Higgs and *Sparticle* mass predictions from the String Landscape

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Table of Contents

1 Statistics of SUSY breaking in the Landscape
   ■ Anthropic + Landscape
   ■ SUSY Breaking Scale

2 Alternative Soft-term Distribution

3 Putting the Hypotheses to the test
   ■ What does the Landscape & LHC data allude to?

4 Results

5 Conclusions
Table of Contents

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4 Results

5 Conclusions
Anthropics + Landscape

- The $\Lambda_{cc}$ problem: Why
  $\Lambda_{cc} \approx 10^{-120} M_P^2 \ll M_P^2$?
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Resolution in the String Landscape: We live in a Pocket Universe (PU) within an Eternally Inflating Multiverse $\Rightarrow$ a wide range of $\Lambda_{cc}$ values for each PU.
The $\Lambda_{cc}$ problem: Why
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Resolution in the String Landscape: We live in a Pocket Universe (PU) within an Eternally Inflating Multiverse \( \Rightarrow \) a wide range of $\Lambda_{cc}$ values for each PU.

Weinberg’s solution: Of $\Lambda_{cc}^{PU}$ in the range $[-M_P^2, M_P^2]$, only\( \Lambda_{cc}^{PU} \lesssim 10^{-120} M_P^2 \) results in a livable PU.
Anthropics + Landscape

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- Much larger a value of $\Lambda_{cc} \Rightarrow$ no galaxy formation $\Rightarrow$ non-livable PU.
Similarly \( m_{\text{weak}} \ll M_P \): Donoghue et al.

\[ m_{\text{weak}}^P \gtrsim (2 - 5)m_{\text{weak}}^O \Rightarrow \text{violates atomic principle} \Rightarrow \text{no observers as we know them.} \]
Similarly $m_{\text{weak}} \ll M_P$: Donoghue et al.
$\Rightarrow$ if $m_{\text{weak}}^\text{PU} \gtrsim (2 - 5)m_{\text{weak}}^\text{OU}$ $\Rightarrow$ violates
atomic principle $\Rightarrow$ no observers as we know them.

- Large negative values correspond to bigger weak scale.
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- Large negative values correspond to bigger weak scale.
- We live in a narrow band $\leftrightarrow (2 - 5)m_{\text{weak}}^O$ which corresponds to $\Delta_{EW} \lesssim 30$. 

\[ \Delta_{EW} = \left| \frac{\text{max RHS contribution}}{m_{Z}^2} \right|. \]

For landscape, the condition is $(m_{PZ}^O)^2$ and $m_{PZ}^O \neq m_{OU}^O = 91.2 \text{ GeV}$. 

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SUSY Breaking Scale

For a fertile patch of the landscape with MSSM as low energy EFT, the distribution of PU vacua is given by $m_{\text{hidden}}^2$

$$dN_{\text{vac}}(m_{\text{hidden}}^2, m_{\text{weak}}, \Lambda_{cc}) = f_{\text{SUSY}} \cdot f_{\text{EWSB}} \cdot f_{cc} \cdot dm_{\text{hidden}}$$

with $m_{\text{soft}} \sim m_{\text{hidden}}^2/M_P$. 
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It was advocated by Douglas, Susskind and Arkani-Hamed et al. that SUSY breaking scales should follow a power-law distribution

$$f_{\text{SUSY}}(m_{\text{hidden}}^2) \sim (m_{\text{hidden}}^2)^{2n_F + n_D - 1}$$

then one expects a bias towards large soft terms i.e.

$$f_{\text{SUSY}} \sim m_{\text{soft}}^n$$

with $n = 2n_F + n_D - 1$. 
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- The EWFT distribution $f_{\text{EWSB}}$ is taken as

$$f_{\text{EWSB}} = \Theta(30 - \Delta_{\text{EW}})$$

which $\to$ large $A_t \to m_h \sim 125 \text{ GeV}$, proper EWSB and $m_{\text{weak}}^{PU} \sim 4m_{\text{weak}}^{OU}$. 
Consequence of Anthropic and Power law Distribution

Large negative $A(t) \Rightarrow$ smaller $\sqrt{\Sigma_{u,t}(\tilde{t}_{1,2})}$ contributions to the weak scale $\rightarrow$ bigger higgs mass.
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4 Results

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- Extra Dimensional theories → Compactification on some manifold (e.g. Calabi-Yau) → scalar fields (moduli).
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     \[ f_{SUSY} = m_{soft}^n. \]
  2. Large Volume Scenario (LVS) (Perturbative & Non-perturbative) leads to a logarithmic draw, i.e.
     \[ f_{SUSY} = \log(m_{soft}). \]
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  \[ m_0(1,2), m_0(3), m_{1/2}, A_0, \tan \beta, \mu, m_A \]

- Only points with \( \Delta_{\text{EW}} \lesssim 30 \) are considered (naturalness resulting from anthropics).

Using these parameters, Higgs and sparticle mass spectrum were calculated using ISAJET code. The results are then compared to \( f_{\text{SUSY}} = m_{\text{soft}} \) draw with \( n = 0 \) (uniform distribution) and \( n = 1 \) (text book example of a single F-breaking field distributed as a complex number in the landscape).
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Table of Contents

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Results

Conclusions
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- Larger $A_0 \Rightarrow$ large stop mixing $\Rightarrow$ large radiative corrections to $m_h \Rightarrow$ peak of higgs distribution 125 GeV.
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- $n = 0$ scan prefers smaller $A_0$ while log-draw and $n = 1$ draw are stretched to higher values.
- Larger $A_0 \Rightarrow$ large stop mixing $\Rightarrow$ large radiative corrections to $m_h \Rightarrow$ peak of higgs distribution $125$ GeV.
- This is a testable prediction of the string landscape: A SM-like higgs $m_h \sim 125$ GeV is reflective of large mixing in the stop sector.
Results-Soft Dilepton Signal

\[ \frac{m_Z^2}{2} \simeq -m_{H_u}^2 - \mu^2 - \Sigma^u_i (t_1, 2) \rightarrow \mu \text{ is SUSY conserving } \Rightarrow \text{ too big a value of } \mu \rightarrow \text{ too big } m_{\text{weak}} \text{ unless one finetunes.} \]
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  \item String landscape favors $\mu(\sim 100 - 350\text{GeV}) \ll m_{soft} \Rightarrow$ small $\mu \to$ light higgsinos.
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- The log-draw gives a broad peak structure \( \sim 8 - 12 \text{ GeV.} \)
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- Current search results from ATLAS with $139\, fb^{-1}$ data $\rightarrow$ slight excess in bins with $m_{\ell\ell} \sim 5 - 10$ GeV. [3]
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- First and Second generation squarks yield peaks in the $10 - 40$ TeV range → decoupling solution to the SUSY flavor and CP problem.
Conclusions

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Why String Landscape?

Emerges automatically in IIB flux compactifications.

String Theory is predictive in a statistical sense from the string landscape.

Successful in solving $\Lambda_{\text{cc}}$ problem when combined with anthropics.

Various statistical distributions for different moduli stabilization models (KKLT, LVS, etc) have been proposed.

Here we have examined the soft-term draw of $\log(m_{\text{soft}})$ as proposed by Broeckel et al.

Statistics of the SUSY-breaking scale from the landscape successfully validates what the LHC sees:

- A SM-like Higgs with $m_h \approx 125$ GeV with sparticles lifted beyond current LHC limits other than the elusive light higgsinos.

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Dark matter content: higgsino-like WIMP and axion.
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