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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some recent progress

Good for this meeting –

- -- derive LHC predictions from string theory (M theory) – select some solutions to focus on, and some assumptions about hidden sector Kahler potential, but generic
- -- unconventional and interesting spectrum and LHC phenomenology, derived
- -- Pythia and Isajet and other software hang up with string theory input!

- Introduction
- Stringy stuff
- All moduli stabilized, spontaneous ~~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

M THEORY COMPACTIFICATIONS ON G_2 MANIFOLDS

Earlier work -- results relevant for realistic 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.

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 $\cancel{\text{SUSY}}$
- -- 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, possibly unique

Only dimensionful input – the Planck scale !

Presumably can combine this with earlier work

STRINGY

- 7 dimensions form a space with G_2 holonomy, preserves 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

Geometry

- 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

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

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

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)

$b_k = 2\pi/c_k$ 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),

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

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)]

Include massless hidden sector quark states Q with 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)

$$W = A_1 \, e^{i \frac{2\pi}{N_c - N_f} \sum_{i=1}^{N} N_i^{(1)} z_i} \det(Q\tilde{Q})^{-\frac{1}{N_c - N_f}} = A_1 \phi^a \, e^{i b_1 \, f_1}$$

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

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

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

- 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:

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

- 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

Q-P>2

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

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

For a metastable dS minimum, “unique” for a given set of microscopic parameters.

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 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?

No solution here – can we still do meaningful phenomenology?

Of course, CC problem may be solved by other physics

Set above V_0 (potential at minimum) to zero at leading order by (assuming we can) tune 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 [but chargino and LSP degenerate at tree level so effect of bound will change – so far haven't had time to include that]

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

Compute GRAVITINO MASS

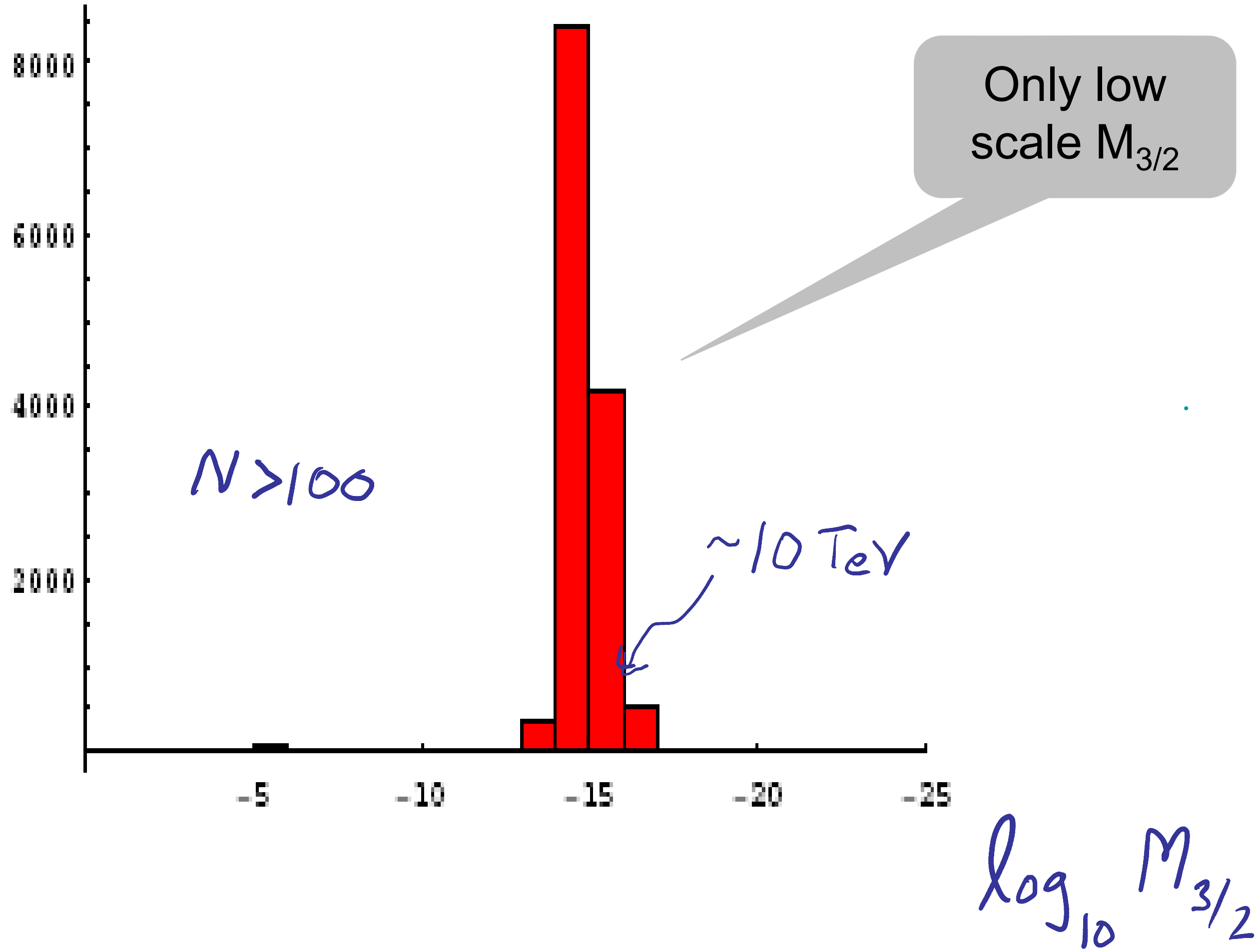
$$m_{3/2} = m_p \sqrt{2}\pi^3 A_2 \left| \frac{P}{Q} \phi_0^{-\frac{2}{P}} - 1 \right| \left(\frac{28Q}{3(Q-P)-8} \right)^{-\frac{7}{2}} e^{-\frac{28}{3(Q-P)-8}} \prod_{i=1}^{N} \left(\frac{7N_i}{3a_i} \right)^{\frac{3a_i}{2}} e^{\phi_0^2/2}$$

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)

!



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

--so

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

since $(\Lambda_g/m_{pl})^3 \quad 10^{-12}$ 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 SU(5) or similar unification at unification scale
- With same assumptions as used so far, get

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

- 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)

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

• Anomaly mediated gaugino masses

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

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

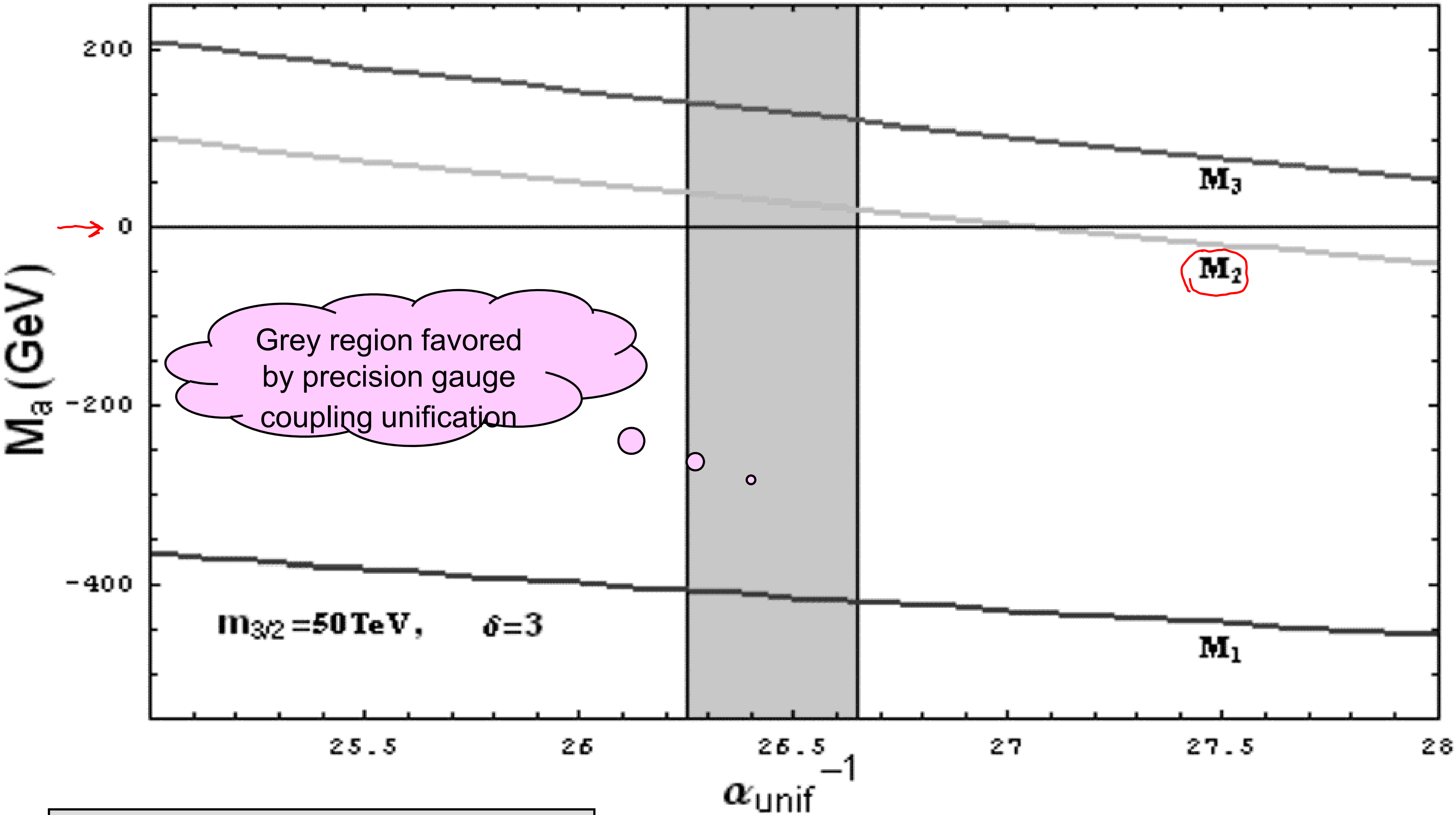
--Note depends on α_{unif} -- potential contributions from KK threshold effects zero here

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

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

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

High scale gaugino masses – not universal



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

- high scale scalar masses

$$m_\alpha^2 \approx \cancel{V_0} + m_{3/2}^2 \left[1 + \frac{9}{4P^2 \ln^2\left(\frac{A_1 Q}{A_2 P}\right)} \left(1 + \frac{2}{(Q-P)\phi_0^2} + \frac{7}{\phi_0^2 P \ln\left(\frac{A_1 Q}{A_2 P}\right)} \right)^2 \times \frac{1}{4\pi} \sum_i \left\{ l^2 \psi_{ii}^\alpha \sin^2\left(2\pi\theta_i^\alpha\right) + l^2 \psi_i^\alpha \sin\left(4\pi\theta_i^\alpha\right) - 2l\psi_i^\alpha \sin\left(2\pi\theta_i^\alpha\right) \right\} \right]$$

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

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

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

- high scale trilinear couplings

$$A_{\alpha\beta\gamma} \approx m_{3/2} e^{-i\gamma_W} \Bigg(1.4876 + 0.024 \Bigg[10.45 + 2\ln\left|\frac{C_{\alpha\beta\gamma}}{Y_{\alpha\beta\gamma}}\right| - 7\ln\left(\frac{14(P+3)}{N}\right)$$

$$-\sum_i \left(\left\{ \frac{1}{2}\ln\left(\frac{\Gamma(1-\theta_i^\alpha)}{\Gamma(\theta_i^\alpha)}\right) - \frac{1}{2\pi} l \psi_i^\alpha \sin\left(2\pi\theta_i^\alpha\right) \right\} + \alpha \to \beta + \alpha \to \gamma \right) \Bigg] \Bigg)$$

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

WHAT ABOUT μ ?

in superpotential

from Kahler potential. (Guidice-Masiero)

physical

$$\mu = \left(\frac{W^*}{|W|} e^{\hat{K}/2} \mu' + \overbrace{m_{3/2} Z - e^{\hat{K}/2} F^{\bar{m}} \partial_{\bar{m}} Z} \right) \left(\tilde{K}_{H_u} \tilde{K}_{H_d} \right)^{-1/2}$$

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

- μ´can vanish with a discrete symmetry (Witten ph/0201018)
- If the Higgs bilinear coefficient Z~1 then typically expect $\mu \sim M_{3/2}$
- Phase of μ interesting – can study it – sign affects spectrum since affects gaugino mass cancellations – no other direct test of sign – use $\mu < 0$ here

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

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 $26.24 \quad \alpha_{unif}^{-1} \quad 26.45$ in full two-loop analysis, for certain range of threshold corrections, $M_{unif}=1.8\text{x}10^{16}$ GeV!

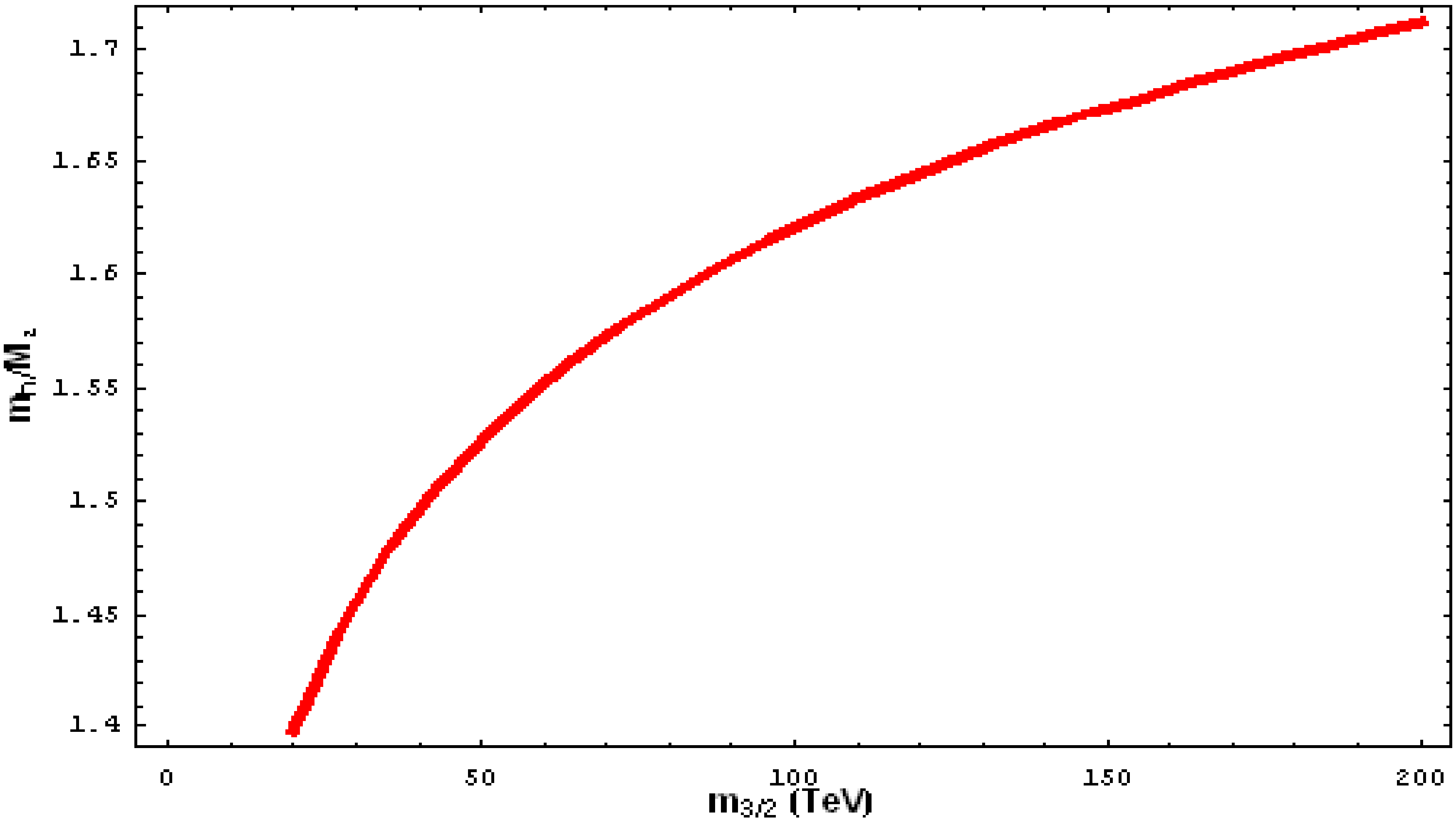
CP VIOLATION

- One common phase for all soft terms
- Don't know if that can be rotated away until understand μ and its phase – if μ real or has same phase as gaugino masses, then no "susy CP problem", no EDMs
- Phases of Yukawas not studied yet – depends on origin of small masses

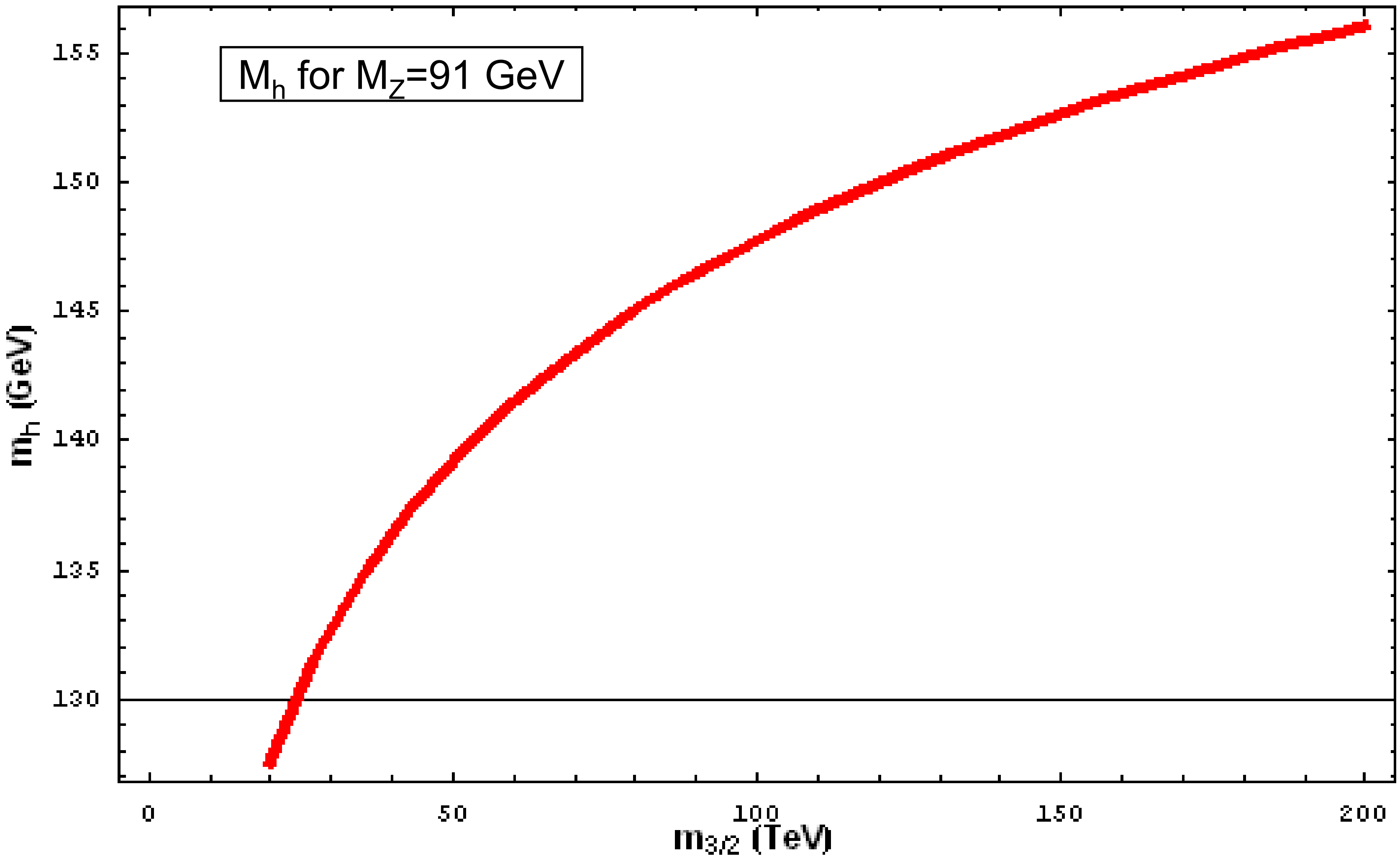
EW SYMMETRY BREAKING

- Can get EWSB, but have little hierarchy
- 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
- But NO approach has succeeded in getting small M_Z

[what mechanism can give small gauge boson masses ??]



1.7
1.65
1.6
1.55
1.5
1.45
1.4
0
50
100
150
200
m3/2 (TeV)



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

LHC 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

- Example – take $M_{3/2}$=70 TeV, μ<0, fixes everything

$$\tilde{g} = 642 \text{ GeV}$$ (physical mass)

$$\tilde{N}_2 = 384 \text{ GeV}$$

$$\tilde{C}_1 = \tilde{N}_1 = 268 \text{ GeV}$$ (tree level degenerate)

$$h^0 \simeq 135 \text{ GeV}$$

$$\sigma(pp \to \tilde{g}\tilde{g}X) \simeq 10 \text{ pb}$$

$$\sigma(pp \to \tilde{C}_1\tilde{C}_1 X) \simeq 0.1 \text{ pb}$$

All other superpartners in multi-TeV region

$\tilde{g} \longrightarrow t\bar{t}N_1 \quad \gtrsim 10^{-3}$ (kinematically sensitive to $m_{\tilde{g}}, m_{N_1}$)

$b\bar{b}N_1 \quad 18\%$

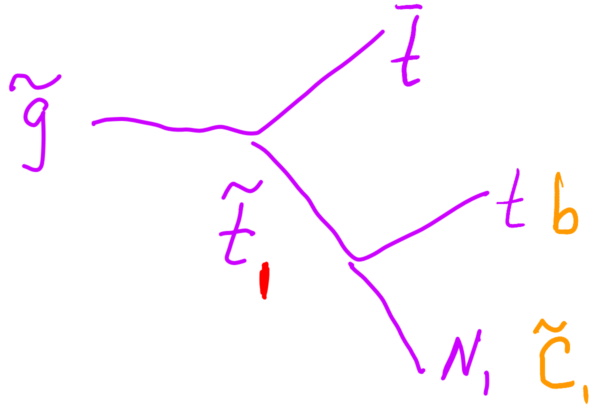
$q\bar{q}N_1 \quad 18\%$

$C_1^- t\bar{b} \quad 11\%$

$C_1^+ \bar{t}b \quad 11\%$

$C_1^\pm q\bar{q}' \quad 36\%$

$N_2 g \quad 4.4\%$ (one loop - note N_2)



$N_2 \rightsquigarrow C_1 q\bar{q}' \quad 2/3$ (via onshell $W^\pm$)

$C_1^\pm \ell^\mp \nu \quad 1/3$

$\tilde{t}_1 \to \tilde{g}t$

Total rates for 10 fb^{-1}:

Same sign tops

$tt + \bar{t}\bar{t} + \cancel{E}_T$ ~ 2000

Same sign charginos ~ 20,000

Same sign dileptons ~ 400

Trileptons ~ few

$4b\text{'s} + X + \cancel{E}_T$ ~ 9000

$4b\text{'s} + 2\ell^{\pm} + X + \cancel{E}_T$ ~ 450

[see e.g. for tops Spiropulu et al, CMS note 2006-102]

Generically other approaches that stabilize moduli (and more generally) occupy different regions of LHC signature space [GK, Kumar, Shao, ph/0610038] – for signals observable in ~ 10 fb^{-1} have

- IIB KKLT vacua → gluino ~ squarks (Choi et al, Baer, Park, Tata, T. Wang)
- IIB very large volume vacua → gluinos >> squarks (Abdussalam, Conlon, Quevedo, Suruliz)
- G_2 vacua → gluino << squarks (Acharya, Bobkov, Kane, Kumar, Shao)

e.g. large charge asymmetry at LHC in one and two lepton + jets + $\not{E}_T$ for large volume, some for KKLT, none for G_2

Lots of such types of ways to distinguish classes of string theories

DARK MATTER

LSP is wino – like anomaly mediation but for different reasons (cancellation here)

Can use Moroi-Randall analysis (ph/9906527) – they assumed 10-100 TeV $M_{3/2}$, similar moduli masses, heavy sfermions, etc

Argued actually generate about observed relic density from moduli and gravitino decays, cosmologically consistent

Expect (GK, Liantao Wang, T Wang ph/0202156) HEAT (+ AMS) – positron excess in atmosphere from

$$\text{wino} + \text{wino} \rightarrow W + W$$

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 – can all phases except CKM one be rotated away from both geometry and susy breaking?
- 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!

WHY ISN'T M_Z ~ TeV?

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

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International Organizing Committee

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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 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