String Phenomenology

on the Eve of the LHC

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Strings and Particle Physics

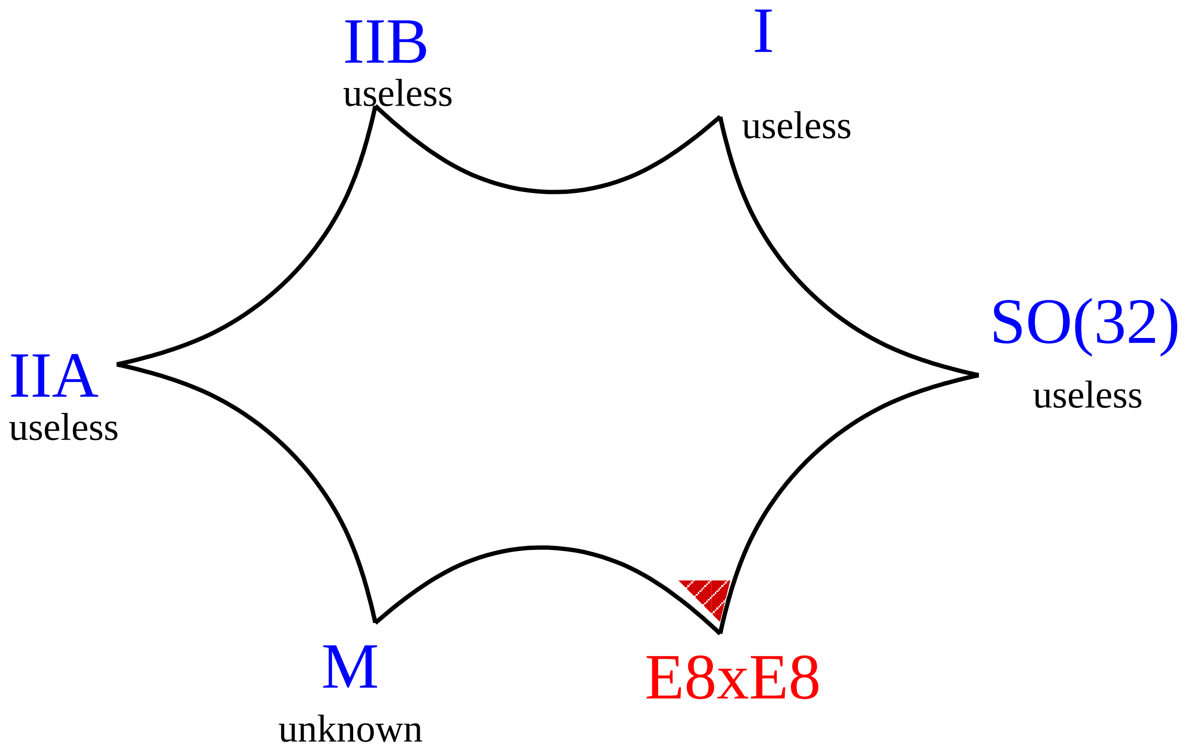
- The String Model-Building Program aims at a general study of possible compactifications/constructions giving rise to a low-energy theory resembling as much as possible the SM (or the MSSM) .

- Hope:
  - If completely realistic models are found, this would provide a proof that string theory may be a unified theory of all particles and interactions
  - In our way we may identify general patterns (e.g. symmetries, extra particle content etc.) which could be present in large classes of realistic vacua.
  - Get new ideas in adressing old problems like e.g. fermion masses an mixings, dark matter/energy,...
  - Obtain, if possible, predictions which could be tested experimentally (e.g. SUSY-breaking MSSM soft terms, dark matter,..)

- It is conceivable that only very few classes (if any) of compactifications will be able to fit all experimental data. If that were the case, it would be also likely that other new testable predictions could be derived from these.
- This may be a formidable task but we believe we now have a much more accurate view of the Flavor Landscape of semirealistic compactifications.
- In addition there is now an extra motivation: With the advent of LHC we have to explore whether experimental information can provide tests of string vacua!.
- We have to try and check what information on possible string compactifications may be extracted from LHC data.

Summary

- Overview of the MSSM String Landscape
  - Local versus global compactifications
  - A brief tour of the MSSM string landscape
- F-theory Grand Unification
- String phenomenology and the LHC
  - Varieties of SUSY breaking
  - Modulus dominated SUSY-breaking in IIB/F-theory models
  - SUSY spectra at LHC in IIB/F-theory models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useless
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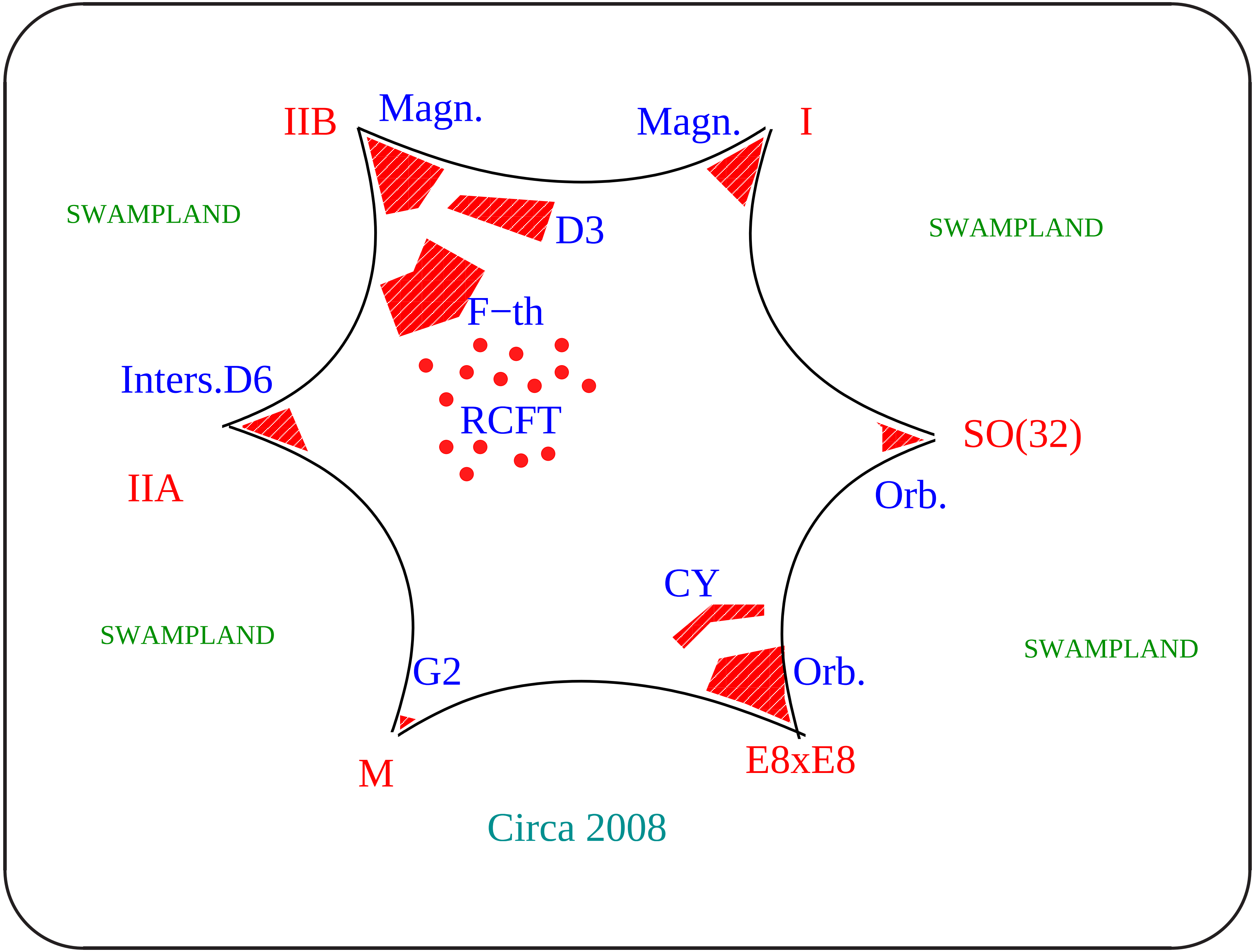
useless
IIA
useless
M
unknown
E8xE8

Circa 1995


IIB
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RCFT
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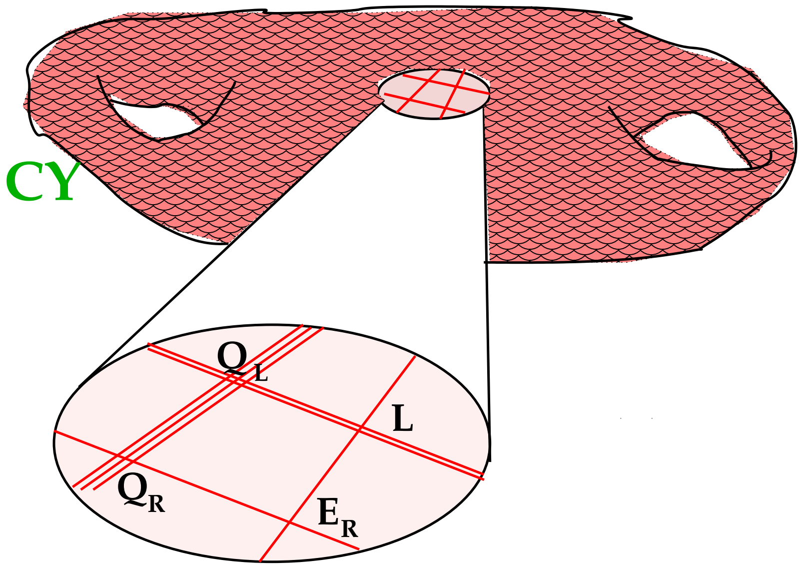
IIA
Orb.
CY
SWAMPLAND
G2
Orb.
SWAMPLAND
M
E8xE8
Circa 2008

Local versus global string 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 Calabi-Yau (CY) compactification consistent at the global level (e.g. global RR tadpole cancellation in Type II theories).
  - 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 [a] 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.

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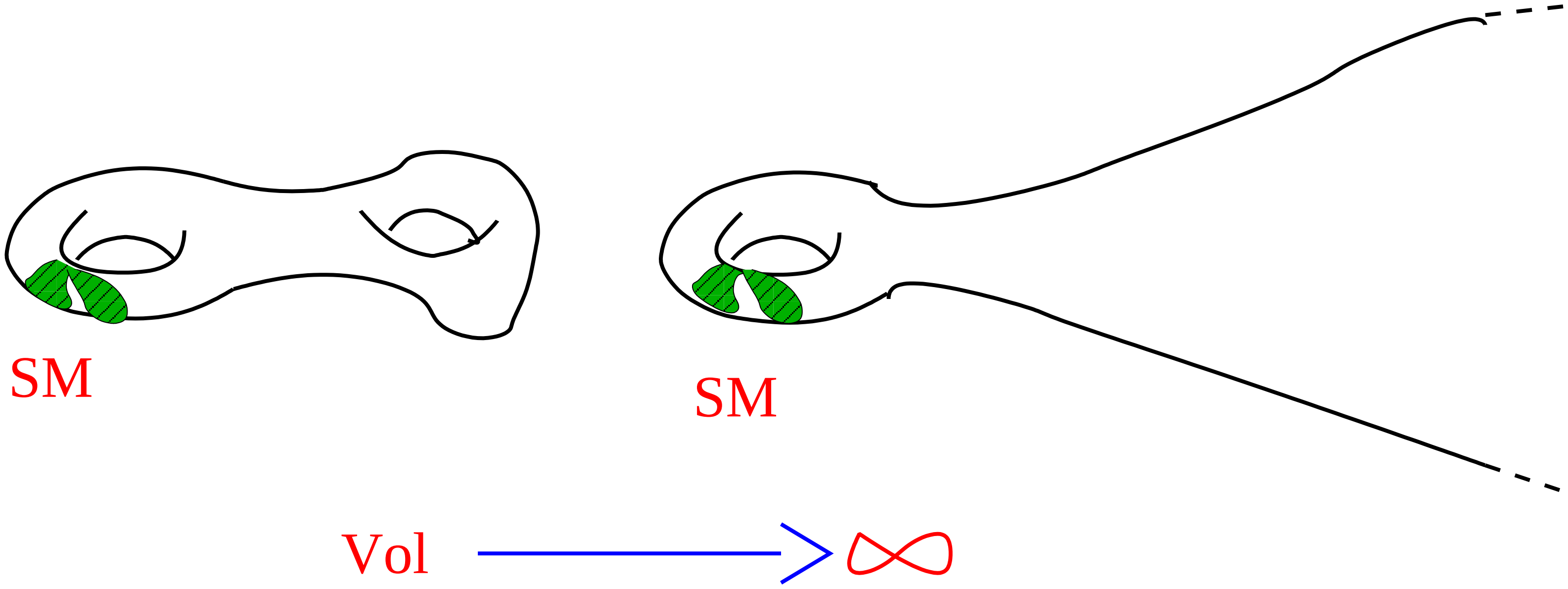
[a] Aldazabal,L.I.,Quevedo,Uranga (2000)

- 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.



- In this case we can neatly separate the SM sector from gravitational physics.
- This is the case of $D3$ branes at singularities (Aldazabal et al. (00)) and some recent F-theory models. (Beasley,Heckman,Vafa (08))

Brief tour of the MSSM landscape

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

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

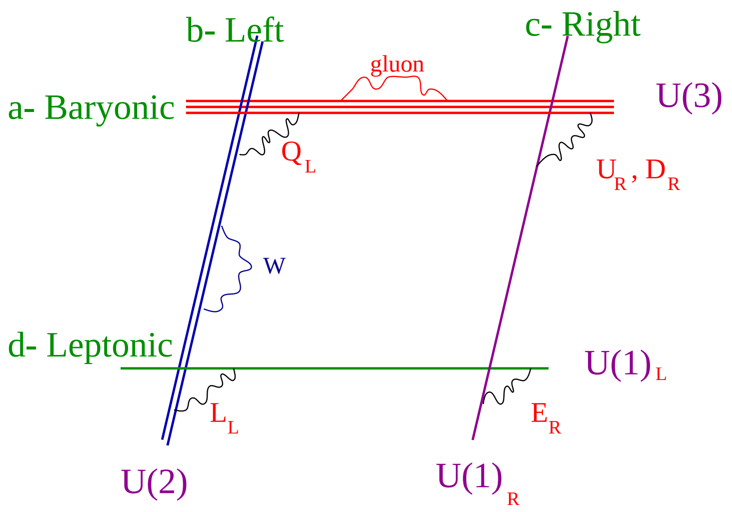
- Hypercharge generator is a linear combination of the $U(1)$'s chosen to get the $SU(5)$ normalization. However threshold corrections are large....
- In addition to the MSSM content there are a number of exotics and vector-like SM triplets, doublets and singlets which become massive by judiciously chosing 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 a CY with 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)).

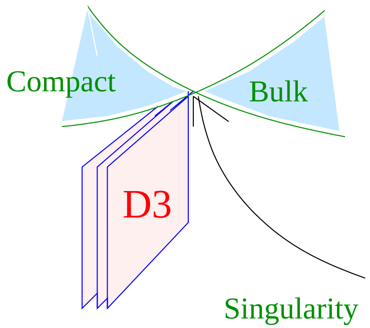
3-a) IIB RCFT orientifolds

- 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!

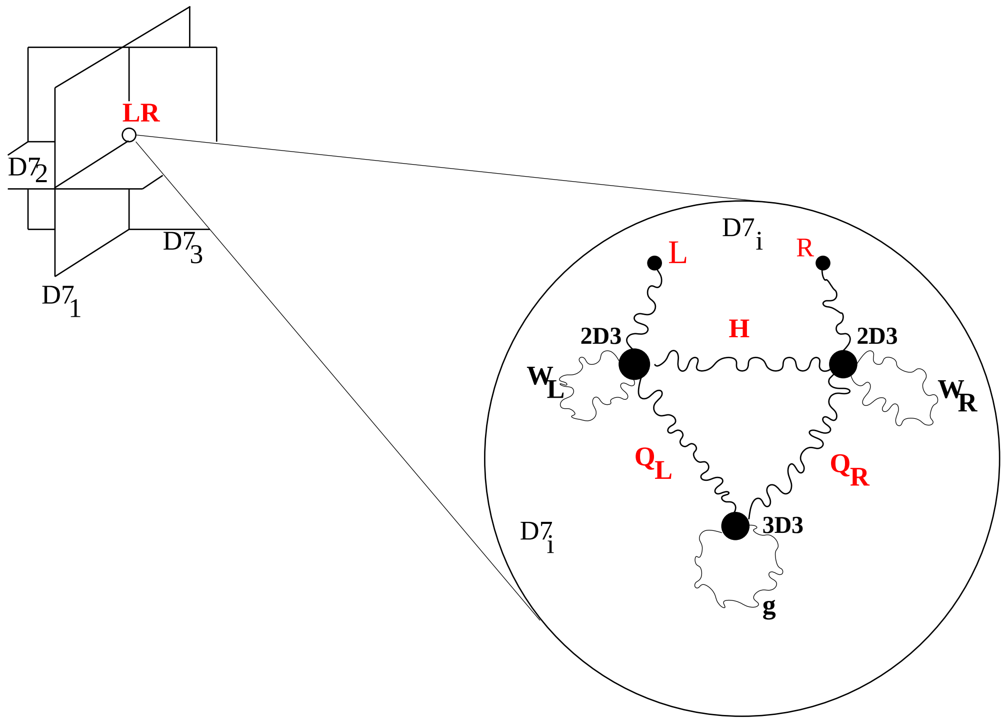
Local MSSM-like constructions

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.



- 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).
- One general property: 3 sets of Higgs doublets.

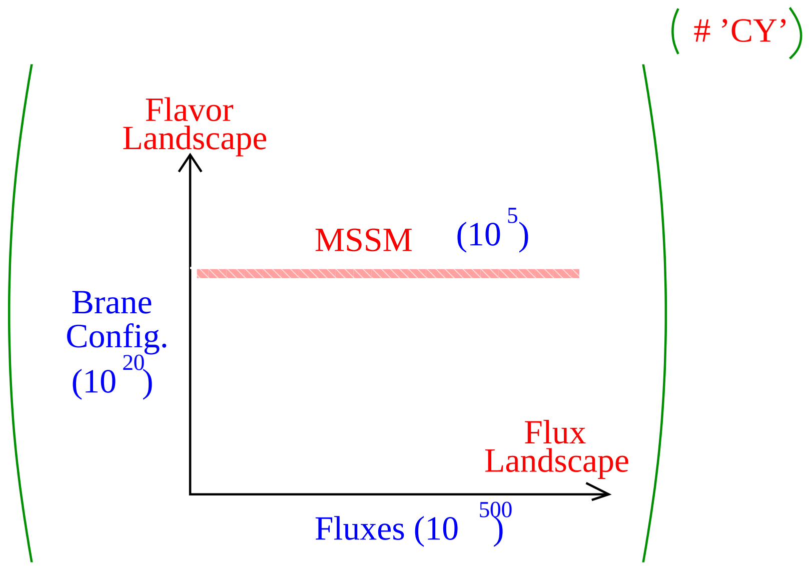
The String MSSM Landscape c. 2008

$Vacua$	Curv	Exot.	unif.	R_p	Yuk.	Mod.Fix.	Number
Het.Orb.	Flat	$\surd$	$\sim\surd$	$\sim\surd$	x	x	$\simeq 10^7$
Het.CY	Curved	$\surd$	$\sim\surd$	$\sim\surd$	x	x	$\sim 10^1$
IIA Inters. D6	Flat	$\surd$	x	$(B-L)$	x	flux	$\simeq 10^6$
IIB Magn. Dp	Flat	$\surd$	x	$(B-L)$	x	flux	$\simeq 10^6$
IIB RCFT	Curved	$\surd$	x	$\sim\surd$	x	x	$\simeq 10^5$
IIB D3 at sing.*	Curved	$\surd$	$\sim\surd$	$B-L$	x	flux	$\simeq 10^1$
Total:					0		$\simeq 10^7$

*local models

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 statistically preferred.

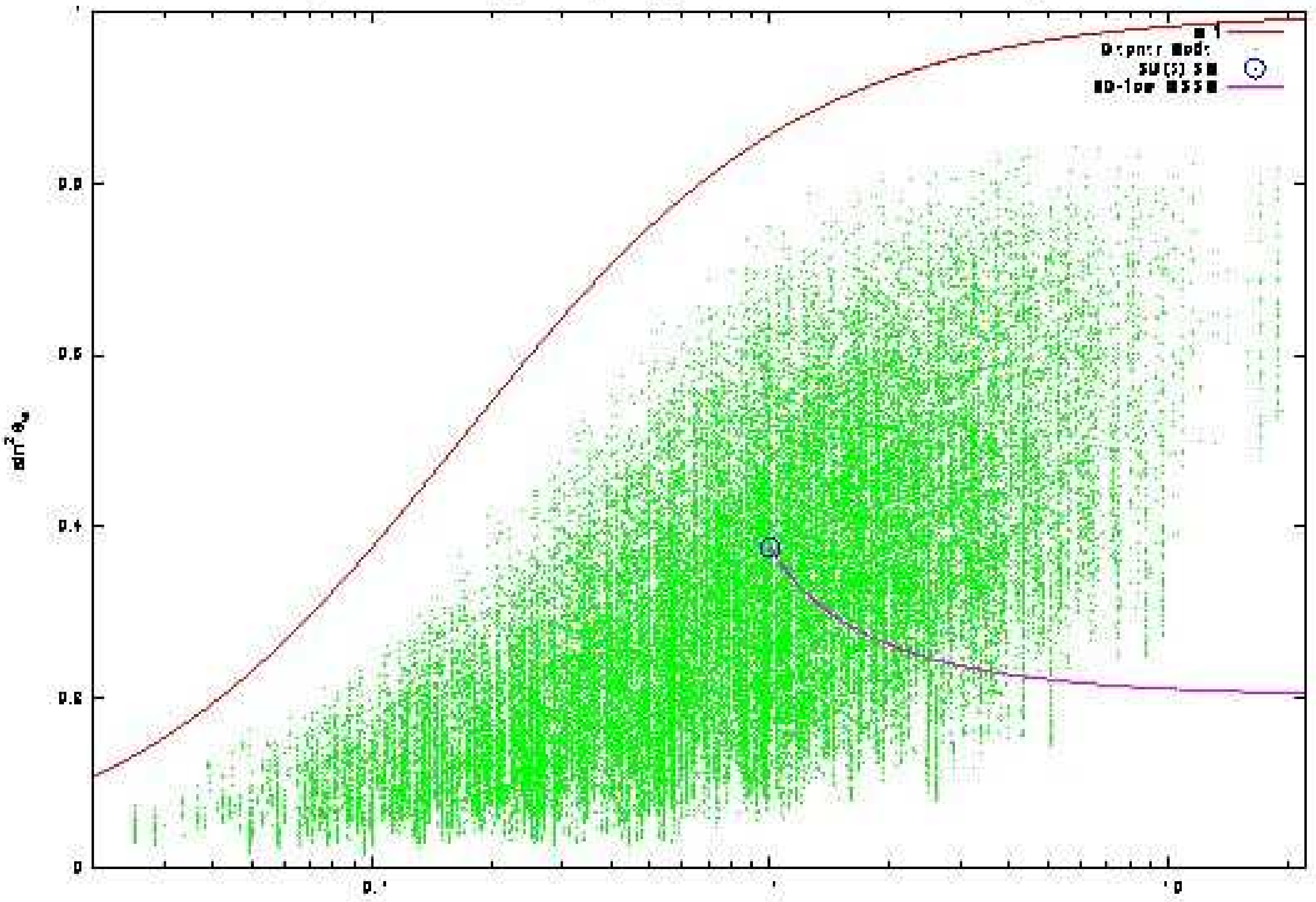
Some generic properties

- 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



Provisional Summary:

- Gauge coupling unification more natural in heterotic compactifications
- Moduli fixing best understood in Type IIB orientifolds
- Bottom-up approach possible in Type IIB, IIA

Can we combine the adventages of Heterotic and Type IIB ?

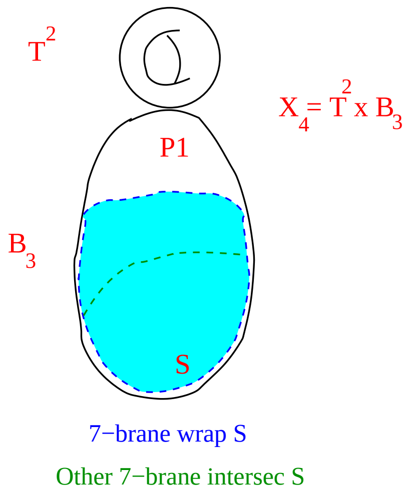
This is possible in F-theory Grand Unification

F-theory Grand Unification

- F-theory [a] may be considered as a non-perturbative version of Type IIB orientifolds. One considers compactifications of a (fake) 12-dimensional theory on a complex 4-fold X_4 with

$$X_4 \simeq T^2 \times B_3 \simeq K3 \times S \tag{2}$$

with the complex structure modulus of T^2 identified with complex dilaton τ.



[a] C. Vafa (1996)

- Main characters: The theory contains F-theory 7-branes whose extra 4 dimensions wrap the 4-fold S. A gauge group lives on the 7-branes.
- New features: Unlike perturbative orientifolds:
  - One can get spinorial reps: one can do $SO(10)$ or E_6 unification
  - Perturbatively forbidden couplings like $10 \times 10 \times 5_H$ are now allowed
- Reconsider GUT's in string theory. Why?
  - Gauge coupling unification from $SU(5)$ or $SO(10)$
  - Moduli fixing in IIB better understood
  - Decoupling of GUT from gravity possible (bottom-up)
- In order to get a bottom-up structure one insists that 4-fold S is shrinkable to zero size. I.e., one can mantain S at fixed size while taking the large volume $m_{Planck} \to \infty$ limit.
- This forces S to be of a particular type: $S =$ Del Pezzo surfaces dP_n.

Grand Unification

- One starts [a] with $SU(5)$ or $SO(10)$ GUT's living on the 7-branes wrapping S.

- Breaking symmetry down to the SM: Neither adjoint scalars nor Wilson lines available in del Pezzo!. Alternative: non-vanishing magnetic $U(1)$ fluxes:

$$SU(5) \longrightarrow_{<F_{U(1)_Y}>\neq 0} SU(3)\times SU(2)\times U(1)_Y \tag{3}$$

$$SO(10) \longrightarrow_{<F_{U(1)_{B-L}}>\neq 0} SU(3)\times SU(2)_L\times SU(2)_R\times U(1)_{B-L} \tag{4}$$

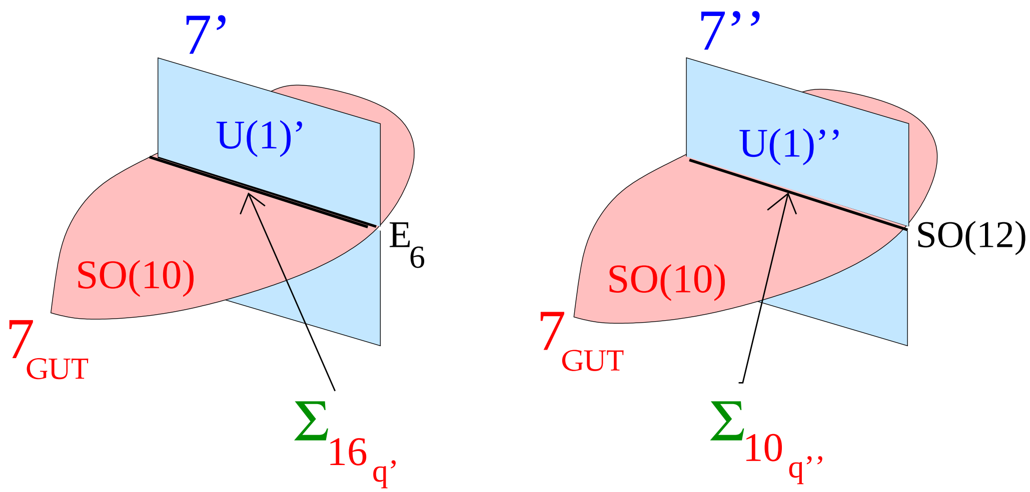
- This can be done in a way consistent with $N=1$ SUSY. Only vector-like matter may appear then.

- Chiral generations: from intersecting 7-branes. Consider the $SO(10)$ case for simplicity: ($SU(5)$ case is analogous).

[a] Beasley,Heckman,Vafa; Donagi,Wijnholt (2008)

Matter curves from intersecting F-theory 7-branes

- Chiral fields appear at the intersection of the GUT 7-branes with some $U(1)$' 7-brane .



- 7-branes intersec at Rieman curves Σ_{16} and Σ_{10} where quark/leptons and Higgs fields live. At those curves the symmetry is enhanced to E_6 or $SO(12)$

$$SO(10)\times U(1)' \in E_6 \ : \ 78 = 45+1 \ + 16_{q'} + \overline{16}_{-q'} \tag{5}$$

$$SO(10)\times U(1)'' \in SO(12) \ : \ 66 = 45+1 \ + 10_{q''} + \overline{10}_{-q''} \tag{6}$$

- Chirality comes from non-vanishing internal fluxes ($U(1) =$ Hypercharge for $SU(5)$, $U(1)_{B-L}$ for $SO(10)$):

$$< F_{U(1)} >\neq 0\,, < F_{U(1)'} >\neq 0\,, < F_{U(1)''} >\neq 0 \tag{7}$$

- Number of generations/Higgsses: given by index theorems i.e.:

$$N(R,q,q') \;=\; h^0(\Sigma, K_\Sigma^{1/2} \otimes L_\Sigma^q \otimes L_\Sigma^{\prime q'}) \tag{8}$$

- E.g. for $\Sigma_{16_{q'}}$ a Riemann curve of genus zero:

$$N_{16} \;=\; q_{B-L}\int_{\Sigma_{16}} F_{U(1)_{B-L}} \;+\; q'\int_{\Sigma_{16}} F_{U(1)'} \;=\; q'\int_{\Sigma_{16}} F_{U(1)'} \tag{9}$$

(one chooses $\int_{\Sigma_{16}} F_{U(1)_{B-L}} = 0$ to avoid quark/lepton splitting). Can choose 3 generations.

- Higgs multiplet:

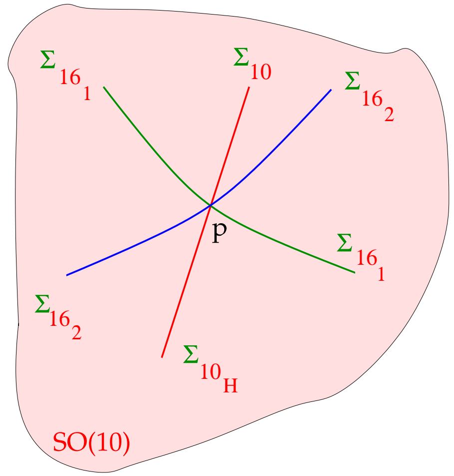
$$10 \;=\; (1,2,2)_0 \;+\; (\overline{3},1,1)_2 + (3,1,1)_{-2} \tag{10}$$

One can easily choose $U(1)$ backgrounds and curves Σ_{10} so that (doublet-triplet splitting)

$$N_{(1,2,2)} \;=\; 1\;,\; N_{(\overline{3},1,1)} = N_{(3,1,1)} \;=\; 0 \tag{11}$$

Yukawa couplings in F-theory GUT's

- Yukawa couplings occur when there are intersections of three different matter curves at a point p (something generic in F-theory). Consider e.g. two different matter curves Σ_{16^1}, Σ_{16^2}



$$Y_{ij} = \sum_p \Psi_{16^1_i}(p)\Psi_{16^2_j}(p)\Psi_{10_H}(p) \rightarrow Y \simeq \begin{pmatrix} 0 & x & x \\ x & 0 & x \\ x & x & 0 \end{pmatrix} \quad (12)$$

- Unrealistic structure! (Not possible to have one eigenvalue much larger than the rest):

- Natural solution: [a] Instead of impossing $\int_{\Sigma_{16^{1,2}}} F_{U(1)_{B-L}} = 0$ allow the more general condition

$$\int_{\Sigma_{16^1}} F_{U(1)_{B-L}} + \int_{\Sigma_{16^2}} F_{U(1)_{B-L}} = 0 \qquad (13)$$

- Then the particle content of each matter curve is reshufled:

$$16^1 \longrightarrow 3 \times R + 2 \times Q_L + 1 \times Q_R \qquad (14)$$

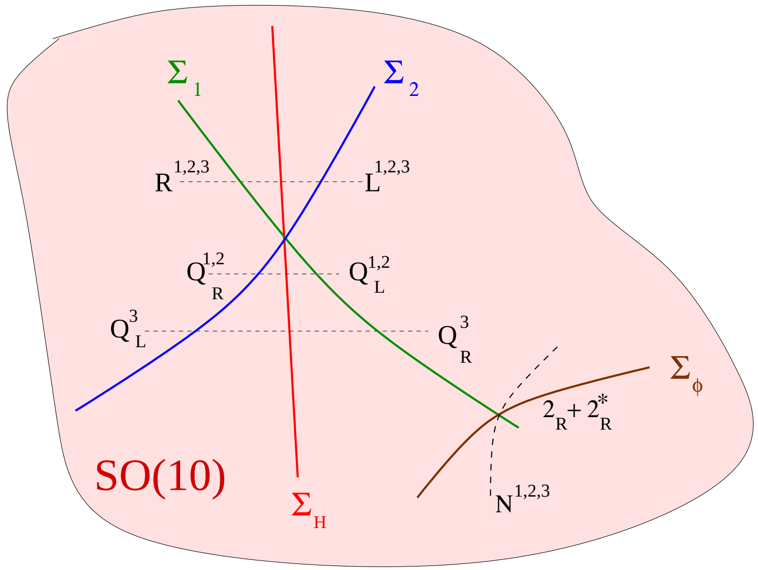
$$16^2 \longrightarrow 3 \times L + 2 \times Q_R + 1 \times Q_L \qquad (15)$$

- Now selfcouplings are allowed and one gets the Yukawa structure

$$Y_Q \sim \begin{pmatrix} x & x & 0 \\ x & x & 0 \\ 0 & 0 & x \end{pmatrix} \; ; \; Y_L \sim \begin{pmatrix} x & x & x \\ x & x & x \\ x & x & x \end{pmatrix} \qquad (16)$$

  – Small mixing for the 3-d generation
  – Leptonic mixing not constrained
  – Hierarchical structure depending on values of wave functionas at intersecting points p

[a] A.Font,L.I. (2008)



Summary

– Phenomenology of F-theory GUT's still under study. Very active field of research [b]

– Important to study whether there could be signatures at LHC...

[b] Beasley,Heckman,Vafa I-II; Donagi,Wijnholt; Aparicio, Cerdeño, L.I.; Marsano,Saulina,Shafer-Nameki; Heckman,Vafa; Font,L.I.; Blumenhagen,Braun,Grimm,Weigand,..(08)

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
    - Production of extra Z' bosons from anomalous $U(1)$'s
    - 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 extract predictions for SUSY breaking soft terms!

Varieties of SUSY breaking

- Two natural sources of spontaneous SUSY-breaking in string models:
  - Closed string antisymmetric 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 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

- 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!

Modulus dominated SUSY breaking in IIB/F-theory

- 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/F-theory 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)).
  - As we will see, if the MSSM resides on D7-branes all scalars and gauginos get soft terms at tree level (not true e.g. in heterotic).
  - 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:

$$L_{soft} \;=\; \frac{1}{2}\sum_a M_a\, \lambda_a\lambda_a \;+\; h.c. \;-\; m_{H_d}^2|H_d|^2 - m_{H_u}^2|H_u|^2 \quad (17)$$

$$-\;\sum_i m_{\tilde{\Phi}_{ij}}^2\, \tilde{\Phi}_i\tilde{\Phi}_j^* \;-\; A_{ij}^{U,D,L}\tilde{\Phi}_i\tilde{\Phi}_j H_{u,d} - \;B\; H_d H_u \;+\; h.c. \quad (18)$$

- 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') :

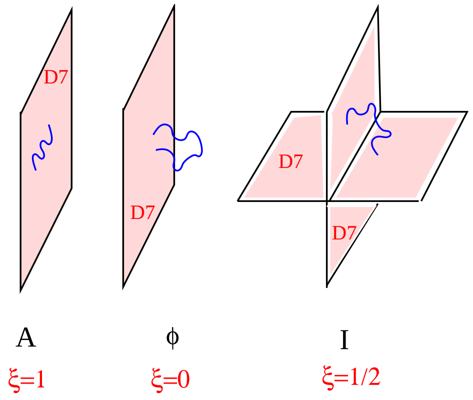
[a] L.I., C. Muñoz, S. Rigolin (98);Kors et al. Lust et al.(04);Bertolini et al.(05);Billo et al.(07)

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 local $D7_s$:* $D7$	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 the situation in F-theory in which GUT branes wrap a local 4-cycle S.

[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:

$$\xi_f^i = \xi_Q^i = \xi_U^i = \xi_D^i = \xi_L^i = \xi_E^i \, . \tag{19}$$

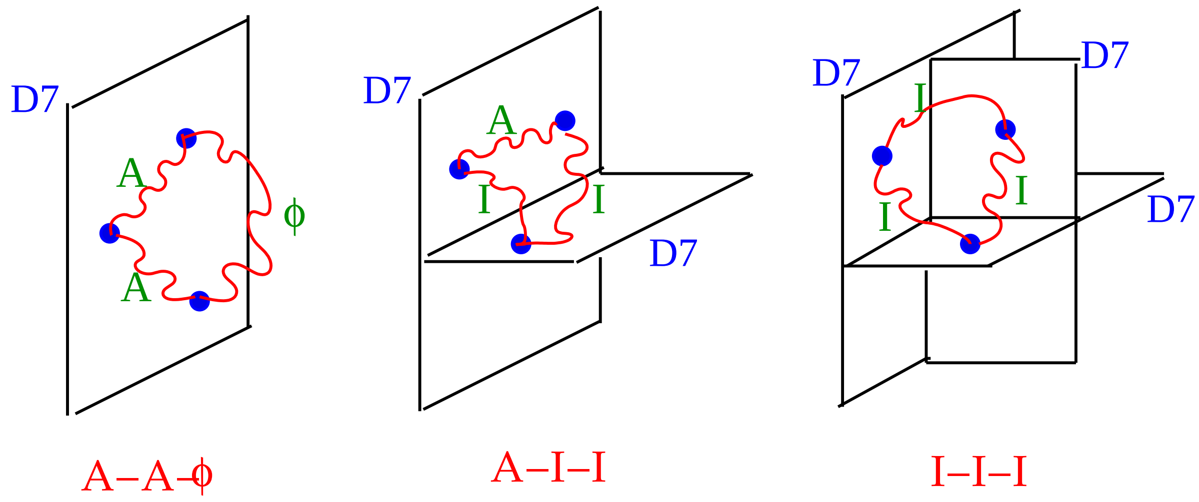
- On the other hand the Higgs fields could have different modular weight than fermion fields. So we will take $\xi_H = \xi_{H_u} = \xi_{H_d} = 0, 1, 1/2$.

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), if present, is supressed in α'.
- Note mixed Kahler-Complex Structure dominance would be disfavored.
- This structure was recently named "mirror mediation"[a].

[a] Conlon (07);Conlon,Cremades,Quevedo (06)

- 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



- In F-theory grand unification only I-I-I Yukawas available.

- 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, hep-th/0805.2943

(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 impposes 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.
  - $2.85 \times 10^{-4} \leq \mathrm{BR}(b \to s\gamma) \leq 4.25 \times 10^{-4}$ (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, $11.6 \times 10^{-10} \leq a_\mu^{\mathrm{SUSY}} \leq 43.6 \times 10^{-10}$.
  - 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)

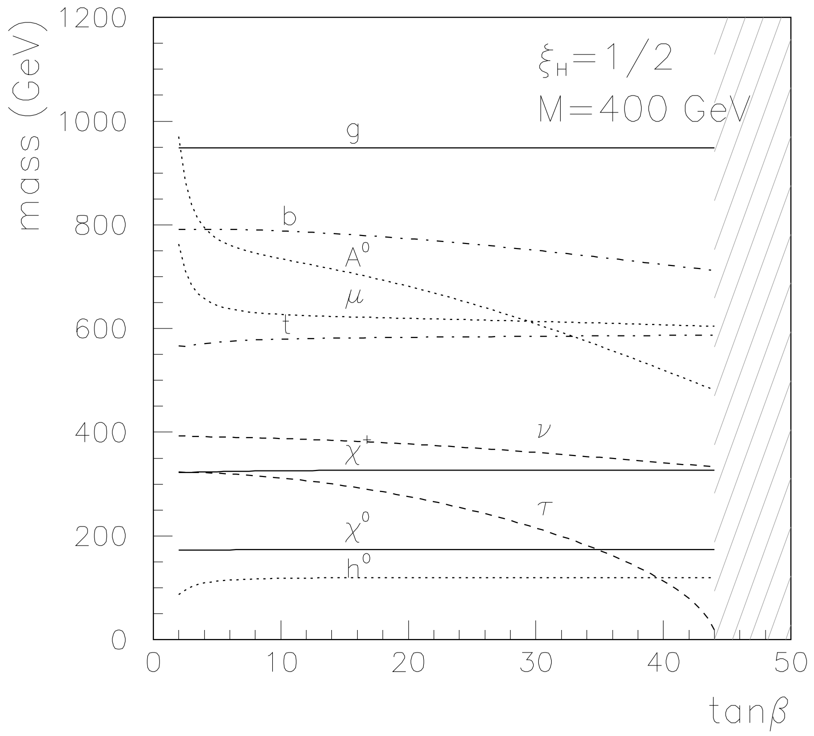


Figure 1: Low-energy supersymmetric spectrum as a function of $\tan\beta$ for $\xi_H = 1/2,$ with $M = 400$ GeV and $\mu < 0$. The ruled area for large $\tan\beta$ is excluded by the occurrence of tachyons in the slepton sector. (Aparicio,L.I.,Cerdeño (08))

Consistency with REW for MSSM at intersecting 7-branes

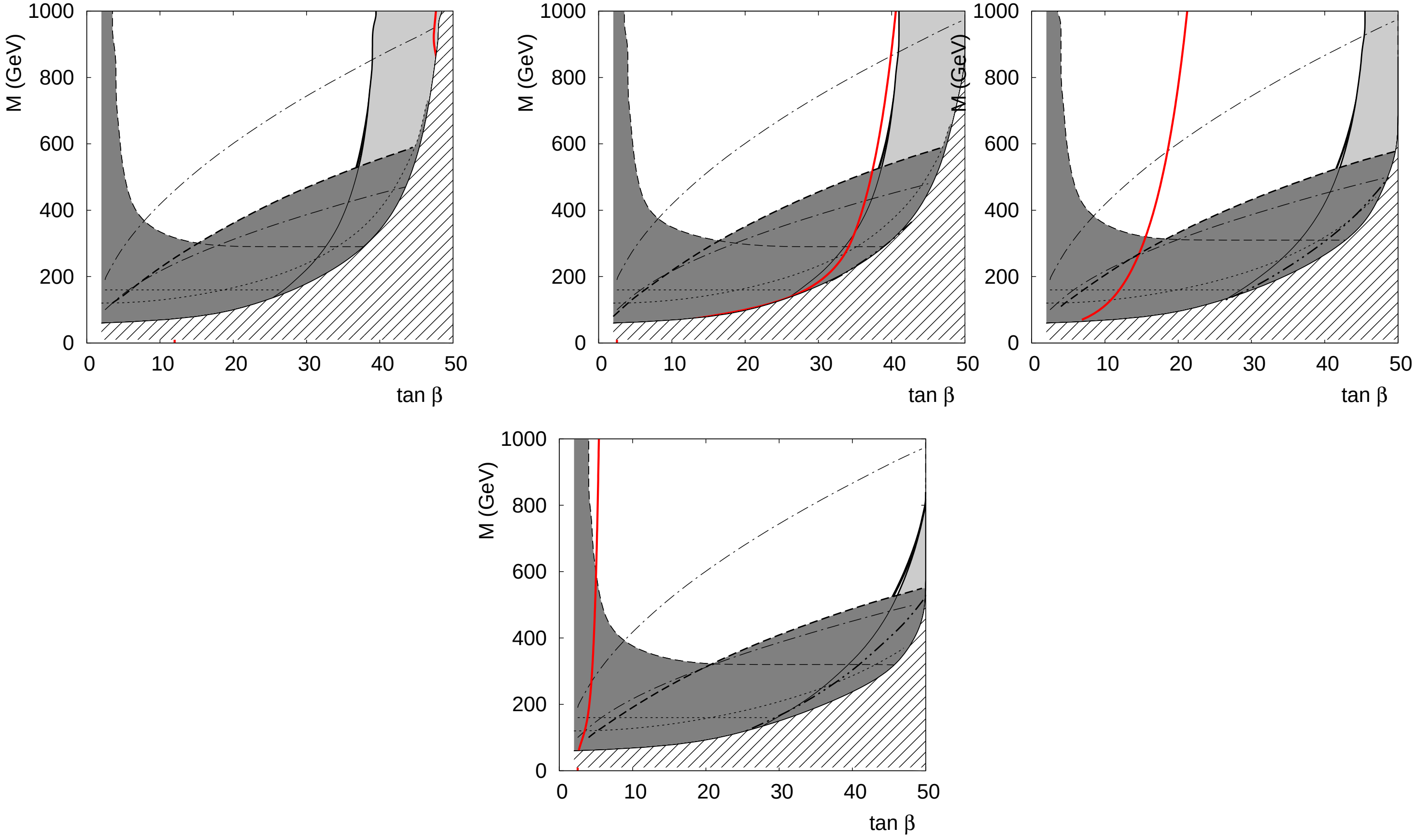


Figure 2: Effect of experimental constraints on the $(M,\ \tan\beta)$ plane for $\xi_H\ =0.5,\ 0.6,\ 0.8,$ and 1 , from left to right and top to bottom. Also shown is CONSISTENCY WITH REWB .

- 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 F-theory 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.

Conclusions

- There has been an important improvement in our understanding of the MSSM landscape in string theory.
- Two strategies:
  - Global models (top-bottom approach)
  - Local models: SM decoupled from gravity
- Gauge coupling unification natural in heterotic whereas moduli fixing and local models only possible in Type II orientifolds
- F-theory grand unification combines adventages of both. Yukawa structure constrained, with a supressed 3-d generation mixing naturally predicted.
- Modulus domination in F-theory/IIB orientifolds gives a specific predictive pattern of SUSY-breaking soft terms.
- LHC can give us important information on the structure of the MSSM string landscape!

The MSSM landscape circa 20xx