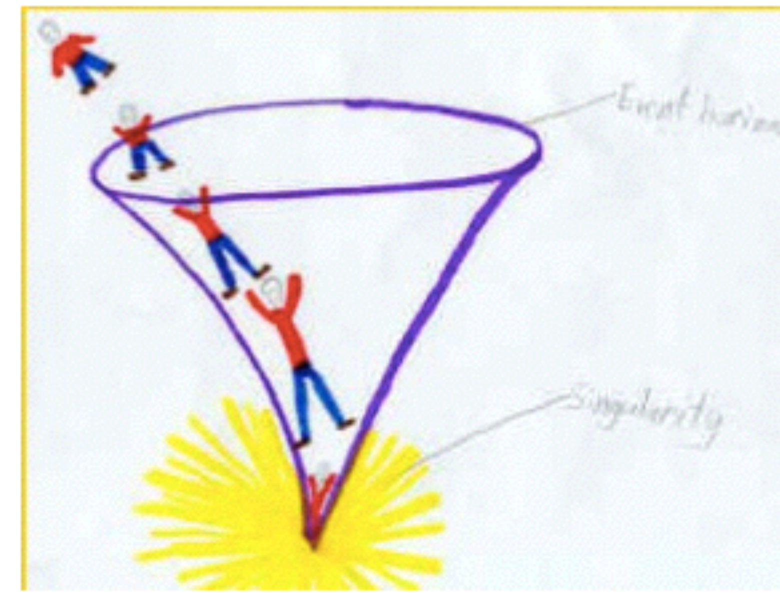
Hawking Radiation from Black-holes

$$ds^2 = \left(1 - \frac{2GM}{r}\right) dt^2 - \left(1 - \frac{2GM}{r}\right)^{-1} dr^2 + r^2 d\Omega^2$$

Black-hole metric as seen by the stationary observer

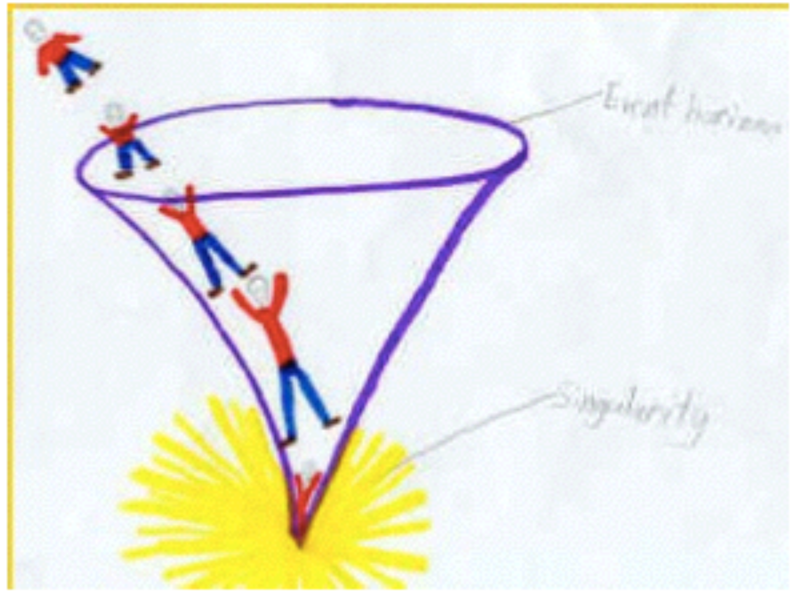


Krushkal coordinates of the free fall observer



$$ds^2 = \frac{2M}{r} \exp\left(1 - \frac{r}{2M}\right) d\bar{u}\, d\bar{v};$$

Zero particles state of



$$\langle 0_{in} |\, a_k^\dagger \, a_k \, | 0_{in} \rangle$$

Appears to

as

$$\langle 0_{out} | a_k^\dagger \, a_k \, | 0_{out} \rangle = \frac{1}{\exp\left(\frac{\hbar\omega}{k_B T_H}\right) - 1}$$

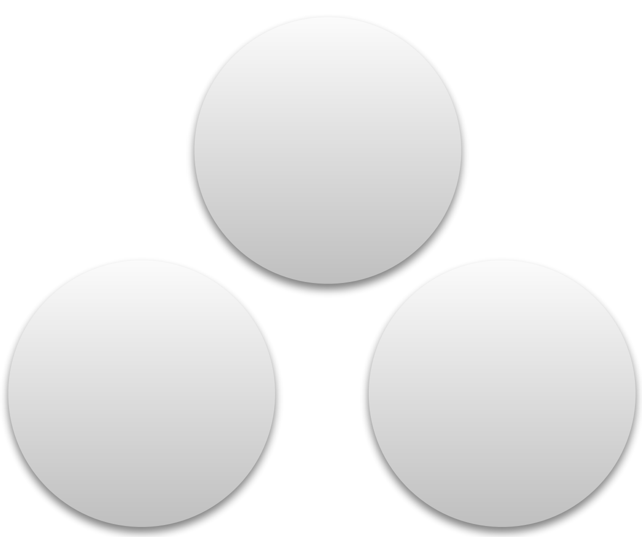
Thermal distribution of particles at the Hawking temperature

Hawking Gibbons temperature during inflation

Conformal coordinates

$$ds^2 = \frac{1}{H^2\eta^2}\left(d\eta^2 - d\rho^2 - \rho^2 d\Omega^2\right)$$

Static coordinates

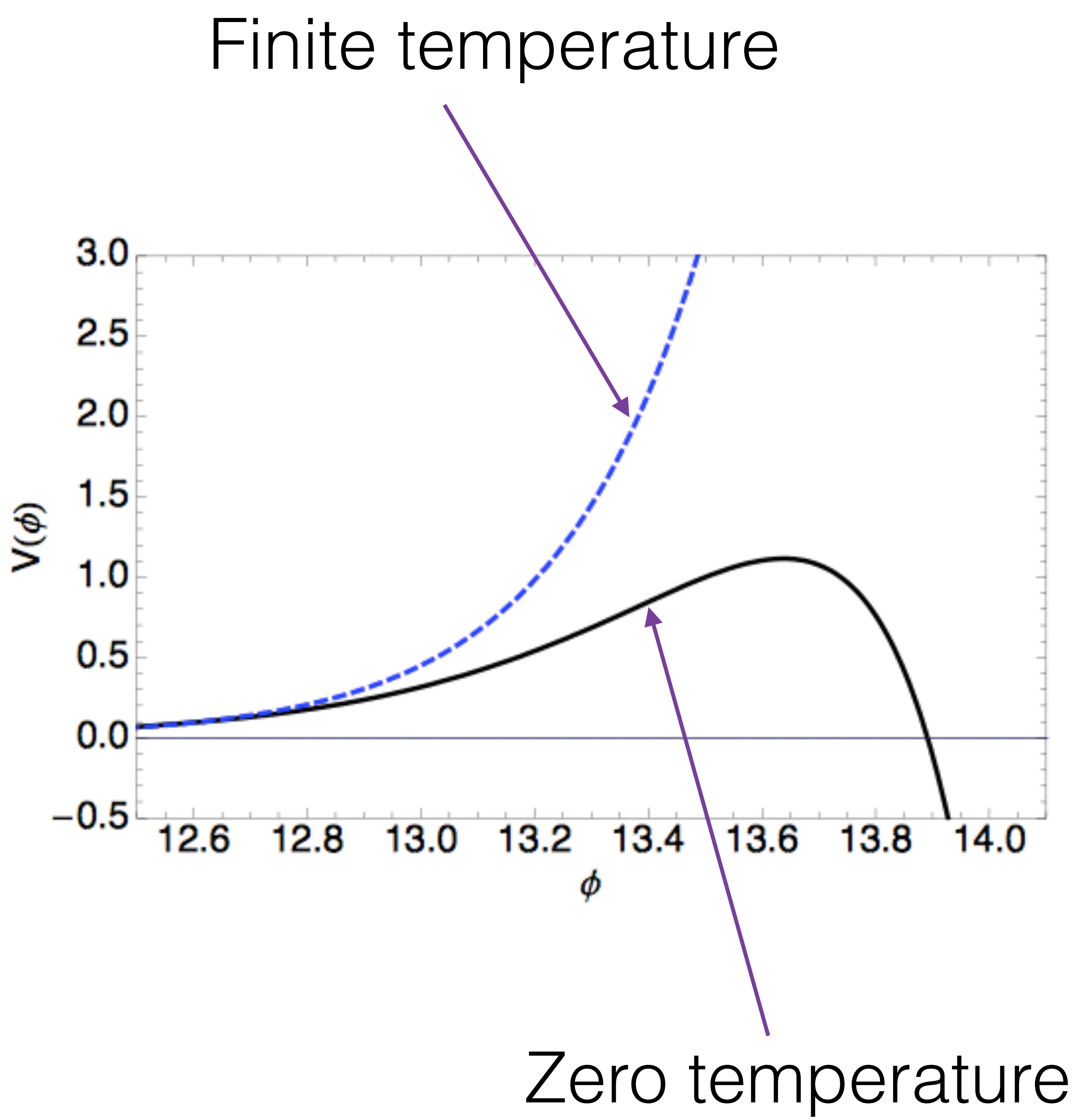


Observer at r=0

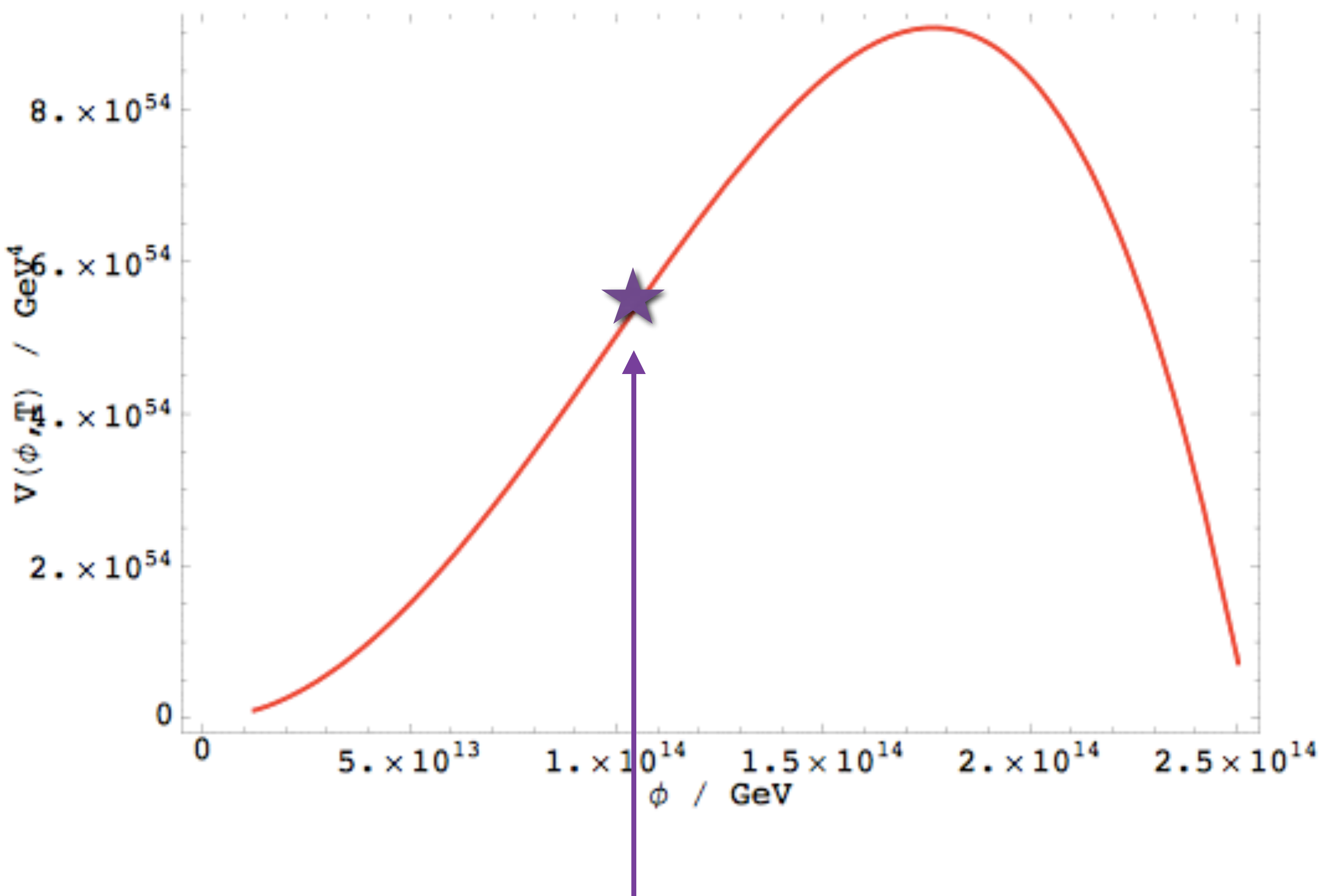
$$ds^2 = (1 - r^2H^2)dt^2 - \frac{1}{(1 - r^2H^2)}dr^2 - r^2 d\Omega^2$$

The static observer in de-Sitter space observes a Hawking-Gibbons temperature

$$T = \frac{H}{2\pi}$$


Finite temperature
Zero temperature
V(ϕ)
ϕ
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
12.6
12.8
13.0
13.2
13.4
13.6
13.8
14.0

Higgs potential at the Hawking Temperature

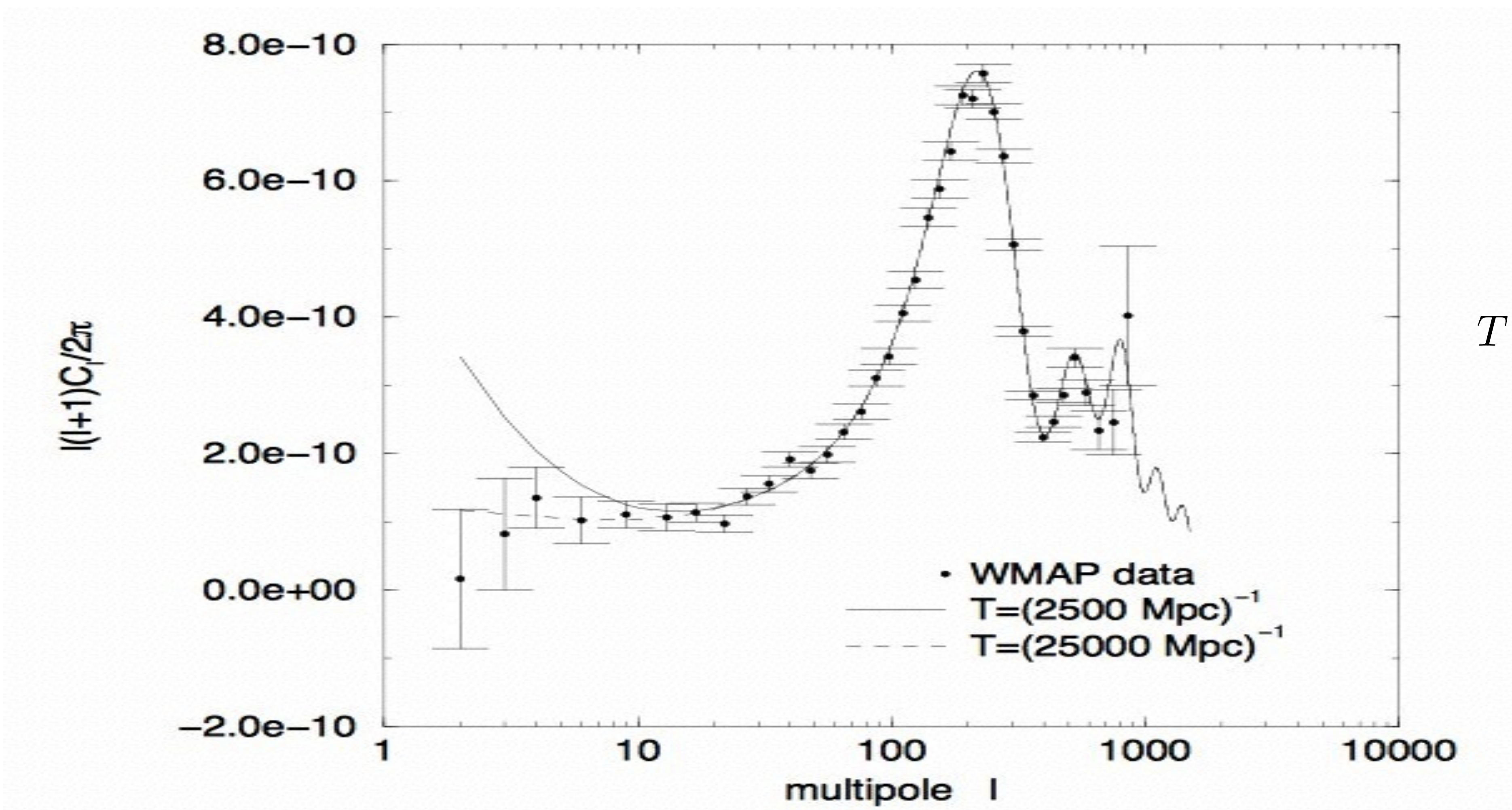


Higgs field on stable region of potential during inflation

Gaurav Goswami and SM arxiv 1406.5644 , PLB (2015).

There is no problem for standard inflation perturbation if inflation temperature is $T = H/2\pi$

$$P_t(k) = A_t(k_0)\left(\frac{k}{k_0}\right)^{n_t} \coth\left[\frac{k}{2T}\right]$$

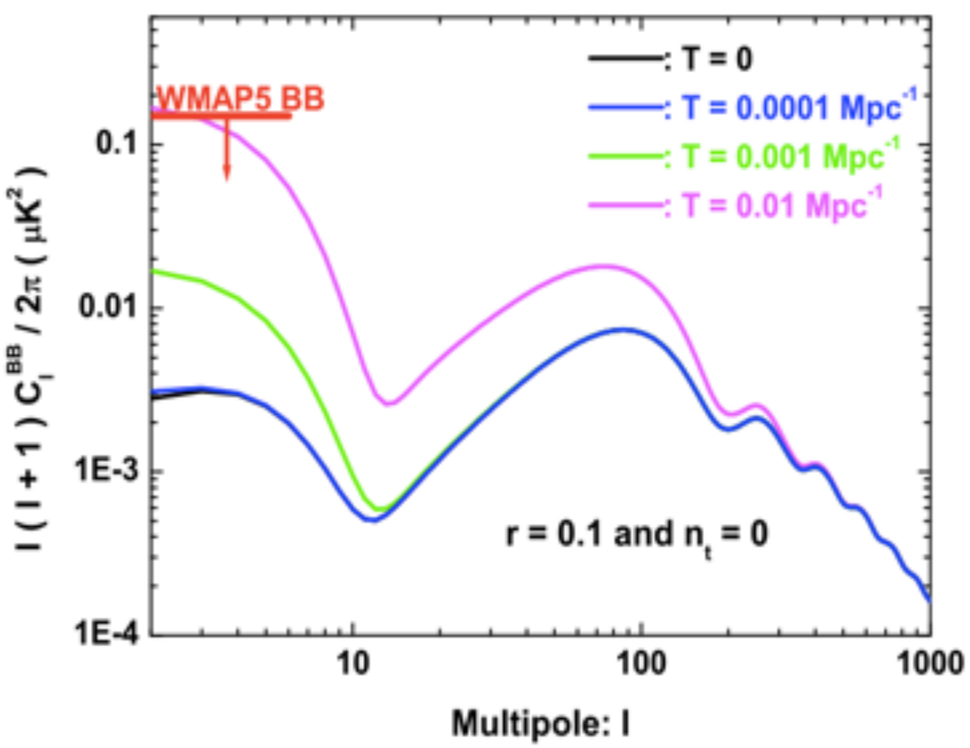


$T < 4H$

Temperature of the inflaton and duration of inflation from WMAP data

K. Bhattacharya, S M, R Rangarajan Phys.Rev.Lett. 96 (2006) 121302

Hawking temperature may show up in the B mode



Enhanced polarization of CMB from thermal gravitational waves

K Bhattacharya, SM, Akhilesh Nautiyal

Phys.Rev.Lett. 97 (2006) 251301

There is no problem of Higgs instability for inflation if the Hawking Gibbons temperature of the de-Sitter space during inflation is taken into account.

Thank You