Phenomenological Implications of Deflected Mirage Mediation (DMM)

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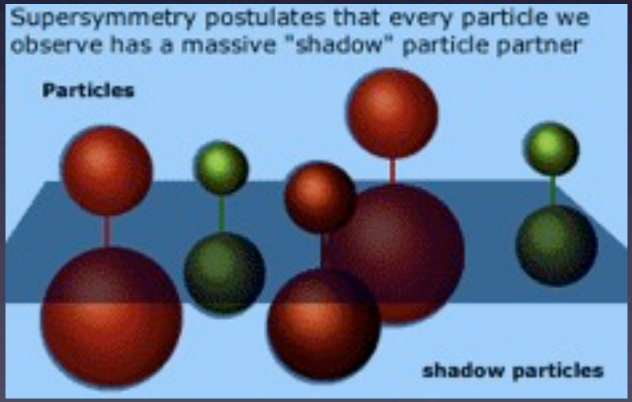


Based on: L.E., I.-W. Kim, P. Ouyang, K. Zurek '08
B. Altunkaynak, L.E., I.-W. Kim, B. Nelson, Y. Rao, 1001.5261, 1006.xxxx

Introduction/Motivation

TeV scale softly broken supersymmetry (SUSY) has many benefits:

(i) Hierarchy problem

(ii) Gauge coupling unification

(iii) Higgs sector/radiative EW breaking

(iv) Dark matter candidate etc....

Most well-motivated+robust framework for physics beyond SM.
Definitive tests of the TeV scale SUSY hypothesis at the LHC!
Depends in detail on SUSY breaking sector.

The Soft SUSY Breaking Sector

Many parameters: 105 in the MSSM

Fortunately, most are not likely to be important...

SUSY flavor/CP problems: assume (can be relaxed carefully)

minimal flavor violation, no nonzero SUSY CP phases

$$105 \longrightarrow \sim 20$$ relevant parameters

gaugino masses: $M_{1,2,3}$

trilinears (3rd gen): $A_{t,b,\tau}$

1st, 2nd gen scalars: $m^2_{Q,u,d,L,e}$

3rd gen: $m^2_{Q_3,u_3,d_3,L_3,e_3}$

also $\mu, b \equiv B\mu$

Option1. Study this set (or certain regions) explicitly.

Example: "Supersymmetry Without Prejudice"

C. Berger et al. 0812.0980

Option 2. Build models.

Many examples...

Prototype: mSUGRA/CMSSM

3 masses, 1 ratio, 1 sign

Beyond mSUGRA: seek minimal models

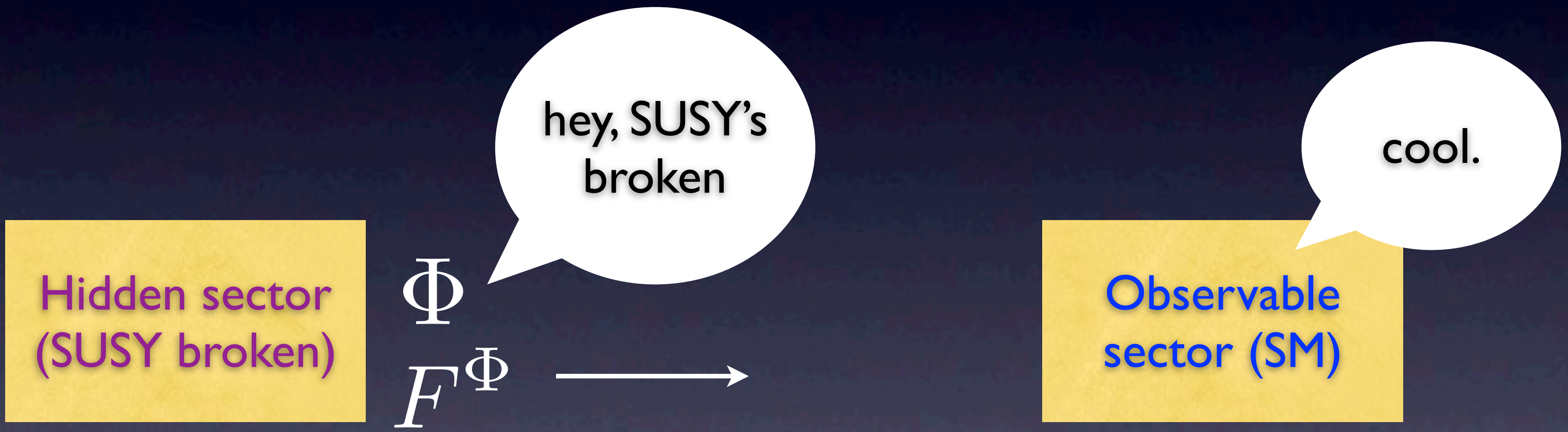
Bottom-up: solve problems of MSSM
Top-down: connections to underlying theory

(ideally both!)

This talk: a particular model framework (DMM)

Building SUSY Models

Hidden sector paradigm:



order parameter of SUSY breaking

standard mediation mechanisms:

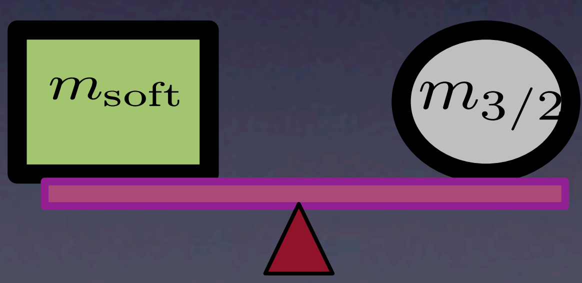
gravity, gauge, anomaly/"bulk"

Mediators side-by-side

Gravity:

$$m_{\mathrm{SUSY}} \sim \frac{F}{M_{\mathrm{Pl}}}$$

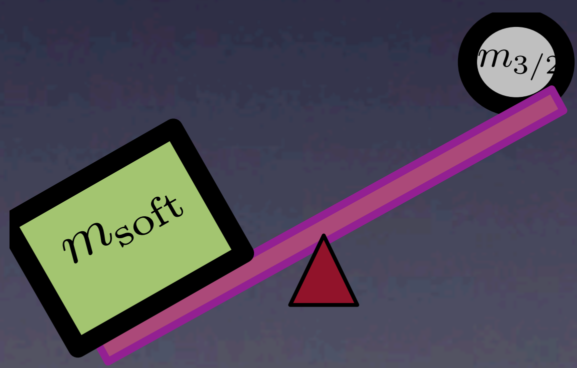
$$m_{3/2} \sim \frac{F}{M_{\mathrm{Pl}}}$$



Gauge:

$$m_{\mathrm{SUSY}} \sim \frac{1}{16\pi^2}\frac{F^X}{X}$$

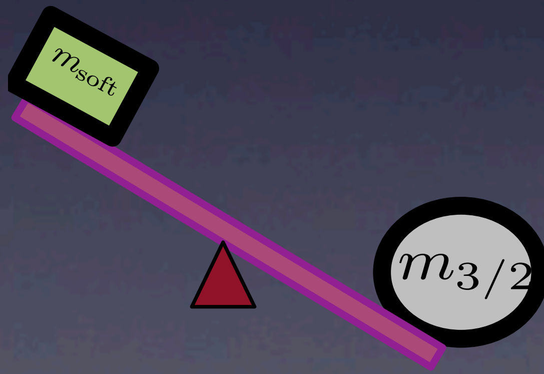
$$m_{3/2} \sim \frac{F^X}{M_{\mathrm{Pl}}}$$



Anomaly:

$$m_{\mathrm{SUSY}} \sim \frac{1}{16\pi^2}\frac{F^C}{C}$$

$$m_{3/2} \sim \frac{F^C}{C}$$



Solves:

mu/Bmu problem*

flavor problem

flavor problem*

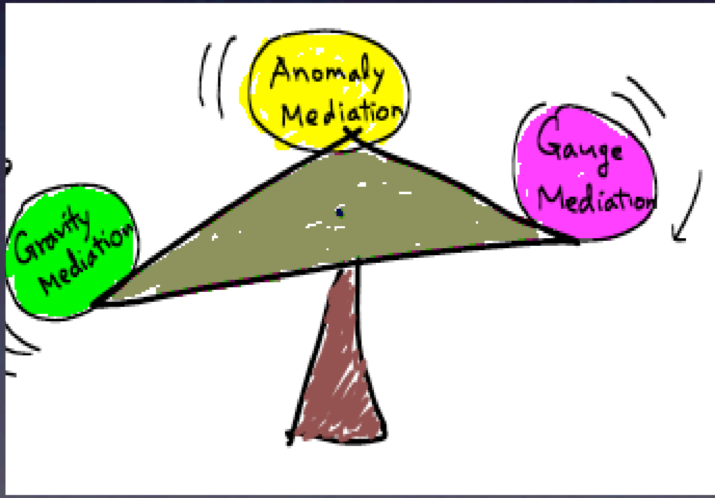
Standard model-building approach:

solve problems of the MSSM (flavor/CP, mu/Bmu, etc.)

typically only 1 mediation mechanism dominates

Alternative approach: purely top-down

"mixed" scenarios: 2 or 3 mediation mechanisms comparable



Motivation:

recent progress in moduli stabilization in string theory

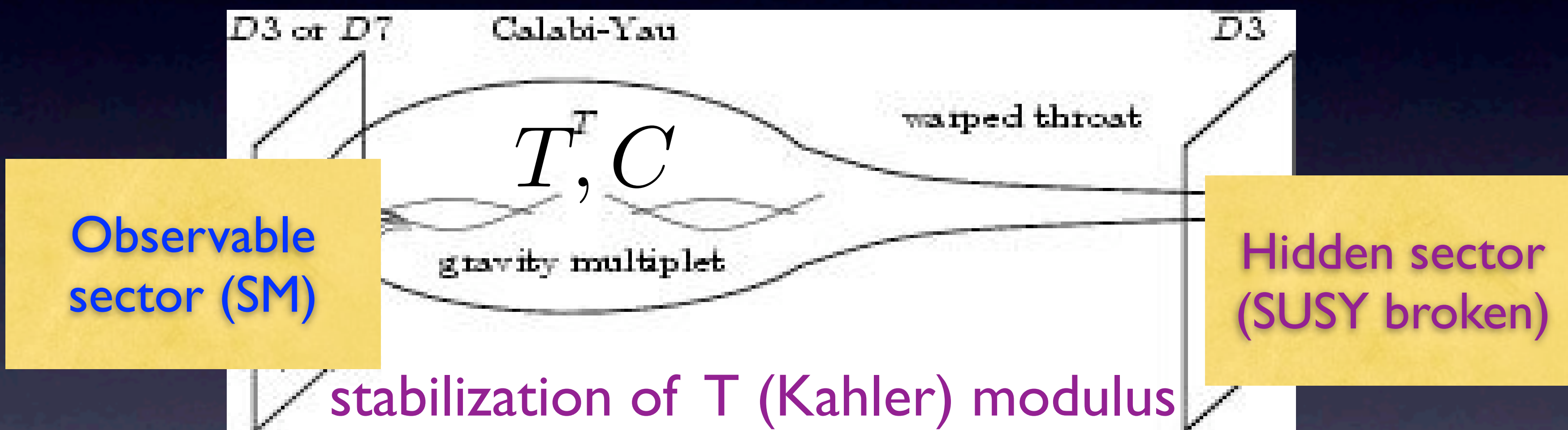
Examples:

mirage mediation (MM), deflected mirage mediation (DMM)

Mirage Mediation (MM)

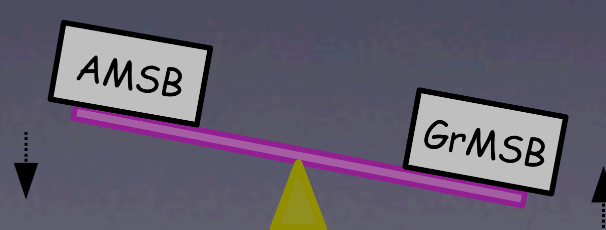
Motivated by KKLT scenario (Type IIB string theory)

Kachru, Kallosh, Linde, Trivedi '03



A mixed modulus-gravity/anomaly mediation model!

$$\frac{F^T}{T+\bar{T}} \sim \frac{1}{\log(M_{\rm Pl}/m_{3/2})}\frac{F^C}{C} \sim \frac{1}{4\pi^2}\frac{F^C}{C}$$

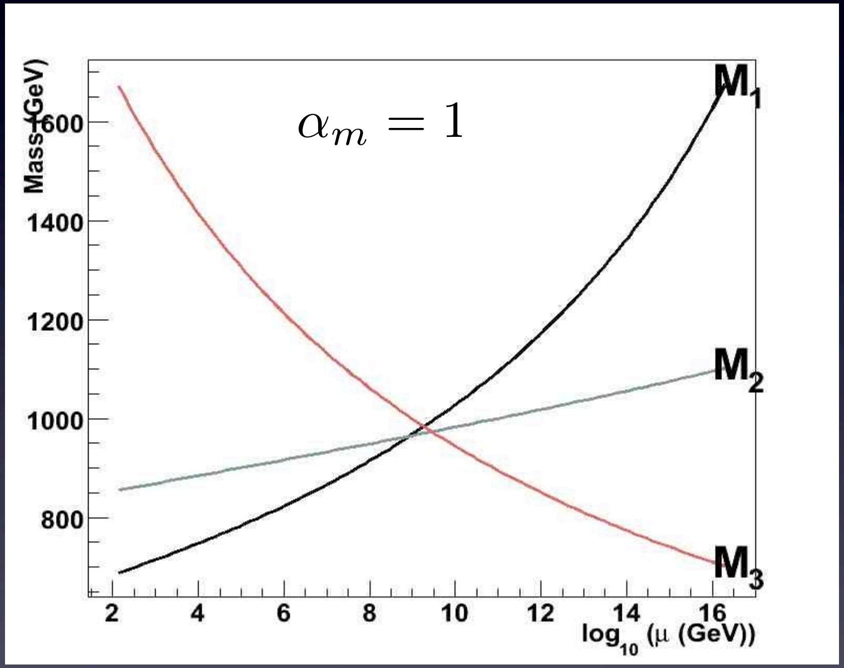


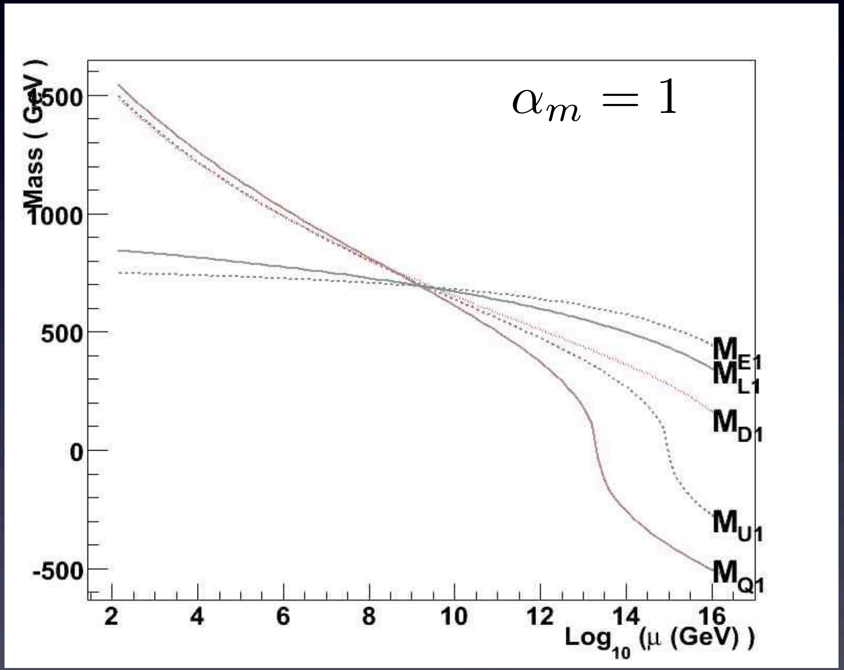
Choi et al. '05, Endo et al. '05,...

Why "mirage"?

Choi et al. , '05,...

Apparent unification of soft terms at "mirage scale"





$$M_{\rm mirage} = M_G \left(\frac{m_{3/2}}{M_{\rm Pl}} \right)^{\frac{\alpha_m}{2}}$$

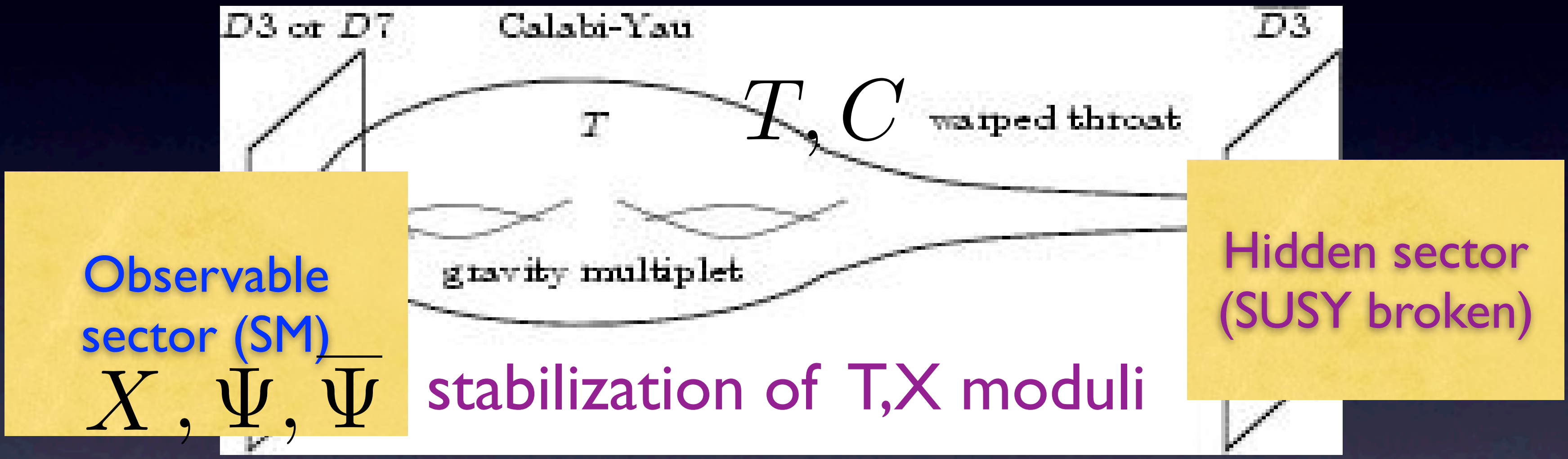
← anomaly/grav effective ratio

$\alpha_m = 1$ (KKLT)

$\alpha_m = 2$ (TeV mirage)

Deflected Mirage Mediation (DMM)

A mixed modulus-gravity/anomaly/gauge mediation model!



$$W_X \sim X^n + X\Psi\Psi$$

X, messengers (generic): can give comparable gauge-mediated terms

$$\frac{F^X}{X} \sim -\frac{2}{n-1}\frac{F^C}{C}$$

$n \geq 3$ or $n < 0$

$$m_{\text{soft}}^{(\text{grav})} \sim m_{\text{soft}}^{(\text{anom})} \sim m_{\text{soft}}^{(\text{gauge})}$$

L.E., I.-W. Kim, P. Ouyang, K. Zurek, 0804.0592, 0806.2330

The Parameters of Deflected Mirage Mediation

MSSM | MSSM $+\Psi, \bar{\Psi}$ (N pairs)

M_Z — $M_{mess} = \langle X \rangle$ — M_G

overall scale: $$\frac{F^T}{T+\bar{T}} = m_0$$

$\tan\beta,\ \mathrm{sign}\mu,\ \{n_i\}$

modular weights
(usually fix these)

ratio: anomaly/grav $$\frac{F^C}{C} = \alpha_m \log(M_{\rm Pl}/m_{3/2}) m_0$$

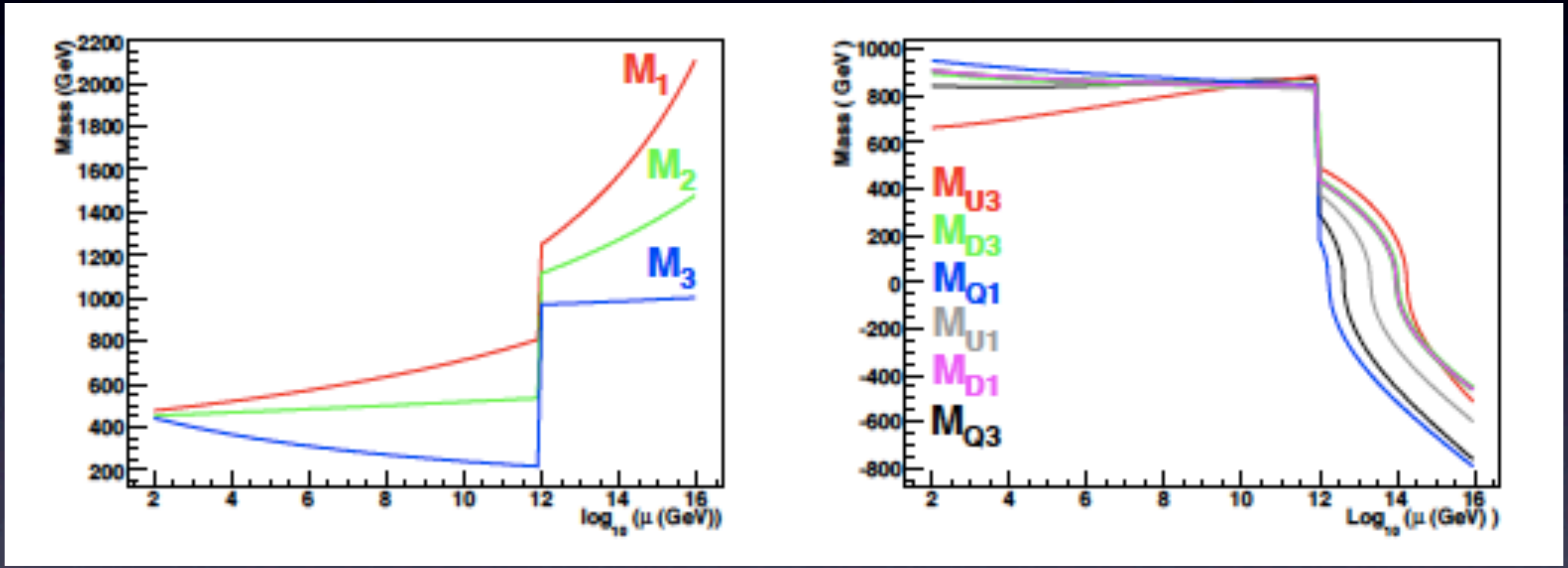
ratio: gauge/anomaly $$\frac{F^X}{X} = \alpha_g \frac{F^C}{C}$$

2 mass scales, 3 ratios (discrete/cont?), 1+ discrete, 1 sign

Idea: can "dial" b/w scenarios with α_m, α_g

Why "deflected mirage"?

$M_{\rm mess} = 10^{12}\,{\rm GeV}, \alpha_m = 1, \alpha_g = 1, N = 3, \tan\beta = 10, \mu > 0$



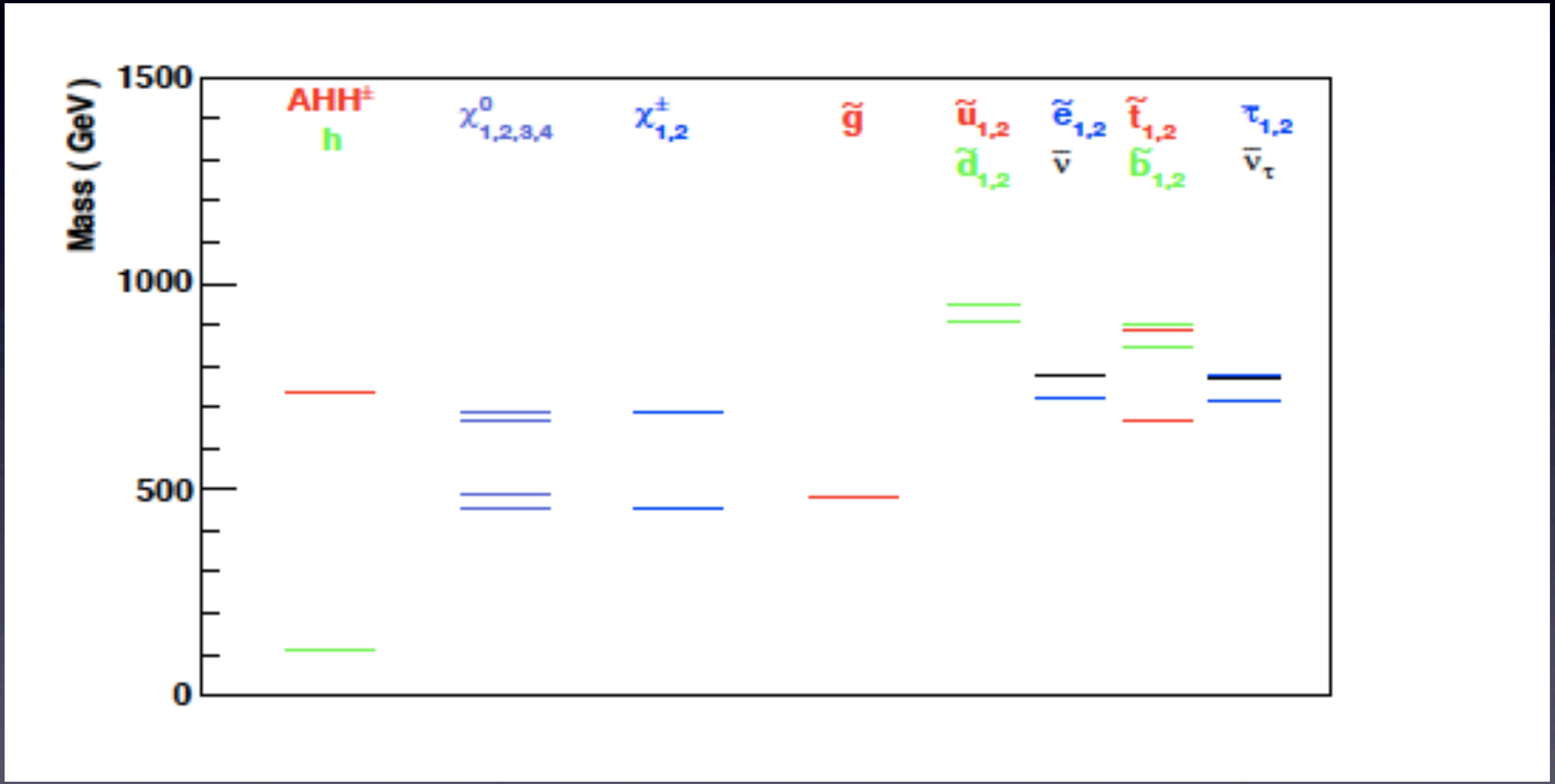
$$M_{\rm mirage} = M_{\rm G}\left(\frac{m_{3/2}}{M_P}\right)^{\alpha_{\rm m}\rho/2} \qquad \rho = \frac{1 + \frac{2Ng_0^2}{16\pi^2}\ln\frac{M_{\rm GUT}}{M_{\rm mess}}}{1 - \frac{\alpha_{\rm m}\alpha_{\rm g}Ng_0^2}{16\pi^2}\ln\frac{M_P}{m_{3/2}}}$$

$\alpha_g > 0$ large thresholds (nonpert. stab.)

$\alpha_g < 0$ small thresholds (pert. stab.)

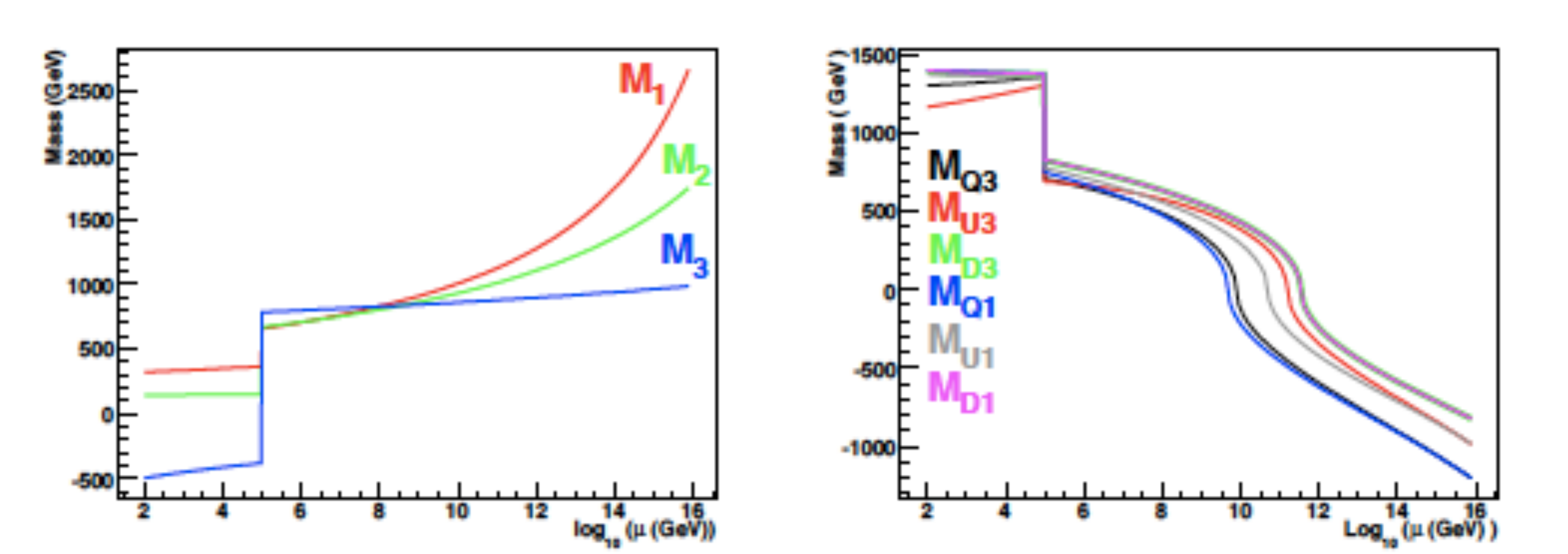
Large thresholds scenario: Mass Spectrum

$$M_{\rm mess} = 10^{12}\,{\rm GeV}, \alpha_m = 1, \alpha_g = 1, N = 3, \tan\beta = 10, \mu > 0$$



compressed gaugino sector due to TeV mirage unification

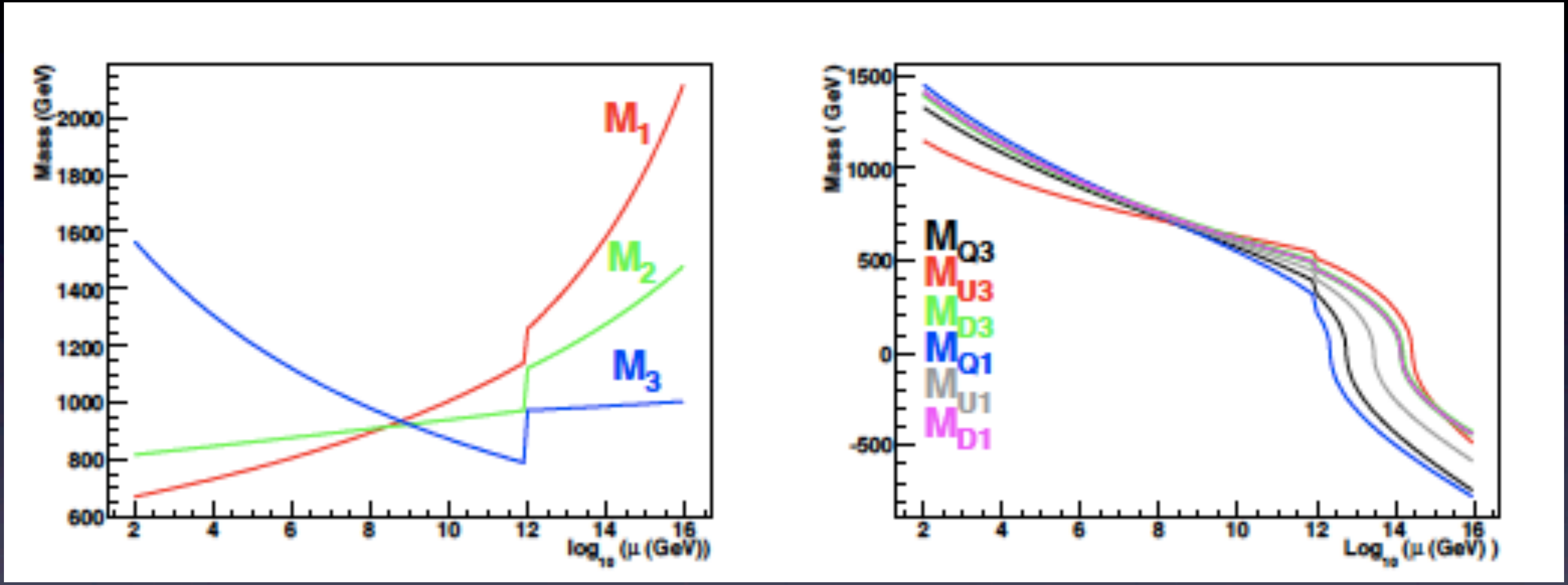
Varying the messenger scale...



$$M_{\rm mess} = 10^5\,{\rm GeV}, \alpha_m = 1, \alpha_g = 1, N = 3, \tan\beta = 10, \mu > 0$$

wino LSP scenario...

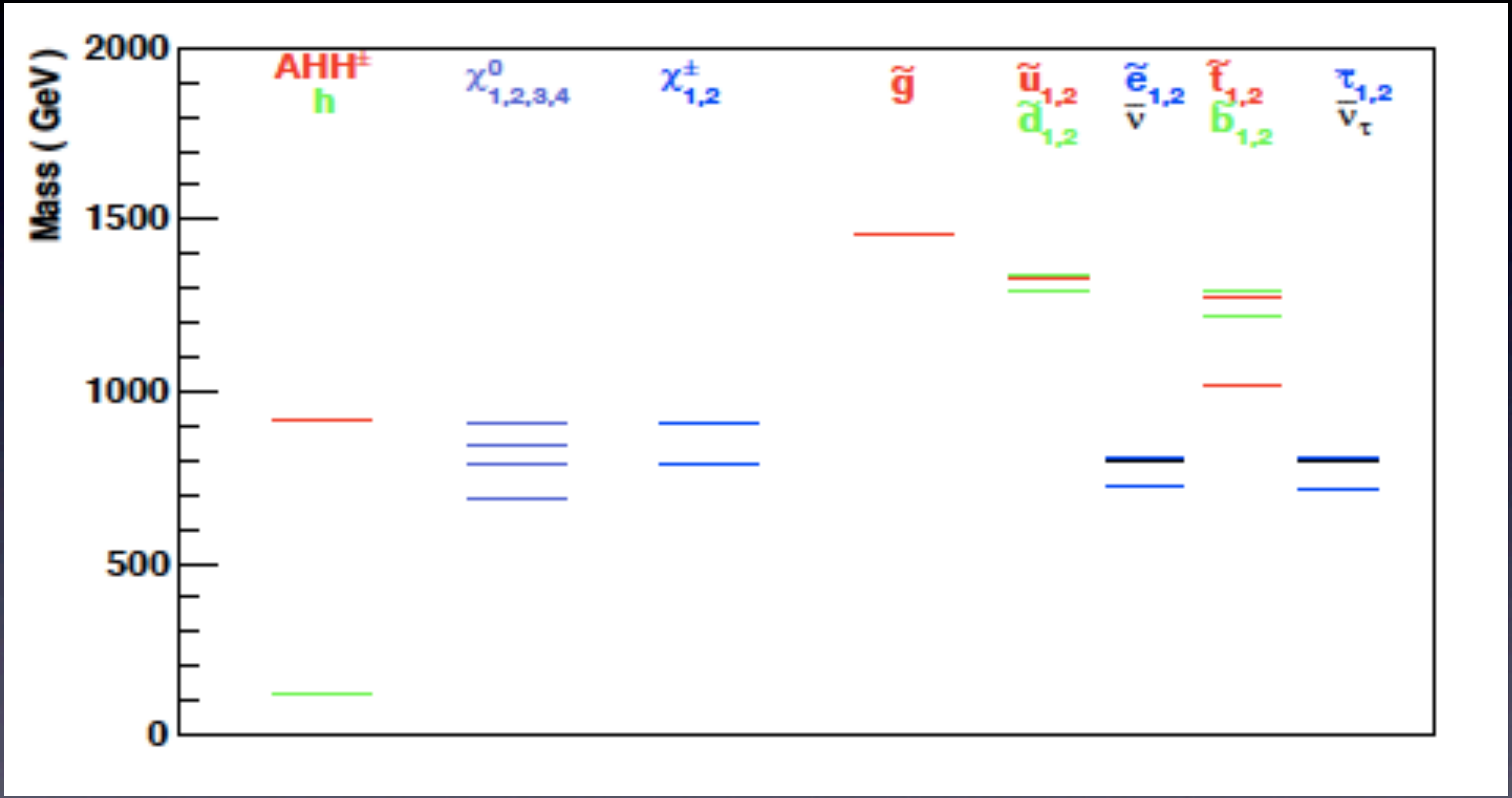
Small threshold scenario... $\alpha_g < 0$



$M_{\rm mess} = 10^{12}\,{\rm GeV}, \alpha_m = 1, \alpha_g = -0.5, N = 3, \tan\beta = 10, \mu > 0$

Small threshold scenario: Mass Spectrum

$M_{\rm mess} = 10^{12}\,{\rm GeV}, \alpha_m = 1, \alpha_g = -0.5, N = 3, \tan\beta = 10, \mu > 0$

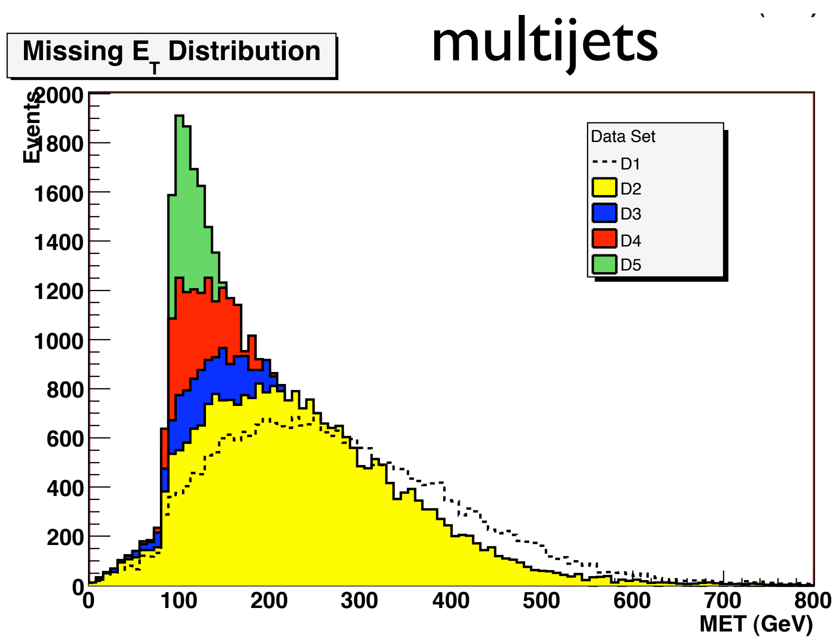


Depends in detail on (deflected) mirage scale!

DMM Collider Phenomenology

First study: effects of gauge mediation. Can be dramatic!

	Parameter Set			α_g Value				
	α_m	M_0	$M_{\rm mess}$	-1.0	-0.5	0	0.5	1.0
Line A	1	2 TeV	10^{12} GeV	$\tilde{\tau}$ LSP	✓	✓	✓	✓✓
Line B	1	1 TeV	10^{8} GeV	✓	✓✓	✓	$\tilde{g}$ LSP	$\tilde{g}$ LSP
Line C	0.771	0.8 TeV	10^{12} GeV	✓	✓	✓	✓	✓
Line D	0.755	0.4 TeV	10^{12} GeV	✓	✓	✓	✓	✓



Model Point	$\sigma_{\rm SUSY}$ (pb)	Trigger Eff.
Line A		
A2	1×10^{-3}	98.8%
A3	5×10^{-3}	99.1%
A4	0.02	98.4%
A5	0.21	73.8%
Line B		
B1	0.38	98.4%
B2	1.54	96.8%
B3	5.56	88.0%
Line C		
C1	0.25	98.9%
C2	0.59	98.6%
C3	1.45	98.0%
C4	3.80	96.1%
C5	11.71	90.2%
Line D		
D1	12.7	95.9%
D2	27.0	94.0%
D3	61.1	91.0%
D4	152.0	84.6%
D5	459.7	67.2%

B. Altunkaynak, L.E., I.-W. Kim, B. Nelson, Y. Rao, 1001.5261

DMM Collider Phenomenology

Current study (in progress):

Landscape of lightest 4 non-SM particle masses

comparison with: mSUGRA D. Feldman, Z. Liu, P. Nath ’07, ’08

“SUSY without Prejudice”

C. Berger, J. Gainer, J.Hewett, T. Rizzo ’08

Scan of 24.75M DMM models: (variety of cuts)

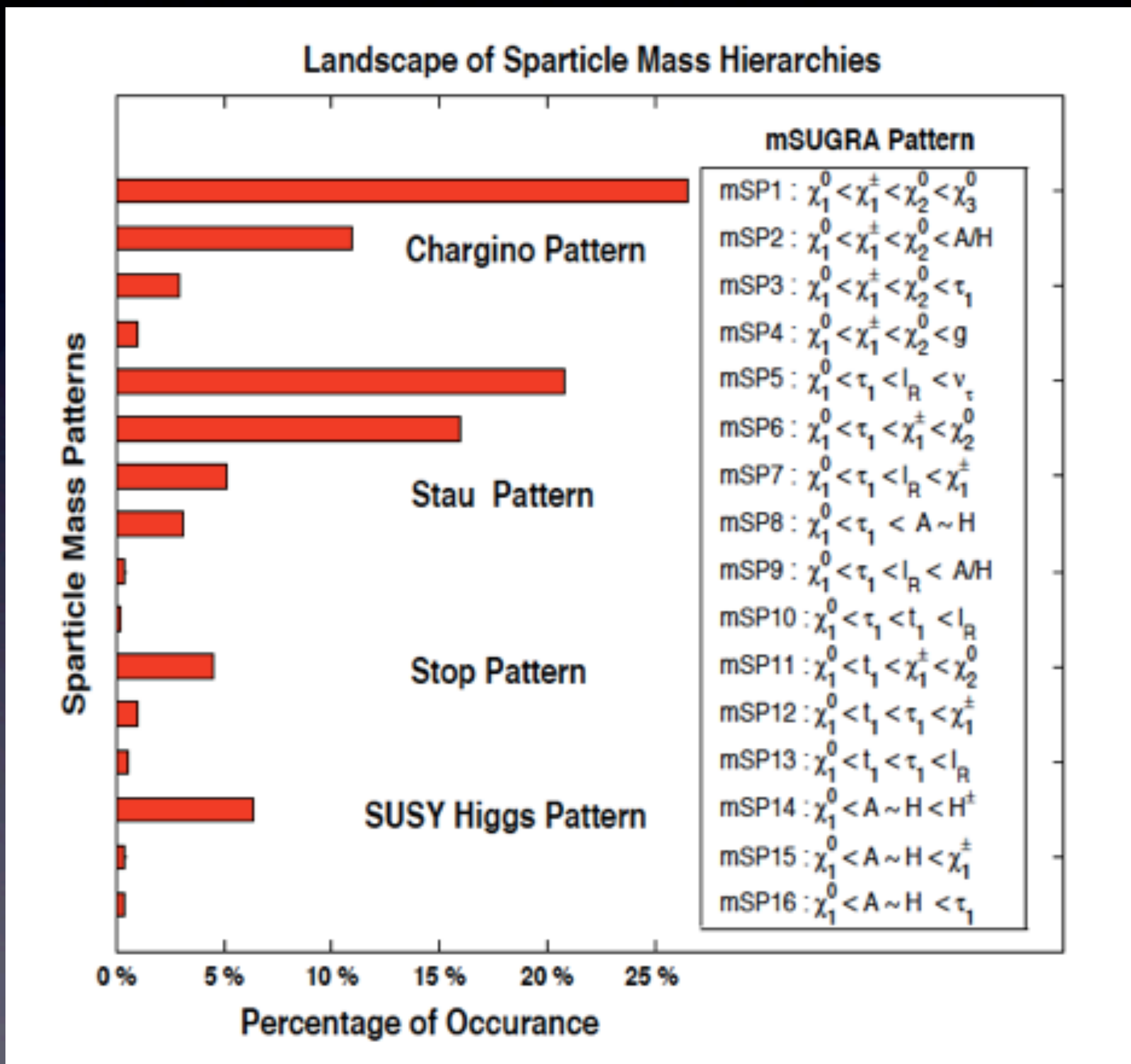
$$1 \leq N \leq 5 \qquad 0 \leq \alpha_m \leq 2$$

$$10^4\,\mathrm{GeV} \leq M_{\mathrm{mess}} \leq 10^{16}\,\mathrm{GeV} \qquad -1 \leq \alpha_g \leq 2$$

$$50\,\mathrm{GeV} \leq m_0 \leq 2\,\mathrm{TeV} \qquad 1 \leq \tan\beta \leq 60$$

B. Altunkaynak, L.E., I.-W. Kim, B. Nelson, Y. Rao, in preparation

Compare: mSUGRA patterns (FLN)



Bounds
$m_h > 100\,\mathrm{GeV}$
$m_{\chi_1^\pm} > 104.5\,\mathrm{GeV}$
$m_{t_1} > 101.5\,\mathrm{GeV}$
$m_{\tau_1} > 98.8\,\mathrm{GeV}$
$0.0855 < \Omega_\chi h^2 < 0.1189$
$229 \times 10^{-6} < \mathcal{BR}(b \to s\gamma) < 481 \times 10^{-6}$
$\mathcal{BR}(B_s \to \mu^+\mu^-) < 9 \times 10^{-6}$
$-11.4 \times 10^{-10} < g_\mu - 2 < 9.4 \times 10^{-9}$

(WMAP3)

Feldman, Liu, Nath '07

DMM Results (preliminary)

	Pattern	% of Models
	$H < A < H^\pm < \chi_1^0$	23.33%
mSP3	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < \tilde{\tau}_1$	21.57%
mSP4	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < \tilde{g}$	12.25%
mSP2	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < H$	7.05%
	$\chi_1^0 < \chi_1^\pm < \tilde{g} < \chi_2^0$	4.24%
mSP3	$\chi_1^0 < \chi_2^0 < \chi_1^\pm < \tilde{\tau}_1$	3.46%
mSP4	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < A$	3.05%
mSP6	$\chi_1^0 < \tilde{\tau}_1 < \chi_2^0 < \chi_1^\pm$	3.03%
mSP2	$\chi_1^0 < \chi_1^\pm < H < A$	2.77%
mSP1	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < \chi_3^0$	2.40%
	$A < H < H^\pm < \chi_1^0$	2.19%
mSP10	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < \tilde{e}_R$	1.81%
mSP7	$\chi_1^0 < \tilde{\tau}_1 < \tilde{e}_R < \chi_2^0$	1.39%
mSP2	$\chi_1^0 < \chi_2^0 < \chi_1^\pm < H$	1.20%

$\Omega_\chi h^2 < 0.1210$

(WMAP upper)

	Pattern	% of Models
	$H < A < H^\pm < \chi_1^0$	27.04%
mSP3	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < \tilde{\tau}_1$	12.51%
mSP3	$\chi_1^0 < \chi_2^0 < \chi_1^\pm < \tilde{\tau}_1$	8.51%
mSP2	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < H$	7.77%
mSP6	$\chi_1^0 < \tilde{\tau}_1 < \chi_2^0 < \chi_1^\pm$	6.96%
mSP2	$\chi_1^0 < \chi_2^0 < \chi_1^\pm < H$	5.97%
mSP1	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < \chi_3^0$	4.12%
mSP4	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < \tilde{g}$	3.48%
mSP7	$\chi_1^0 < \tilde{\tau}_1 < \tilde{e}_R < \chi_2^0$	3.22%
mSP7	$\chi_1^0 < \tilde{\tau}_1 < \tilde{e}_R < \chi_1^\pm$	2.98%
mSP6	$\chi_1^0 < \tilde{\tau}_1 < \chi_1^\pm < \chi_2^0$	2.23%
mSP4	$\chi_1^0 < \chi_2^0 < \chi_1^\pm < \tilde{g}$	2.08%
mSP8	$\chi_1^0 < \tilde{\tau}_1 < H < A$	1.91%
mSP2	$\chi_1^0 < \chi_1^\pm < \chi_2^0 < A$	1.86%
mSP2	$\chi_1^0 < \chi_2^0 < \chi_1^\pm < A$	1.76%

$0.0997 < \Omega_\chi h^2 < 0.1221$

(WMAP7)

$m_h > 110\,\mathrm{GeV}$ + updated mass bounds, indirect bounds

Summary and Outlook

- SUSY model building: important for testing TeV-scale SUSY hypothesis in LHC era
- Theory-motivated "mixed" scenarios: typically do not solve low energy problems of MSSM, but allow for means to "dial" between known scenarios and yield distinctive low energy spectra
- Deflected mirage mediation: string-motivated mixed gravity-gauge-anomaly mediation model
- Current study: "landscape" of DMM models, comparison w/ mSUGRA and "SUSY without Prejudice" studies. Still need to characterize dark matter-allowed regions fully.
- Stay tuned!