Vacuum Stability in No-Scale Supersymmetry or Gaugino Mediation

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Outline

1. Higgs Exempt No-Scale
    - Motivations for Higgs Exempt No-Scale
    - Parameter Space
2. HENS Vacuum Stability
    - General Vacuum Stability Considerations
    - Vacuum Stability in HENS

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Constraints on Flavor Violation

- Experimental bounds on lepton flavor violation quite strong

$$Br(\mu \to e\gamma) < 1.2 \times 10^{-11}$$
$$Br(\tau \to \mu(e)\gamma) \lesssim \times 10^{-8}$$

- Ways to meet these strong constraints
  1. Large Scalar masses
     - Tend to reintroduce naturalness problems
  2. Small off-diagonal components in scalar mass matrices
     - Method considered here
- Considerations phenomenologically motivated

Generalized No-Scale Approach to Flavor Problem

- No-Scale Models are known to have MFV
  - Low-scale masses purely from RG running
  - Sleptons tend to be quite light being the LSP
- Higgs bosons are flavorless
- Higgs Exempt No-Scale Supersymmetry
  - Same as No-Scale except scalar Higgs bosons have mass

$$m_{\tilde{f}} = 0 \quad A_{ijk} = 0 \quad m_{\tilde{\chi}} = m_{1/2} \quad m^2_{H_{u,d}} \neq 0 \quad \tan\beta \quad sgn(\mu)$$

- Neutralino LSP is possible with non-zero Higgs masses
  - Possible dark matter candidate
- Sleptons still very light

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Soft Masses of the HENS model

- Approximate expressions for some soft masses in HENS models

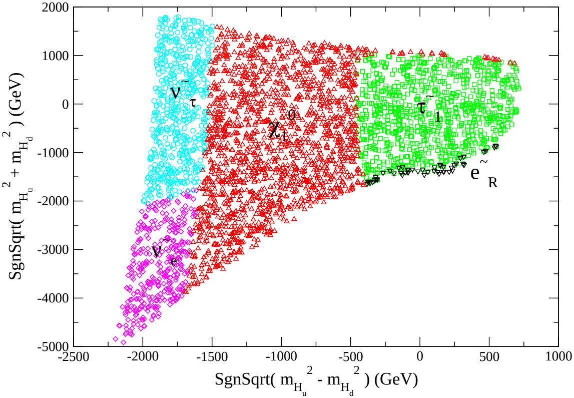
$$M_1 \simeq (0.43)\, M_{1/2}, \quad M_2 \simeq (0.83)\, M_{1/2}, \quad M_3 \simeq (2.6)\, M_{1/2}$$
$$m_L^2 \simeq \left[(0.68)\, M_{1/2}\right]^2 + \frac{1}{2}(0.052)\, S_{GUT}$$
$$m_E^2 \simeq \left[(0.39)\, M_{1/2}\right]^2 - (0.052)\, S_{GUT}$$

- Electroweak constraints on the parameter space

$$m_Z^2 \simeq -2(m_{H_u}^2 + |\mu|^2) + \frac{2}{\tan^2\beta}(m_{H_d}^2 - m_{H_u}^2)$$
$$m_A^2 = m_{H_u}^2 + m_{H_d}^2 + 2|\mu|^2$$

LSP and Parameter Space in HENS Models

- The parameter space and LSP for the HENS model for $M_{1/2} = 500$ GeV and $\tan\beta = 10$ scanning over Higgs masses



Outline

Imaginary Part of The Vacuum Energy

- The contributions to the vacuum to vacuum transition

$$\langle \phi | e^{-HT} | \phi \rangle_0 + \langle \phi | e^{-HT} | \phi \rangle_{Bounce}$$

- The vacuum to vacuum transitions

$$N \int \mathcal{D}\phi e^{-S(\phi)} = \langle \phi | e^{-HT} | \phi \rangle = \sum \langle \phi | n \rangle \langle n | \phi \rangle e^{-E_n T} \sim e^{-E_0 T}$$

- Summing all the bounce contributes to the E_{Vac}

$$E_{Vac} = E_0 + K e^{-S_b[\bar{\phi}]}$$

- The bounce contribution has an imaginary part

$$\mathbf{Im}[E_{Vac}] = \mathbf{Im}[K] e^{-S_b[\bar{\phi}]} = -\Gamma$$

Is the Vacuum Short Lived?

- Lifetime of the vacuum

$$\frac{1}{\tau V} = \Gamma/V = Ae^{-S_b[\bar{\phi}]} \quad (S_b > 400 \ \ )$$
$$S_b[\bar{\phi}] = \int d^4x_E \left(\left| \nabla\bar{\phi}_i \right|^2 + U(\bar{\phi}_1, ..., \bar{\phi}_i) \right) = T[\bar{\phi}_i] + V[\bar{\phi}_i]$$

- Relative depth of the two vacua affects the lifetime of the vacuum ($V[\bar{\phi}_i]$ decreases)
- More minima → short vacuum lifetime ($\Gamma = \sum_i \Gamma_i$)
- Larger size and number of vevs, longer vacuum lifetime ($T[\bar{\phi}_i]$ larger because change in ϕ larger)
- Larger barrier, vacuum lifetime longer ($V[\bar{\phi}_i]$ larger)

Vacuum Stability

- Supersymmetric theories have many scalar fields
- Vacuum structure from many scalar fields can have metastable SM vacuum
- Soft terms contributing to instability of SM vacuum
    - Negative scalar masses squared
    - Large negative trilinear terms
- Well know constraint insufficient

$$|A_u|^2 \leq 3[m^2_{Q_u} + m^2_u + m^2_{H_u} + |\mu|^2]$$

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Origin of CCB and UFB of HENS Models

- Large negative Higgs masses and small slepton masses can lead to UFB or deep CCB

$$\begin{aligned} V &= (m_2^2-\mu^2)|H_2|^2+(m_{\tau_L}^2+m_{\tau R}^2)|\tau|^2+m_{L_i}^2|L|^2 \\ &+ \frac{1}{8}(g_1^2+g_2^2)(|H_2|^2+|\tau|^2-|L_i|^2)^2+|\mu H_2-y_\tau\tau^2|^2 \end{aligned}$$

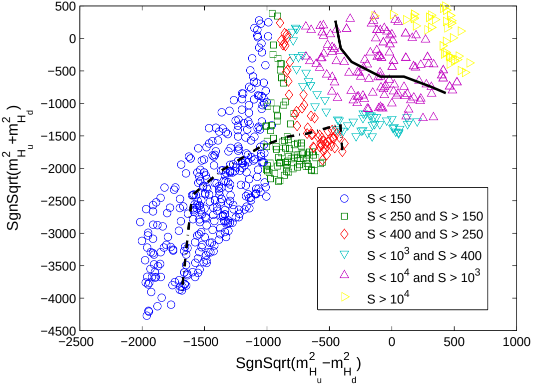
- For UFB take $\tau^2=\mu H_2/y_\tau$, use $|L_i|$ to cancel D term

$$V_{UFB}=(m_2^2-\mu^2+m_{L_i}^2)|H_2|^2+\frac{\mu}{y_\tau}(m_{\tau_L}^2+m_{\tau_R}^2+m_{L_i}^2)|H_2|+\cdots$$

- For smaller values of m_2^2, CCB also occur with $F\neq 0$
  - Because y_τ small, $F=0$ forces large $|\tau|$
  - Taking $F\neq 0$ allows $(m_{\tau_L}^2+m_{\tau_R}^2)|\tau|^2$ to be suppressed

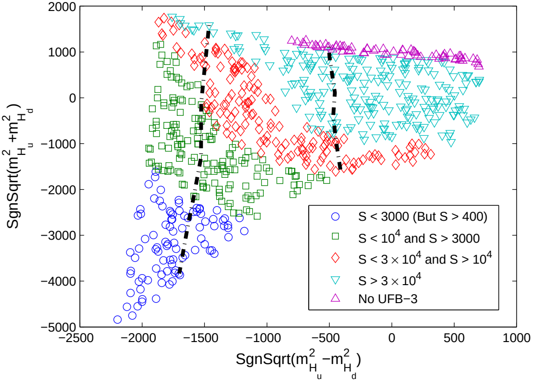
Vacuum Constraints Large tan β

- The bounce action for $M_{1/2} = 500$ and $\tan\beta = 30$ ($\tau_{L,R}$, H_1, H_2, L_i)



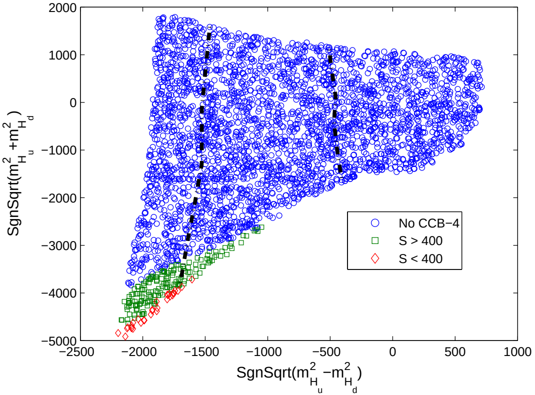
Vacuum Constraints Small tan β

- The bounce action for $M_{1/2} = 500$ and $\tan\beta = 10$ ($\tau_{L,R}$, H_1, H_2, L_i)



Vacuum Constraints Small $\tan\beta$ Continued

- The bounce action for $M_{1/2} = 500$ and $\tan\beta = 10$ ($t_{L,R}$, H_1, H_2)



Summary

- Small scalar SUSY masses alleviate large FCNC while still being able to meeting collider and dark matter constraints
- Much of the parameter space is from large negative Higgs masses
- Large negative Higgs masses (deep minima) and small slepton masses (small barrier) lead to short vacuum lifetimes
- Vacuum stability places strong constraints on HENS parameter space for large tan β
- The constraints on small tan β are quite weak