String Phenomenology

on the Eve of the LHC

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String Theory and Particle Physics

- String Theory provides us with a unified framework for Gravitation and Particle Physics but
  - Can the SM be embedded into string theory?
  - Does string theory make physical predictions?
- Indeed, even before dealing with the details of the embedding of the SM, string theory provides us with three remarkable predictions.
  - Gravity exists.
  - Lightest matter fields transform as simple gauge group representations, with a few indices, mostly like (bi)fundamentals.
  - There is a large landscape of string vacuum solutions, some differing from others in a slight variation of discrete parameters
- It does of course make more specific predictions like Regge behaviour of amplitudes, string and KK excitations...

- Those may only be tested if the string scale is accesible to the LHC.
- If that is not the case we will have to be ingenious and look for methods to either
  - Obtain low-energy predictions from specific classes of compactifications which could be compared with low energy data.

  and/or

  - Use e.g LHC data to restrict as much as possible the string compactification possibilities
- Cosmology could also provide important information!.
- In any event we have to look for string constructions embedding the SM: Study the (MS)SM string landscape.

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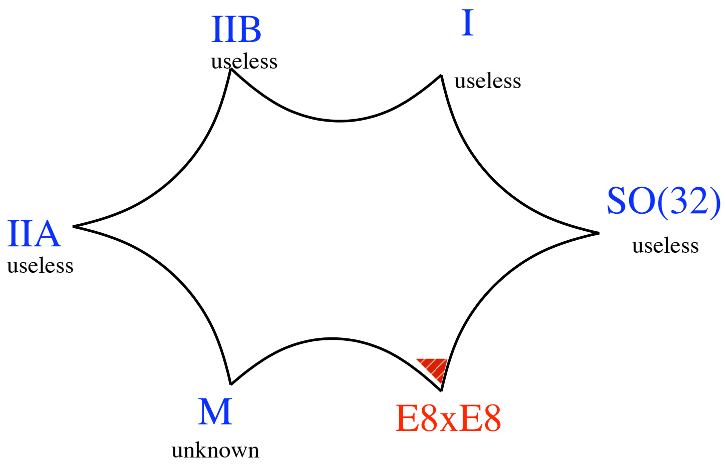
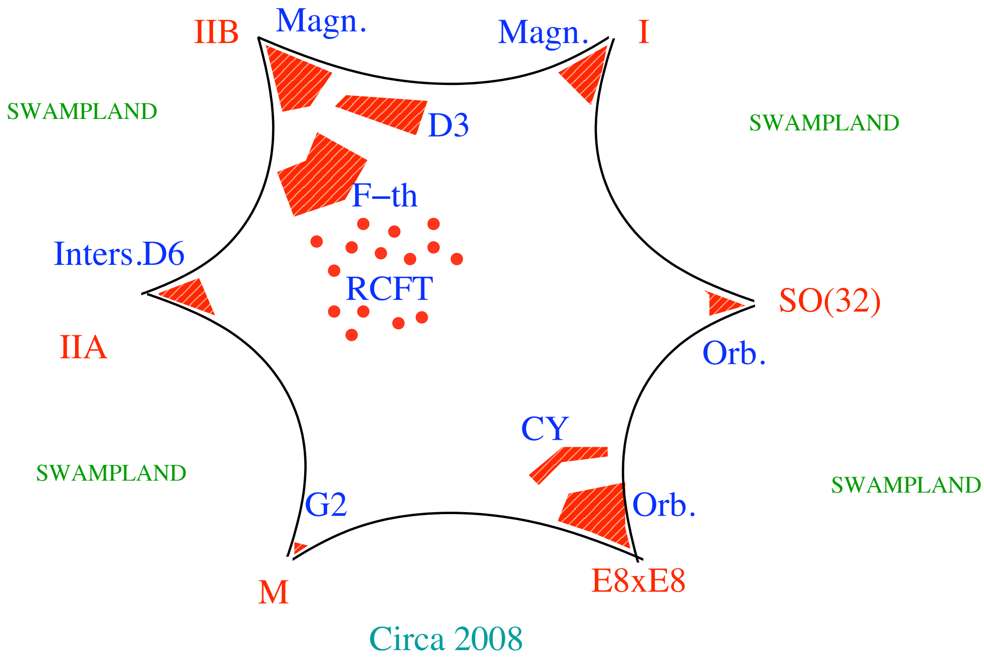
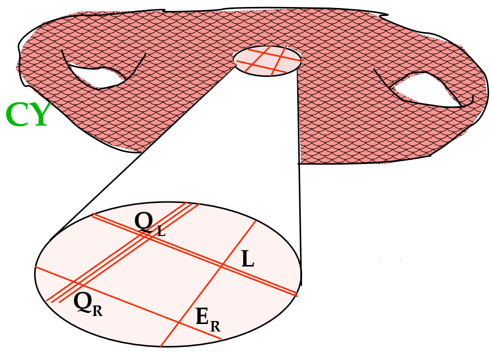


Circa 1995



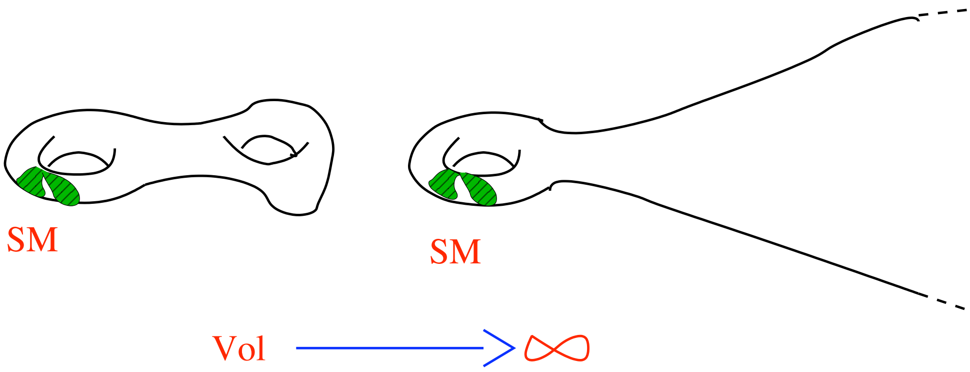
Local versus global models

- One important new possibility from branes : Gauge bosons and matter fields may live in $D < 10$.
- One may consider then two approaches:
  - Global models. One insists in having a complete compact CY compactification consistent at the global level (e.g. global RR tadpole cancellation).
  - Local models. One considers local configurations of lower dimensional Dp-branes, $p \leq 7$ which are localized on some area of the CY and reproduce SM physics. One does not then care about global aspects of the compactification and assume that eventually the configuration may be embedded inside a fully consistent global model.



- This bottom-up approach is not available in heterotic or Type I models since the SM fields live in the bulk 6 dimensions of the CY.
- In principle a globally consistent compactification is more satisfactory. On the other hand local configurations of Dp-branes may be more efficient in trying to identify promising string vacua, independent of details of the global theory.

- A stronger version of a local construction is requesting that the local SM/GUT physics decouples from the gravitational sector in the $Vol \to \infty$ limit.



- This is the case of $D3$ branes at singularities (Aldazabal et al. (00)) and some recent F-theory models. (Beasley et al. (08))

Brief tour of the MSSM landscape

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1-a) $E_8 \times E_8$ Heterotic Orbifold vacua

- One compactifies on an orbifold T^6/Z_N or $T^6/Z_N \times Z_M$. Best studied examples: $Z_3, Z_2 \times Z_2, Z_6 - II, Z_{12} - II$. (L.I.Nilles, Quevedo (87); Antoniadis et al.(87);Faraggi, Nanopoulos (93);Cleaver et al.(99); Much revived recently: Kobayashi et al.(04);Buchmuller et al.(06);Lebedev et al.(07); Kim (07). Gauge group has the structure

$$SU(3) \times SU(2)_L \times U(1)^n \times G_{hidden} \quad (1)$$

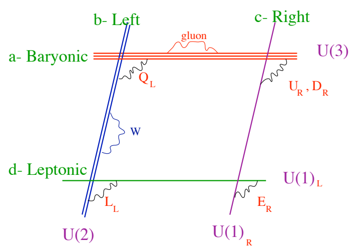
- Hypercharge generator is a linear combination of the $U(1)$'s chosen to get the $SU(5)$ normalization. However threshold corrections are large....
- In addition to the MSSM content there are a number of exotics and vector-like SM triplets, doublets and singlets which become massive by judiciously chosing appropriate flat directions in the (charged) singlets moduli space. Testing sufficient F- and D-flatness is a complicated business...

1-b) $E_8 \times E_8$ on eliptically fibered CY manifolds

- In these models one considers stable $SU(4)$ or $SU(5)$ bundles on eliptically fibered CY manifolds. They lead respectively to $SO(10)$ and $SU(5)$ GUT-like models. Symmetry is further broken to the SM by Wilson line backgrounds. This requires a non-trivial fundamental group.
- Not easy to find examples!! Two types of models studied in some detail:
  - $SU(4)$ instanton background, $Z_3 \times Z_3$ fund. group (Ovrut et al.(04)) Here the gauge group is $SM + U(1)_{B-L}$, has 3 families, 2 sets of Higgs multiplets and no exotics. There is an extra $U(1)_{B-L}$(Cannot be broken?).
  - $SU(5)$ instanton background, Z_2 fund. group. (Bouchard,Donagi (05)). Here one gets the SM group, 3 families, 0,1,2 Higgs multiplets, no exotics.
- In these models getting no extra matter fields beyond MSSM is simpler.

2) IIA Intersecting D6 models in orbifold orientifolds

- Here MSSM matter arises at the intersection of $D6$-branes



- The examples best studied based on $Z_2 \times Z_2$ (Cremades et al;(03); Cvetic,Shiu,Uranga (01);Marchesano,Shiu (04)) Z_6 (Honecker,Ott (05)) and Z_6' (Bailin,Love (06);Gmeiner,Honecker (07)).
- Problem: generic presence of massless SM adjoints. They are absent in models with D6-branes wrapping rigid cycles.....
- Mirrors of these models may be obtained in terms of IIB orientifolds with magnetized $D9$,$D7$,$D5$ (Bachas (95);Antoniadis et al.(00);Cascales,Uranga (03)).

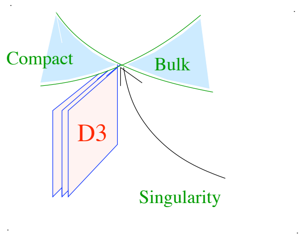
3-a) IIB RCFT orientifolds

- A large class of Type IIB Rational Conformal Field Theory (RCFT) orientifold models, of order 210000 with MSSM-like spectra were constructed in 2004-2006 by Schellekens and colaborators.
- These are non-geometrical compactifications in which the CY geometry is replaced by RCFT Gepner models with total central charge $c = 9$.
- They have just the spectrum of the MSSM and vectorlike matter.
- No exotics. Some have gauge coupling unification (but extra vector-like matter).
- Limitation: correspond to particular points in CY space. Do not know yet how to extract the effective action, feasible in principle.
- But one of the richest sets of MSSM-like solutions in the literature!

Local MSSM-like constructions

3-b) IIB D3-branes at singularities

- Simplest example of 'bottom-up approach' (Aldazabal et al. 2000)). Here chirality is obtained by locating stacks of $D3$ branes on top of local singularities in the CY.



- Simplest MSSM-like examples : L-R model from a Z_3 singularity. It has natural gauge coupling unification at an intermediate scale $M_s \simeq 10^{11}$ GeV. Requires D7-branes.

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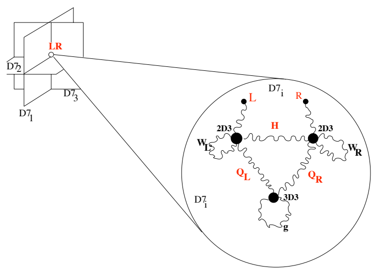
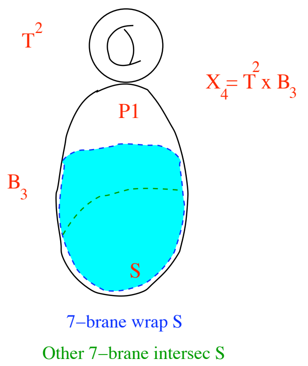


- Other MSSM-like examples may be obtained from other singularities like Δ_{27}, dP_8(Berenstein et al (01);Verlinde,Wijnholt (05)). (No D7-branes involved).
- An alternative to the desert: the MSSM at the IR limit of a duality cascade. (H. Verlinde et al.)

3-c) GUT's in local F-theory

- One considers compactifications of a 12-dimensional F-theory on a CY complex 4-fold X_4 down to $D = 4$. The CY 4-fold must be elliptically fibered over a complex 3-dimensional CY B_3, meaning that locally one can write

$$X_4 \simeq T^2 \times B_3 \simeq K3 \times S \quad (2)$$



- The gauge group in F-theoretical 7-branes goes beyond what one can get in perturbative Type IIB orientifold $D7$-branes:both exceptional groups and spinorial reps. may be obtained.
- Recently Beasley, Heckmann and Vafa; Donagi,Wijnholt have constructed LOCAL F-theory models with a $SU(5)$ or $SO(10)$ GUT gauge group. Insisting on the decoupling of GUT from gravity fixes $S = dP_n$, and no heterotic dual exists.
- Breaking of GUT symmetry down to MSSM by magnetic flux through hypercharge direction. Not available in heterotic case.
- Beasley et al. obtain 3 gen. MSSM-like models with no exotics. They are local brane models which are consistent with gauge coupling unification.
- Back to (almost) uniqueness? Insisting in decoupling leads to a quite constrained corner with $S = dP_8$.... (see talk by C. Vafa).

The String MSSM Landscape c. 2008

$Vacua$	Pert/Curv	Exot.	unif.	R_p	Yuk.	Mod.Fix.	Number
Het.Orb.	P/NC	$\surd$	$\sim\surd$	$\sim\surd$	x	x	$\simeq 10^7$
Het.CY	P/C	$\surd$	$\sim\surd$	$\sim\surd$	x	x	$\sim 10^1$
IIA Inters. D6	P/NC	$\surd$	x	$(B-L)$	x	flux	$\simeq 10^6$
IIB Magn. Dp	P/NC	$\surd$	x	$(B-L)$	x	flux	$\simeq 10^6$
IIB RCFT	P/C	$\surd$	x	$\sim\surd$	x	x	$\simeq 10^5$
IIB D3 at sing.*	P/C	$\surd$	$\sim\surd$	$B-L$	x	flux	$\simeq 10^1$
F-th GUT's*	NP/C	$\surd$	$\sim\surd$	$\surd$	x	flux	$\simeq 10^1$
Total:					0		$\simeq 10^7$

*local models

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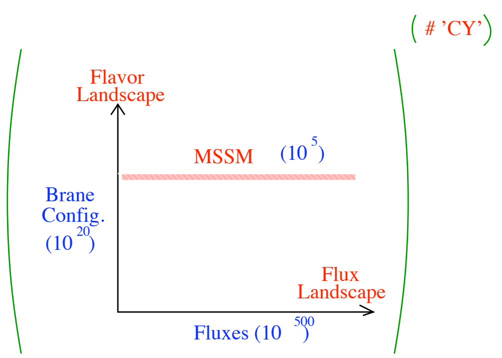
Some landscape statistics

- Statistic analysis done in some examples: RCFT(Schellekens et al.(05-07); $Z_2 \times Z_2$, Z_6,Z_6' orientifolds (Gmeiner,Lust,Honecker(05);Douglas,Taylor (06); Gmeiner,Honecker(08)); Heterotic Z_6'(Lebedev et al. (06);Dienes (07)).
- $10^{20}, 10^{10}, 10^{28}, 10^{23}, 10^7$, models respectively (Cannot be directly compared!). Naive structure (i.e. for RCFT models based on 168 Gepner models):



- However one expects correlations (e.g. RR-tadpoles, Freed Witten anomalies..)
- 3 generation MSSM not particularly likely!

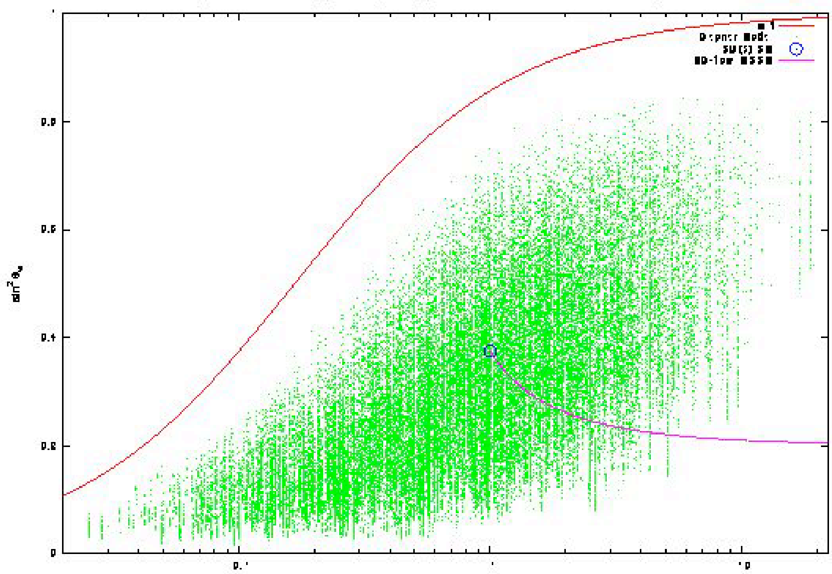
Some generic properties

- Extra vector-like or adjoint exotics beyond MSSM. They are probably an artifact of working with models in particularly simple points of moduli space (Toroidal orbifolds, RCFT's).
- Is low energy SUSY generic?
  - There is an interesting recent analysis with RCFT orientifolds [a]:
  - Out of 3×10^6 tachyon-free, NS-tadpole free SM configurations 98% had SUSY in the bulk.
  - Only 896 had no RR-tadpoles : They all had $N = 1$ SUSY spectra!!
  - 'Supersymmetry is very persistent'. Perhaps $N = 1$ SUSY is the simplest way for SM vacua to be consistent and stable?
- Gauge coupling unification not generic in orientifolds.

[a] Gato-Rivera,Schellekens (08)

Gauge Coupling Unification Landscape in RCFT Orientifolds

Figure 6: Gauge coupling constants at the string scale



- Some problems to address:
  - Proceed with the exploration of the MSSM landscape.
  - Improve our understanding of the $D = 4$ effective action, both for flat backgrounds and CY compactifications.
  - Try to construct semirealistic models with fixed moduli.
  - Study possible sources of SUSY-breaking in the MSSM landscape.
- Some recent progress:
  - Stringy instanton contributions to charged superpotentials.
  - Moduli fixing in certain CY manifolds.
  - Computation of MSSM SUSY-breaking soft terms in terms of the effective $N = 1$ sugra action.
  - SUSY breaking and gauge mediation in string theory settings.

Stringy instantons and non-perturbative superpotentials

- Perturbative contributions to the Yukawa couplings may be not sufficient in order to get agreement with experiment.
- In string models often phenomenologically desired couplings are perturbatively forbidden by $U(1)$ symmetries. That includes:
  - Certain Yukawa couplings (e.g. U-quark Yukawas in $SU(5)$ models from Type II orientifolds).
  - Neutrino Majorana masses
  - μ-term

Broken U(1) global symmetries

- In Type II orientifolds some $U(1)$'s (anomalous or not) can get a mass combining with some RR fields. The corresponding $U(1)_X$ symmetry remains perturbatively to all orders as an effective global symmetry. That is the case e.g. baryon number and lepton number in MSSM-like models.

- It has been recently realized however that non-perturbative stringy instanton effects [a] may give rise to superpotential operators

$$\frac{1}{M_s^{n-3}} e^{-M} \Phi_{q_1} ... \Phi_{q_n} \neq 0 \ ; \ \sum_i q_i \neq 0 \qquad (3)$$

with M a IIA complex structure (IIB Kahler modulus) field whose imaginary

[a] Becker^2,Strominger (95);Witten (96,99);Harvey,Moore (99)

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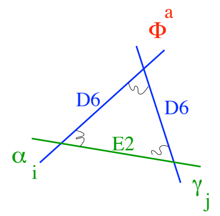
part shifts under a $U(1)_X$ gauge transformation of parameter Λ_x like

$$M \longrightarrow M + i\Lambda_x \left(\sum_i^n q_i\right) \qquad (4)$$

- so that the the operator is fully gauge invariant. These non-perturbative amplitudes are generated by certain string instanton effects with additional fermionic zero modes charged under the $U(1)$'s (Ganor (96);Florea et al;L.I.,A.Uranga;Blumenhagen et al (06))



$$L_{E2} \sim d_a^{ij} \ \alpha_i \Phi^a \gamma_j$$

$$\int d\theta^2 d^n\alpha \, d^n\gamma \, e^{-S_{E2}} \, e^{-d_a^{ij} \, (\alpha_i \Phi^a \gamma_j)} \simeq \int d\theta^2 \, e^{-M_{E2}} \, \Phi^n \qquad (5)$$

Some phenomenological applications

- 1) Majorana ν_R neutrino masses. They are forbidden $U(1)_{L,R}$ gauge symmetries. Instantons can generate (L.I., Uranga; R. Blumenhagen, M. Cvetic, T. Weigand (06).)

$$e^{-S_{E2}}\ \nu_R \nu_R \tag{6}$$

- The ν_R Majorana masses may easily be a few orders of mag. below M_s

$$M_{\nu_R}\ \simeq\ M_s\, d^2\, \exp(-\frac{V_{\Pi_M}}{g_s}) \tag{7}$$

- 2) The μ-term in the MSSM . Often forbidden by PQ-like gauged $U(1)$ symmetries:

$$e^{-S_{Ins}}\ H\overline{H} \tag{8}$$

- 3) Yukawa couplings which may be forbidden perturbatively (Blumenhagen et al (07);L.I.,Uranga (07)). E.g. U-quark $10 \times 10 \times 5$ couplings in $U(5)$ GUT-like models.
- 4) Superpotential couplings involving hidden sector fields, possibly usefull in fixing moduli and/or breaking SUSY (Florea et al.; Akerblom et al.(06); Buican,Franco(08)).

Some recent string instanton work

:

- Neutral zero mode structure of these stringy instantons (Argurio et al.;Bianchi et al.;L.I.Schellekens,Uranga; Petersson (07)).
- Multinstanton effects by which $U(1)$ instantons may contribute to the superpotential (Garcia-Etxebarria,Uranga,Marchesano (07); Blumenhagen,Schmidt-Sommerfeld).
- Analogous $E3, E-1$ instanton effects are present in IIB settings with $D3$-branes at singularities (Florea et al.; R. Argurio et al.;Bianchi,Kiritsis (07); Aharony et al.;L.I., Uranga;Forcella et al.; Billo et al.(08)).
- New instanton-induced couplings appear also in the presence of closed string fluxes (both for the superpotential and Kahler potential) (Billo et al. (08)).
- The holomorphicity of the non-perturbative superpotential (Akerblom et al.(07);Blumenhagen, Schmidt-Sommerfeld (08)) as well as the heterotic-Type I S-duality matching of instanton corrections to gauge kinetic functions (Camara,Dudas (08)) have been studied..

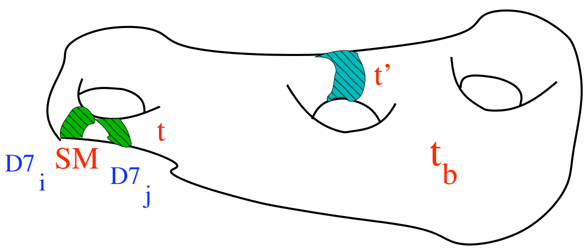
Moduli fixing: IIB

'Flux revolution':(Bousso,Polchinski (00);GKP (01);KKLT (03)).

- First attempts: IIB orientifolds/F-theory: KKLT
  - Flux induced superpotential fixes complex structure moduli and dilaton. Constant superpotential term W_0 very small
  - Non-perturbative instanton effects fix the Kahler moduli. AdS SUSY vacuum.
  - Anti-D3-branes trapped on a throat allow to up-lift to a SUSY-breaking dS vacuum.
- Explicit models (no SM) realizing the first two steps exist (Denef et al. (05)). However control over α' corrections not great (see e.g. Denef (07)).
- SM is supossed to reside at D7 or/and D3 branes. Interesting options for MSSM embedding would be F-theory and D3-branes at singularities.

The Large Volume Models

- This is an interesting alternative/variant proposed by Balasubramanian, Berglund, Conlon and Quevedo. Good control over α' corrections.
  - Models with a large volume modulus T_b and a number of small (blowing up) moduli T_i. (Complex structure and dilaton fixed by fluxes).



  - simplest CY example ($\mathbf{P}^4_{[1,1,1,6,9]}$):

$$K = -2log((t_b^{3/2} - t^{3/2}) + \frac{\xi}{2g_s^{3/2}} \quad (9)$$

– ξ from α' correction(Becker[2],Haack,Louis (02)).
– Combined with non-perturbative superpotential $W = W_0 + ce^{-aT}$ give rise to minima at

$$Vol \simeq t_b^{3/2} \simeq e^{at} \gg 1 \ ; \ t \simeq \frac{\xi^{2/3}}{g_s} \qquad (a \simeq 2\pi/g_s N) \qquad (10)$$

– Exponentially large volume $t_b^{3/2}$.
– Depending on $g_s N$ the string scale may be GUT, Intermediate or TeV scale. $W_0 \simeq 1 - 10$. and no fine-tuning of W_0 in intermediate scale case.

- In general LVS as long as $h_{12} > h_{11} > 1$ and one blowing-up mode. Further examples have also been studied. (Cicoli,Conlon,Quevedo; Blumenhagen, Moster,Plauschinn (08)). Stabilization of extra Kahler moduli beyond T_b, T_s requires string one-loop corrections.

Moduli fixing: IIA

- The structure of RR and NS fluxes richer. Turning them on one obtains perturbative superpotentials depending on BOTH Kahler and CS moduli.
- One can construct explicit AdS simple string vacua with all moduli stabilized at the perturbative level in a controlable regime. (De Wolfe et al.;Camara et al. (05); see Acharya et al.(07) from M-th inspired settings).
- T-duality suggests the existence of further geometric (Kaloper,Myers (99);Derendinger et al.;Villadoro,Zwirner; Camara et al. (05)) and non-geometric fluxes (Shelton, Taylor, Wecht (05); Aldazabal et al..(06)) which could be turned on. Including those one finds SUSY Minkowski vacua with all moduli perturbatively stabilized (Micu, Palti,Tasinato (08)).
- Validity of supergravity approximation not obvious with non-geometric fluxes.... Still posibly the largest fraction of the string flux landscape could be non-geometric....

String Phenomenology and LHC

Low or High string scale?

- Most popular possibilities:
  - String scale is $\simeq$ 1 TeV:
    - Effects on SM amplitudes from the exchange of Regge resonances or KK states (Accomando et al. (99), Cullen et al (00), Anchordoqui et al., Lust et al (08)
    - Production of extra Z' bosons from anomalous $U(1)$'s (Ghilencea et al.(02);Feldman et al (06);Coriano et al. (06); Anastasopoulos et al. (08)).
    - Black holes...
  - String scale is large (e.g. $M_s = M_{GUT}$) and SUSY is found at LHC
    - Obtain predictions for SUSY-breaking soft terms
- A 1 TeV string scale sounds unlikely to many of us...
- We should make an effort to obtain predictions for SUSY breaking soft terms!

Varieties of SUSY breaking

- Two natural sources of spontaneous SUSY-breaking in string models:
  - Closed string fluxes
  - Dynamical SUSY breaking in a gauge sector
- Some options for SUSY-breaking mediation
  - Gravity mediation. It is a natural option since the Kahler T_i and C.S. moduli U_m are natural candidates as mediators.
  - Gauge mediation String models with a gauge-mediating sector have been obtained (Diaconescu et al (05);Garcia-Etxevarria,Uranga (06)). They asume that the closed string moduli are frozen. So SUSY-breaking decoupled from the moduli fixing problem...
  - Anomaly mediation. Requires 'sequestering'. This may appear naturally in models with large warpping (Kachru, McAllister, Sundrum (07)).

SB Mediation	Origin	Virtues	Problems	String Impl.
Gravity	Moduli, fluxes	Generic	FCNC?	Fluxes, Mod. fixing
Gauge	Dynamical	FCNC ok	μ, B param.	Mediators ($5+5^*$), Asume mod.fix.
Anomaly	Any	FCNC ok, generic	subleading, $\tilde{m}_l^2 < 0$	Strong warpping
Mirage[a]	mod.+anom.	FCNC ok	non-generic	one modulus KKLT?

[a] Choi et al.(05).

- Gauge and Anomaly mediation quite independent of ultraviolet physics.
- Moduli SUSY breaking does depend on UV physics. LHC may give us information about the underlying string compactification. (See e.g.Kane et al.(07)).

Modulus dominated SUSY breaking in IIB

- One can compute the soft terms under the asumption of Kahler modulus dominance, $F_{T_i} \neq 0$ (Brignole et al.(94)). This is an interesting possibility in Type IIB because:
  - In IIB orientifolds that corresponds to asuming the presence of non-vanishing RR and NS ISD $(0,3)$ fluxes which are known to solve the classical equations of motion (Giddings, Kachru, Polchinski (01)).
  - If the MSSM resides on D7-branes all scalars and gauginos get soft terms at tree level.
  - Soft terms may be aproximately flavour blind so that dangerous FCNC may be supressed.
- We will be asuming that the moduli are all stabilized with $M_s = M_{GUT}$.

- MSSM SUSY-breaking soft terms:

$$L_{soft} = \frac{1}{2}\sum_a M_a \lambda_a\lambda_a + h.c. - m_{H_d}^2|H_d|^2 - m_{H_u}^2|H_u|^2 \quad (11)$$

$$- \sum_i m_{\tilde{\Phi}_{ij}}^2 \tilde{\Phi}_i\tilde{\Phi}_j^* - A_{ij}^{U,D,L}\tilde{\Phi}_i\tilde{\Phi}_j H_{u,d} - B\, H_d H_u + h.c. \quad (12)$$

- To compute the soft terms is then important to know the gauge kinetic functions f_a and also the Kahler metrics of the matter fields $K_{ij}\Phi_i\Phi_j^*$.
- The moduli dependence of these metrics have been computed for simple cases either by dimensional reduction or explicit string correlators [a].
- Qualitatively one has the structure (ξ='modular weight') :

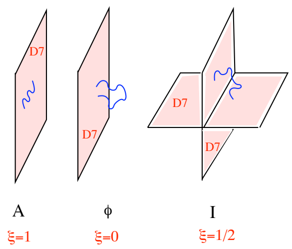
[a] L.I., C. Muñoz, S. Rigolin (98);Kors et al. Lust et al.(04);Bertolini et al.(05);Billo et al.(07)

Compactification	f_a	K_{ij}	W_{ijk}
Heterotic	S+..	$\frac{1}{(T+T^*)^n}$	$W_{ijk}(T)$
IIB Orientifolds:$D3$	S+..	$\frac{1}{(T+T^*)}$	W_{ijk}
IIB Orientifolds:$D7$	T+..	$\frac{1}{(T+T^*)^\xi}$, $\xi = 0, 1, 1/2$	$W_{ijk}(U)$
IIB LVC[a] :$D7$	T_s+..	$\frac{(T_s+T_s^*)/(T_b+T_b^*)}{(T_s+T_s^*)^\xi}$, $\xi = 0, 1, 1/2$	$W_{ijk}(U)$

- If Khaler moduli T dominates gaugino masses are only obtained to leading order if MSSM at D7-branes. We asume this is the case.
- We will compute soft terms triggered by a local modulus $F_{T_s} \neq 0$ corresponding to the 4-cycles the MSSM 7-branes wrap. This is in the spirit of the LVS and F-theory scenarios.

[a] Conlon,Cremades,Quevedo (06).

- We have three type of 7-brane matter fields A, ϕ, I corresponding to modular weights 1,0,1/2 respectively.



- Within the philosophy of gauge coupling unification (which may require going to the F-theory case)one can assume unified modular weights:

$$\xi_f^i \;=\; \xi_Q^i = \xi_U^i = \xi_D^i = \xi_L^i = \xi_E^i \,. \tag{13}$$

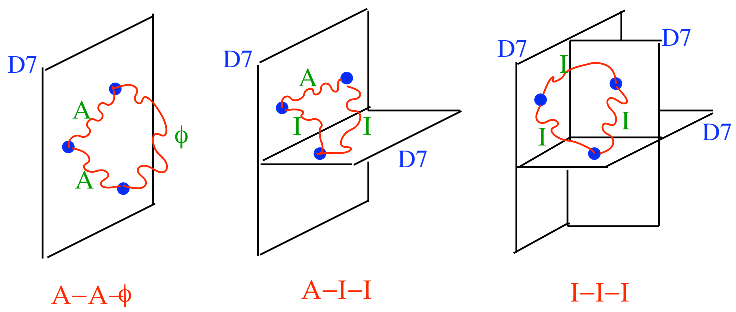
- On the other hand the Higgs fields could have different modular weight than fermion fields. So we will take $\xi_H = \xi_{H_u} = \xi_{H_d} = 0, 1, 1/2$.

Moduli dominance and flavor universality

- Supression of FCNC:Scalar masses should be essentially flavour blind. This is easily the case in modulus mediation because:
  - Flavour structure in superpotential Yukawa couplings depends only on the Complex Structure fields U, NOT on the moduli
  - Quarks and leptons may easily have all same modular weights $\xi_f^i = \xi_f$.
  - Additional flavour dependence from magnetic fluxes (required for chirality) is supressed in α'.
- Note mixed Kahler-Complex Structure dominance would be disfavored.
- This structure was recently named "mirror mediation"[a].

[a] Conlon (07)

- Additional constraint on possible modular weights of MSSM particles: There should exist at least one trilinear Yukawa, that of the top quark. It turns out there are only three types of Yukawa couplings



- The same types of Yukawa couplings exist in F-theory compactifications.
- For each of these three configurations the results for soft terms may be computed from general $N = 1$ supergravity formulae [a]:

[a] Aparicio,L.I.,Cerdeño (08)

(ξ_L, ξ_R, ξ_H)	Coupling	M	m_L^2	m_R^2	m_H^2	A	B
$(1, 1, 0)$	(A-A-ϕ)	M	0	0	$\|M\|^2$	$-M$	$-2M$
$(1/2, 1/2, 1)$	(I-I-A)	M	$\frac{\|M\|^2}{2}$	$\frac{\|M\|^2}{2}$	0	$-M$	0
$(1/2, 1/2, 1/2)$	(I-I-I)	M	$\frac{\|M\|^2}{2}$	$\frac{\|M\|^2}{2}$	$\frac{\|M\|^2}{2}$	-3/2M	$-M$

- One can take the above values for soft terms as boundary conditions at the GUT/String scale.
- The scheme is very predictive, there are only two free parameters M, μ . Once one imposses REW symmetry breaking one has just one free parameter M which sets the scale.
- One can solve (numerically) the renormalization group equations from the String to the Weak scale and compute the low energy SUSY spectrum and Higgs potential. (use SPheno2.2.3 and micrOMEGAs).

- A number of non-trivial experimental constraints should be obeyed:
  - LEP limits on SUSY particles and lightest Higgs boson.
  - $2.85 \times 10^{-4} \leq \text{BR}(b \to s\gamma) \leq 4.25 \times 10^{-4}$ (Heavy Flavour Averaging Group).
  - BR$(B_s^0 \to \mu^+\mu^-) < 5.8 \times 10^{-8}$ at 95% c.l. (CDF)
  - Anomalous magnetic moment of the muon, $11.6 \times 10^{-10} \leq a_\mu^{\text{SUSY}} \leq 43.6 \times 10^{-10}$.
  - WMAP limits on cold dark matter (applied to neutralino LSP), $0.1037 \leq \Omega h^2 \leq 0.1161$.
- It turns out that scheme with MSSM in bulk 7-branes $(A - A - \phi)$ not compatible with these and REW breaking.

SUSY spectrum for MSSM at intersecting 7-branes (I-I-I)

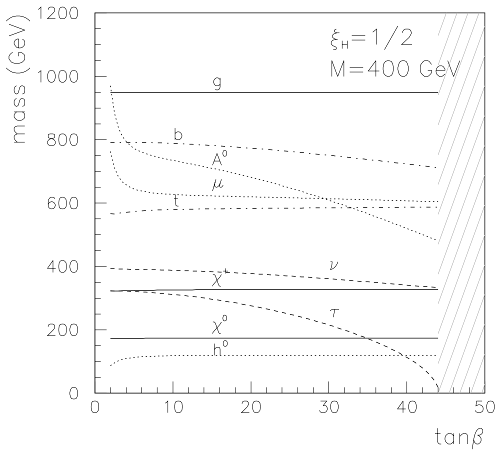


Figure 1: Low-energy supersymmetric spectrum as a function of $\tan\beta$ for $\xi_H = 1/2$, with $M = 400$ GeV and $\mu < 0$. The ruled area for large $\tan\beta$ is excluded by the occurrence of tachyons in the slepton sector. (Aparicio,L.I.,Cerdeño (08))

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Consistency with REW for MSSM at intersecting 7-branes

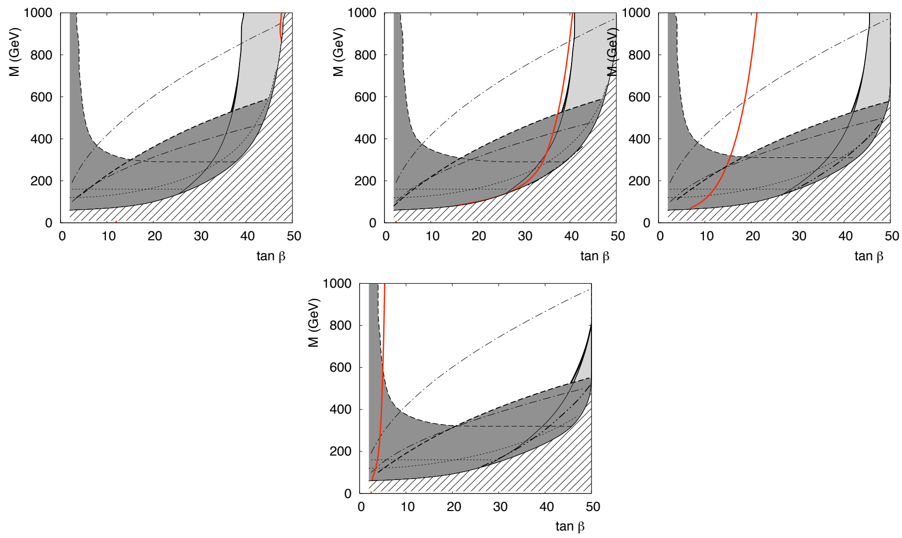

Figure 2: Effect of experimental constraints on the $(M, \tan\beta)$ plane for $\xi_H = 0.5, 0.6, 0.8,$ and 1 , from left to right and top to bottom. Also shown is CONSISTENCY WITH REWB .

- In order to get neutralino dark matter in agreement with WMAP results one should be in the coannihilation region with $m_{\chi^0} \simeq m_{\tilde{\tau}}$. In order to achieve correct EW symmetry breaking in this coannihilation region one needs $\xi_H \simeq 0.6$.
- This in very close to the configuration with all particles residing at intersecting 7-branes. The small deviations may be atributed to subleading corrections (e.g. magnetic fluxes).

LHC reach for modulus dominated SUSY B:

- Making use of the missing energy signal for squarks and gluinos one finds LHC will be able to start testing the intersecting 7-brane scheme for

Int. Lumin.	M	$m_{\tilde{q}}$	$m_{\tilde{g}}$	$m_{\chi^0} \simeq m_{\tilde{\tau}}$
1 fb^{-1}	≤ 650	≤ 1.3	≤ 1.5	≤ 300
10 fb^{-1}	≤ 900	≤ 1.8	≤ 2.0	≤ 400

- This is an example of how finding SUSY at LHC could give us important information about an underlying string vacuum.

Will LHC give us information about String Theory?

Some options

- Hyperoptimistic: String Theory at a TeV: string, KK excitations, Z's, warpping,... Explict tests of ST.
- Optimistic/Realistic: SUSY is found at LHC! Measurement of Sparticle masses will constrain the SM landscape. That may lead to additional predictions.
- Pesimistic: Only the Higgs field found. Would make an anthropic explanation for the EW hierarchy much more likely. We will have to come to grips with the question of what SM parameters are anthropic and which ones are not and how that may be realized in string theory.
- The unexpected.

The MSSM landscape circa 20xx