Mirage Models Confront the LHC:

Phenomenology of String-Motivated Effective Field Theories

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Outline

1. Introduction
2. KKLT Model Overview
3. Parameter Scans
4. Detection Prospects

Kachru, Kallosh, Linde, and Trivedi

- I will be discussing so-called 'mirage models', in which the gaugino masses unify at $M_{EW} < M < M_P$
- Specifically I will be discussing KKLT, a class of anomaly-mediated SUSY-breaking models that is one of the broadest realizations of mirage mediation
- The KKLT model is a model of Type-IIB string theory compactified on a Calabi-Yau orientifold
- KKLT localizes matter and Higgs fields on D3 branes, D7 branes, or a twisted sector between D3 and D7 branes

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KKLT - II

- In the KKLT framework, the gaugino masses roughly follow the pattern at the electroweak scale:

$$M_1 : M_2 : M_3 = (1.0+0.66\alpha) : (1.93+0.19\alpha) : (5.87-1.76\alpha)$$

- Compare to the mSUGRA values of:

$$M_1 : M_2 : M_3 = 1 : 2 : 6$$

- In addition to the parameter α, we have continuous parameters m_0 and $\tan\beta$ and $\mathrm{sign}(\mu)$. $m_{1/2}$ and A_0 are fixed.

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KKLT - III

- In addition, we have discreet parameters depending on the localization of each of the matter and Higgs fields
- There are three possibilities:
  - $n = 0$ for fields localized on single stacks of $D7$ branes
  - $n = \frac{1}{2}$ for different $D7$ stacks or twisted sectors between $D3$ and $D7$ branes
  - $n = 1$ for fields localized on stacks of $D3$ branes
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KKLT - IV

- We can now write down all of the gaugino masses, trilinear couplings, and scalar masses:

$$\begin{aligned} M_a &= M_0 + b_a g_{\text{str}}^2 M_g \\ A_{ijk} &= -(3 - n_i - n_j - n_k) M_0 + (\gamma_i + \gamma_j + \gamma_k) M_g \\ m_i^2 &= (1 - n_i) M_0^2 - \theta_i M_0 M_g - \dot{\gamma}_i M_g^2 \end{aligned}$$

- $M_g \equiv \frac{m_{3/2}}{16\pi^2}$
- $\dot{\gamma}_i$ and θ_i are anomalous dimensions set by the gauge couplings, beta-function coefficients, and Yukawa couplings.

Free Parameters

- We performed a grid-like scan with flat priors over m_0, α, and $\tan\beta$ for the nine permutations of $n_{m,h} = 0, \frac{1}{2}, 1$.
- α takes on the natural bounds of $[0, 2]$
  - Negative values and higher values are possible, but poorly motivated theoretically
- m_0 is allowed to range from $1 - 5\mathrm{TeV}$
- $\tan\beta$ is allowed to range from $2 - 56$

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Restrictions

- For each point, we write down the high-scale terms and evolve the RGEs with softsusy
- At the electroweak scale, we require that the points:
  - exhibit convergent radiative electroweak symmetry breaking
  - satisfy LEP limits for superpartners
  - have a neutral, stable LSP
  - $\mathcal{B}(B_S^0 \to \mu^+\mu^-) \in [2.00, 4.09] \times 10^9$
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Initial Findings

- A heavy Higgs requires a heavy mass spectrum. A relatively low dark matter abundance requires a lighter LSP.
- These two compete with one another making the model inconsistent with both sets of observed results. That is, unless we can deplete the neutralino relic density

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Initial Findings - II

- This can occur in KKLT in two circumstances:
  - There is a near-degeneracy between the lightest chargino and the neutralino
  - There is a near-degeneracy between the lightest stau and the neutralino
- These two mass spectra provide a co-annihilation channel that allows for a heavy mass spectrum and an appropriate amount of dark matter
- In these two cases, we find that the neutralino is entirely bino-like or entirely Higgsino-like.
- Across all nine combinations of modular weights, this allows us to categorize the phenomenology of the KKLT model into two distinct types

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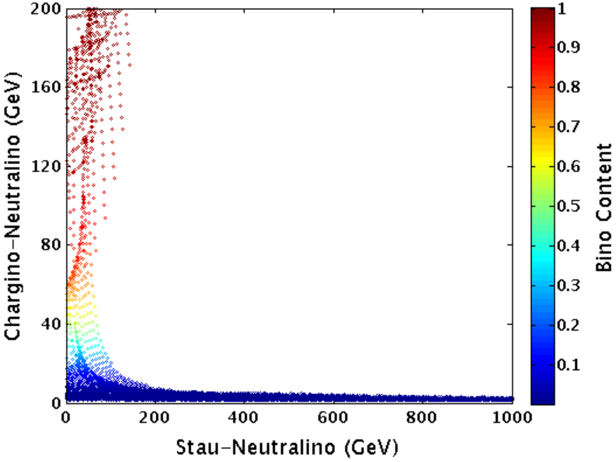
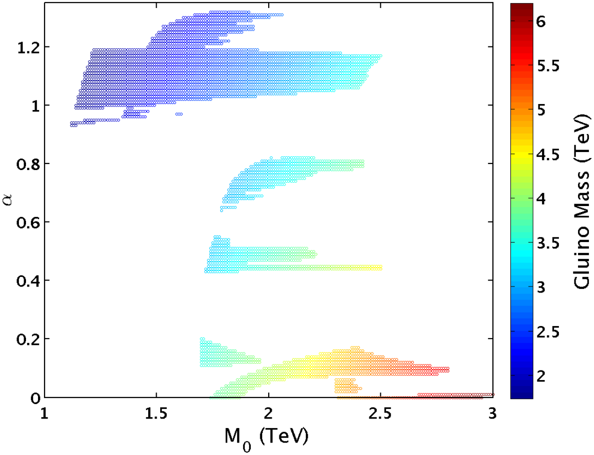
The Well-Tempered Neutralino $(n_m, n_h) = (\frac{1}{2}, 0)$



Bino-Like Region

	$n_H = 0$	$n_H = \frac{1}{2}$	$n_H = 1$
$n_M = 0$	$\alpha = 1.0 - 1.1$ $M_0 = 1.2 - 2.5$ $\tan\beta = 24 - 32$	$\alpha = 1.0 - 1.3$ $M_0 = 1.4 - 2.0$ $\tan\beta = 10 - 30$	$\alpha = 0 - 0.2$ $M_0 = 1.7 - 2.8$ $\tan\beta = 51 - 52$
$n_M = \frac{1}{2}$	$\alpha = 1.0 - 1.8$ $M_0 = 1.6 - 4.0$ $\tan\beta = 6 - 50$	$\alpha = 0.5 - 0.8$ $M_0 = 1.8 - 2.5$ $\tan\beta = 12 - 35$	$\alpha = 0$ $M_0 = 2.3 - 3.0$ $\tan\beta = 53 - 54$
$n_M = 1$	–	–	–

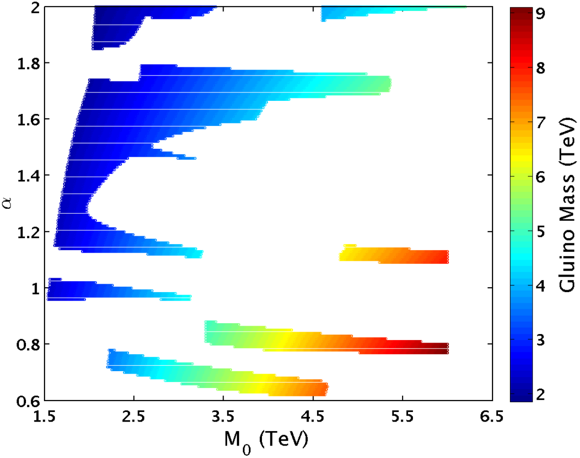
Bino-Like Region - II



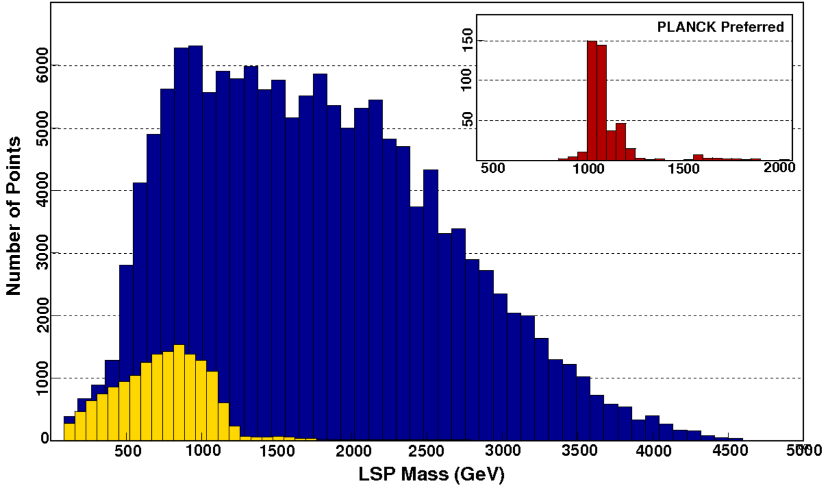
Higgsino-Like Region

	$n_H = 0$	$n_H = \frac{1}{2}$	$n_H = 1$
$n_M = 0$	$\alpha = 2.0$ $M_0 = 2.5 - 3.4$ $\tan\beta = 48 - 51$	$\alpha = 1.9 - 2.0$ $M_0 = 2.0 - 2.7$ $\tan\beta = 42 - 48$	–
$n_M = \frac{1}{2}$	$\alpha = 1.0 - 1.8$ $M_0 = 1.6 - 4.0$ $\tan\beta = 6 - 50$	$\alpha = 1.5 - 1.8$ $M_0 = 2.4 - 5.0$ $\tan\beta = 7 - 52$	$\alpha = 2.0$ $M_0 = 4.6 - 5.0$ $\tan\beta = 34 - 45$
$n_M = 1$	$\alpha = 0.7$ $M_0 = 2.2 - 4.6$ $\tan\beta = 6 - 29$	$\alpha = 0.8$ $M_0 = 3.3 - 5.0$ $\tan\beta = 8 - 46$	$\alpha = 1.1$ $M_0 = 4.8 - 5.0$ $\tan\beta = 18 - 29$

Higgsino-Like Region - II

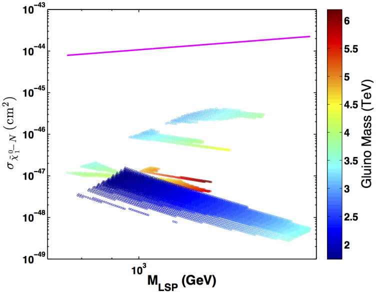


LSP Masses


PLANCK Preferred
50
100
150
500
1000
1500
2000
Number of Points
0
1000
2000
3000
4000
5000
6000
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
LSP Mass (GeV)

Spin-Independent Cross-Section

Points with Bino-Like LSPs



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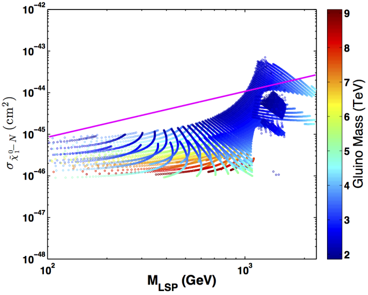

Spectra

	Key Physical Masses (GeV)					Cross Sections (fb)	
Name	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\tau}}$	$m_{\tilde{t}_1}$	$\Omega_\chi h^2$	$\sigma_{8\mathrm{TeV}}$	$\sigma_{14\mathrm{TeV}}$
Higgsino-A	1201	1204	1334	1340	0.072	0.04	4.7
Higgsino-B	1203	1206	1472	1385	0.076	0.31	23.8
Higgsino-C	145.6	147.8	1661	1369	0.003	1525	3542
Higgsino-D	353.5	354.9	2871	2801	0.014	44.3	142.4
Higgsino-E	826.1	827.3	2992	2530	0.076	0.42	4.8
Higgsino-F	105.7	107.1	1131	3704	0.002	5114	10990
Higgsino-G	353.6	354.7	1161	4816	0.014	44.3	142.8
Bino-A	1432	1758	1460	1607	0.127	.00095	0.41
Bino-B	957	1125	1098	979	0.044	0.71	36.6
Bino-C	1549	1775	1947	1782	0.128	.00079	0.95
Bino-D	760	1451	761	2619	0.078	.00019	.0086
Bino-E	1415	2138	1423	2999	0.115	.00018	.0057
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KKLT Discovery Prospects

- With a 125 GeV Higgs and relatively low neutralino content, the KKLT model escapes detection at 8 TeV
- The remaining region has a heavy mass spectrum, often with 1 TeV LSPs or higher
- Points with $\mathcal{O}(100)$ GeV Higgsino-like LSPs have a high $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$ degeneracy
  - This provides a coannihilation channel to deplete the neutralino relic density
  - Also results in events that are hard to detect at colliders
- Easiest to detect with low-jet and mono-jet searches, though backgrounds are high and hard to eliminate
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