Sparticle and Higgs boson masses from the landscape: dynamical vs. spontaneous SUSY breaking

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arXiv:2103.12123

Pheno 2021 meeting, May 25, 2021

(dedicated to memory of Joe Polchinski)
● In string theory, only one mass scale: \( m_P \approx 2.4 \times 10^{18} \text{ GeV} \)

● Then how do widely disparate mass scales arise, e.g. \( CC \approx 10^{-120} m_P^2 \)
or the weak scale \( m(\text{weak}) \approx 100 \text{ GeV} \) or QCD scale \( \approx 1 \text{ GeV} \)?

● **CC:** Weinberg’s anthropic solution: in eternally inflating multiverse, if \( CC \) much bigger than measured value, universe would expand so quickly that structure (galaxies) wouldn’t form: these ‘pocket universe’ would not be suitable for evolution of life (structure principle)

● **QCD** is different: QCD scale arises non-perturbatively (dynamically) from dimensional transmutation: QCD becomes confining at \( m(\text{proton}) \approx m_P \times \exp(-8\pi^2/g^2) \) when \( g^2 \approx 1.8 \)
• Weak scale: in SM, quadratic divergences $\rightarrow m(\text{weak}) \rightarrow m_P$: but can (implausibly) tune $\mu^2$ such that $m(\text{weak}) \sim 100$ GeV

• Weak scale SUSY stabilizes weak scale, but does not explain magnitude

• e.g. for SUGRA breaking, $W(\text{Polonyi}) = m^2(h + \beta)$ for lone superfield $h$: gives right answer if $m \sim 10^{11}$ GeV and $\beta \sim m_P$ (must implausibly put in by hand)

• But maybe instead SUSY breaking dynamical (like QCD):
  $m^2 \sim m_P^2 \exp(-8\pi^2/g_{\text{hidden}}^2)$

• e.g. hidden sector gauge group $SU(N)$ becomes confining (gaugino condensation) at: $\Lambda(GC) \sim 10^{13}$ GeV $\Rightarrow m = \sqrt{\Lambda^3/m_P} \sim 10^{11}$ GeV
When $g$ becomes confining $\sim 1-2$, then SUSY breaking scale uniformly distributed across the decades of possibilities:  
then in landscape context, \[ f_{\text{SUSY}}^{\text{DSB}} \sim \frac{1}{m_{\text{soft}}} \]

see e.g Dine, Gorbatov, Thomas (2008)
In landscape context (used to solve CC problem), expect $\sim 10^{500}$ string vacua (Denef & Douglas)

vacua distributed as:

$$dN_{\text{vac}}[m^2_{\text{hidden}}, m_{\text{weak}}, \Lambda_{\text{cc}}] = f_{\text{SUSY}} \cdot f_{\text{EWSB}} \cdot f_{cc} \cdot dm^2_{\text{hidden}}$$

For spontaneous SUSY breaking (mass scale included, perturbative)

$$f_{\text{SSB SUSY}} \sim m^{n}_{\text{soft}}$$

where $n = 2n_F + n_D - 1$ and $n_F$ are the number of hidden sector SUSY breaking $F$-fields and $n_D$ is the number of hidden sector $D$-breaking fields contributing to the overall SUSY breaking

Thus, in landscape, DSB favors low soft terms while SSB favors large soft terms!

single $F$ term distributed uniformly as complex number

[footnote: $f_{cc}$ doesn't contribute to SUSY breaking scale determination (Douglas)]
From Agrawal, Barr, Donoghue, Seckel (ABDS, 1998): if pocket universe value of weak scale too displaced from measured value in our universe (OU) [factor 2-5], then complex nuclei and hence atoms will not form: pocket universe will not sustain life as we know it!

can calculate $m(\text{weak})$ in MSSM

for $m(\text{weak})^{\text{PU}} < 4 \times m(\text{weak})^{\text{OU}}$: then

atomic principle

also: veto CCB
and noEWSB minima

\[
\frac{(m_Z^2)^2}{2} = \frac{m_{H_d}^2 + \Sigma_d - (m_{H_u}^2 + \Sigma_u) \tan^2 \beta}{\tan^2 \beta - 1} - \mu^2 \sim -m_{H_u}^2 - \Sigma_u - \mu^2
\]

\[
f_{\text{EWSB}} = \Theta(30 - \Delta_{\text{EW}})
\]
Assume fertile patch of landscape where MSSM is LE-EFT

Can scan over parameters in models which allow DEW<30: e.g.

\[ m_0(1,2), m_0(3), m_{1/2}, A_0, \tan \beta, \mu, m_A \quad (NUHM3) \]

- \( m_0(1,2) : 0.1 - 60 \text{ TeV}, \)
- \( m_0(3) : 0.1 - 20 \text{ TeV}, \)
- \( m_{1/2} : 0.5 - 10 \text{ TeV}, \)
- \( A_0 : -50 - 0 \text{ TeV}, \)
- \( m_A : 0.3 - 10 \text{ TeV}, \)

\( \mu = 150 \text{ GeV while } \tan \beta : 3 - 60 \)

upper limits set beyond anthropic upper limits:
lower limits set to compare against previous scans, but can be lower yet
as expected, DSB (gray) prefers small soft terms while SSB (red) prefers large

n=2 from KKLT stabilization; see Broeckel et al.
Higgs masses: DSB $\Rightarrow m(h) \ll 125$ GeV while SSB prefers $m(h) \sim 125$ GeV

DSB $\Rightarrow$ highly mixed Higgs while SSB prefers decoupled Higgs
DSB \Rightarrow \text{sparticles masses below LHC limits;}
SSB prefers \Rightarrow \text{sparticles masses above LHC limits!}

[smaller lower scan limits make matters worse for DSB]
Conclusions:

- DSB beautiful theory:

- DSB might explain exponential suppression of weak scale

- DSB predicts $m(h) \ll 125$ GeV and excluded sparticles

- SSB in landscape: $m(h) \sim 125$ GeV and sparticles $> \text{LHC limits}$

- then, exponential suppression of weak scale arises as does the CC: weak scale as big as possible such that atomic principle (existence of atoms) still holds