MSSM Higgses as Inflaton

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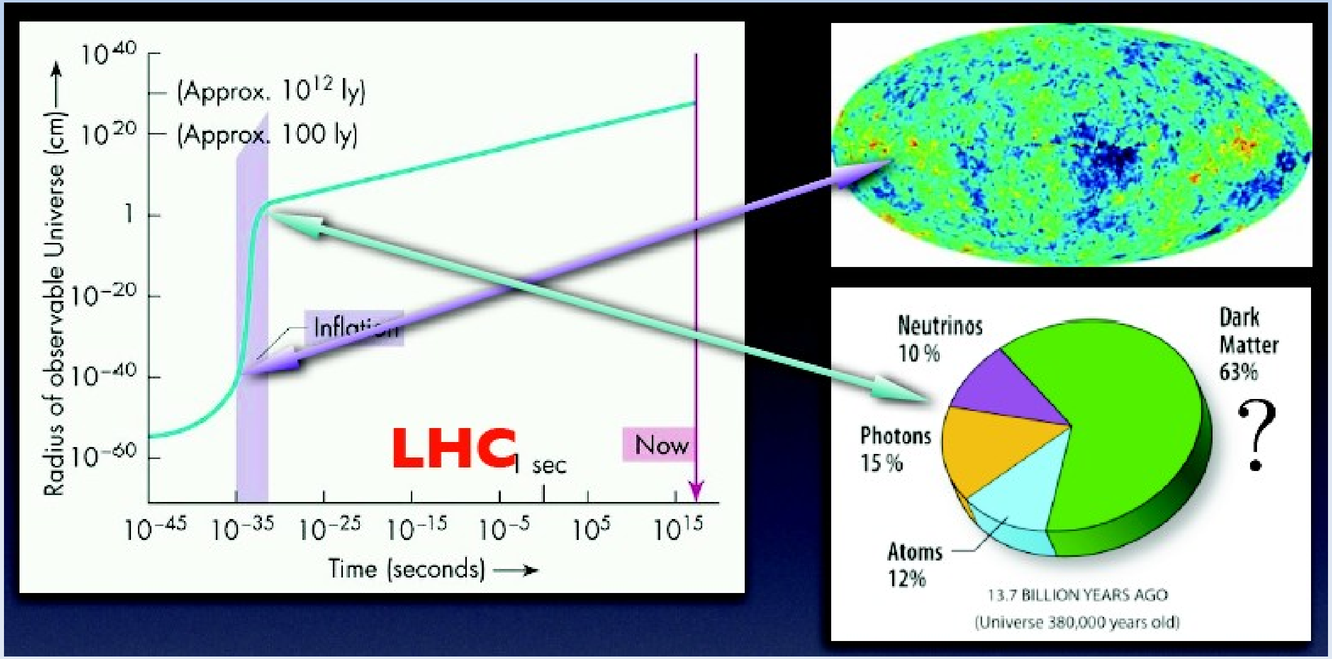
hep-ph/arXiv: 1103.5758 AC, Anupam Mazumdar

Motivation

Slow-roll inflation enjoys enormous success in the context of CMB.



[Mazumdar, Rocher, Phys. Rept. 2010]

- Need to (p)reheat, exciting the visible sector particles
- Good to have inflaton from the visible sector

Motivation

Searching for the inflaton (bottom-up) :

Supersymmetry already offers lots of scalar fields!

The Minimal Supersymmetric Standard model (with R- parity) :

- Minimal SUSY extension of SM
- SUSY breaking sector is parametrized
- Has flat directions (lifted by SUSY breaking terms and possibly additional non-renormalizable terms)

[Gherghetta, Kolda, Martin; Nucl.Phys. B468 (1996) 37-58]

udd and LLE flat directions can act as inflaton, and if neutrinos have Dirac mass, NHL too can be a candidate.

[Allahverdi, Enqvist, Garcia-Bellido, Jokinen, Mazumdar, JCAP 0706:019,2007;
Allahverdi, Enqvist, Garcia-Bellido, Mazumdar, PRL 97, 2006;
Allahverdi, Dutta, Mazumdar, PRL 99, 2007]

The Potential

How about MSSM Higgses?

- $H_1 H_2$ is D- flat. The F- term contribution already lifts the flatness, although by a small amount, thanks to the smallness of *μ*.

The Superpotential：

$$\mathcal{W} = \mu \mathbf{H_1}.\mathbf{H_2} + \frac{\lambda_k}{k} \frac{(\mathbf{H_1}.\mathbf{H_2})^k}{M_P^{2k-3}},$$

- *μ* term is of the order of 100 GeV- 1 TeV (about the EWSB scale).

- Any number of Planck suppressed non- renormalizable terms may be present.

The Potential

The soft supersymmetry breaking terms：

$$V_{H,Soft} = m_1^2|H_1|^2 + m_2^2|H_2|^2 + (B\mu H_1.H_2 + h.c.)$$

- In the MSSM with R-parity, parametrising the SUSY breaking in the Higgs sector
- The coefficients are of the order of about a TeV, as required by weak- scale Supersymmetry breaking.

The Potential

The scalar potential along the flat direction :

$$\tilde{V}(\varphi,\theta) = \frac{1}{2}m^2(\theta)\varphi^2 + (-1)^{(k-1)}2\lambda_k'\mu\cos((2k-2)\theta)\varphi^{2k} + 2\lambda_k'^2\varphi^{2(2k-1)},$$

where $\varphi = \sqrt{2}|\phi|$ and,

$$H_1 = \frac{1}{\sqrt{2}}(\phi,0)^T, \qquad H_2 = \frac{1}{\sqrt{2}}(0,\phi)^T,$$

$$m^2(\theta) = \frac{1}{2}(m_1^2 + m_2^2 + 2\mu^2 - 2B\mu\cos 2\theta),$$

$$\lambda_k' = \frac{\lambda_k}{2^{(2k-1)}M_P^{2k-3}}.$$

The Potential

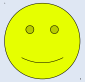
- Assume B and μ to be real, experimental constraints on the complex phases come from EDM measurements. Zero phase is well- motivated in the context of weak scale SUSY.

[Pospelov, Ritz; Annals Phys.318, 2005]

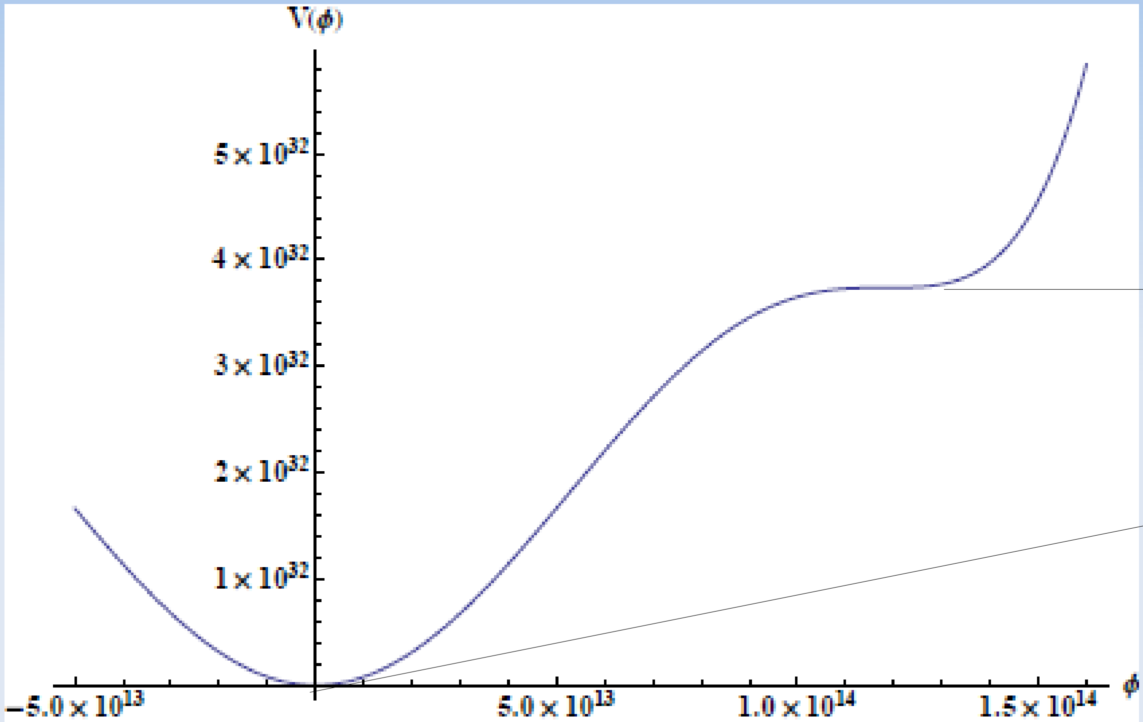
- The potential can have a local minimum in the angular direction for $\theta = 0$,

- And a suitable (the first derivative needs to be small too) *inflection point* at φ_0 , *if,*

$$m_0^2 = \frac{k^2\mu^2}{(2k-1)} + \tilde{\lambda}^2 \quad .$$



Inflection Point Inflation



Slow-roll regime

- EW symmetry restored.
- (P)reheating

moduli problem avoided

We have : $\varphi_0 \sim 10^{14}$ GeV,

$V(\varphi_0) = V_0 \simeq 10^{32}$ GeV^4

$$H_{inf} \simeq \sqrt{\frac{V_0}{3M_P^2}} = \frac{k-1}{\sqrt{3k(2k-1)}}\frac{m_0\varphi_0}{M_P}$$

$\sim 10^{-1}$ GeV

Inflection Point Inflation

Sub-Planckian VEV, scale of inflation is low.

- Inflation ends when $|\eta| \sim 1$.
- This corresponds to $\frac{|\varphi_0 - \varphi|}{\varphi_0} \sim \left(\frac{\varphi_0}{8k(2k-1)M_P}\right)^2 \sim 10^{-8}$.
- Can get sufficient e-foldings :

$$N_{\rm COBE} \simeq 66.9 + (1/4)\ln(V(\varphi_0)/M_P^4) \sim 45$$

[Liddle, Leach, PRD 68: 2003;
Burgess, Easther,Mazumdar, Mota, Multamaki, JHEP 0505, 2005]

Confronting the recent data (WMAP7 + BAO + H0) :

[Komatsu et al, 2010]

Inflection Point Inflation

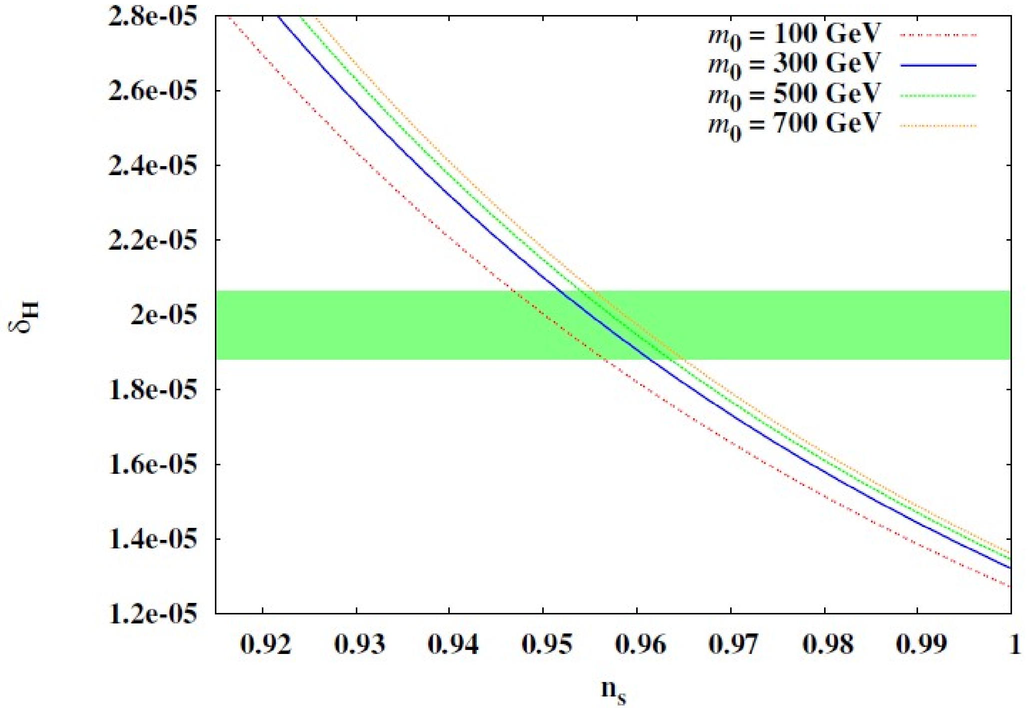


FIG. 1: δ_H and n_s have been plotted for different values of m_0 and at the inflection point VEV, $\varphi_0 \sim 3 \times 10^{14}$ GeV. We have used $k = 2$ in the superpotential, we have taken $\lambda_2' M_P = 1.4 \times 10^{-8}$. The green band denotes 2σ allowed band of δ_H. Although the splitting between these curves are not so sensitive to the inflaton mass, varying λ_2' it is possible to span the complete range in the n_s-δ_H plane.

k = 2 case :

Needs small coefficient of the non-renormalizable term :

$$\lambda_2 \sim 10^{-8}$$.

However, there are others :
QQQL and UUDE
Not forbidden by R-parity, constrained from p decay.
Needs to be suppressed by about the same order !

[Arnowitt, Nath, Murayama, Ellis …]

Inflection Point Inflation

k =3 case :

The non-renormalizable term can have $\lambda_3 \sim O(1)$.

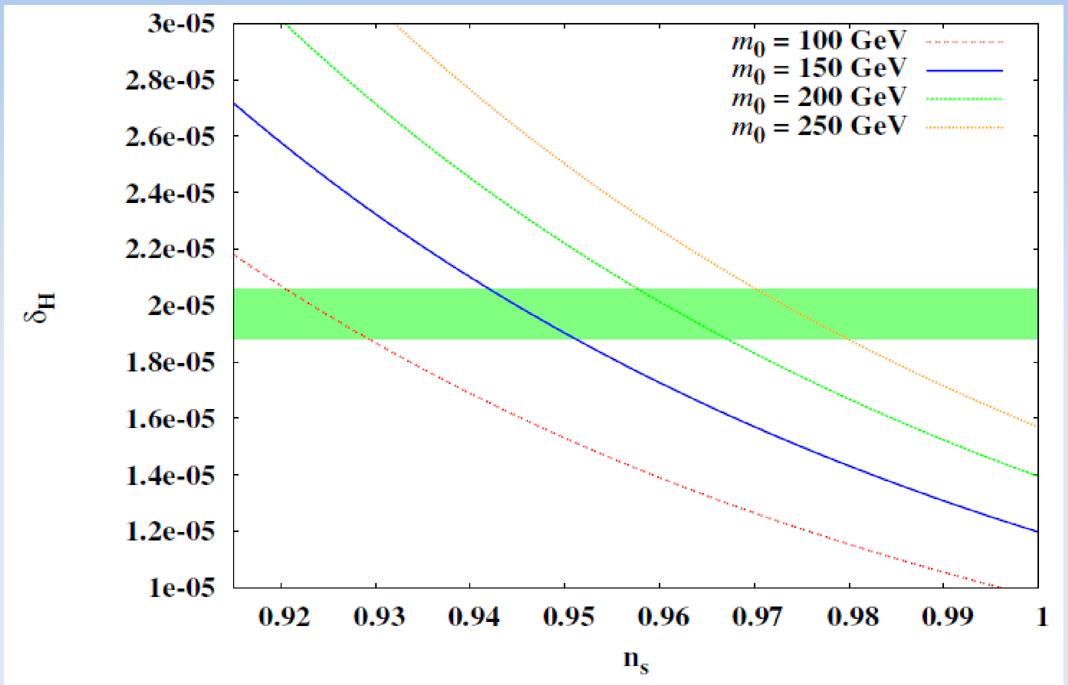


FIG. 2: δ_H and n_s have been plotted for different values of m_0 and at the inflection point VEV, $\varphi_0 \sim 3 \times 10^{14}$ GeV. We have used $k = 3$ in the superpotential, we have taken $\lambda_3' M_P^3 = -0.71$. The green band denotes 2σ allowed band of δ_H.

Inflection Point Inflation

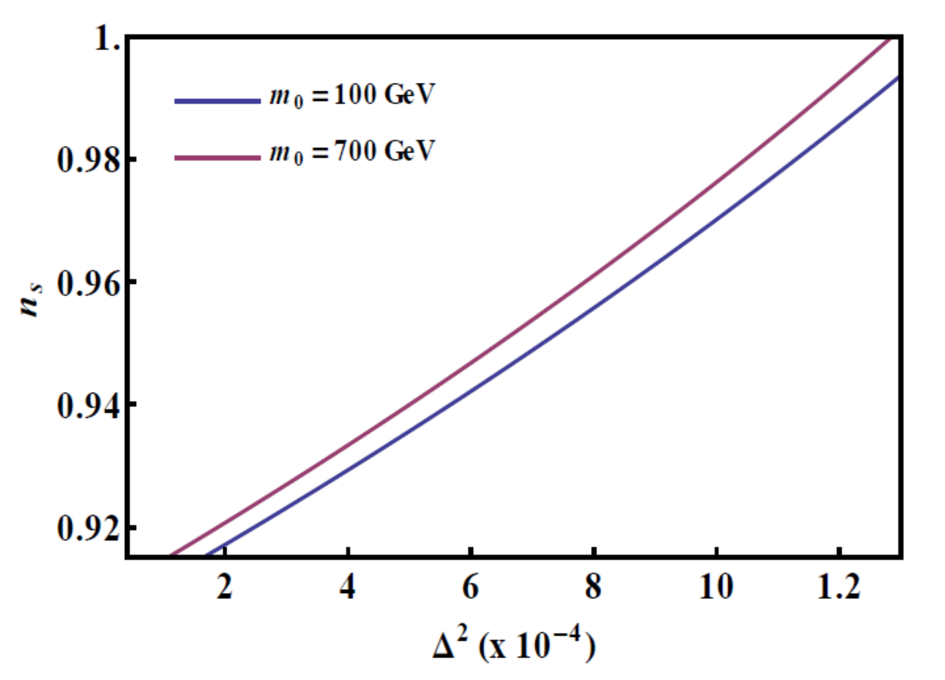


FIG. 3: n_s has been plotted against vs Δ^2 for different values of m_0 for $k = 2$ case with $\lambda_2' M_P = 1.4 \times 10^{-8}$.

- Fine tuning needed :

$$\Delta^2 = 32k^2(2k-1)^2\lambda^2\mathcal{N}^2_{\rm COBE}\left(\frac{M_P}{\varphi_0}\right)^4$$

$$\Delta^2 \sim 10^{-3} \implies \tilde{\lambda} \sim 10^{-8} .$$

$$m_0^2 = \frac{k^2\mu^2}{(2k-1)} + \tilde{\lambda}^2$$

- Small tensor to scalar ratio, unobservable gravity waves
- Small (~-.002) negative running of the scalar spectral index

Fine Tuning and EWSB

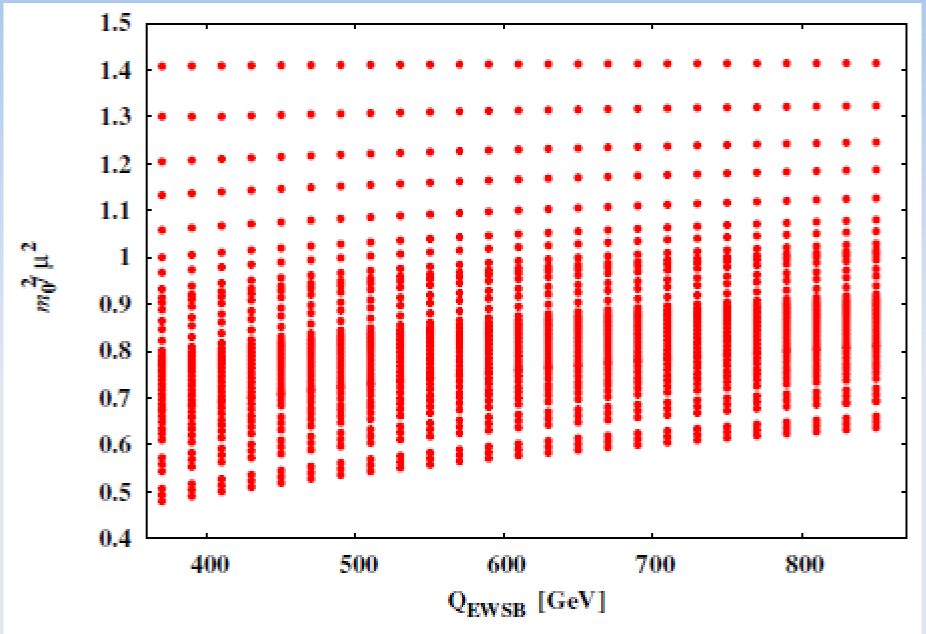


FIG. 4: A sample plot where the ratio m_0^2/μ^2, see Eq. (14), for $k = 2$, has been evaluated at the EWSB scale. The corresponding value at a high scale, $\varphi_0 \sim 10^{14}$ GeV, is set to 4/3, with an accuracy of 0.1%. The RGE accuracy in *SuSpect* is about 0.01%.

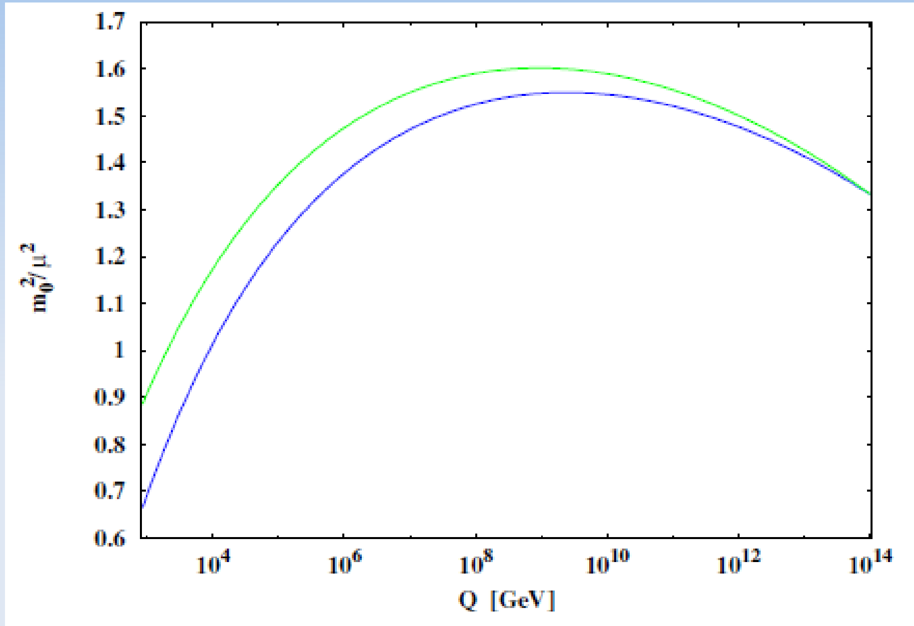
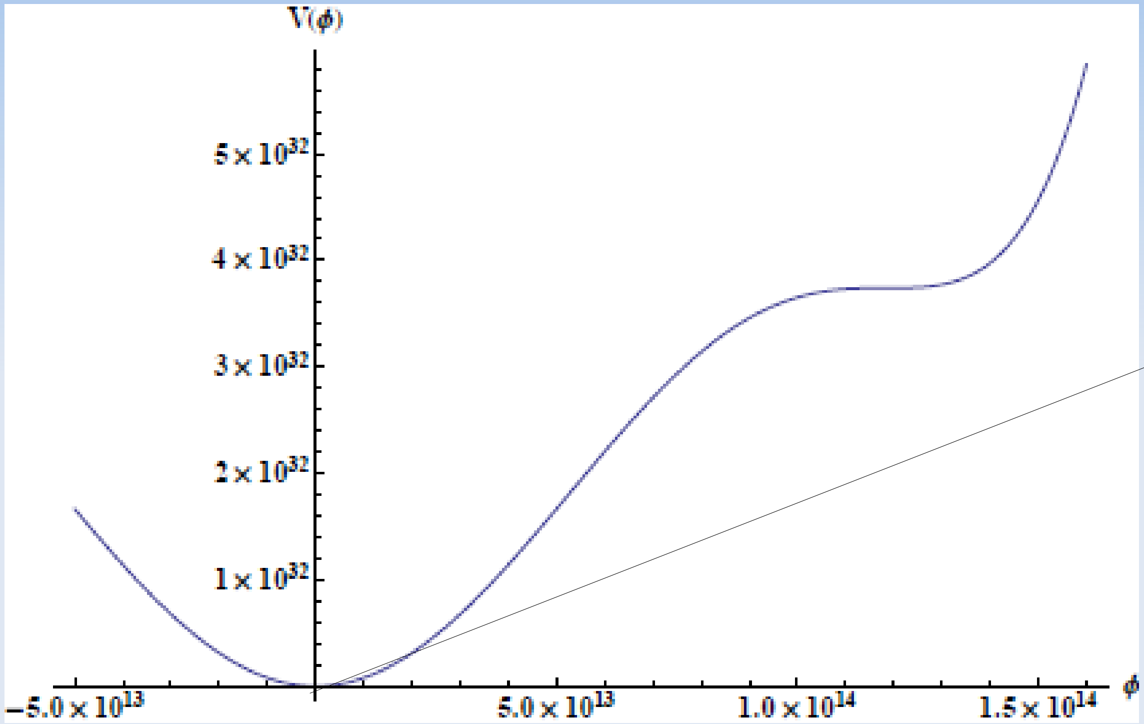


FIG. 5: The ratio m_0^2/μ^2 for $k = 2$, has been evolved from 10^{14} GeV to the EWSB scale (chosen to be 850 GeV). The green line and the blue line correspond to $m_0 = 323.4$ GeV and $m_0 = 354$ GeV at 10^{14} GeV respectively. The ratio at the high scale (10^{14} GeV) is set to 4/3, with an accuracy of 0.1%. The RGE accuracy in *SuSpect* is about 0.01%.

No specific tuning at EWSB scale.

(P)reheating



- Point of enhanced symmetry.
- Efficient (P)reheating, within 1 Hubble time, rapid thermalization expected.
- No relic topological defect

[for LLE inflaton: Allahverdi, Ferrantelli, Garcia-Bellido, Mazumdar; hep-ph/1103.2123]

The final reheat temperature : $T_{\rm rh} = \left(\frac{30}{\pi^2 g_*}\right)^{1/4} \rho_0^{1/4} \simeq 2\times 10^8~{\rm GeV}$

with $g_* = 228.75$ (all MSSM d.o.f.), $\rho_0 = (4/15) m_0^2 \phi_0^2$.

Conclusion

- inflaton embedded within a visible sector

- there are few candidates and now the MSSM Higgs can be accounted as one of them.

- fine tuning problem

  RG flow indicates that at low scales there is no severe fine tuning in the MSSM parameters

- With k = 2, additional suppression needed

Thank You

Initial Conditions

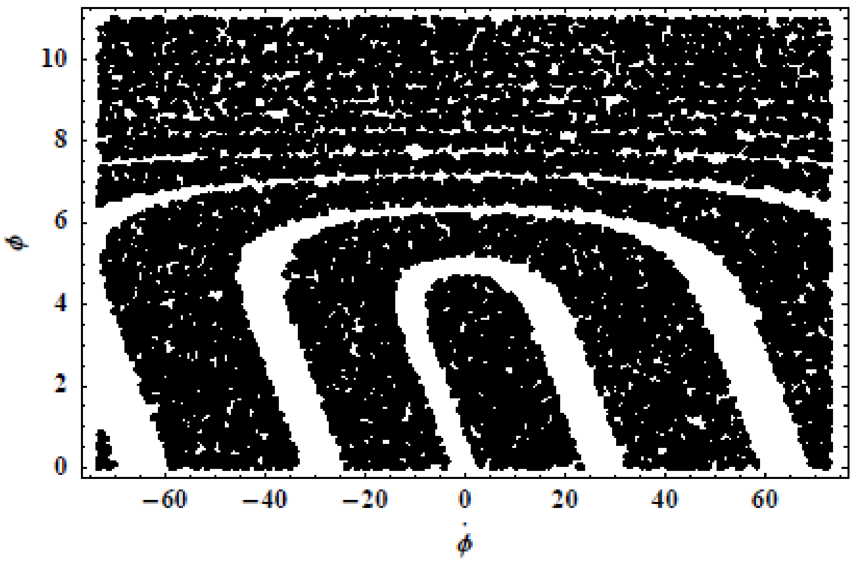


FIG. 4: We plot initial values of ϕ versus $\dot{\phi}$ for $H_{\rm false} = 10^2 m_\phi$. The dots show the initial values for which ϕ settles to $\pm\phi_0$ and the white bands ∩ show the critically damped regions where ϕ settles to zero.

Attraction towards the inflection Point :

- MSSM has metastable vacua
- Need inflation in the flase vacua
- If $m<H_{false}$, scalar fields can get displaced
- If started at a small VEV, MSSM inflaton can obtain quantum jumps of the order H_{false} /2 pi
- Need the rms value greater than the VEV at the inflection point : need ~10^{16} efoldings of false vacuum inflation.

[Allahverdi, Dutta, Mazumdar, hep-ph/08064557]

- In the string landscape favorable conditions exist [Allahverdi, Frey, Mazumdar;hep-th/0701233]

- Some generic features
  - Inflaton from well-motivated particle physics model, no ad-hoc couplings involved
  - After inflation excites the the MSSM degrees of freedom, efficient (p)reheating
  - Small Hubble parameter during inflation : moduli problem can be avoided
  - Sub-Planckian VEV
  - SUGRA corrections can be ignored

[Allahverdi, Mazumdar, Enqvist, Garcia-Bellido, Jokinen]

Some issues and possible solutions :

- Initial condition :
  - ★ Attractor behavior of the inflection point, if preceded by flase vacuum inflation with large number of e-foldings [Allahverdi, Dutta, Mazumdar]
  - ★ In the string landscape favorable conditions exist [Allahverdi, Frey, Mazumdar]
- Severe fine tuning needed at the scale of the inflection point :
  - ★ Dynamically satisfied by RGE [Allahverdi, Dutta, Santoso; AC, Mazumdar]
  - ★ Extra vacuum energy [Enqvist, Mazumdar, Stephens; Hotchkiss,Mazumdar, Nadathur]
- With k = 2, additional suppression needed

Inflection Point Inflation (extra)

The slow-roll parameters :

$$
\begin{aligned}
\epsilon(\varphi) &= \frac{1}{2}\left(\frac{V'(\varphi)}{V(\varphi)}\right)^2 = \frac{M_P^2}{2V_0^2}(\alpha_1 + \frac{\alpha_3}{2}(\varphi-\varphi_0)^2)^2, \\
\eta(\varphi) &= M_P^2 \frac{V''(\varphi)}{V(\varphi)} = M_P^2 \frac{\alpha_3}{V_0}(\varphi-\varphi_0), \\
\xi(\varphi) &= M_P^4 \frac{V'(\varphi)V'''(\varphi)}{V(\varphi)^2} \\
&= M_P^4 \frac{\alpha_3}{V_0^2}(\alpha_1 + \frac{\alpha_3}{2}(\varphi-\varphi_0)^2).
\end{aligned}
$$

where,

$$
\begin{aligned}
V_0 &= \mu^2 k \frac{(k-1)^2}{(2k-1)^2}\left(\frac{k|\mu||\lambda_k'|^{-1}}{2(2k-1)}\right)^{1/k-1} \\
&= \frac{(k-1)^2 m_0^2}{k(2k-1)}\varphi_0^2 + \mathcal{O}(\lambda^2), \\
\alpha_1 &= \tilde{\lambda}^2 \left(\frac{k|\mu||\lambda_k'|^{-1}}{2(2k-1)}\right)^{1/2k-2} + \mathcal{O}(\lambda^4) \\
&= 8(k-1)^2\lambda^2 m_0^2 \varphi_0 + \mathcal{O}(\lambda^4), \\
\alpha_3 &= 8(k-1)^2 \frac{m_0^2}{\varphi_0} + \mathcal{O}(\lambda^2).
\end{aligned}
$$

$$
\begin{aligned}
\lambda^2 &= \frac{2k-1}{8(k-1)^2}\frac{\tilde{\lambda}^2}{\mu^2 k^2} = \frac{\tilde{\lambda}^2 m_0^{-2}}{8(k-1)^2}, \\
\varphi_0 &= \left(\frac{k|\mu||\lambda_k'|^{-1}}{2(2k-1)}\right)^{1/(2k-2)}(1-\lambda^2) + \mathcal{O}(\lambda^4), \\
&= \left(\frac{m_0|\lambda_k'|^{-1}}{2\sqrt{2k-1}}\right)^{1/2k-2}(1-\lambda^2) + \mathcal{O}(\lambda^4).
\end{aligned}
$$

Inflection Point Inflation (extra)

The amplitude of the scalar perturbation :

$$\delta_H \simeq \frac{1}{5\pi}\sqrt{\frac{2}{3}2k(2k-1)(2k-2)}\left(\frac{m_0 M_P}{\varphi_0^2}\right)\frac{1}{\Delta^2}\sin^2[\mathcal{N}_{\rm COBE}\sqrt{\Delta^2}] .$$

The scalar spectral index :

$$n_s = 1 - 4\sqrt{\Delta^2}\cot[\mathcal{N}_{\rm COBE}\sqrt{\Delta^2}] ,$$

where,

$$\Delta^2 = 32k^2(2k-1)^2\lambda^2\mathcal{N}_{\rm COBE}^2\left(\frac{M_P}{\varphi_0}\right)^4 .$$

[Allahverdi et al, Lyth et al]

Renormalization Group equations

$$\frac{d\mu}{d\mathcal{E}} = \frac{\mu}{16\pi^2}\left(3f_t^2 + 3f_b^2 + f_\tau^2 - 3g_2^2 - g_Y^2\right),$$

$$\frac{dB}{d\mathcal{E}} = \frac{1}{8\pi^2}\left(-3f_t^2A^t - 3f_b^2A^b - f_\tau^2A^\tau + 3g_2^2M_2 + g_Y^2M_1\right),$$

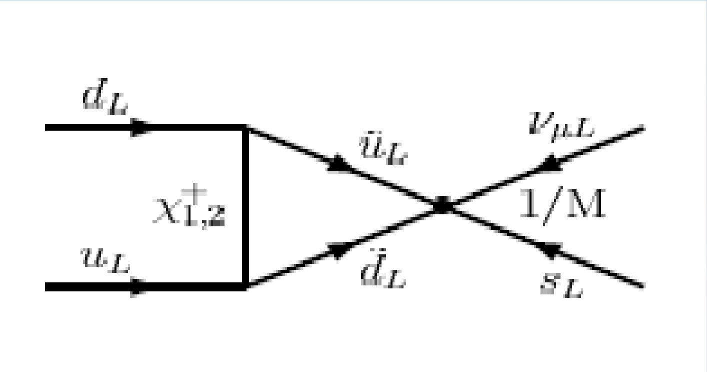
$$\frac{dm_1^2}{d\mathcal{E}} = \frac{1}{8\pi^2}\left(3f_b^2(m_1^2 + m_{\tilde{Q}_3}^2 + m_{\tilde{b}_R}^2 + |A^b|^2) + f_\tau^2(m_1^2 + m_{\tilde{l}_3}^2 + m_{\tilde{\tau}_R}^2 + |A^\tau|^2) - 3g_2^2|M_2|^2 - g_Y^2|M_1|^2 - \frac{1}{2}g_Y^2S_Y\right),$$

$$\frac{dm_2^2}{d\mathcal{E}} = \frac{1}{8\pi^2}\left(3f_t^2(m_2^2 + m_{\tilde{Q}_3}^2 + m_{\tilde{t}_R}^2 + |A^t|^2) - 3g_2^2|M_2|^2 - g_Y^2|M_1|^2 + \frac{1}{2}g_Y^2S_Y\right),$$

where, $S_Y = \frac{1}{2}\Sigma_i Y_i m_i^2$.

Proton decay

For example :



[P. Nath's talk, 2007]

[Arnowitt, Nath, Murayama, Hisano, Ellis ….]