EMERGENCE of the WEAK SCALE from M THEORY WITH STABILIZED MODULI and UNIFICATION, and ASSOCIATED COLLIDER and DARK MATTER PHENOMENOLOGY

-- *compactify on manifolds with* G_2 *holonomy*

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Acharya, Bobkov, Kane, Kumar, Jing Shao, hep-ph/0701034

some recent progress

- Introduction
- Stringy stuff
- All moduli stabilized, spontaneous $\bcancel{\text{susy}}$
- Cosmological Constant? – set small → EW scale
- $M_{3/2}$ sets scale for all masses, and μ
- Moduli masses
- Soft-breaking Lagrangian, gaugino and squark masses
- Precesion gauge coupling unification
- Phenomenology, LHC, DM
- Summary
- Workshop

11-4=7 so compactify 11D M theory directly on 7D manifold

Earlier work -- results relevant for SM physics such as existence of non-abelian gauge fields and chiral fermions; general form of Kahler potential; issues related to local constructions (e.g. SU(5) $\longrightarrow$ SM) such as proton decay, threshold corrections to gauge couplings, Yukawas.

- Atiyah and Witten, th/0107177
- Acharya and Witten, th/0109152
- Witten, ph/0201018
- Beasley and Witten, th/0203061
- Friedmann and Witten, th/0211269
- Acharya and Valandro, ph/0512144
- Acharya and Gukov, th/0409101
- etc.
- Recently 2 papers posted by Bourjaily, third coming, on embeddings

Don’t discuss these here

Our work:

Given a set of (dimensionless) “microscopic” parameters characterizing the vacua, simultaneously

-- Generate the EW scale in a unique metastable de Sitter vacuum with spontaneous $\text{SU}\cancel{\text{S}}\text{Y}$

-- Stabilize all moduli

-- Consistent with standard gauge unification ($M_{unif} \sim 10^{16}$ GeV)

-- Assume a natural GUT visible sector breaking to MSSM chiral spectrum →phenomenological predictions, e.g. for LHC and DM,

Only dimensionful input – the Planck scale !

Presumably can combine this with earlier work

Philosophy – look for solutions that can describe our world

STRINGY

- 7 dimensions form a space with G_2 holonomy, known to preserve supersymmetry in 4D
- No fluxes -- not needed for stabilization in our case, tend to raise masses to string scale
- In these vacua, non-Abelian gauge fields localized along 3D submanifolds at which there is an orbifold singularity [Acharya, th/9812205;th/0011089; Achaya-Gukov th/0409191]
- Chiral fermions localized at points at which there are conical singularities [Acharya and Witten, th/0109152, Acharya and Gukov, th/0409191; Atiyah and Witten, th/0107177]
- Generically two 3D submanifolds do not intersect in a 7D space, so no light matter fields charged under both SM gauge group and hidden sector gauge groups → susy breaking generically gravity mediated in these vacua

- Joyce, and Kovalev, have constructed examples of G_2 manifolds without singularities
- Dualities with heterotic and Type IIA vacua suggest the existence of singular examples
- Can extend Kovalev's constructions to include orbifold singularities, and Yang-Mills fields
- Get similar picture from M theory dual of the heterotic string on a CY manifold at large complex structure

Existence of a global manifold with G_2 holonomy with realistic gauge and chiral structure probably guaranteed by stringy duality arguments from heterotic and IIA – but not yet constructed

Nevertheless, expect lack of G_2 mathematical knowledge will not prevent going ahead with most aspects of the physics

MODULI STABILIZATION

- All G_2 moduli fields s_i have axionic partners t_i which have a shift symmetry in the absence of fluxes (different from heterotic or IIB) – such symmetries can only be broken by non-perturbative effects
- So in zero-flux sector only contributions to superpotential are non-perturbative, from strong dynamics (e.g. gaugino condensation or instantons) – focus on former
- In M theory the superpotential, and gauge kinetic function, in general depend on all the moduli -- expect the effective supergravity potential has isolated minima
- See explicitly here that the hidden sector gaugino condensation produces an effective potential that stabilizes all moduli

A set of Kahler potentials, consistent with G_2 holonomy and known to describe some explicit examples, was given by Beasley-Witten th/0203061; Acharya, Denef, Valandro th/0502060, with

$$K = -3\ln(4\pi^{1/3} V_X)$$

$$V_X = \prod_{i=1}^{N} s_i^{a_i}, \quad \text{with} \quad \sum_{i=1}^{N} \underline{a_i} = 7/3$$

We assume we can use this. More generally the volume will be multiplied by a function with certain invariances.

Assume hidden sector gaugino condensation

gauge kinetic function

$$W = \sum_{k=1}^{M} A_k e^{i b_k f_k}$$

Keep two terms – enough to find solutions with good properties such as being in supergravity regime, simple enough to do most calculations semi-analytically (as well as numerically)

b_k=2π/c_k where c_k are dual coxeter numbers of hidden sector gauge groups --- A_k are constants of order unity, and depend on threshold corrections to gauge couplings, some computed by Friedmann and Witten

The gauge kinetic functions here are integer linear combinations of all the moduli (Lukas, Morris th/0305078),

$$f_k = \sum_{i=1}^{N} \underline{N_i^k}\, z_i \,.$$

The microscopic constants a_i, b_k, A_k, N_i^k are determined for a given G_2 manifold (but not yet known for relevant ones) -- they completely characterize the vacua – not dependent on moduli

Focus on the (well-motivated) case where two hidden sector gauge kinetic functions are equal (the corresponding three-cycles are in the same homology class)]

Expect massless hidden sector quark states Q, assume N_c colors, N_f flavors, $N_f<N_c$ -- then (Affleck, Dine, Seiberg PRL 51(1983)1026, Seiberg hep-th/9402044, hep-th/9309335, Lebedev,Nilles, Ratz th/0603047)

$$W = A_1\, e^{i\frac{2\pi}{N_c-N_f}\sum_{i=1}^{N} N_i^{(1)} z_i} \det(Q\tilde{Q})^{-\frac{1}{N_c-N_f}} = A_1 \phi^a\, e^{ib_1\, f_1}$$

and define an effective meson field

$$\phi \equiv \left(\det(Q\tilde{Q})\right)^{1/2} = \phi_0 e^{i\theta}$$

Chiral fermions localized at pointlike conical singularities, so bulk moduli s_i should have little effect on local physics, so assume matter Kahler potential slowly varying

$$W = A_1 \phi^a \, e^{ib_1 f} + A_2 e^{ib_2 f}$$

$$K = -3 \ln(4\pi^{1/3} V_X) + \phi\bar{\phi}$$

- We also looked at chiral families in both hidden sectors, more chiral families in each – no changes in qualitative results (in paper)

The N=1 SUGRA scalar potential is then given by:

$$\begin{aligned} V \ = \ & \frac{e^{\phi_0^2}}{48\pi V_X^3}\left[\left(b_1^2 A_1^2 \phi_0^{2a} e^{-2b_1\vec{\nu}\cdot\vec{a}} + b_2^2 A_2^2 e^{-2b_2\vec{\nu}\cdot\vec{a}} + 2b_1 b_2 A_1 A_2 \phi_0^a e^{-(b_1+b_2)\vec{\nu}\cdot\vec{a}} \cos((b_1-b_2)\vec{N}\cdot\vec{t} + a\theta)\right)\right. \\ & \times \sum_{i=1}^{N} a_i(\nu_i)^2 + 3(\vec{\nu}\cdot\vec{a})(b_1 A_1^2 \phi_0^{2\alpha} e^{-2b_1\vec{\nu}\cdot\vec{a}} + b_2 A_2^2 e^{-2b_2\vec{\nu}\cdot\vec{a}} + (b_1+b_2) A_1 A_2 \phi_0^a e^{-(b_1+b_2)\vec{\nu}\cdot\vec{a}} \\ & \times \cos((b_1-b_2)\vec{N}\cdot\vec{t} + a\theta)) + 3(A_1^2 \phi_0^{2a} e^{-2b_1\vec{\nu}\cdot\vec{a}} + A_2^2 e^{-2b_2\vec{\nu}\cdot\vec{a}} + 2A_1 A_2 \phi_0^a e^{-(b_1+b_2)\vec{\nu}\cdot\vec{a}} \qquad (101) \\ & \times \cos((b_1-b_2)\vec{N}\cdot\vec{t} + a\theta)) + \frac{3}{4}\phi_0^2 \,(A_1^2 \phi_0^{2\alpha} \left(\frac{a}{\phi_0^2} + 1\right)^2 e^{-2b_1\vec{\nu}\cdot\vec{a}} + A_2^2 e^{-2b_2\vec{\nu}\cdot\vec{a}} \\ & \left. + 2A_1 A_2 \phi_0^a \left(\frac{a}{\phi^2} + 1\right) e^{-(b_1+b_2)\vec{\nu}\cdot\vec{a}} \cos((b_1-b_2)\vec{N}\cdot\vec{t} + a\theta))\right]. \end{aligned}$$

- Can minimize the above potential analytically in the large hidden sector 3-cycle volume approximation (i.e. volumes >1). Consistently take higher order effects into account.

- Check the results self-consistently.

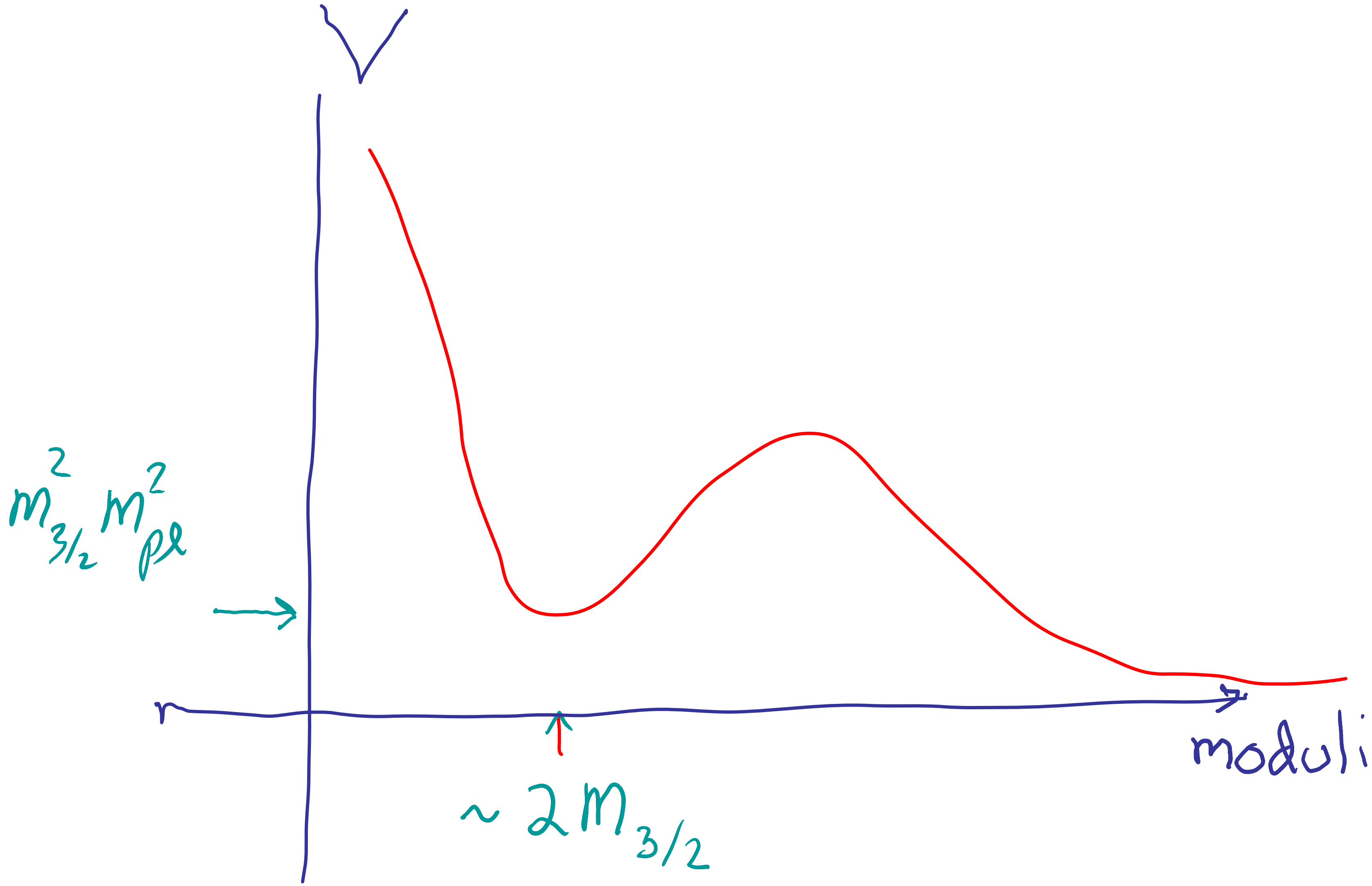
- After long analysis, find to lowest order

$$s_i = \frac{a_i \nu}{N_i}, \quad \text{with} \quad \nu \approx \frac{3}{14\pi}\frac{PQ}{Q-P}\log\left(\frac{A_1 Q}{A_2 P}\right)$$

Q-P>2

$$\phi_0^2 \approx 1 - \frac{2}{Q-P} + \sqrt{1-\frac{2}{Q-P}} - \frac{7}{P\log\left(\frac{A_1 Q}{A_2 P}\right)}\left(\frac{3}{2} + \sqrt{1-\frac{2}{Q-P}}\right)$$

metastable dS minimum, unique for given microscopic parameters – positive chiral fermion F-term vev crucial



V
$m_{3/2}^2 m_{pl}^2$
$\sim 2m_{3/2}$
moduli

leading order condition for energy density at minimum positive easy to satisfy

$$3 - \frac{8}{Q-P} - \frac{28}{P\log\left(\frac{A_1 Q}{A_2 P}\right)} < 0$$

[equality makes potential vanish at minimum]

→~ 30% of entire parameter space (defined so supergravity valid, N>100) has gravitino mass $\lesssim$ 100 TeV

→Gaugino masses suppressed over entire parameter space by stringy factor ~ 35-85

Recall – no fluxes, no anti-branes – susy broken spontaneously (not explicitly)

COSMOLOGICAL CONSTANT?

CC problem presumably solved by other physics

No solution here – can we still do meaningful phenomenology?

To study this, set above V_0 (potential at minimum) to zero at leading order by (assuming) tuning of A_1Q/A_2P

We check that tuning V_0 to all orders numerically has little effect on $M_{3/2}$ and on superpartner masses

Now study these solutions, with

-- CC tuned to be small

-- μ from (Giudice-Masiero) Higgs mixing term in Kahler potential

-- assume GUT visible sector → MSSM by Wilson lines (very natural)

and require

-- radiative EW symmetry breaking

***LEP lower bound on chargino mass

-- precision two loop gauge coupling unification including all high scale corrections

Compute GRAVITINO MASS

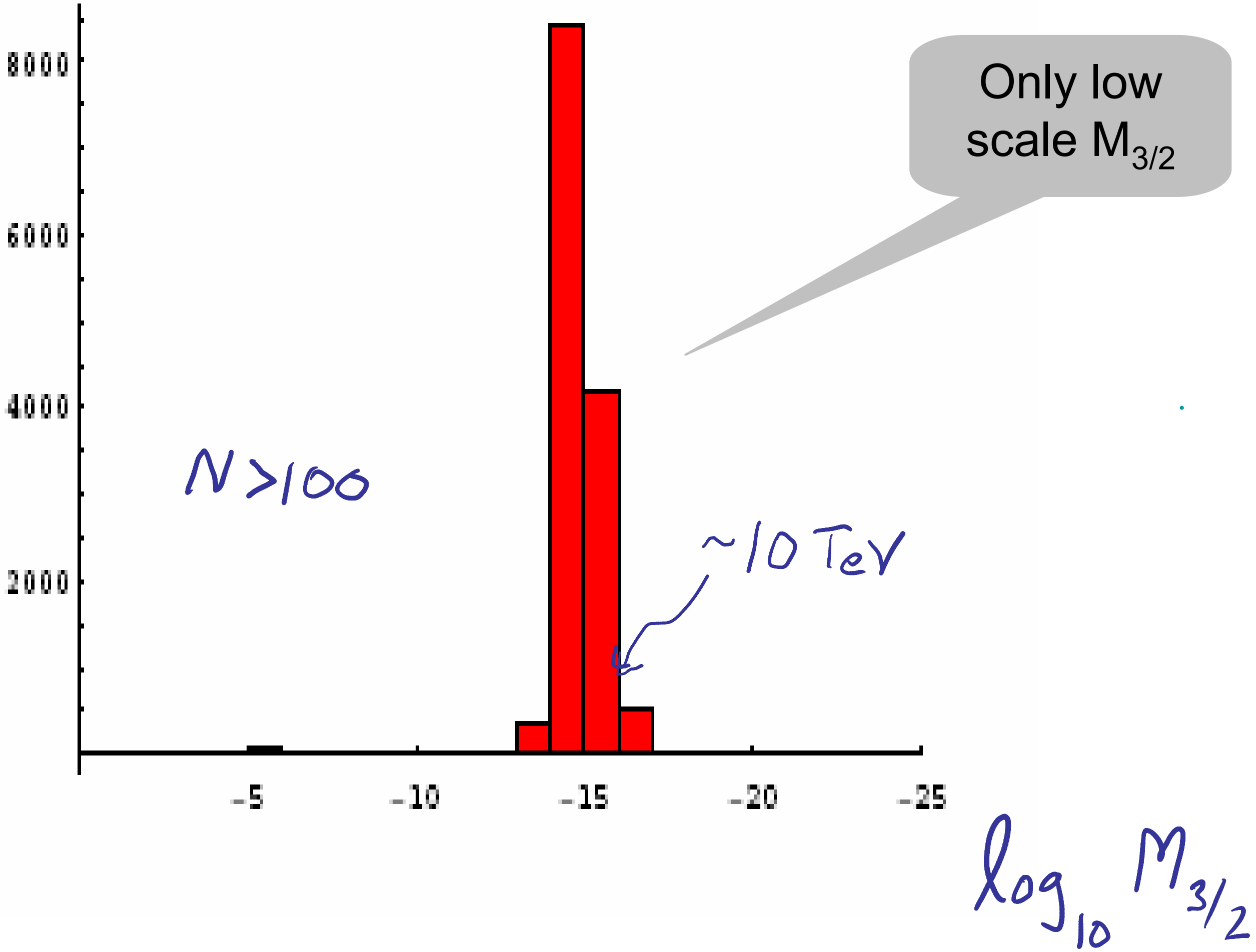
$$m_{3/2} = m_p \sqrt{2}\pi^3 A_2 \left| \frac{P}{Q}\phi_0^{-\frac{2}{P}} - 1 \right| \left(\frac{28Q}{3(Q-P)-8}\right)^{-\frac{7}{2}} e^{-\frac{28}{3(Q-P)-8}} \prod_{i=1}^{N} \left(\frac{7N_i}{3a_i}\right)^{\frac{3a_i}{2}} e^{\phi_0^2/2}$$

where the meson vev is now given by:

$$\phi_0^2 \approx -\frac{1}{8} + \frac{1}{Q-P} + \frac{1}{4}\sqrt{1-\frac{2}{Q-P}} + \frac{2}{Q-P}\sqrt{1-\frac{2}{Q-P}}\,.$$

Can scan P,N to see typical $M_{3/2}$ (keeping $V_X>1$ so sugra approximation valid, and $3<P<100$)

!



Only low scale $M_{3/2}$

What makes moduli superpotential and therefore $m_{3/2}$ small generically?

-- absence of fluxes – in zero flux G_2 sector all moduli have classical shift symmetry (but not in heterotic or Type II) – then superpotential can only be renormalized by non-perturbative effects ~ $\exp(-1/g^2)$

-- gaugino condensation scale is $\Lambda_g \sim m_{pl} e^{-2\pi \mathrm{Im}f/3Q}$ from an asymptotically free SU(Q) hidden sector gauge theory – $1/g^2 \sim \mathrm{Im}f$

-- when CC is tuned to zero $\mathrm{Im}f = \Sigma N_i s_i = 14Q/\pi$ → $\Lambda_g = m_{pl} e^{-28/3} \approx 2\times 10^{14}\,\mathrm{GeV}$

--so

$$m_{3/2}/m_{pl} \sim (\Lambda_g/m_{pl})^3 / 8\sqrt{\pi} V_7^{3/2} \text{ so } m_{3/2} \lesssim 100\ \mathrm{TeV}$$

since $(\Lambda_g/m_{pl})^3 \lesssim 10^{-12}$ and $V_7^{3/2} > 1$

Condition from setting CC to zero at tree level seems to imply a relation between small CC and $M_{3/2}$ ~ TeV → do not have to *independently* tune CC to be small *and* $M_{3/2}$ to be ~ TeV !

TREE LEVEL GAUGINO MASSES

- Universal since assumed SU(5) or similar unification at unification scale
- With same assumptions as used so far, get

$$M \approx -\frac{e^{-i\gamma w}}{\underline{P\log\left(\frac{A_1 Q}{A_2 P}\right)}}\left(1+\frac{2}{\phi_0^2\,(Q-P)}+\frac{7}{\phi_0^2\,P\log\left(\frac{A_1 Q}{A_2 P}\right)}\right)\times \underline{m_{3/2}}$$

- Independent of SM or hidden sector gauge kinetic functions and details of internal manifold (a_i) and number of moduli N
- Gaugino masses suppressed by factor only depending on microscopic theory since leading term ~0 and corrections ~ 1/(volume of 3-cycle)

$$M \approx -\frac{e^{-i\gamma w}}{84}\left(1+\frac{2}{3\phi_0^2}+\frac{7}{84\phi_0^2}\right)\times m_{3/2} \approx -e^{-i\gamma w}\,\underline{0.024\times m_{3/2}}$$

• Anomaly mediated gaugino masses

Gaillard, Nelson,Wu,hep-th/09905122; Bagger et. al.: hep-th/9911029

$$(M)_a^{am} = -\frac{g_a^2}{16\pi^2}\left[-\left(3C_a - \sum_\alpha C_a^\alpha\right)e^{\hat{K}/2}W^* + \left(C_a - \sum_\alpha C_a^\alpha\right)e^{\hat{K}/2}F^m K_m + 2\sum_\alpha C_a^\alpha e^{\hat{K}/2}F^m \partial_m \ln \widetilde{K}_\alpha\right]$$

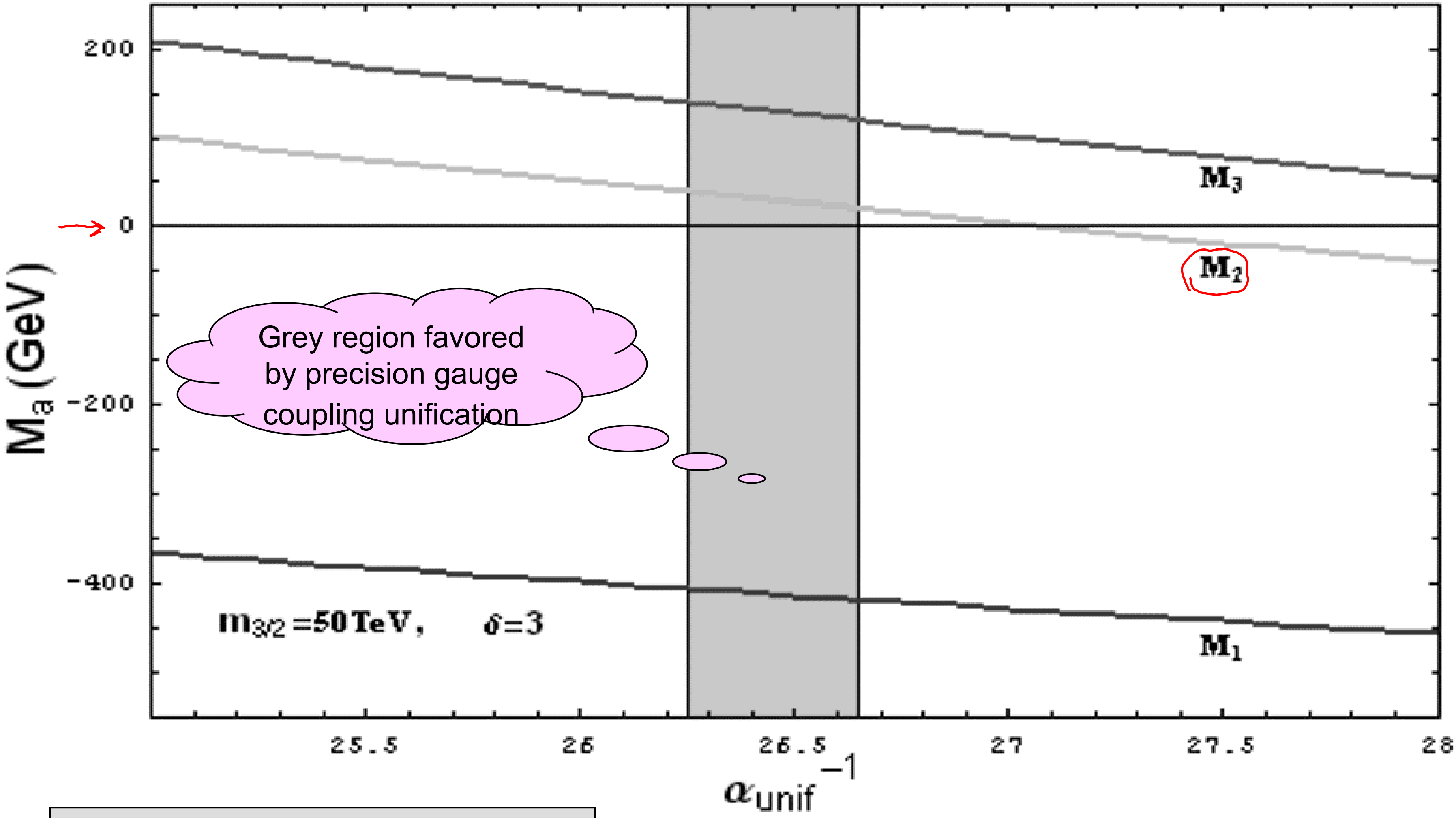
--Note depends on α_{unif} -- potential contributions from KK threshold effects zero here

•Lift the Type IIA Kahler potential (Bertolini et al th/0512067) to M-theory.

$$\widetilde{K}_{\overline{\alpha}\beta} = \delta_{\overline{\alpha}\beta}\prod_{i=1}^{n}\left(\frac{\Gamma(1-\theta_i^\alpha)}{\Gamma(\theta_i^\alpha)}\right)^{\frac{1}{2}} \quad , \quad \tan\left(\pi\theta_i^\alpha\right) = c_i^\alpha\left(s_i\right)^l$$

Tree level and anomaly mediated contributions almost same size, so major cancellations, depending on α_{unif} – somewhat surprising

High scale gaugino masses – not universal



Grey region favored by precision gauge coupling unification

Note M_2 small so wino LSP, M_3 runs to be larger at low scale

- high scale scalar masses

$$m_\alpha^2 \approx \cancel{V_0} + m_{3/2}^2\left[1+\frac{9}{4P^2\ln^2\left(\frac{A_1Q}{A_2P}\right)}\left(1+\frac{2}{(Q-P)\phi_0^2}+\frac{7}{\phi_0^2 P\ln\left(\frac{A_1Q}{A_2P}\right)}\right)^2 \times\frac{1}{4\pi}\sum_i\left\{l^2\psi_{ii}^\alpha\sin^2\left(2\pi\theta_i^\alpha\right)+l^2\psi_i^\alpha\sin\left(4\pi\theta_i^\alpha\right)-2l\,\psi_i^\alpha\sin\left(2\pi\theta_i^\alpha\right)\right\}\right]$$

- If we require zero CC at tree-level and $Q-P=3$:

$$m_\alpha^2 \approx m_{3/2}^2\left[\underset{\uparrow}{1}-\frac{0.0013}{4\pi}\sum_i\left\{l^2\psi_{ii}^\alpha\sin^2\left(2\pi\theta_i^\alpha\right)+l^2\psi_i^\alpha\sin\left(4\pi\theta_i^\alpha\right)-2l\,\psi_i^\alpha\sin\left(2\pi\theta_i^\alpha\right)\right\}\right]$$

→Universal heavy scalars $m_\alpha \approx m_{3/2}$

- high scale trilinear couplings

$$A_{\alpha\beta\gamma} \approx m_{3/2} e^{-i\gamma_W} \Bigg(\underset{\uparrow}{1.4876} + 0.024 \Bigg[10.45 + 2\ln\left|\frac{C_{\alpha\beta\gamma}}{Y_{\alpha\beta\gamma}}\right| - 7\ln\left(\frac{14(P+3)}{N}\right) - \sum_i \left(\left\{ \frac{1}{2}\ln\left(\frac{\Gamma(1-\theta_i^{\alpha})}{\Gamma(\theta_i^{\alpha})}\right) - \frac{1}{2\pi} l \psi_i^{\alpha} \sin\left(2\pi\theta_i^{\alpha}\right) \right\} + \alpha \to \beta + \alpha \to \gamma \right) \Bigg] \Bigg)$$

- Note A_t will run to a few TeV at low scale

WHAT ABOUT μ ?

physical

$$\mu = \left(\frac{W^*}{|W|} e^{\hat{K}/2} \overset{\text{in superpotential}}{\mu'} + \overbrace{m_{3/2} Z - e^{\hat{K}/2} F^{\bar{m}} \partial_{\bar{m}} Z}^{\text{from Kahler potential. (Guidice-Masiero)}} \right) \left(\tilde{K}_{H_u} \tilde{K}_{H_d} \right)^{-1/2}$$

$$B\mu = \left(\tilde{K}_{H_u} \tilde{K}_{H_d} \right)^{-1/2} \left(\frac{W^*}{|W|} e^{\hat{K}/2} \mu' \left(e^{\hat{K}/2} F^{m} \left[\hat{K}_m + \partial_m \ln \mu' \right] - m_{3/2} \right) + \left(2 m_{3/2}^2 + V_0 \right) Z \right)$$

- μ' can vanish with a discrete symmetry (Witten ph/0201018)
- If the Higgs bilinear coefficient Z~1 then typically expect $\mu \sim M_{3/2}$

MODULI MASSES

- diagonalize for simplest case with all $a_i=7/(3N)$ – all eigenvalues positive, with N-1 having

$$M_s \approx 2M_{3/2}$$

and one heavy state with mass ~ 500 $M_{3/2}$

- Gravitino and moduli problems with BBN etc likely OK but not checked carefully yet

PHENOMENOLOGY

-- Study all solutions with $m_{3/2}$ in TeV region

GAUGE COUPLING UNIFICATION

- Gaugino masses depend on α_{unif}, and α_{unif} depends on corrections to gauge couplings from low scale superpartner thresholds, so feedback
- Big cancellation between tree level and anomaly contributions to gaugino masses, so large sensitivity
- Squarks and sleptons in complete multiplets so do not affect unification, but higgs, higgsinos, and gauginos do – μ large so unification depends most on M_3/M_2 (here μ large and higgsinos heavy, not like split susy)
- For SU(5) if higgs triplets lighter than M_{unif} their threshold contributions make unification harder, so assume triplets as heavy as unification scale
- Scan parameter space of α and threshold corrections, find good region for $26.24 \lesssim \alpha_{unif}^{-1} \lesssim 26.45$ in full two-loop analysis, for reasonable threshold corrections!

PHASES

$$W = A_1 \varphi^a e^{ib_1 f} + A_2 e^{-ib_2 f}$$

A_1, A_2, φ have phases $\varphi_1, \varphi_2, \theta$

At minimum, $\sin\left((b_1 - b_2)\vec{N}\cdot\vec{t} + a\theta + \varphi_1 - \varphi_2\right) = 0$

$\cos\left(\qquad\qquad\qquad\qquad\right) = -1$

So only phase left is $\gamma_W = b_2 \vec{N}\cdot\vec{t} + \varphi_2$

Gaugino masses ~ ∂W so same phase

Anomaly mediation pieces also ~ W or ∂W so same phase

After analysis, trilinears too!

μ can have a different phase, from the Kahler potential

$B\mu$ and μ have same phase if Giudice-Masiero

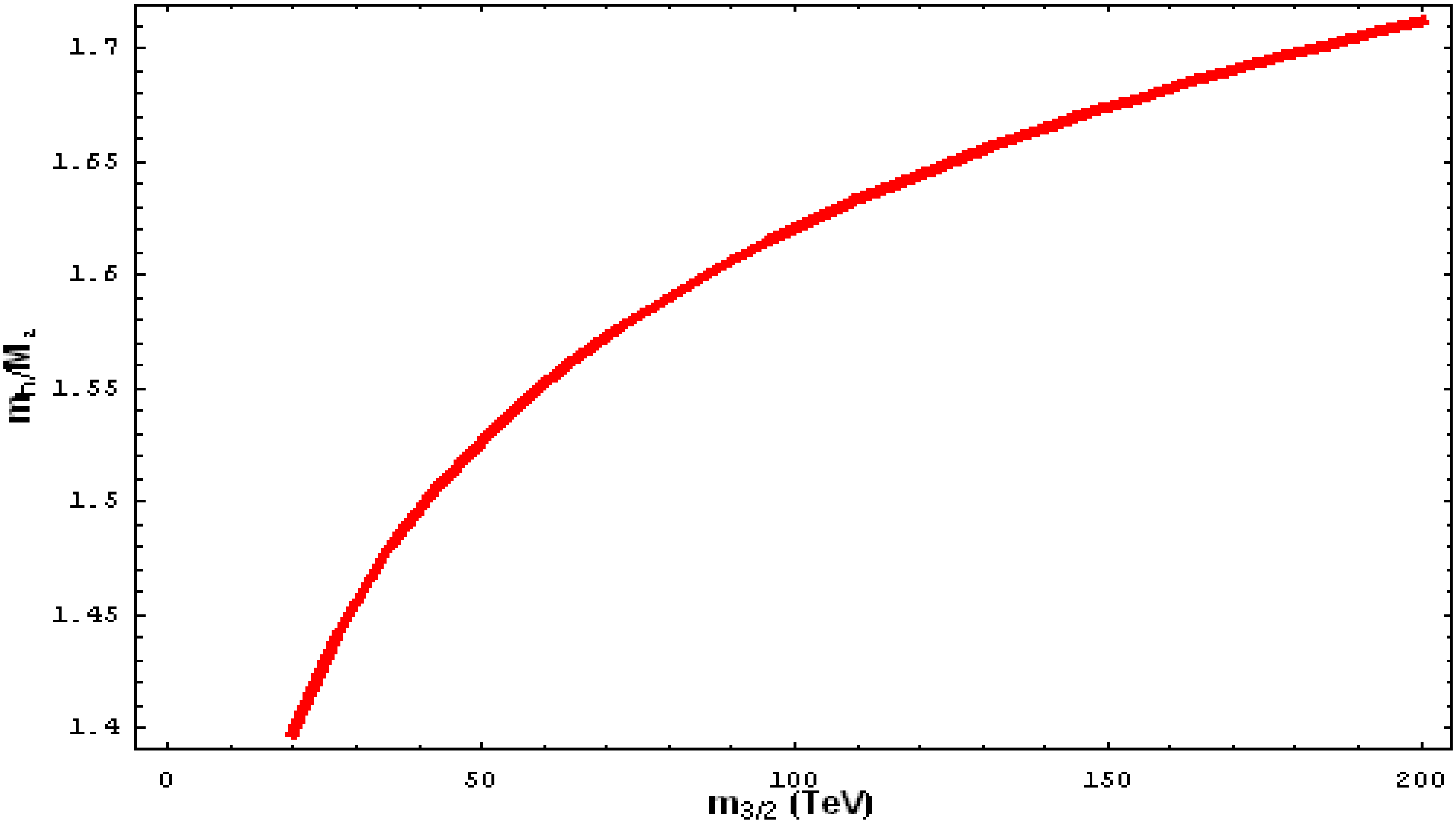
But -- all high scale

-- finite correction to chargino mass ~ μ is large, has phase of μ

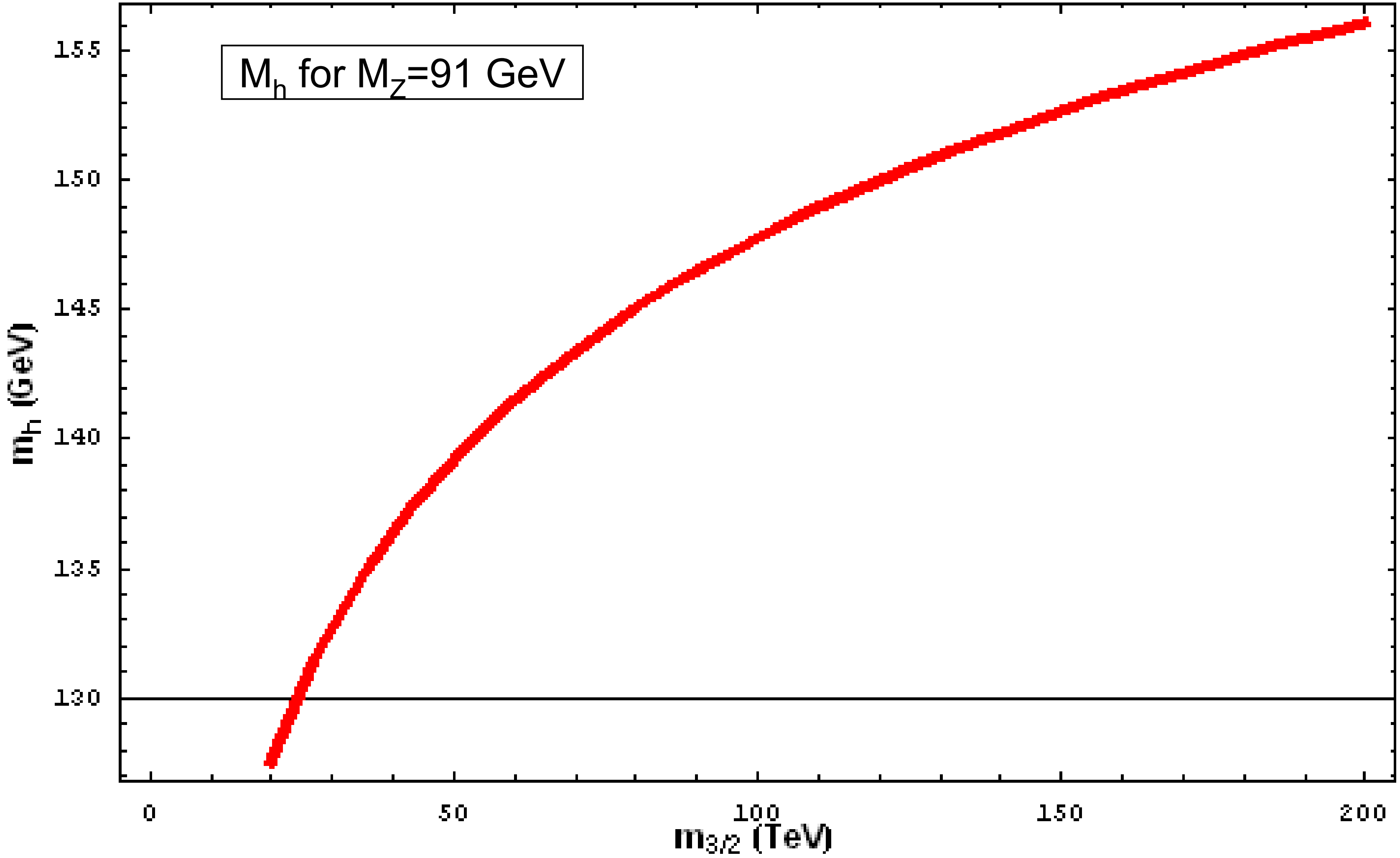
EW SYMMETRY BREAKING

- Can get EWSB
- Compute tanβ from underlying theory, tanβ≈1.5!
- Basically, $M_{3/2}$ ~ TeVs, so μ ~ TeVs, so M_Z ~ TeV expected – can tune it small
- Apparently no mechanism to suppress M_Z if start with SU(5) MSSM
- But NO approach has succeeded in getting small M_Z

  [what mechanism can give small gauge boson masses ??]
- Study NMSSM, different embeddings



1.7
1.65
1.6
1.55
1.5
1.45
1.4
m_h/M_z
0
50
100
150
200
$m_{3/2}$ (TeV)


M_h for M_Z=91 GeV
m_h (GeV)
155
150
145
140
135
130
0
50
100
150
200
$m_{3/2}$ (TeV)

LHC and Dark Matter phenomenology

- Have seen explicitly here that it makes sense to go from string theory to superpartner masses – study production cross sections and decays and find LHC signatures

- Low scale superpartner masses fully determined relative to $M_{3/2}$ for these solutions – no parameters

- G_2 spectrum distinctive – will get characteristic signatures that occupy finite regions in “signature space”

- Gluinos light so large cross section

LSP type – $\tilde{W}$, $\tilde{B}$, or $\tilde{W}$ +some $\tilde{B}$ -- not $\tilde{H}$ – depends on sign of μ

$\tilde{B}$ overcloses universe if normal cosmology, so only OK if extra entropy generated from moduli and gravitino decay – calculable for us

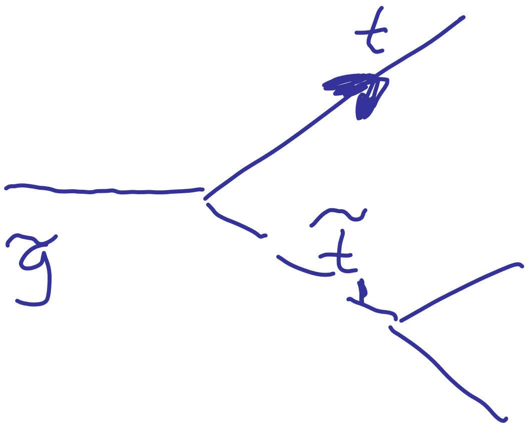
$\tilde{W}$ LSP means LEP chargino bound requires $M_{\tilde{C}} \gtrsim 85$ GeV → $M_{3/2} \gtrsim 30$ TeV

Relic density can be ~1/4 for thermal history of universe if wino plus ~ 10% bino

If pure wino LSP get small relic density, but can have LSPs produced by moduli and gravitino decay – Randall-Moroi considered numbers like ours and say it may work – we're doing the full calculation

Mainly produce $\tilde{g}$, $m_{\tilde{g}} \gtrsim$ few hundred GeV

Dominant decay via virtual $\tilde{t}_1$ since RGE running makes it lighter



- $\tilde{t}_1$ mainly RH so $\tilde{t}_1 \to Wb$ suppressed
- for $\tilde{W}$ LSP, $\tilde{t}_1 \not\to \tilde{N}_1 t$, so
  $\tilde{t}_1 \to \tilde{N}_2 t$, so $\tilde{g} \to t\bar{t}\tilde{N}_2$
- for $\tilde{B}_{LSP}$, $\tilde{t}_1 \to \tilde{N}_1 t$ so $\tilde{g} \to t\bar{t}\tilde{N}_1$
- $\tilde{N}_2 \to \tilde{C}_1 \ell^{\pm} \nu$, $\tilde{C}_1 q' \bar{q}$
- Normally $\tilde{C}_1, \tilde{N}_1$ tree level degenerate
- $\tilde{g} \to \tilde{N}_{2,1}\, g$

$\tilde{N}_1, \tilde{C}_1$ 80-140 GeV
$\tilde{N}_2$ 120-250 GeV

Emphasize can qualitatively distinguish different classes of string theory

KKLT vacua – scalars and gauginos both suppressed relative to $M_{3/2}$ – so squark production big – can trace to susy AdS minima so all susy breaking by uplifting term

LARGE volume vacua (Quevedo et al) – only gauginos suppressed relative to $M_{3/2}$ – AdS minima are broken susy so effect of uplift small → gluino production dominates

So these two types have very different charge asymmetries

G_2 – gaugino masses very non-universal, while LARGE volume has universal tree level gaugino masses but anomaly mediation masses also suppressed, so universal gaugino masses, and so heavier gluinos

Wino LSP particularly amusing:

HEAT (+AMS) data -- expect (GK, Liantao Wang, T Wang ph/0202156) positron excess in atmosphere from

wino + wino → W + W

so long as wino mass > W mass

PAMELA expected to report this summer (AMS currently not scheduled to fly)

Lots to do:

- G_2 mathematics, analysis with singularities
- MSSM embeddings -- families
- GUT embedding – 3-2-1? SU(5)? SO(10)? E6? Extra U(1)s? Family symmetry?
- Statistics of G_2 vacua
- Calculate relevant Kahler potentials
- μ--origin?, Bμ
- Then calculate Higgs vevs, derive EWSB, calculate tanβ and M_Z from first principles
- Study phase structure and CP violation
- Confirm no gravitino, moduli problems
- Check flavor-changing effects OK – any predictions?
- How does baryogenesis work?
- Calculate relic density
- Strong CP problem, axions
- Neutrino masses – mechanisms?
- Discrete symmetries, R-parity? – LSP stable?
- Inflation
- LHC phenomenology!

GOOD STUFF:

- Reasonable string construction
- Embedding SM forces and quarks, leptons, stabilizing moduli, breaking susy, gauge compling unification, and emergence of full gauge hierarchy, all simultaneously, seems exciting!
- Unique metastable deS potential (affect statistics—2^N AdS vacua?)!
- $M_{3/2}$ ~ TeV emerges if set tree level CC to zero!
- Gaugino masses always suppressed by stringy factor!
- Gluino mass few hundred GeV, easy to see quickly at LHC (maybe at Tevatron)!
- Squark, slepton masses ~ $M_{3/2}$
- Probably no flavor problem – maybe opportunities
- Can study origins of CPV
- Accomodates radiative EWSB in usual susy sense (but M_Z?…)
- Calculate tanβ from first principles!
- Probably wino LSP, smaller thermal relic density but moduli decay may give correct relic density
- Can write minimal phenomenological model with only microscopic parameters from which all soft parameters can be calculated, study LHC signatures

Hope dependence on a_i, b_i, A_k, N_i^k, P, Q is not too weak, since we would like to measure them, learn about them

With good data, some dependence on them remains – need to be able to do stringy calculations to figure it out, e.g. flavor dependence of Kahler potential

Workshop

“Physics and mathematics of G_2 compactifications”

Michigan Center for Theoretical Physics

May 3-5, 2007

International Organizing Committee

Acharya, Bobkov, Gukov, Joyce, Kane, Kumar, Larsen, Liu, Lykken

Sign up on MCTP website

Back-up slides

Will do semi-analytic examples for case when the two hidden sector gauge kinetic functions are equal, get in particular

$$\frac{A_2}{A_1} = \frac{1}{\alpha} e^{-\frac{7}{3}(b_1 - b_2)\nu}$$

and

$$s_i = \frac{a_i \nu}{N_i}$$

with

$$\nu = \frac{3}{14\pi} \frac{P\,Q}{P - Q} \log\left(\frac{A_2 P}{A_1 Q}\right)$$

This special case is well motivated:

- Consider a G_2 manifold constructed as a total space of fibration where the fibers are 4-dim K_3 surfaces varying over a 3-dim sphere S^3 or S^3 / Z_q

- If the generic K_3 fiber has both SU(4) and SU(5) orbifold singularities, then the G_2 manifold also will have two such singularities, parameterized by two disjoint copies of the sphere

- In this case $N_i^1 = N_i^2$ because $\hat{Q}_1$ and $\hat{Q}_2$ are in the same homology class

WHY ARE ALL THE MODULI STABILIZED/

-- in general the gauge kinetic function and therefore the superpotential depends on all the moduli, so they can all be stabilized nonperturbatively at same time hierarchy is generated

-- why is gauge kinetic function expected to depend on all the moduli here (but not in heterotic or typeII)? – in M theory only one kind of moduli, vs 3 kinds in 10D string theory – since gauge kinetic function linear in moduli it is in general a linear combination of all rather than only a subset

-- could some of the coefficients be zero? – very unlikely for two reasons

- Moduli correspond to 3-cycles in geometry – number of 3-cycles in M theory larger than number of supersymmetric 3-cycles in general, so they cannot form a complete basis – so a given one has to be written in a basis of all
- Also, in the basis in which the kahler potential is given by the usual formula it is very unlikely the gauge kinetic function will be aligned precisely along the direction of the basis vectors

WHY DOES ONE GET A dS MINIMUM FROM CHARGED MATTER IN AT LEAST ONE HIDDEN SECTOR?

-- F-term contribution to the scalar potential due to the matter in the hidden sector is fairly large, cancels the $3W^2$ term and gives a vacuum with positive energy density

WHY ARE TREE LEVEL GAUGINO MASSES SUPPRESSED RELATIVE TO GRAVITINO MASS?

-- the dS minimum is near the “would be” susy AdS extremum from the pure gauge hidden sectors – the matter F-term gives a large contribution to the vacuum energy but does not contribute to the gaugino masses

-- the gaugino mass is proportional to the moduli F-terms which are nearly zero near the susy point – the non-vanishing contribution comes from the subleading order, which is suppressed by the 1/V expansion

WHY IS THE CONSTRUCTION CONSISTENT WITH FULL GAUGE COUPLING UNIFICATION/

-- Have full M theory – need $M_{11} > M_{GUT}$

-- Have $M_{11} \sim m_{pl}/\sqrt{V_7}$ and $M_{GUT} \sim m_{pl}/V(Q)$ where

$$V_7=\Pi s_i{}^{a}i \quad \text{and } V(Q)=\mathrm{Im}f=\Sigma N_i s_i$$

-- Since V_7 a product and $V(Q)$ a sum, and $0<a_i\sim 1/N<1$, $M_{11}>M_{GUT}$

HOW CAN ONE CALCULATE THE SOFT MASSES RELIABLY WITHOUT KNOWING THE KALHER METRIC IN M THEORY?

-- Need Kahler metric for visible sector matter for

- Anomaly mediated gaugino mass contributions
- Scalars
- Trilinears
    - In our analysis we used the Bertolini et al results from typeIIA and lifted it to M theory, since there is a limit of M theory which is equivalent to IIA

-- Then found that for N$\gtrsim$50 moduli the contributions to soft parameters from matter kahler metric are negligible

-- So expect lact of detailed knowledge about kahler metric in M theory should not affect the low scale soft parameters much