GUTs, Inflation, 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.)
- Strong CP Problem.

Grand Unified Theories (GUTs)

- Unification of SM / MSSM gauge couplings;
- Unification of matter/quark-lepton multiplets;
- Electric charge quantization; Magnetic monopoles.
- Seesaw physics / neutrino oscillations;
- Quark-Lepton mass relations;
- New source for baryo-leptogenesis;
- Inflation / Observable gravity waves (Planck)

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.

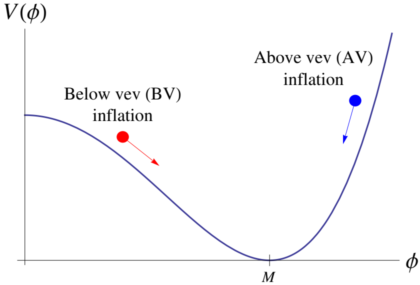
Tree Level Gauge Singlet Higgs Inflation

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

- Consider the following Higgs Potential:

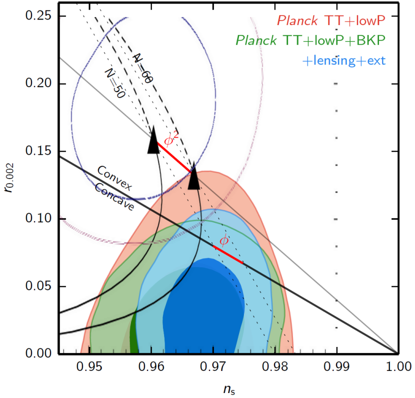
$$V(\phi) = V_0 \left[1 - \left(\frac{\phi}{M}\right)^2\right]^2 \quad \longleftarrow \text{(tree level)}$$

  Here ϕ is a gauge singlet field.



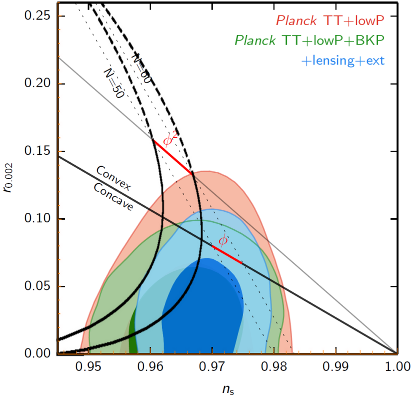
- WMAP/Planck data favors BV inflation ($r \lesssim 0.1$).

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).

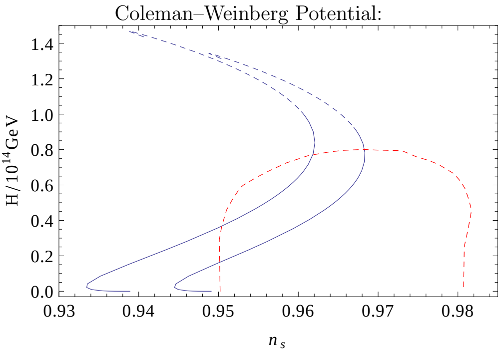
Coleman–Weinberg Potential:



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).

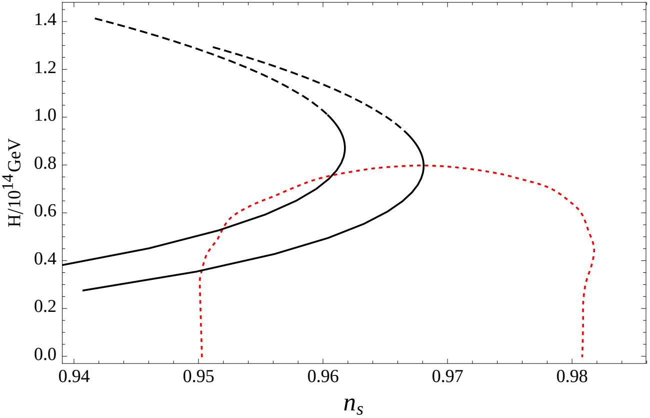
Coleman-Weinberg Potential		Higgs Potential	
$M_X \sim 2\, V_0^{1/4}$(GeV)	$\tau(p \to \pi^0 e^+)$ (years)	$M_X \sim V_0^{1/4}$(GeV)	$\tau(p \to \pi^0 e^+)$ (years)
5.0×10^{15}	1.8×10^{34}	1.0×10^{16}	2.8×10^{35}
1.0×10^{16}	2.8×10^{35}	1.2×10^{16}	5.8×10^{35}
1.2×10^{16}	5.8×10^{35}	1.4×10^{16}	1.1×10^{36}
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.



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 $2.8 \times 10^{-16}\ \mathrm{cm}^{-2}$ 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.

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

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

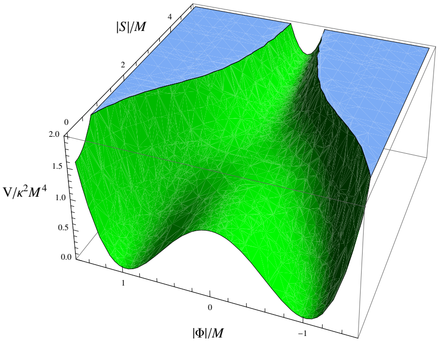
$\Rightarrow$ W is a unique renormalizable superpotential

- Tree Level Potential

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

- SUSY vacua

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



- 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.

$U(1)_R$ 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.

- 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

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

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

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

- 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) $B = 0.7 \Rightarrow f(B) = 1.03 \Rightarrow n_s \simeq 0.966.$

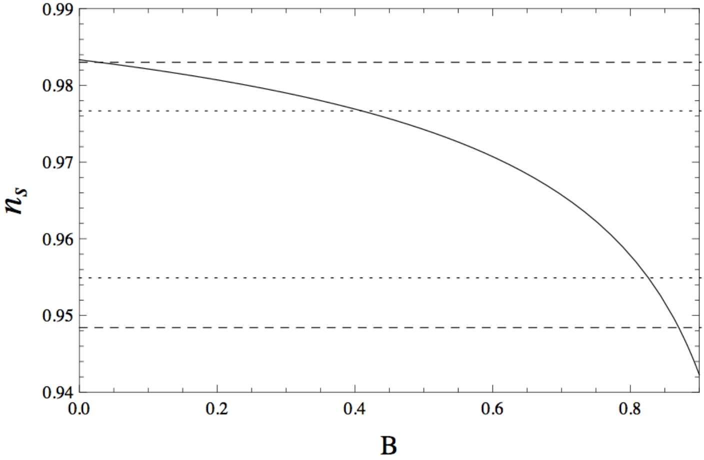


Figure: Spectral index n_s vs. B. The region between the two dotted (dashed) lines corresponds to 1σ (2σ) limit obtained by Planck 2015.

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

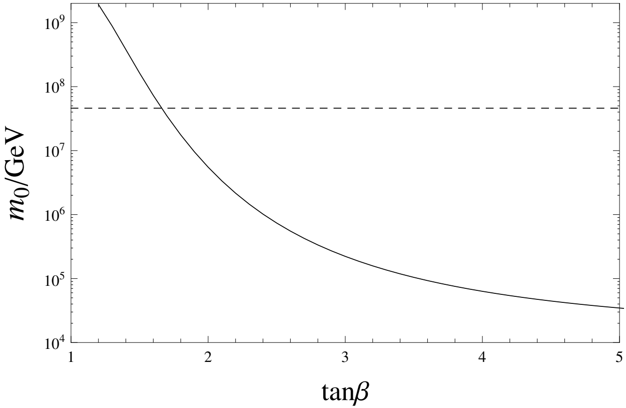


Figure: Soft scalar mass m_0 as a function of $\tan\beta$.

Non-minimal Kähler potential

$$K = |S|^2 + |\Phi|^2 + |\overline{\Phi}|^2 + \kappa_S \frac{|S|^4}{4m_p^2} + \kappa_{S\phi}\frac{|S|^2|\Phi|^2}{m_p^2} + \kappa_{S\overline{\phi}}\frac{|S|^2|\overline{\Phi}|^2}{m_p^2} + \kappa_{SS}\frac{|S|^6}{6m_p^4} + \cdots$$

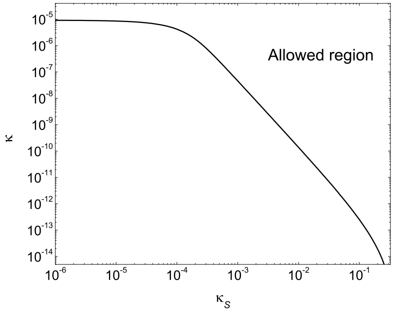


Figure: The region in the κ and κ_S plane satisfying $\mathcal{R} = 4.86 \times 10^{-5}$.

Non-minimal Kähler potential

In some cases, $n_s \approx 0.98 - 2\kappa_s$.

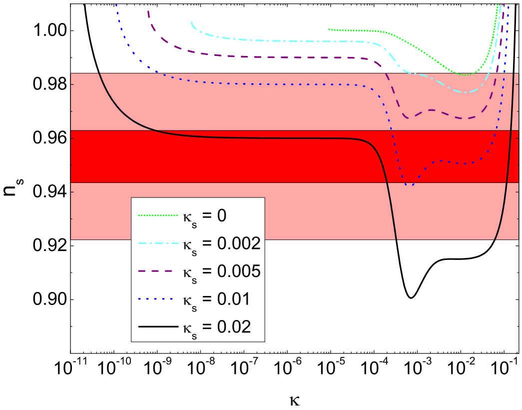


Figure: n_s as a function of κ for different values of κ_S ($\mathcal{N} = 1$). The red and pink bands correspond to the WMAP 1σ and 2σ range [?].

Consider the superpotential:

$$
\begin{aligned}
W &= \kappa S(\bar{H}^c H^c - M^2) - \beta S \frac{(\bar{H}^c H^c)^2}{M_S^2} + \lambda_1 \frac{N^2 h^2}{M_S} + \lambda_2 \frac{N^2 \bar{N}^2}{M_S} \\
&+ \lambda_{ij} F_i^c F_j h + \gamma_i \frac{\bar{H}^c \bar{H}^c}{M_S} F_i^c F_i^c + aGH^c H^c + bG\bar{H}^c \bar{H}^c
\end{aligned}
$$

$$
R : H^c(0), \bar{H}^c(0), S(1), G(1), F(1/2), F^c(1/2), N(1/2), \bar{N}(0), h(0);
$$

$$
PQ : H^c(0), \bar{H}^c(0), S(0), G(0), F(-1), F^c(0), N(-1), \bar{N}(1), h(1).
$$

$$
\begin{aligned}
V_{PQ} &= 2|N|^2 m_{3/2}^2 \left(4\lambda_2^2 \frac{|N|^4}{m_{3/2}^2 M_S^2} - |A|\lambda_2 \frac{|N|^2}{m_{3/2} M_S} + 1 \right) \\
|\langle N \rangle| &= |\langle \bar{N} \rangle| = (m_{3/2} M_S)^{1/2} \left(\frac{|A| + \sqrt{|A|^2 - 12}}{12\lambda_2} \right)^{1/2}.
\end{aligned}
$$

μ term, axion and hybrid inflation

- The inflaton potential contains, in addition to the desired minimum at f_a, a local minimum at the origin, with a barrier separating the two.
- One should make sure that the desired minimum is reached after inflation, without generating excessive amount of entropy.
- In this case the subsequent reheating and leptogenesis proceeds in a more conventional way and the μ term $\sim m_{3/2} \sim$ TeV.

SUSY SO(10)

- Fermion families reside in $\underset{\sim}{16}_i (i=1,2,3)$;
- predicts 'right handed' neutrino $\Rightarrow$ non-zero neutrino masses through seesaw mechanism.
- Automatic Z_2 'matter' parity if $SO(10) \to$ MSSM using only tensor repsns. Also means stable cosmic strings (in addition to monopoles)
- Yukawa couplings include

$$16_i 16_j 10,\ 16_i 16_j 126, \mathrm{etc.}$$

- $16_3 16_3 10$ yields $t - b - \tau$ unification

$$Y_t = Y_b = Y_\tau = Y_\nu \text{ (not so in non-SUSY SO(10))}$$

- In the 'old days' (B. Ananthanarayan, G. Lazarides and Q. Shafi, 1991) it was used to predict the top quark mass

- Nowadays, one employs $t - b - \tau$ unification to make predictions, such as sparticle masses, which can be tested at the LHC (Baer et al.,Raby et al., ...);
- $t - b - \tau$ Yukawa unification can also be realized in $SU(4)_c \times SU(2)_L \times SU(2)_R$, a maximal subgroup of SO(10);

$$m_{16},\ m^2_{H_u},\ m^2_{H_d},\ m_{1/2},\ A_0,\ \tan\beta,\ \mathsf{sign}(\mu)$$

$$\begin{aligned} 0 \le m_{16} &\le 30\,\mathrm{TeV} \\ 0 \le m_{H_u} &\le 35\,\mathrm{TeV} \\ 0 \le m_{H_d} &\le 35\,\mathrm{TeV} \\ 0 \le m_{1/2} &\le 5\,\mathrm{TeV} \\ 30 \le \tan\beta &\le 60 \\ -3 \le A_0/m_0 &\le 3 \end{aligned}$$

In order to quantify Yukawa coupling unification, we define the quantity

$$R_{tb\tau} = \frac{\max(y_t, y_b, y_\tau)}{\min(y_t, y_b, y_\tau)}.$$

	Point 1	Point 2	Point 3	Point 4
m_{16}	21370	20230	18640	26130
$m_{1/2}$	93.41	364	579	1021
A_0/m_{16}	-2.43	-2.13	-2.09	-2.11
$\tan\beta$	57.2	51	50	52
m_{H_d}	22500.0	26770	24430	34210
m_{H_u}	13310.0	23260	21780	30590
m_h	126.7	125	124	124
m_H	9389	3192	3145	4066
m_A	9328	3171	3125	4040
$m_{H^\pm}$	9390	3193	3147	4067
$m_{\tilde{g}}$	750	1375	1853	2991
$m_{\tilde{\chi}^0_{1,2}}$	122, 285	232, 491	323,661	557,1114
$m_{\tilde{\chi}^0_{3,4}}$	19295, 19295	6048,6048	4570,4571	6315,6315
$m_{\tilde{\chi}^\pm_{1,2}}$	286, 19330	493,6021	664,4542	1118,6275
$m_{\tilde{u}_{L,R}}$	21389,21132	20230,20115	18653,18574	26187,26079
$m_{\tilde{t}_{1,2}}$	7389,8175	3465,5356	3089,5447	4376,7901
$m_{\tilde{d}_{L,R}}$	21389,21513	20230,20333	18653,18742	26187,26304
$m_{\tilde{b}_{1,2}}$	7836,8234	5417,6047	5534,6584	8038,9652
$m_{\tilde{\nu}_1}$	21196	20128	18565	26037
$m_{\tilde{\nu}_3}$	15502	15066	14032	19441
$m_{\tilde{e}_{L,R}}$	21193,21717	20123,20416	18559,18779	26027,26319
$m_{\tilde{\tau}_{1,2}}$	7490,15463	8048,15079	7796,14042	9984,19455
$\Omega_{CDM}h^2$	12642	190	972	1377
$R_{tb\tau}$	1.06	1.00	1.05	1.07
$BF(\to b\bar{b}_i)$	0.33	0.13	0.07	0.06
$BF(\to t\bar{t}_i)$	0.15	0.15	0.69	0.75
$BF(\to t\bar{b}_j + c.c.)$	0.45	0.33	0.22	0.18

Consider $M_3 : M_2 : M_1 = -2 : 3 : 1$.

	Point 1	Point 2	Point 3
μ	3729	2913	2526
m_h	125	124	123
m_H	747	572	558
m_A	742	568	554
$m_{H^\pm}$	753	580	567
$m_{\tilde{\chi}^0_{1,2}}$	895, 3739	848, 2932	709, 2540
$m_{\tilde{\chi}^0_{3,4}}$	3742, 4822	2935, 4562	2543, 3849
$m_{\tilde{\chi}^\pm_{1,2}}$	3789, 4774	2978, 4516	2579, 3809
$m_{\tilde{g}}$	7694	7266	6239
$m_{\tilde{u}_{L,R}}$	7667, 6824	7219, 6415	6295, 5635
$m_{\tilde{t}_{1,2}}$	5331, 6560	5239, 6367	4390, 5370
$m_{\tilde{d}_{L,R}}$	7668, 6814	7220, 6406	6296, 5628
$m_{\tilde{b}_{1,2}}$	5553, 6526	5434, 6333	4591, 5341
$m_{\tilde{\nu}_{1,2}}$	4148	3870	3487
$m_{\tilde{\nu}_3}$	3898	3641	3243
$m_{\tilde{e}_{L,R}}$	4153, 2234	3875, 2009	3491, 2068
$m_{\tilde{\tau}_{1,2}}$	1094, 3875	881, 3620	1061, 3225
$\Delta(g-2)_\mu$	3.11×10^{-11}	3.71×10^{-11}	4.97×10^{-11}
σ_{SI}(pb)	1.59×10^{-11}	7.08×10^{-11}	1.00×10^{-10}
σ_{SD}(pb)	4.69×10^{-10}	11.60×10^{-9}	2.89×10^{-9}
$\Omega_{CDM}h^2$	6.5	0.8	4.0
$R_{tb\tau}$	1.02	1.03	1.04

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):

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

	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
σ_{SI}(pb)	1.21×10^{-14}	1.92×10^{-14}	1.85×10^{-14}
σ_{SD}(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 $M_{\rm Planck}$, 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.
- Susy hybrid inflation compatible with axion physics.
- b-τ YU in 4-2-2: NLSP Gluino, NLSP Stop
- t-b-τ YU in 4-2-2 (NUHM2): Gluino lightest colored particle (can be $\sim$ 2-3 TeV)