Inflation, GUTs and Phenomenology

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Physics Beyond the Standard Model

- Neutrino Physics: SM + Gravity suggests $m_\nu \lesssim 10^{-5}$ eV, which disagrees with neutrino data;
- Dark Matter: SM offers no plausible DM candidate;
- Origin of matter in the universe;
- Electric Charge Quantization: Unexplained in the SM;
- CMB Isotropy / Anisotropy, Origin of Structure require ideas beyond Hot Big Bang Cosmology (which comes from SM + General Relativity.)

Magnetic Monopoles in Unified Theories

Any unified theory with electric charge quantization predicts the existence of topologically stable ('tHooft-Polyakov) magnetic monopoles. Their mass is about an order of magnitude larger than the associated symmetry breaking scale.

Examples:

1. SU(5) $\rightarrow$ SM (3-2-1)

   Lightest monopole carries one unit of Dirac magnetic charge even though there exist fractionally charged quarks;

2. $SU(4)_c \times SU(2)_L \times SU(2)_R$ (Pati-Salam)

   Electric charge is quantized with the smallest permissible charge being $\pm(e/6)$;

   Lightest monopole carries two units of Dirac magnetic charge;

Magnetic Monopoles in Unified Theories

Examples:

3. SO(10) $\rightarrow$ 4-2-2 $\rightarrow$ 3-2-1

   Two sets of monopoles:

   First breaking produces monopoles with a single unit of Dirac charge.
   Second breaking yields monopoles with two Dirac units.

4. E_6 breaking to the SM can yield 'lighter' monopoles carrying three units of Dirac charge.

   The discovery of primordial magnetic monopoles would have far-reaching implications for high energy physics & cosmology.

Inflationary Cosmology

[Guth, Linde, Albrecht & Steinhardt, Starobinsky, Mukhanov, Hawking, . . .]

Successful Primordial Inflation should:

- Explain flatness, isotropy;
- Provide origin of $\frac{\delta T}{T}$;
- Offer testable predictions for n_s, r, $dn_s/d\ln k$;
- Recover Hot Big Bang Cosmology;
- Explain the observed baryon asymmetry;
- Offer plausible CDM candidate;

Physics Beyond the SM?

Slow-roll Inflation

- Inflation is driven by some potential $V(\phi)$:
- Slow-roll parameters:

$$\epsilon = \frac{m_p^2}{2}\left(\frac{V'}{V}\right)^2, \ \eta = m_p^2\left(\frac{V''}{V}\right).$$

- The spectral index n_s and the tensor to scalar ratio r are given by

$$n_s - 1 \equiv \frac{d\ln\Delta_{\mathcal{R}}^2}{d\ln k}, \ r \equiv \frac{\Delta_h^2}{\Delta_{\mathcal{R}}^2},$$

where Δ_h^2 and $\Delta_{\mathcal{R}}^2$ are the spectra of primordial gravity waves and curvature perturbation respectively.

- Assuming slow-roll approximation (i.e. $(\epsilon, |\eta|) \ll 1$), the spectral index n_s and the tensor to scalar ratio r are given by

$$n_s \simeq 1 - 6\epsilon + 2\eta, \ r \simeq 16\epsilon.$$

- The tensor to scalar ratio r can be related to the energy scale of inflation via

$$V(\phi_0)^{1/4} = 3.3 \times 10^{16}\, r^{1/4} \text{ GeV}.$$

- The amplitude of the curvature perturbation is given by

$$\Delta_{\mathcal{R}}^2 = \frac{1}{24\pi^2} \left(\frac{V/m_p^4}{\epsilon} \right)_{\phi=\phi_0} = 2.43 \times 10^{-9} \text{ (WMAP7 normalization)}.$$

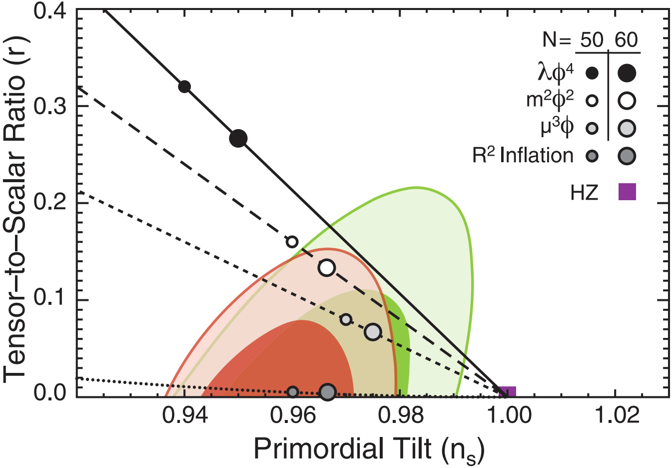
- The spectrum of the tensor perturbation is given by

$$\Delta_h^2 = \frac{2}{3\,\pi^2} \left(\frac{V}{m_P^4} \right)_{\phi=\phi_0}.$$

- The number of e-folds after the comoving scale $l_0 = 2\,\pi/k_0$ has crossed the horizon is given by

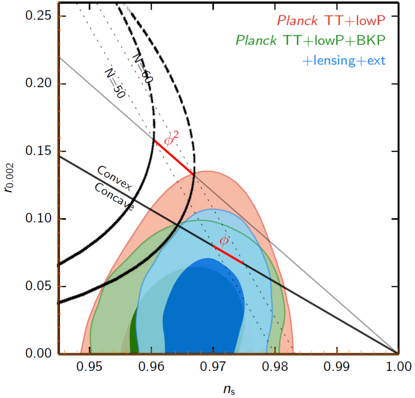
$$N_0 = \frac{1}{m_p^2} \int_{\phi_e}^{\phi_0} \left(\frac{V}{V'} \right) d\phi.$$

Inflation ends when $\max[\epsilon(\phi_e), |\eta(\phi_e)|] = 1$.



WMAP nine year data

Radiatively Corrected ϕ^2 Potential:

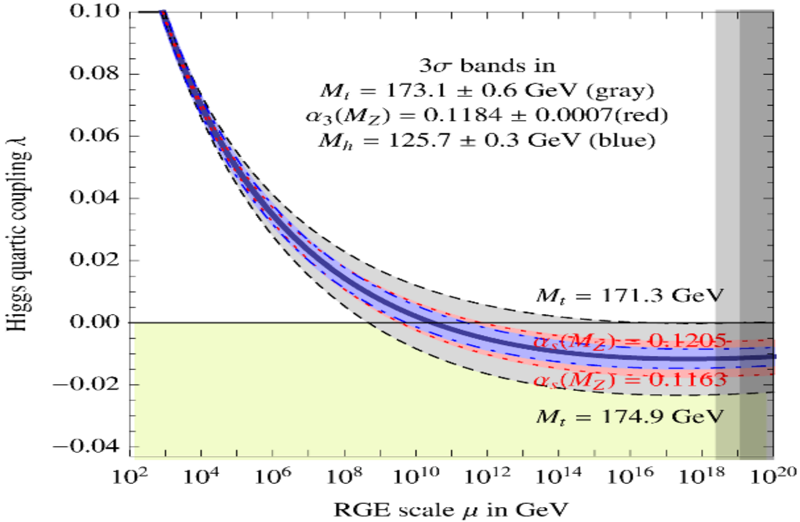


n_s vs. r for radiatively corrected ϕ^2 potential, superimposed on Planck and Planck+BKP 68% and 95% CL regions taken from arXiv:1502.01589. The dashed portions are for $\kappa < 0$. N is taken as 50 (left curves) and 60 (right curves).

SM Higgs Quartic Coupling

Update of RGE analysis (@ 3-loop level)

Buttazzo et al., JHEP 12 (2013) 089



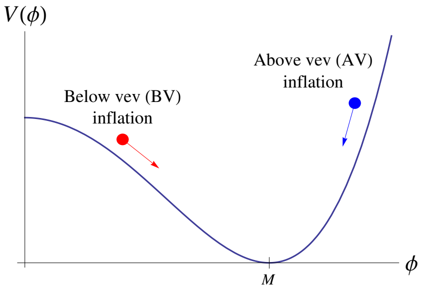
Tree Level Gauge Singlet Higgs Inflation

[Kallosh and Linde, 07; Rehman, Shafi and Wickman, 08]

- Consider the following Higgs Potential:

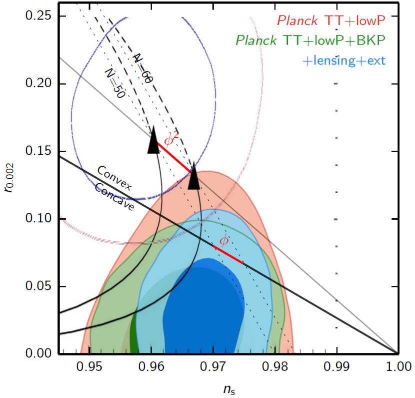
$$V(\phi) = V_0 \left[1 - \left(\frac{\phi}{M}\right)^2\right]^2 \quad \longleftarrow \text{(tree level)}$$

Here ϕ is a gauge singlet field.



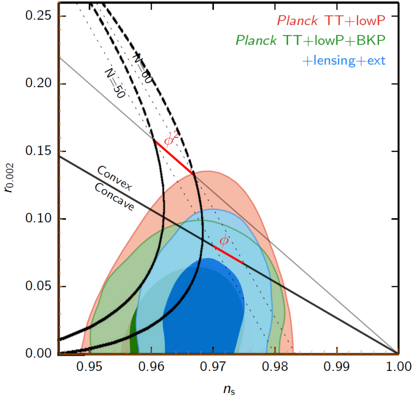
- WMAP/Planck data favors BV inflation ($r \lesssim 0.1$).

Higgs Potential:



n_s vs. r for Higgs potential, superimposed on Planck and Planck+BKP 68% and 95% CL regions taken from arXiv:1502.01589. The dashed portions are for $\phi > v$. N is taken as 50 (left curves) and 60 (right curves).

Coleman–Weinberg Potential:



n_s vs. r for Coleman–Weinberg potential, superimposed on Planck and Planck+BKP 68% and 95% CL regions taken from arXiv:1502.01589. The dashed portions are for $\phi > v$. N is taken as 50 (left curves) and 60 (right curves).

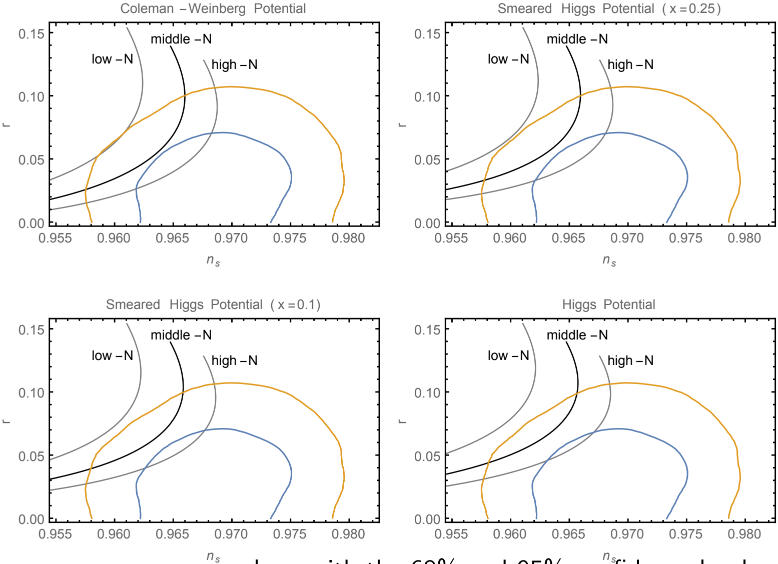


Figure: n_s vs. r curves along with the 68% and 95% confidence level contours given by the Planck collaboration (Planck TT+lowP+BKP+lensing+ext).

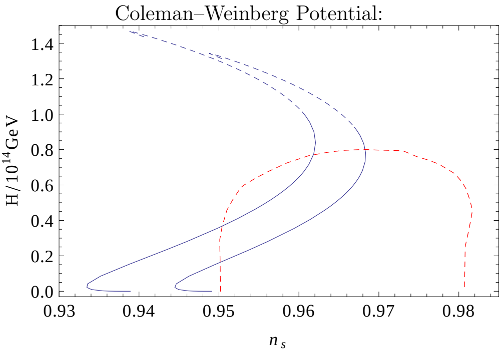
Coleman–Weinberg Potential:

n_s $(N = 50)$	r $(N = 50)$	n_s $(N = 60)$	r $(N = 60)$
0.935	0.00112	0.946	0.00112
0.952	0.026	0.961	0.0254
0.958	0.0498	0.966	0.0471
0.961	0.0712	0.968	0.0652
0.961	0.141	0.968	0.119
0.96	0.161	0.967	0.134
0.956	0.208	0.964	0.171
0.951	0.256	0.959	0.211
0.94	0.324	0.95	0.27
0.939	0.33	0.949	0.276
0.94	0.32	0.95	0.268

Coleman-Weinberg Potential		Higgs Potential	
$M_X \sim 2\,V_0^{1/4}$(GeV)	$\tau(p \to \pi^0 e^+)$ (years)	$M_X \sim V_0^{1/4}$(GeV)	$\tau(p \to \pi^0 e^+)$ (years)
5.0×10^{15}	1.8×10^{34}	1.0×10^{16}	2.8×10^{35}
1.0×10^{16}	2.8×10^{35}	1.2×10^{16}	5.8×10^{35}
1.2×10^{16}	5.8×10^{35}	1.4×10^{16}	1.1×10^{36}
1.8×10^{16}	2.9×10^{36}	1.6×10^{16}	1.8×10^{36}
2.2×10^{16}	6.6×10^{36}	1.8×10^{16}	2.9×10^{36}
2.7×10^{16}	1.5×10^{37}	2.1×10^{16}	5.5×10^{36}
3.5×10^{16}	4.2×10^{37}	2.4×10^{16}	9.3×10^{36}
6.0×10^{16}	3.6×10^{38}	2.9×10^{16}	2.0×10^{37}

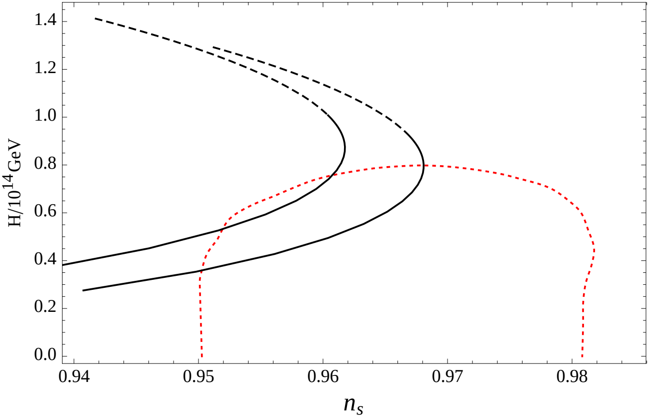
Table: Superheavy gauge bosons masses and corresponding proton lifetimes with $\alpha_G = \frac{1}{35}$ in the CW and Higgs models. Note that since the lifetime depends only on M_X, the results shown here apply equally well to the BV and AV branches in each model.

- Where does ϕ come from?
  (1) Associated with spontaneous breaking of global $U(1)_{B-L}$, $U(1)_X$ in $SU(5)$, or $U(1)_L$ (majoran dark matter);
  (2) Breaks gauged $U(1)_{B-L}$ (in this case B-L gauge coupling should be $\lesssim 10^{-3}$);
  (3) Associated with $U(1)_{PQ}$ if we employ non-minimal coupling to gravity.
- Topological Defects:
  Cosmic strings and magnetic monopoles may survive inflation if the symmetry breaking scale is comparable to H (Hubble constant) during inflation.
- Example: $SO(10) \to SU(4)_C \times SU(2)_L \times SU(2)_R \to SU(3)_C \times SU(2)_L \times U(1)_Y$.
  Second breaking yields monopoles carrying two units of Dirac magnetic charge.



n_s vs. H for Coleman–Weinberg potential, superimposed on Planck TT+lowP+BKP 95% CL region taken from arXiv:1502.02114. The dashed portions are for $\phi > v$. N is taken as 50 (left curves) and 60 (right curves).

Higgs Potential:



Primordial Monopoles

- Let's consider how much dilution of the monopoles is necessary. $M_I \sim 10^{13}$ GeV corresponds to monopole masses of order $M_M \sim 10^{14}$ GeV. For these intermediate mass monopoles the MACRO experiment has put an upper bound on the flux of 2.8×10^{-16} cm^{-2} s^{-1} sr^{-1}. For monopole mass $\sim 10^{14}$ GeV, this bound corresponds to a monopole number per comoving volume of $Y_M \equiv n_M/s \lesssim 10^{-27}$. There is also a stronger but indirect bound on the flux of $(M_M/10^{17}$ GeV$)10^{-16}\mathrm{cm}^{-2}$ s^{-1} sr^{-1} obtained by considering the evolution of the seed Galactic magnetic field.
- At production, the monopole number density n_M is of order H_x^3, which gets diluted to $H_x^3 e^{-3N_x}$, where N_x is the number of e-folds after $\phi = \phi_x$. Using

$$Y_M \sim \frac{H_x^3 e^{-3N_x}}{s},$$

where $s = (2\pi^2 g_S/45)T_r^3$, we find that sufficient dilution requires $N_x \gtrsim \ln(H_x/T_r) + 20$. Thus, for $T_r \sim 10^9$ GeV, $N_x \gtrsim 30$ yields a monopole flux close to the observable level.

Supersymmetry

- Resolution of the gauge hierarchy problem
- Predicts plethora of new particles which LHC should find
- Unification of the SM gauge couplings at

  $M_{GUT} \sim 2 \times 10^{16}$ GeV
- Cold dark matter candidate (LSP)
- Radiative electroweak breaking
- String theory requires supersymmetry (SUSY)

Alas, SUSY not yet seen at LHC

SUSY Higgs (Hybrid) Inflation

[Dvali, Shafi, Schaefer; Copeland, Liddle, Lyth, Stewart, Wands '94]

[Lazarides, Schaefer, Shafi '97][Senoguz, Shafi '04; Linde, Riotto '97]

- Attractive scenario in which inflation can be associated with symmetry breaking $G \longrightarrow H$
- Simplest inflation model is based on

$$W = \kappa\, S\, (\Phi\, \overline{\Phi} - M^2)$$

  $S =$ gauge singlet superfield, $(\Phi\,,\overline{\Phi})$ belong to suitable representation of G

- Need $\Phi\,,\overline{\Phi}$ pair in order to preserve SUSY while breaking $G \longrightarrow H$ at scale $M \gg$ TeV, SUSY breaking scale.
- R-symmetry

$$\Phi\,\overline{\Phi} \rightarrow \Phi\,\overline{\Phi}, \;\; S \rightarrow e^{i\alpha}\, S, \;\; W \rightarrow e^{i\alpha}\, W$$

$\Rightarrow \quad W$ is a unique renormalizable superpotential

- Some examples of gauge groups:

$$G = U(1)_{B-L}, \text{ (Supersymmetric superconductor)}$$

$$G = SU(5) \times U(1), \quad (\Phi = 10), \quad \text{(Flipped } SU(5))$$

$$G = 3_c \times 2_L \times 2_R \times 1_{B-L}, \ (\Phi = (1, 1, 2, +1))$$

$$G = 4_c \times 2_L \times 2_R, \ (\Phi = (\overline{4}, 1, 2)),$$

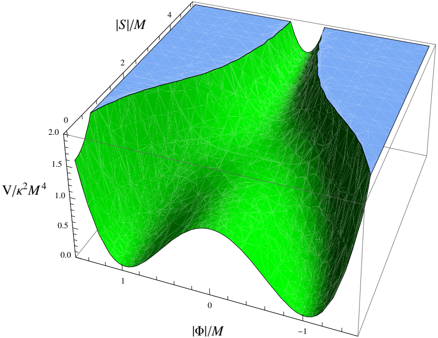
$$G = SO(10), \ (\Phi = 16)$$

- Tree Level Potential

$$V_F = \kappa^2 \left(M^2 - |\Phi^2|\right)^2 + 2\kappa^2 |S|^2 |\Phi|^2$$

- SUSY vacua

$$|\langle\overline{\Phi}\rangle| = |\langle\Phi\rangle| = M,\ \langle S\rangle = 0$$



Take into account radiative corrections (because during inflation $V \neq 0$ and SUSY is broken by $F_S = -\kappa\, M^2$)

- Mass splitting in $\Phi - \overline{\Phi}$

$$m_{\pm}^2 = \kappa^2\, S^2 \pm \kappa^2\, M^2, \quad m_F^2 = \kappa^2\, S^2$$

- One-loop radiative corrections

$$\Delta V_{\text{1loop}} = \frac{1}{64\pi^2}\text{Str}[\mathcal{M}^4(S)(\ln\frac{\mathcal{M}^2(S)}{Q^2} - \frac{3}{2})]$$

- In the inflationary valley ($\Phi = 0$)

$$V \simeq \kappa^2\, M^4 \left(1 + \frac{\kappa^2 \mathcal{N}}{8\pi^2} F(x)\right)$$

where $x = |S|/M$ and

$$F(x) = \frac{1}{4}\left(\left(x^4+1\right)\ln\frac{\left(x^4-1\right)}{x^4} + 2x^2\ln\frac{x^2+1}{x^2-1} + 2\ln\frac{\kappa^2 M^2 x^2}{Q^2} - 3\right)$$

- Tree level + radiative corrections + minimal Kähler potential yield:
$$n_s = 1 - \frac{1}{N} \approx 0.98.$$
- $\delta T/T$ proportional to M^2/M_p^2, where M denotes the gauge symmetry breaking scale. Thus we expect $M \sim M_{\mathsf{GUT}}$ for this simple model.
- Since observations suggest that n_s lie close to 0.97, there are at least two ways to realize this slightly lower value:
(1) include soft SUSY breaking terms, especially a linear term in S;
(2) employ non-minimal Kähler potential.

Full Story

Also include supergravity corrections + soft SUSY breaking terms

- The minimal Kähler potential can be expanded as

$$K = |S|^2 + |\Phi|^2 + |\overline{\Phi}|^2$$

- The SUGRA scalar potential is given by

$$V_F = e^{K/m_p^2}\left(K_{ij}^{-1} D_{z_i} W D_{z_j^*} W^* - 3m_p^{-2}|W|^2\right)$$

where we have defined

$$D_{z_i} W \equiv \frac{\partial W}{\partial z_i} + m_p^{-2}\frac{\partial K}{\partial z_i} W;\; K_{ij} \equiv \frac{\partial^2 K}{\partial z_i \partial z_j^*}$$

and $z_i \in \{\Phi, \overline{\Phi}, S, ...\}$

[Senoguz, Shafi '04; Jeannerot, Postma '05]

- Take into account sugra corrections, radiative corrections and soft SUSY breaking terms:

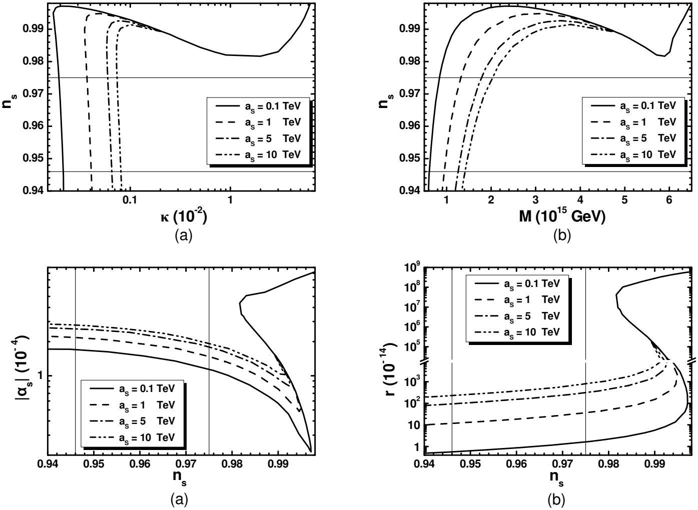
$$V \simeq \kappa^2 M^4 \left(1 + \left(\frac{M}{m_p}\right)^4 \frac{x^4}{2} + \frac{\kappa^2 \mathcal{N}}{8\pi^2} F(x) + a_s \left(\frac{m_{3/2} x}{\kappa M}\right) + \left(\frac{m_{3/2} x}{\kappa M}\right)^2\right)$$

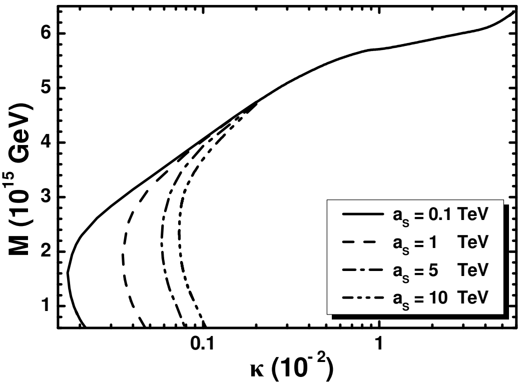
where $a_s = 2\,|2-A|\cos[\arg S + \arg(2-A)]$, $x = |S|/M$ and $S \ll m_P$.

Note: No 'η problem' with minimal (canonical) Kähler potential !

Results

[Pallis, Shafi, 2013; Rehman, Shafi, Wickman, 2010]





M (10^{15} GeV)
6
5
4
3
2
1
0.1
1
κ (10^{-2})
a_S = 0.1 TeV
a_S = 1 TeV
a_S = 5 TeV
a_S = 10 TeV

MSSM μ-Problem and Inflation

$U(1)_R$ symmetry prevents a direct μ term but allows the superpotential coupling

$$\lambda H_u H_d S$$

Since $\langle S \rangle$ acquires a non-zero VEV $\propto m_{3/2}$ from supersymmetry breaking, the MSSM μ term of the desired magnitude is realized.

μ-Term Inflation

- U(1) R-symmetry yields the following unique renormalizable superpotential:

$$W = S(\kappa\overline{\Phi}\Phi - \kappa M^2 + \lambda H_u H_d).$$

- Include SUSY breaking/SUGRA, the inflationary potential is

$$V(\phi) = m^4\left(1 + A\ln\left[\frac{\phi}{\phi_0}\right]\right) - 2\sqrt{2}m_G m^2\phi,$$

$$\phi = \sqrt{2}\mathrm{Re}[S],\ m \equiv \sqrt{\kappa}M,$$

$$A = \frac{1}{4\pi^2}\left(\lambda^2 + \frac{N_\Phi}{2}\kappa^2\right).$$

- Successful inflation/gauge symmetry breaking requires $\lambda > \kappa$.

μ-Term Inflation

- MSSM μ-term

$$\mu = \frac{\lambda}{\kappa} m_G \equiv \gamma m_G .$$

$$n_s \simeq 1 - \frac{2}{N_0} f(B), \; B = \frac{2\sqrt{2}\, m_G\, \phi_0}{A\, m^2}$$

- For N_0=60:
  1) $B = 0 \Rightarrow f(B) = 1/2 \Rightarrow n_s \simeq 0.98$.
  2) $B = 0.7 \Rightarrow f(B) = 1.03 \Rightarrow n_s \simeq 0.966$.

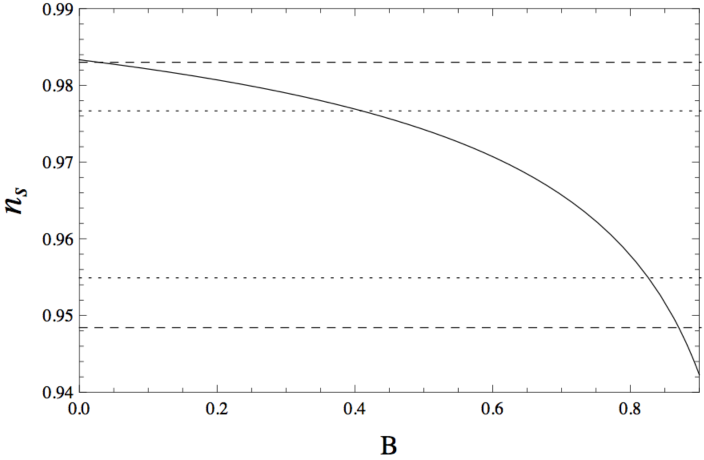


Figure: Spectral index n_s vs. B. The region between the two dotted (dashed) lines corresponds to 1σ (2σ) limit obtained by Planck 2015.

Inflaton Decay:

-
$$\Gamma(\phi \to \tilde{H}_u \tilde{H}_d) = \frac{\lambda^2}{8\pi} m_\phi .$$
$$\Rightarrow T_r \gtrsim 3.2 \times 10^{11}\ \text{GeV}.$$

- Cosmology with gravitinos:
  1) LSP gravitino not realized.
  2) If m_G is sufficiently large, LSP is still in thermal equilibrium when inflaton/gravitino decay

$$\Rightarrow m_G \gtrsim (4.6 \times 10^7\ \text{GeV}) \left(\frac{m_{\text{LSP}}}{2\text{TeV}}\right)^{2/3} .$$

Minimal scenario yields split SUSY

$m_0 \sim m_G \sim \mu (\Rightarrow \tan\beta \approx 2, m_h \approx 125\text{GeV})$

$M_{1/2} \sim$ TeV $\Rightarrow$ Wino dark matter

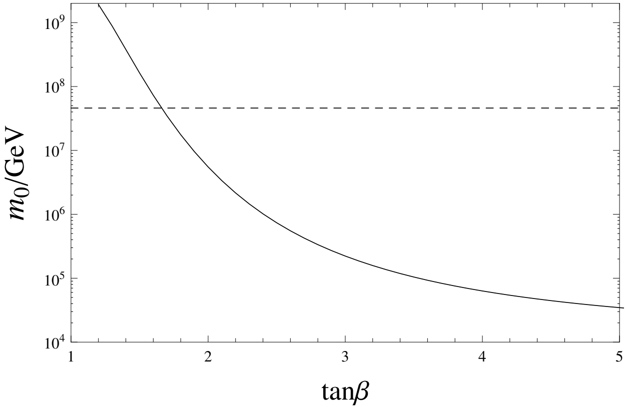


Figure: Soft scalar mass m_0 as a function of $\tan\beta$.

b-τ YU in $SU(4) \times SU(2)_L \times SU(2)_R$ (422)

- $m_{16},\ m_{H_i},\ M_i,\ A_0,\ \tan\beta,\ sign(\mu)$
- $m_{16} \equiv$ Universal soft SUSY breaking (SSB) sfermion mass
- $m_{H_d,H_u} \equiv$ Universal SSB MSSM Higgs masses.
- $M_i \equiv$ SSB gaugino masses.
$$M_1 = \tfrac{3}{5}M_2 + \tfrac{2}{5}M_3$$
- $A_0 \equiv$ Universal SSB trilinear interaction
- $\tan\beta = \frac{v_u}{v_d}$
- $\mu \equiv$ SUSY bilinear Higgs parameter $\mu > 0$

Random scans for the following parameter range (NUHM2):

$$\begin{array}{rcccl} 0 & \leq & m_{16} & \leq & 20\,\mathrm{TeV}, \\ 0 & \leq & M_2 & \leq & 5\,\mathrm{TeV}, \\ 0 & \leq & M_3 & \leq & 5\,\mathrm{TeV}, \\ -3 & \leq & A_0/m_{16} & \leq & 3, \\ 0 & \leq & m_{H_d} & \leq & 20\,\mathrm{TeV}, \\ 0 & \leq & m_{H_u} & \leq & 20\,\mathrm{TeV} \\ 2 & \leq & \tan\beta & \leq & 60, \\ \multicolumn{3}{l}{\mu > 0,} & \multicolumn{2}{l}{m_t = 173.3\,\mathrm{GeV}.} \end{array}$$

	Point 1	Point 2	Point 3	Point 4	Point 5
m_{16}	12730	9839	17640	7477	11940
M_1	1172	1903	1462	1496	1700
M_2	1820	2881	2327	2335	2660
M_3	550	435.3	165	237	260
m_{H_d}, m_{H_u}	11720, 14690	5967, 7279	12890, 5640	6624, 1513	3111, 5478
$\tan\beta$	36.3	41.3	52.9	32.4	39.0
A_0/m_0	-2.07	-2.41	-2.62	-2.56	-2.63
m_t	173.3	173.3	173.3	173.3	173.3
μ	4957	9186	19086	8552	13149
$\Delta(g-2)_\mu$	0.82×10^{-11}	0.72×10^{-11}	0.28×10^{-11}	0.97×10^{-11}	0.45×10^{-11}
m_h	126.4	125.9	123.9	125	123.3
m_H	2262	2157	1799	7900	3058
m_A	2247	2144	1788	7849	3039
$m_{H^\pm}$	2264	2160	1802	7901	3061
$m_{\tilde{\chi}^0_{1,2}}$	641,1682	918, 2585	770,2276	715, 2087	837, 2441
$m_{\tilde{\chi}^0_{3,4}}$	4973, 4974	9137, 9137	18924, 18924	8537, 8537	13101, 13101
$m_{\tilde{\chi}^\pm_{1,2}}$	1697, 4979	2604, 9133	2281, 18927	2104, 8534	2457, 13090
$m_{\tilde{g}}$	1625	1314	879	790	943
$m_{\tilde{u}_{L,R}}$	12743, 12860	9988, 9900	17708, 17538	7616, 7393	12019, 11977
$m_{\tilde{t}_{1,2}}$	689, 6131	1042, 4668	5577, 7056	781, 4077	901, 5263
$m_{\tilde{d}_{L,R}}$	12743, 12715	9988, 9853	17708, 17721	7617, 7525	12019, 11933
$m_{\tilde{b}_{1,2}}$	6234, 8566	4706, 5997	6884, 7646	4125, 5259	5293, 7047
$m_{\tilde{\nu}_1}$	12859	10035	17634	7562	12091
$m_{\tilde{\nu}_3}$	11262	8267	12950	6496	10076
$m_{\tilde{e}_{L,R}}$	12846, 12581	10027, 9814	17630, 17854	7554, 7623	12081, 11906
$m_{\tilde{\tau}_{1,2}}$	9129, 11263	5711, 8239	5525, 12875	5399, 6519	7366, 10045
σ_{SI}(pb)	0.71×10^{-13}	0.16×10^{-13}	0.70×10^{-14}	0.62×10^{-14}	0.27×10^{-13}
σ_{SD}(pb)	0.18×10^{-9}	0.19×10^{-11}	0.14×10^{-14}	0.41×10^{-12}	0.59×10^{-16}
$\Omega_{CDM}h^2$	0.13	0.86	0.45	0.09	0.123
R	1.06	1.18	1.04	1.19	1.09

	Point 1	Point 2	Point 3
m_{16}	19100	19550	19680
M_1	1799.48	1910.12	1978.2
M_2	2853	3025	3129
M_3	219.2	237.8	240.01
m_{H_d}	15940	16270	17000
m_{H_u}	10530	10350	10810
A_0/m_0	-2.584	-2.586	-2.554
$\tan\beta$	50.2	49.93	50.81
m_h	124	124	125
m_H	2586	4277	4647
m_A	2571	4250	4617
$m_{H^\pm}$	2590	4278	4649
$m_{\tilde{\chi}^0_{1,2}}$	932, 2741	987, 2895	1018, 2988
$m_{\tilde{\chi}^0_{3,4}}$	19309, 19309	19995, 19995	19758, 19758
$m_{\tilde{\chi}^\pm_{1,2}}$	2748, 19326	2903, 2001	2996, 19770
$m_{\tilde{g}}$	1019	1069	1075
$m_{\tilde{u}_{L,R}}$	19187, 19003	19646, 19446	19784, 19566
$m_{\tilde{t}_{1,2}}$	4640, 6790	4777, 7082	5174, 7283
$m_{\tilde{d}_{L,R}}$	19187, 19185	19646, 19640	19784, 19776
$m_{\tilde{b}_{1,2}}$	6664, 7659	6954, 8070	7137, 8091
$m_{\tilde{\nu}_1}$	19117	19569	19696
$m_{\tilde{\nu}_3}$	14107	14428	14478
$m_{\tilde{e}_{L,R}}$	19111, 19274	19562, 19738	19690, 19884
$m_{\tilde{\tau}_{1,2}}$	6372, 14039	6521, 14348	6388, 14399
$\sigma_{SI}(\text{pb})$	1.21×10^{-14}	1.92×10^{-14}	1.85×10^{-14}
$\sigma_{SD}(\text{pb})$	1.05×10^{-14}	4.54×10^{-14}	9.64×10^{-14}
$\Omega_{CDM}h^2$	0.108	0.083	0.035
$R_{tb\tau}$	1.07	1.09	1.09

Summary

- If $r \sim 0.1 - 0.02$, then inflation models based on the Higgs / Coleman-Weinberg potentials can provide simple / realistic frameworks for inflation, with minimal coupling to gravity.
- There is a lower bound on H (Hubble constant) in these models. This is important for topological defects in GUT models involving intermediate scales.
- If $r \lesssim 0.01$, then supersymmetric hybrid inflation models are especially interesting. These work with inflaton field values below M_{Planck}, and supergravity corrections are under control. The simplest versions employ TeV scale SUSY, and hopefully LHC 14 will find it.
- μ-term assisted hybrid inflation consistent with Wino dark matter and a 125 GeV SM-like Higgs. Gluino mass in the TeV range.
- b-τ YU in 4-2-2: NLSP Gluino, NLSP Stop
- t-b-τ YU in 4-2-2 (NUHM2): NLSP Gluino