Sightseeing in the Landscape

Contents

- Landscape remarks
  (physics/06041340, Dutch version 1998)
- RCFT orientifolds
  (with Huiszoon,Fuchs, Schweigert,Walcher)
- 2003-2004 results
  (with Dijkstra,Huiszoon)
- 2005-2006 results
  (with Anastasopoulos,Dijkstra,Kiritsis, hep-th/0605226)

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- 2003: Non-uniqueness got a name: The Landscape

My point of view:

(physics/06041340 (1998))

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- 4-D Quantum gravity implies that the SM is part of a huge landscape
- Fits nicely with some of the great discoveries in the history of science (heliocentric model, theory of Evolution...)
- String Theory has never looked better...
- ...but it has never looked harder.

So what can we still do?

- Explore unknown regions of the landscape
- Establish the likelyhood of standard model features (gauge group, three families, ...)
- Convince ourselves that standard model is a plausible vacuum
- Understand vacuum statistics
- Understand cosmological likelyhood
- Understand “anthropicity”

Orientifolds of Gepner Models

Earlier footprints

C. Angelantonj, M. Bianchi, G. Pradisi, A. Sagnotti and Y. S. Stanev, Phys. Lett. B **387** (1996) 743 [arXiv:hep-th/9607229].

R. Blumenhagen and A. Wisskirchen, Phys. Lett. B **438**, 52 (1998) [arXiv:hep-th/9806131].

G. Aldazabal, E. C. Andres, M. Leston and C. Nunez, JHEP **0309**, 067 (2003) [arXiv:hep-th/0307183].

I. Brunner, K. Hori, K. Hosomichi and J. Walcher, arXiv:hep-th/0401137.

R. Blumenhagen and T. Weigand, JHEP **0402** (2004) 041 [arXiv:hep-th/0401148].

G. Aldazabal, E. C. Andres and J. E. Juknevich, JHEP **0405**, 054 (2004) [arXiv:hep-th/0403262].

The long road to the chiral SSM

- Angelantonj, Bianchi, Pradisi, Sagnotti, Stanev (1996)
  Chiral spectra from Orbifold-Orientifolds

- Aldazabal, Franco, Ibanez, Rabadan, Uranga (2000)
  Blumenhagen,Görlich,Körs,Lüst (2000)
  Ibanez, Marchesano, Rabadan (2001)
  Non-supersymmetric SM-Spectra with RR tadpole cancellation

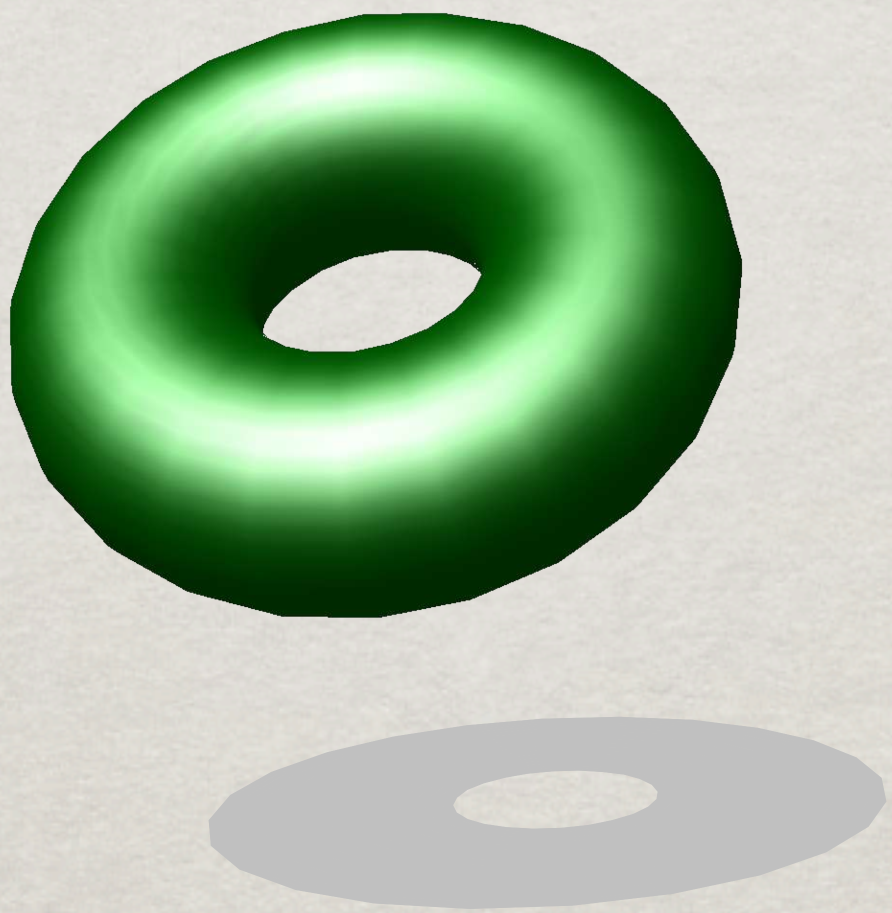
- Cvetic, Shiu, Uranga (2001)
  Supersymmetric SM-Spectra with chiral exotics

- Blumenhagen, Görlich, Ott (2002)
  Honecker (2003)
  Supersymmetric Pati-Salam Spectra with brane recombination

- Dijkstra, Huiszoon, Schellekens (2004)
  Supersymmetric Standard Model (Gepner Orientifolds)

- Honecker, Ott (2004)
  Supersymmetric Standard Model (Z_6 orbifold/orientifold)

Closed String Partition Function



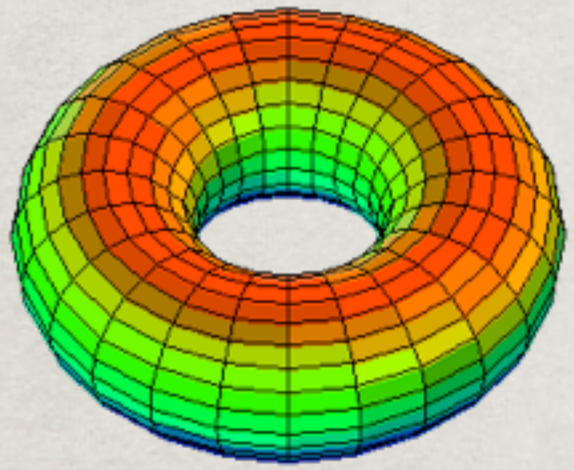
$$P(\tau,\bar{\tau}) = \sum_{ij} \chi_i(\tau) Z_{ij} \chi_j(\bar{\tau})$$

Type IIB

Orientifold Partition Functions

Orientifold Partition Functions

$\frac{1}{2}$ {



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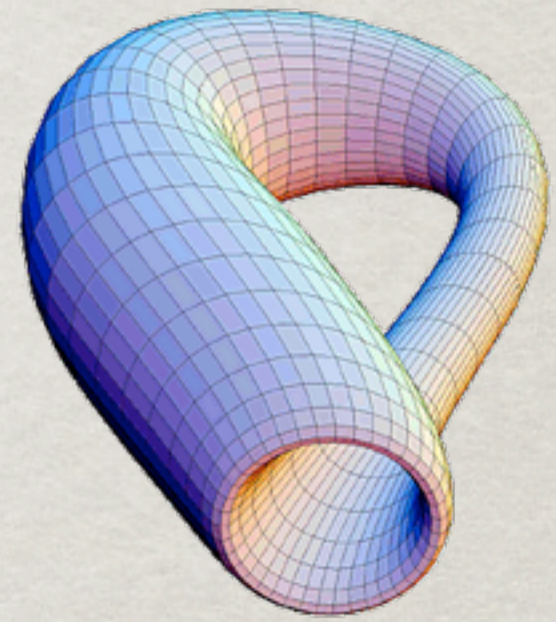

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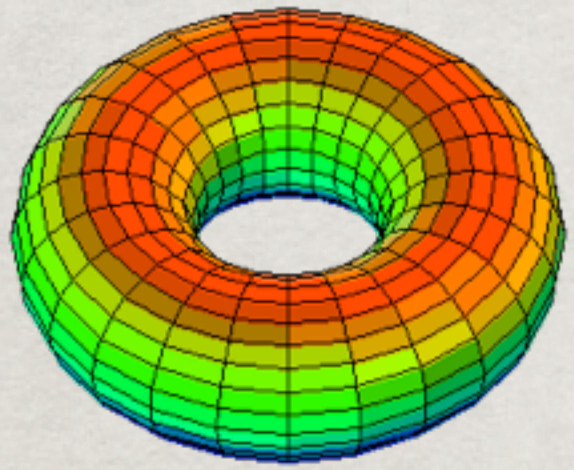
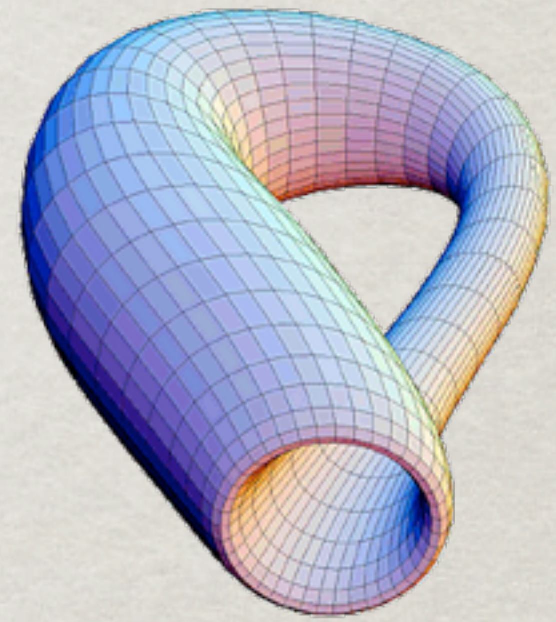
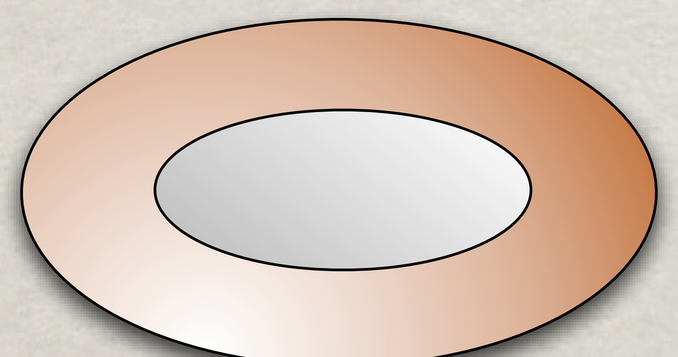
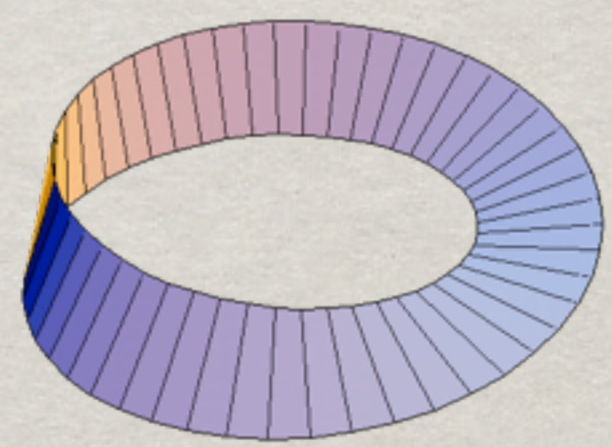
$\frac{1}{2}$ $\Big\{$  $+$  $\Big\}$

$\frac{1}{2}$ $\Big\{$  $+$  $\Big\}$

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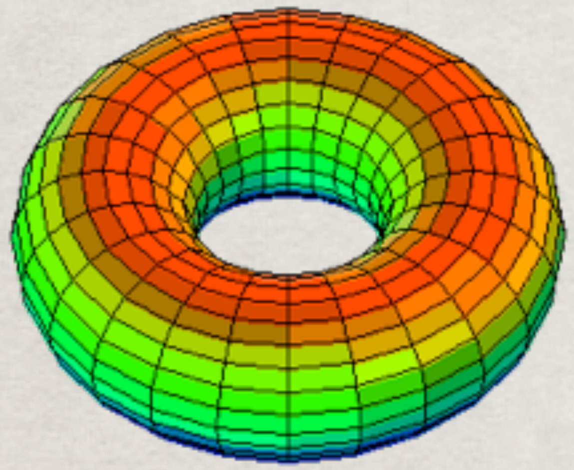

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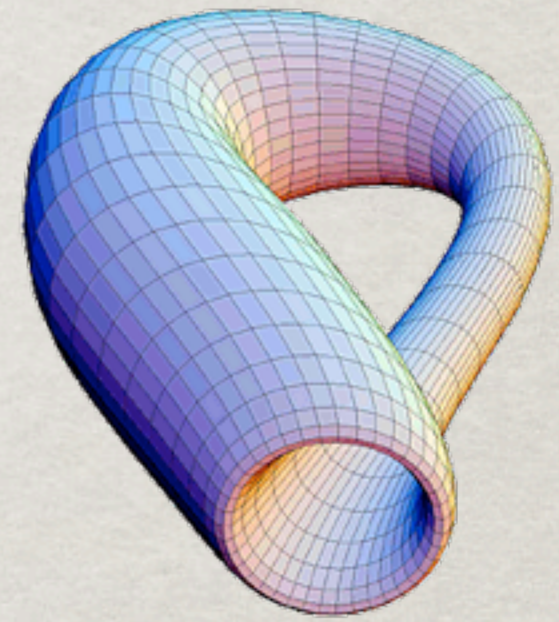
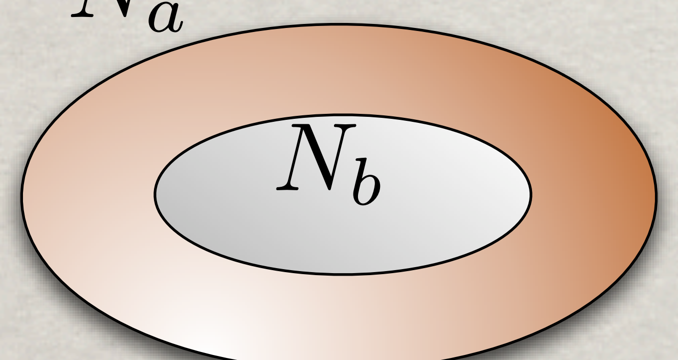


}

$\frac{1}{2}$ {

N_a



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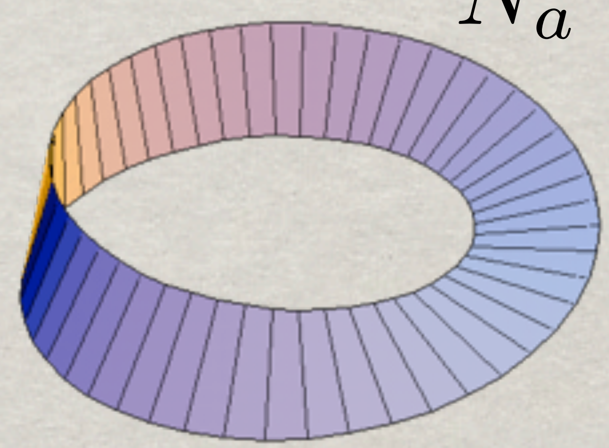

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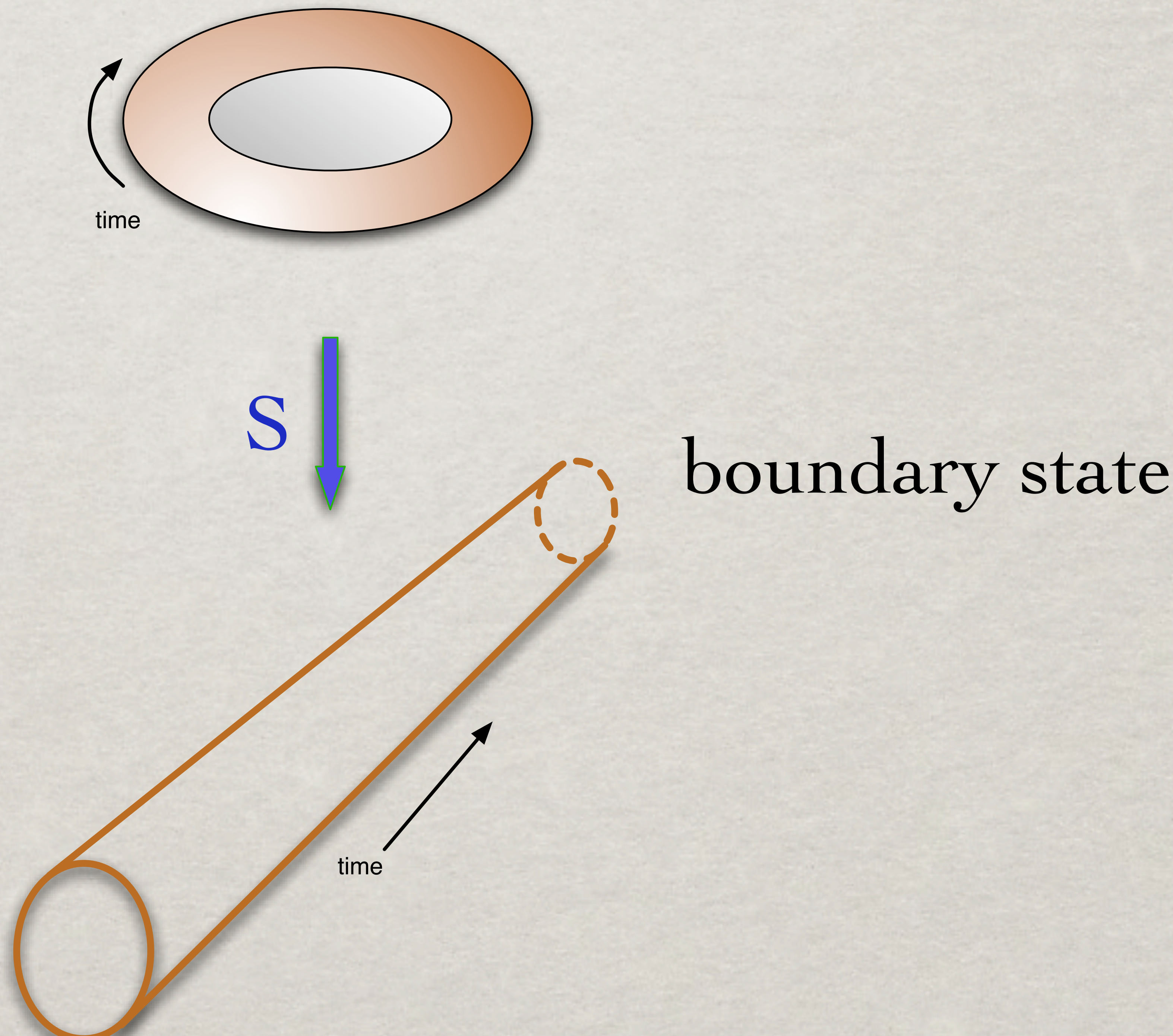
Transverse Channel



Gepner Models

Building Blocks:
Minimal N=2 CFT

$$c = \frac{3k}{k+2}, \quad k = 1, \ldots, \infty$$

168 ways of solving $\sum_i c_{k_i} = 9$

Spectrum:

$$h_{l,m} = \frac{l(l+2) - m^2}{4(k+2)} + \frac{s^2}{8}$$

$(l = 0, \ldots k; \quad q = -k, \ldots k+2; \quad s = -1, 0, 1, 2)$

(plus field identification)

$4(k+2)$ simple currents

Tensoring

- Preserve world-sheet susy
- Preserve space-time susy (GSO)
- Use surviving simple currents to build MIPFs
- This yields one point in the moduli space of a Calabi-Yau manifold

Selecting MIPFs and Orientifolds

Each tensor product has a discrete group $\mathcal{G}$
of simple currents: $J \cdot a = b$

Choose:

- A subgroup $\mathcal{H}$ of $\mathcal{G}$
- A rational matrix $X_{\alpha\beta}$ defined on $\mathcal{H}$

- An element K of $\mathcal{G}$
- A set of signs $\beta_K(J)$ defined on $\mathcal{H}$

Conditions

[definition: $Q_J(a) \equiv h(a) + h(J) - h(Ja)$]

$\mathcal{H}$	$N_J h_J \in \mathbf{Z},\ \text{for all } J \in \mathcal{H}$
$X_{\alpha\beta}$	$2X_{\alpha\beta} = Q_{J_\alpha}(J_\beta) \text{ mod } 1, \alpha \neq \beta$ $X_{\alpha\alpha} = -h_{J_\alpha}$ $N_\alpha X_{\alpha\beta} \in \mathbb{Z} \text{ for all } \alpha, \beta$
K	$Q_I(K) = 0 \text{ mod } 1 \text{ for all } I \in \mathcal{H}, I^2 = 0.$
$\beta_K(J)$	$\beta_K(J)\beta_K(J') = \beta_K(JJ')e^{2\pi i X(J,J')} \quad , J, J' \in \mathcal{H}$

A MIPF

(0+2)^2 + (1+3)^2 + (4+6)*(13+15) + (5+7)*(12+14)
+ (8+10)^2 + (9+11)^2 + (12+14)*(5+7) + (13+15)*(4+6)
+ (16+18)*(25+27) + (17+19)*(24+26) + (20+22)^2 + (21+23)^2
+ (24+26)*(17+19) + (25+27)*(16+18) + (28+30)^2 + (29+31)^2
+ (32+34)^2 + (33+35)^2 + (36+38)*(45+47) + (37+39)*(44+46)
+ (40+42)^2 + (41+43)^2 + (44+46)*(37+39) + (45+47)*(36+38)
+ (48+50)*(57+59) + (49+51)*(56+58) + (52+54)^2 + (53+55)^2
+ (56+58)*(49+51) + (57+59)*(48+50) + (60+62)^2 + (61+63)^2

....

+ 2*(2913)*(2915) + 2*(2914)*(2912) + 2*(2915)*(2913)
+ 2*(2916)^2 + 2*(2917)^2 + 2*(2918)^2 + 2*(2919)^2
+ 2*(2920)^2 + 2*(2921)^2 + 2*(2922)^2 + 2*(2923)^2
+ 2*(2924)*(2926) + 2*(2925)*(2927) + 2*(2926)*(2924)
+ 2*(2927)*(2925) + 2*(2928)^2 + 2*(2929)^2 + 2*(2930)^2
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Boundaries and Crosscaps*

- Boundary coefficients

$$R_{[a,\psi_a](m,J)} = \sqrt{\frac{|\mathcal{H}|}{|\mathcal{C}_a||\mathcal{S}_a|}}\psi_a^*(J)S^J_{am}$$

- Crosscap coefficients

$$U_{(m,J)} = \frac{1}{\sqrt{|\mathcal{H}|}}\sum_{L\in\mathcal{H}} e^{\pi i(h_K - h_{KL})}\beta_K(L)P_{LK,m}\delta_{J,0}$$

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$(m, J): \quad J \in \mathcal{S}_m$

with $Q_L(m) + X(L, J) = 0 \bmod 1$ for all $L \in \mathcal{H}$

$\mathcal{S}_m : J \in \mathcal{H}$ with $J \cdot m = m$

(Stabilizer of m)

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$[a, \psi_a]$, ψ_a is a character of the group $\mathcal{C}_a$

$\mathcal{C}_a$ is the Central Stabilizer of a

$$\mathcal{C}_i := \{J \in \mathcal{S}_i \mid F_i^X(K,J) = 1 \text{ for all } K \in \mathcal{S}_i\}$$

$$F_i^X(K,J) := \mathrm{e}^{2\pi\mathrm{i}X(K,J)}\, F_i(K,J)^*$$

$$S^J_{Ki,j} = F_i(K,J)\, \mathrm{e}^{2\pi\mathrm{i}Q_K(j)}\, S^J_{i,j}\,.$$

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The Fixed point resolution matrices

S^J_{am} (of a WZW model W)

Modular transformation matrices of the WZW model W^J defined by folding the extended Dynkin diagram of W by the symmetry defined by J

Schellekens, Yankielowicz (1989)
Fuchs,Schellekens,Schweigert (1995)

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*Huiszoon, Fuchs, Schellekens, Schweigert, Walcher (2000)

The P-matrix*

$$P = \sqrt{T} S T^2 S \sqrt{T}$$

$$T \quad : \quad \tau \to \tau + 1$$
$$S \quad : \quad \tau \to -\frac{1}{\tau}$$

**Sagnotti, Pradisi, Stanev*

Coefficients

- Klein bottle

$$K^i = \sum_{m,J,J'} \frac{S^i{}_m U_{(m,J)} g^{\Omega,m}_{J,J'} U_{(m,J')}}{S_{0m}}$$

- Annulus

$$A^i_{[a,\psi_a][b,\psi_b]} = \sum_{m,J,J'} \frac{S^i{}_m R_{[a,\psi_a](m,J)} g^{\Omega,m}_{J,J'} R_{[b,\psi_b](m,J')}}{S_{0m}}$$

- Moebius

$$M^i_{[a,\psi_a]} = \sum_{m,J,J'} \frac{P^i{}_m R_{[a,\psi_a](m,J)} g^{\Omega,m}_{J,J'} U_{(m,J')}}{S_{0m}}$$

$$g^{\Omega,m}_{J,J'} = \frac{S_{m0}}{S_{mK}} \beta_K(J) \delta_{J',J^c}$$

Partition Functions

- Closed

$$\frac{1}{2}\left[\sum_{ij}\chi_i(\tau)Z_{ij}\chi_i(\bar{\tau})+\sum_i K_i\chi_i(2\tau)\right]$$

- Open

$$\frac{1}{2}\left[\sum_{i,a,n}N_aN_bA^i{}_{ab}\chi_i(\frac{\tau}{2})+\sum_{i,a}N_aM^i{}_a\hat{\chi}_i(\frac{\tau}{2}+\frac{1}{2})\right]$$

N_a: Chan-Paton multiplicity

Tadpoles & Anomalies

- Tadpole cancellation condition:

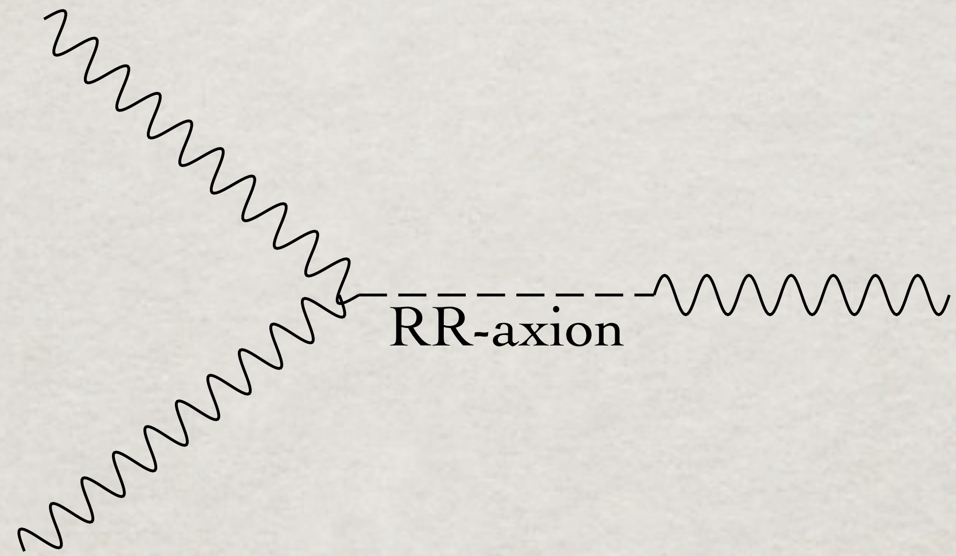
$$\sum_b N_b R_{b(m,J)} = 4\eta_m U_{(m,J)}$$

- Cubic $\mathrm{Tr}F^3$ anomalies cancel
- Remaining anomalies by Green-Schwarz mechanism
- In rare cases, additional conditions for global anomaly cancellation*

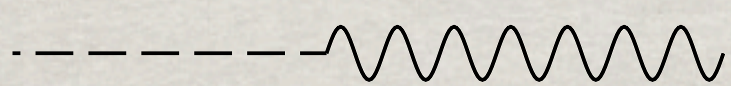
**Gato-Rivera, Schellekens (2005)*

Abelian Masses

Green-Schwarz mechanism



Axion-Vector boson vertex



Generates mass vector bosons of anomalous symmetries

$(e.g.\ B + L)$

But may also generate mass for non-anomalous ones

$(Y, B - L)$

Scope of the Search

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- 168 Gepner models

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- 5403 MIPFs

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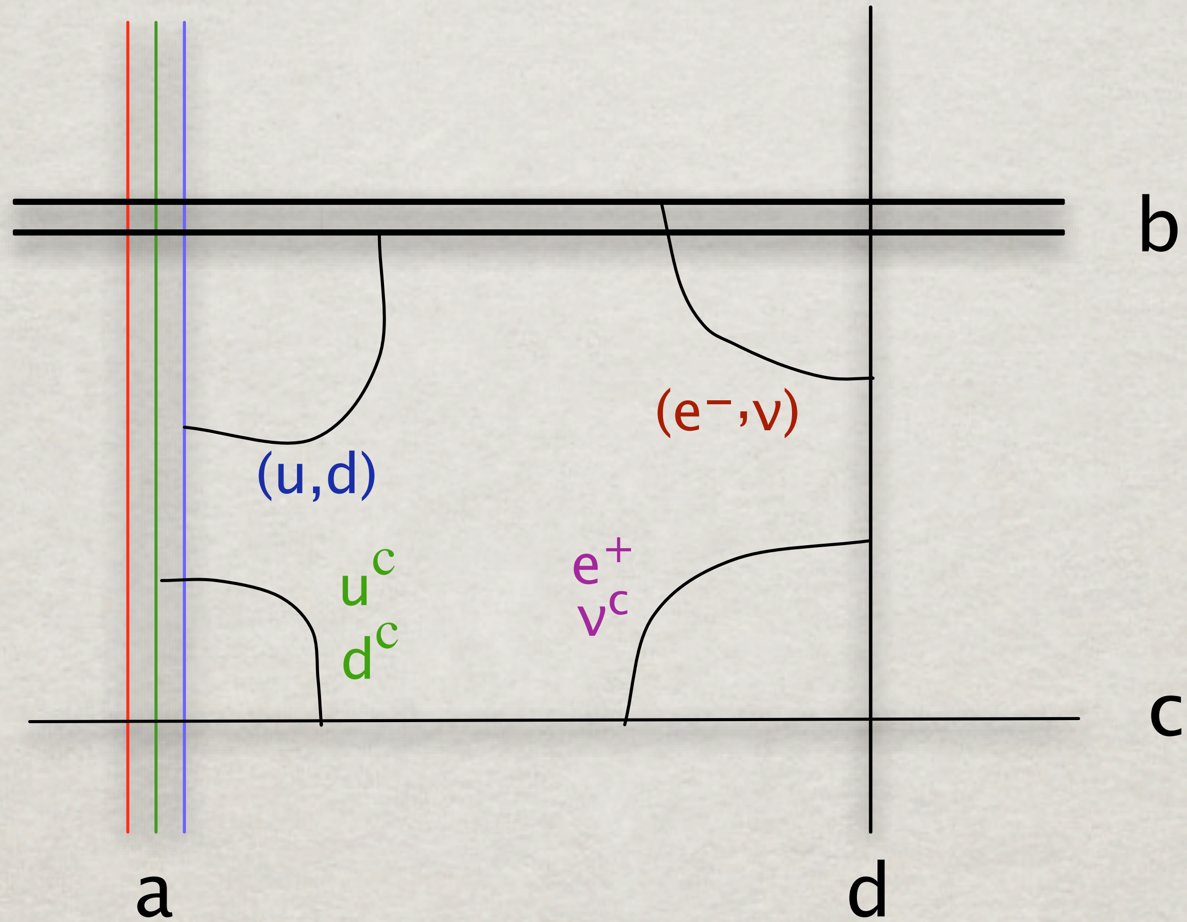
Essential to decide what to search for!

What to search for

The Madrid model



Chiral SU(3) x SU(2) x U(1) spectrum:

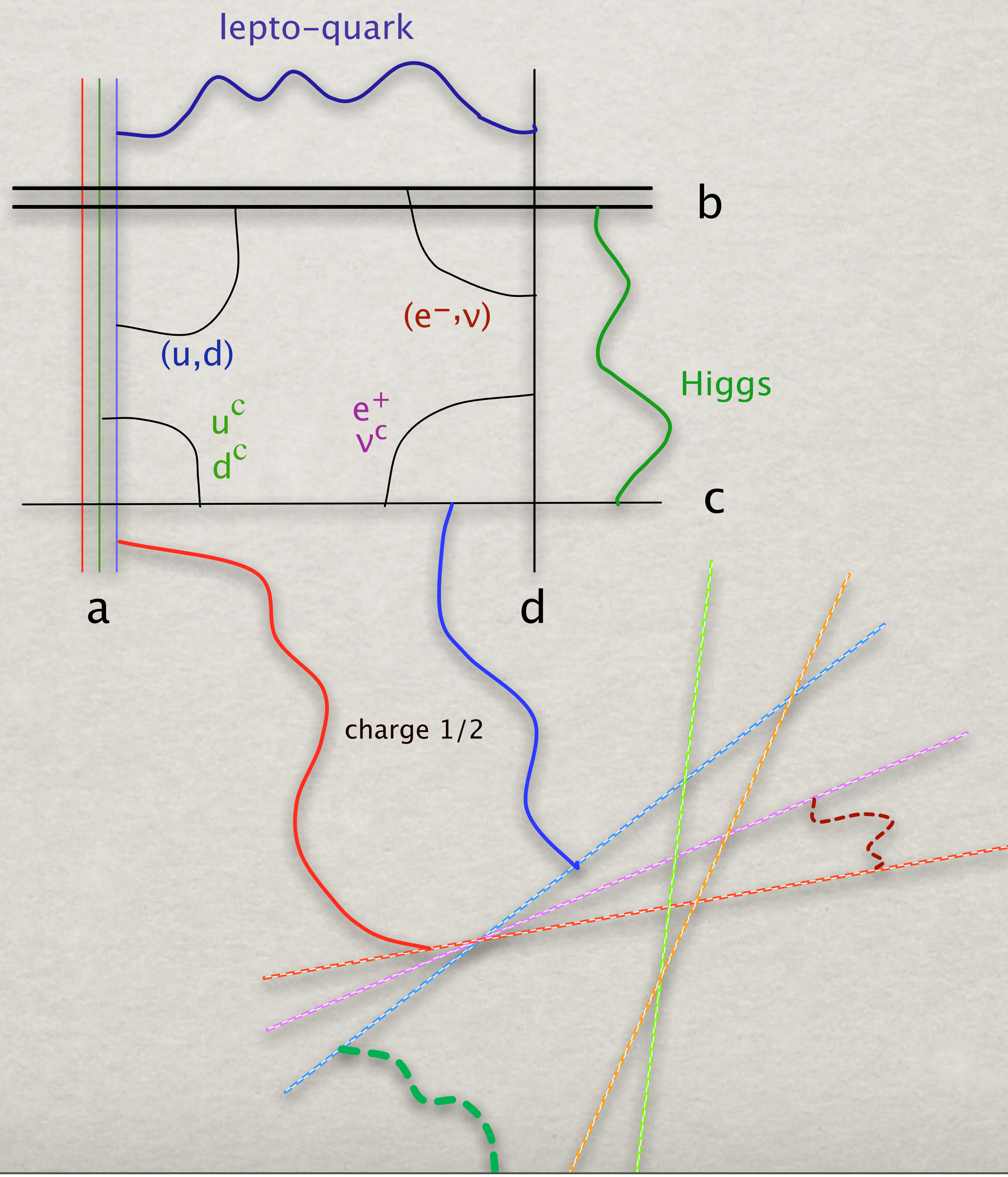
$$3(u,d)_L + 3u^c_L + 3d^c_L + 3(e^-,\nu)_L + 3e^+_L$$

Y massless $\quad Y = \frac{1}{6}Q_a - \frac{1}{2}Q_c - \frac{1}{2}Qd$

N=1 Supersymmetry

No tadpoles, global anomalies

The hidden Sector



Chirality

- Non-chiral (vector-like): no restrictions
- CP-chiral, SM-non-chiral: Mirrors, Higgs pairs or righthanded neutrinos
- SM-chiral: 3 families

Brane Configurations

Type	CP Group	B-L
0	U(3) x Sp(2) x U(1) x U(1)	massless
1	U(3) x U(2) x U(1) x U(1)	massless
2	U(3) x Sp(2) x O(2) x U(1)	massless
3	U(3) x U(2) x O(2) x U(1)	massless
4	U(3) x Sp(2) x Sp(2) x U(1)	massless
5	U(3) x U(2) x Sp(2) x U(1)	massless
6	U(3) x Sp(2) x U(1) x U(1)	massive
7	U(3) x U(2) x U(1) x U(1)	massive

STATISTICS

Total number of 4-stack configurations	45761187347637742772 (45.7 x 10^{18})
Total number scanned	4.37522E+19
Total number of SM configurations	45051902 fraction: 1.0 x 10^{-12}
Total number of tadpole solutions	1649642 fraction: 3.8 x 10^{-14} (*)
Total number of distinct solutions	211634

(*) cf. Gmeiner, Blumenhagen, Honecker, Lüst, Weigand: "One in a Billion"

RCFT orientifolds with Standard Model Spectrum

Tim Dijkstra, Lennaert Huiszoon and Bert Schellekens

On this page you can search through all our supersymmetric, tadpole-free D=4, N=1 orientifold vacua with a three family chiral fermion spectrum identical to that of the Standard Model. They were constructed in a semi-systematic way by considering orientifolds of all Gepner Models (see *Phys.Lett.B609:408-417* and *Nucl.Phys.B710:3-57* for more information). Since the publication of these papers all spectra have been re-analysed and checked for the presence of global (Witten) anomalies. A few cases (less than 1%) needed correction. All spectra in this database are now free from global anomalies, and the total number is 210,782, slightly more than reported in these papers.

As explained in referenced articles the standard model gauge group can be realized in different ways (which we call *types*). In addition to these factors, the gauge group usually has extra *hidden* gauge group factors. Chiral states with one leg in the standard model gauge group are not permitted.
All these models of course have the same *chiral* spectrum for the standard model gauge group, except for the higgs-sector of which we do not know how it is realized in nature.

These models then differ in multiplicities of the non-chiral particles, hidden gauge group, higgs sector coupling constants on the string scale, and others.
To search for your favorite realization you can use the form below to filter our set with an condition. Example:

```
type==0 && nrHidden<2
```

You can consult a list of valid field names. Also much more complicated expressions are possible, see the syntax description.

Filter form

Two output formats are provided. The first only gives the number of answers, the second lists all the spectra satisfying the search criteria. Be warned that output can be very large and take up to a minute to compile; at the moment we have

Filter form

Two output formats are provided. The first only gives the number of answers, the second lists all the spectra satisfying the search criteria. Be warned that output can be very large and take up to a minute to compile; at the moment we have 210,782 models in the database, which means you can generate hunderds of MBs of output!

Filter condition

```
udmir=0 && umir==0 && dmir==0 && enmir==0 && emir==0 && nmir==0 &&
aadj==0 && badj==0 && cadj==0 && dadj==0 &&
aa==0 && ba==0 && ca==0 && da==0
&& as==0 && bs==0 && cs==0&& ds==0
```

Output format

Summary for each model | Filter

```
Gauge group: U(3) x Sp(2) x Sp(2) x U(1) x Sp(6) x Sp(4) x Sp(2)

Number of representations: 19

3 x (V ,V ,0 ,0 ,0 ,0 ,0 ) chirality 3
3 x (V ,0 ,V ,0 ,0 ,0 ,0 ) chirality -3
3 x (0 ,V ,0 ,V ,0 ,0 ,0 ) chirality 3
3 x (0 ,0 ,V ,V ,0 ,0 ,0 ) chirality -3
2 x (V ,0 ,0 ,V ,0 ,0 ,0 )
2 x (0 ,V ,V ,0 ,0 ,0 ,0 )
2 x (V ,0 ,0 ,0 ,V ,0 ,0 )
2 x (V ,0 ,0 ,0 ,0 ,V ,0 )
2 x (V ,0 ,0 ,0 ,0 ,0 ,V )
1 x (0 ,V ,0 ,0 ,V ,0 ,0 )
1 x (0 ,0 ,V ,0 ,V ,0 ,0 )
2 x (0 ,0 ,0 ,V ,0 ,V ,0 )
1 x (0 ,0 ,0 ,0 ,V ,0 ,V )
2 x (0 ,0 ,0 ,0 ,0 ,V ,V )
2 x (0 ,0 ,0 ,0 ,A ,0 ,0 )
1 x (0 ,0 ,0 ,0 ,S ,0 ,0 )
5 x (0 ,0 ,0 ,0 ,0 ,A ,0 )
5 x (0 ,0 ,0 ,0 ,0 ,S ,0 )
1 x (0 ,0 ,0 ,0 ,0 ,0 ,S )

Summary:
Higgs: (2,1/2)+(2*,1/2)                    2
Non-chiral SM matter (Q,U,D,L,E,N):  0  0  0  0  0  0
Adjoints:                               0  0  0  0
Symmetric Tensors:                      0  0  0  0
Anti-Symmetric Tensors:                 0  0  0  0
Lepto-quarks: (3,-1/3),(3,2/3)             1  0
Non-SM (a,b,c,d)                       12  6  6  4
Hidden (Total dimension)             162 (chirality 0)
```

$$\sin^2(\theta_w) = .3610368$$

$$\frac{\alpha_3}{\alpha_2} = .8660246$$

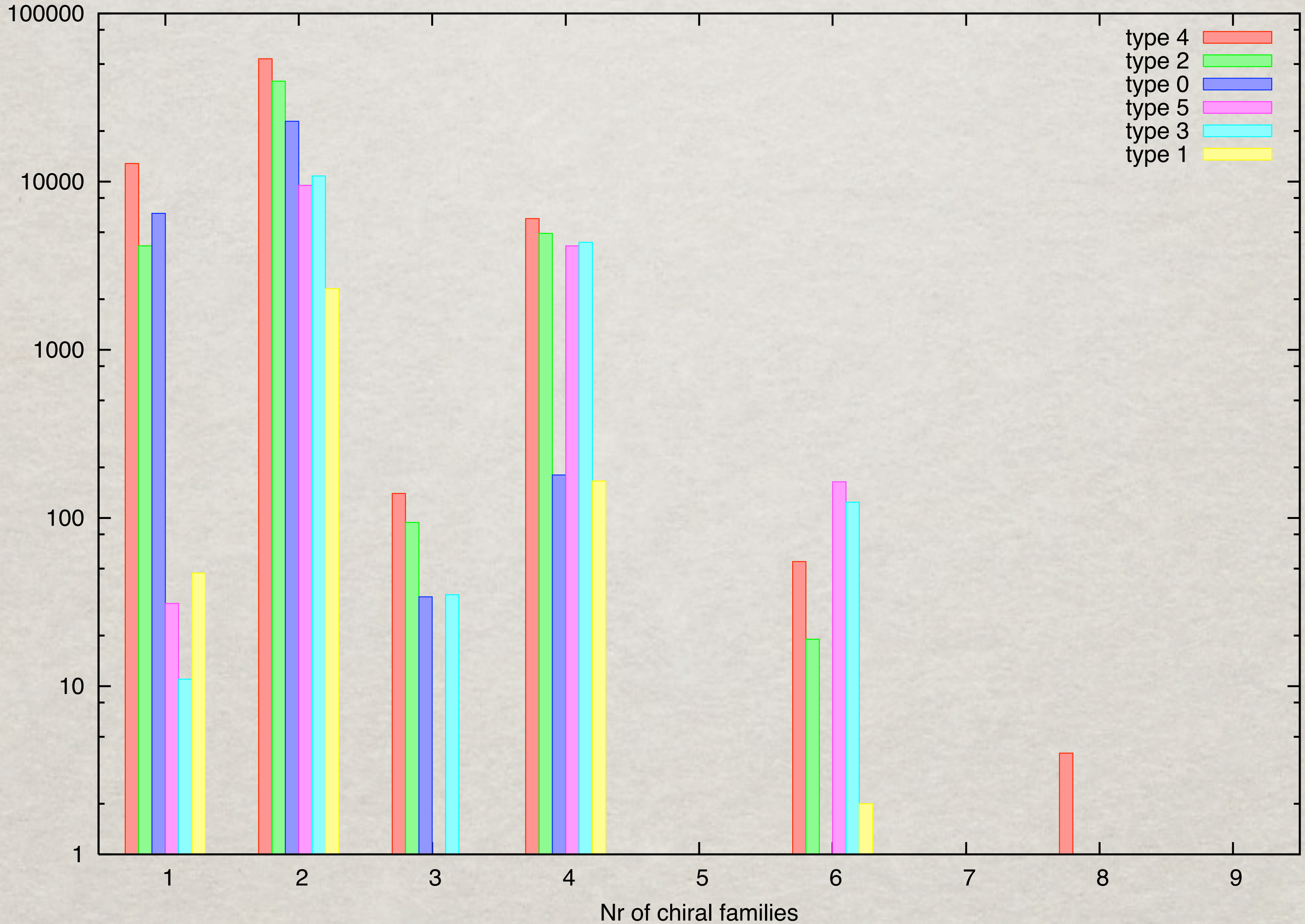
```
Standard model type: 6
Number of factors in hidden gauge group: 0
Gauge group: U(3) x Sp(2) x U(1) x U(1)

Number of representations: 19

 3 x  (V ,V ,0 ,0 ) chirality 3
 3 x  (V ,0 ,V ,0 ) chirality -3
 3 x  (V ,0 ,V*,0 ) chirality -3
 9 x  (0 ,V ,0 ,V ) chirality 3
 5 x  (0 ,0 ,V ,V ) chirality -3
 3 x  (0 ,0 ,V ,V*) chirality -3
 2 x  (V ,0 ,0 ,V )
10 x  (0 ,V ,V ,0 )
 2 x  (Ad,0 ,0 ,0 )
 2 x  (A ,0 ,0 ,0 )
```

....

```
    Higgs:   (2,1/2)+  2*,1/2)              5
Non-chiral SM matter   (Q,U,D,L,E,N):  0  0  0  3  1  0
  Adjoints:                            2  0  9  3
  Symmetric Tensors:                   1 10  7  3
  Anti-Symmetric Tensors:              1 14  3  2
    Lepto-quarks:   3,-1/3),  3,2/3)      1  0
 Non-SM    a,b,c,d)                     0  0  0  0
 Hidden    Total dimension)             0   (chirality 0)
```

$$\sin^2(\theta_w) = .5271853$$

$$\frac{\alpha_3}{\alpha_2} = 3.2320501$$


100000
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10
1
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type 5
type 3
type 1
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2
3
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6
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8
9
Nr of chiral families

Unbiased search*

Require only:

- U(3) from a single brane
- U(2) from a single brane
- Quarks and leptons, Y from at most four branes
- $G_{CP} \supset$ SU(3) × SU(2) × U(1)
- Chiral G_{CP} fermions reduce to quarks, leptons (plus non-chiral particles) but
- No fractionally charged mirror pairs
- Massless Y

Allowed Features

- (Anti)-quarks from anti-symmetric tensors
- leptons from anti-symmetric tensors
- family symmetries
- non-standard Y-charge assignments
- Unification (Pati-Salam, (flipped) SU(5), trinification)*
- Baryon and/or lepton number violation
- ....

*a,b,c,d may be identical

Chan-Paton gauge group

$$G_{CP} = U(3)_a \times \left\{ \begin{array}{c} U(2)_b \\ Sp(2)_b \end{array} \right\} \times G_c \qquad (\times G_d)$$

Embedding of Y:

$$Y = \alpha Q_a + \beta Q_b + \gamma Q_c + \delta Q_d + W_c + W_d$$

Q: Brane charges (for unitary branes)

W: Traceless generators

Classification

$$Y = (x - \frac{1}{3})Q_a + (x - \frac{1}{2})Q_b + \underbrace{xQ_C + (x-1)Q_D}$$

Distributed over c and d

Allowed values for x

1/2	Madrid model, Pati-Salam, Flipped SU(5)
0	(broken) SU(5)
1	Antoniadis, Kiritsis, Tomaras
-1/2, 3/2	
any	Trinification ($x = 1/3$) (orientable)

The basic orientable model

$$U(3) \times U(2) \times U(1) \times U(1)$$

$3 \times (V, V^*, 0, 0)$	(u,d)
$3 \times (V^*, 0, V, 0)$	d^c
$3 \times (V^*, 0, 0, V)$	u^c
$6 \times (0, V, V^*, 0)$	(e^-, ν) + H_1
$3 \times (0, V, 0, V^*)$	H_2
$3 \times (0, 0, V, V^*)$	e^+

"D-branes at singularities"

Results

- Searched all MIPFs with $<$ 1750 boundaries (4557 of 5403 MIPFs)
- 19345 chirally different SM embeddings found
- Tadpole conditions solved in 1900 cases (18 “old” ones)

Statistics

Value of x	Total
0	21303612
1/2	124006839*
1	12912
-1/2, 3/2	0
any	1250080

*Previous search: 45051902

Realizations

- Bottom-Up configuration: any brane configuration that yields 3 chiral families
- Top-Down configuration: any such configuration realized with boundary states
- String Vacuum: Top-down configuration with tadpole cancellation (with or without hidden sector)

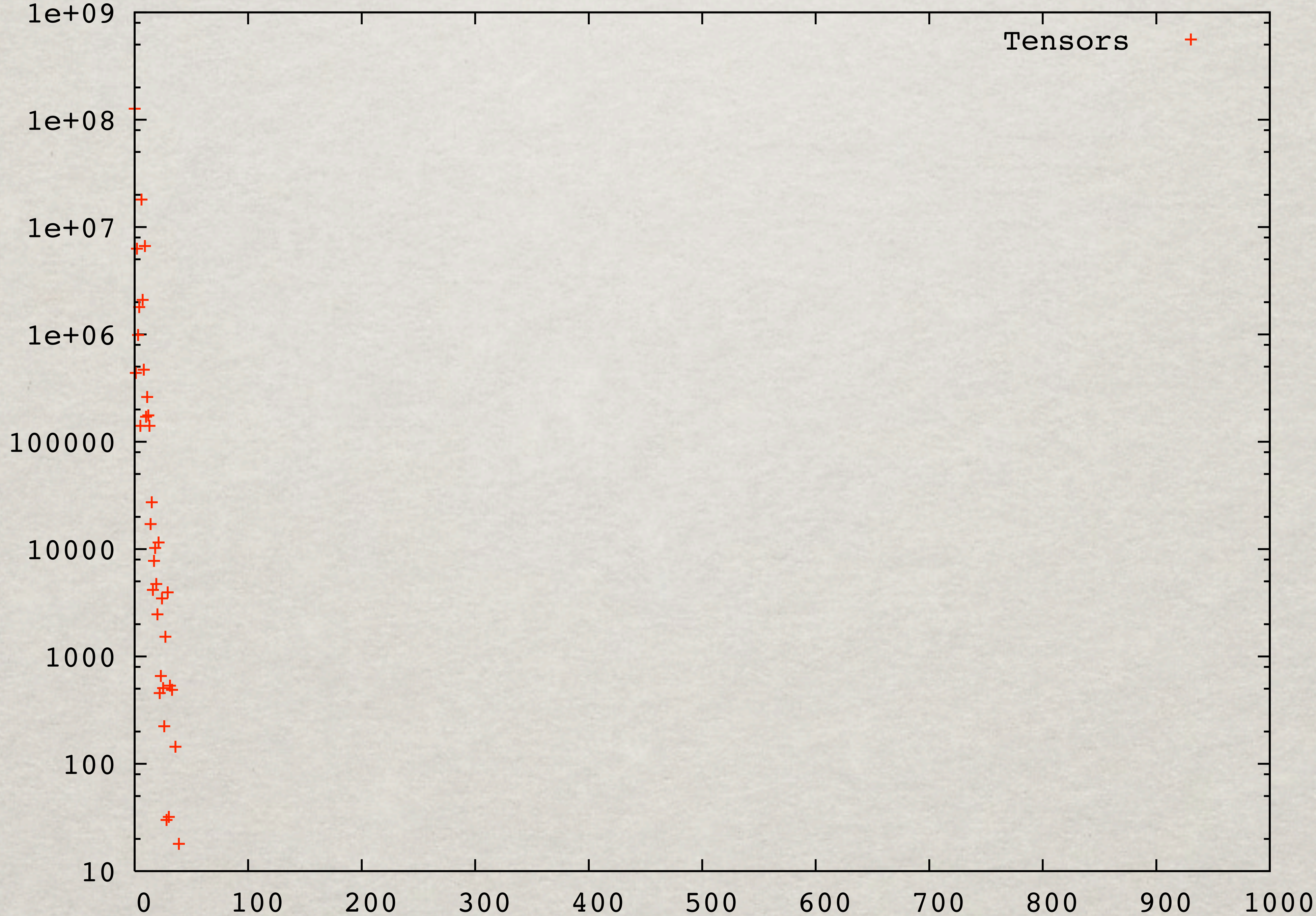
Bottom-up vs Top-down (1)

x	Config.	stack **c**	stack **d**	Bottom-up	Top-down	Occurrences	Solved
1/2	UUUU	C,D	C,D	27	9	5194	1
1/2	UUUU	C	C,D	103441	434	1056708	31
1/2	UUUU	C	C	10717308	156	428799	24
1/2	UUUU	C	F	351	0	0	0
1/2	UUU	C,D	-	4	1	24	0
1/2	UUU	C	-	215	5	13310	2
1/2	UUUR	C,D	C,D	34	5	3888	1
1/2	UUUR	C	C,D	185520	221	2560681	31
1/2	USUU	C,D	C,D	72	7	6473	2
1/2	USUU	C	C,D	153436	283	3420508	33
1/2	USUU	C	C	10441784	125	4464095	27
1/2	USUU	C	F	184	0	0	0
							Continued on next page

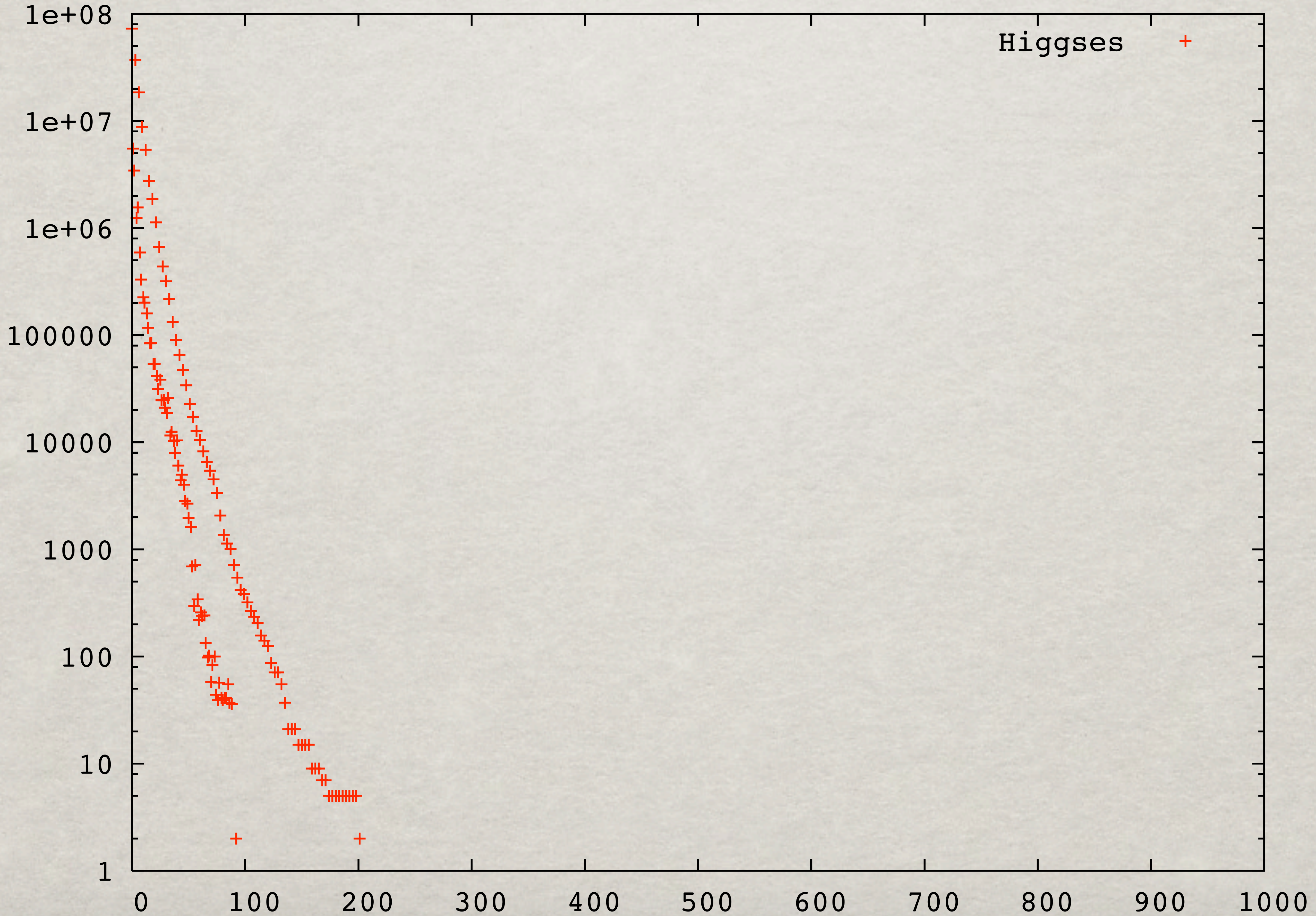
≤ 3 CP-chiral mirror pairs
≤ 3 CP-chiral Susy Higgs pairs
≤ 6 CP-chiral singlets (right-handed neutrinos)

x	Config.	stack **c**	stack **d**	Bottom-up	Top-down	Occurrences	Solved
1/2	USU	C	-	104	2	222	0
1/2	USU	C,D	-	8	1	4881	1
1/2	USUR	C	C,D	54274	31	49859327	19
1/2	USUR	C,D	C,D	36	2	858330	2
0	UUUU	C,D	C,D	5	5	4530	2
0	UUUU	C	C,D	8355	44	54102	2
0	UUUU	D	C,D	14	2	4368	0
0	UUUU	C	C	2890537	127	666631	9
0	UUUU	C	D	36304	16	6687	0
0	UUU	C	-	222	2	15440	1
0	UUUR	C,D	C	3702	39	171485	4
0	UUUR	C	C	5161452	289	4467147	32
0	UUUR	D	C	8564	22	50748	0
0	UUR	C	-	58	2	233071	2
0	UURR	C	C	24091	17	8452983	17
1	UUUU	C,D	C,D	4	1	1144	1
1	UUUU	C	C,D	16	5	10714	0
1	UUUU	D	C,D	42	3	3328	0
1	UUUU	C	D	870	0	0	0
1	UUUR	C,D	D	34	1	1024	0
1	UUUR	C	D	609	1	640	0
3/2	UUUU	C	D	9	0	0	0
3/2	UUUU	C,D	D	1	0	0	0
3/2	UUUU	C, D	C	10	0	0	0
3/2	UUUU	C,D	C,D	2	0	0	0
$*$	UUUU	C,D	C,D	2	2	5146	1
$*$	UUUU	C	C,D	10	7	521372	3
$*$	UUUU	D	C,D	1	1	116	0
$*$	UUUU	C	D	3	1	4	0

CP-Chiral Tensors



CP-chiral Higges



Most frequent models

nr	Total occ.	MIPFs	Chan-Paton Group	spectrum	x	Solved
1	9801844	648	$U(3) \times Sp(2) \times Sp(6) \times U(1)$	VVVV	1/2	Y!
2	8479808(16227372)	675	$U(3) \times Sp(2) \times Sp(2) \times U(1)$	VVVV	1/2	Y!
3	5775296	821	$U(4) \times Sp(2) \times Sp(6)$	VVV	1/2	Y!
4	4810698	868	$U(4) \times Sp(2) \times Sp(2)$	VVV	1/2	Y!
5	4751603	554	$U(3) \times Sp(2) \times O(6) \times U(1)$	VVVV	1/2	Y!
6	4584392	751	$U(4) \times Sp(2) \times O(6)$	VVV	1/2	Y
7	4509752(9474494)	513	$U(3) \times Sp(2) \times O(2) \times U(1)$	VVVV	1/2	Y!
8	3744864	690	$U(4) \times Sp(2) \times O(2)$	VVV	1/2	Y!
9	3606292	467	$U(3) \times Sp(2) \times Sp(6) \times U(3)$	VVVV	1/2	Y
10	3093933	623	$U(6) \times Sp(2) \times Sp(6)$	VVV	1/2	Y
11	2717632	461	$U(3) \times Sp(2) \times Sp(2) \times U(3)$	VVVV	1/2	Y!
12	2384626	560	$U(6) \times Sp(2) \times O(6)$	VVV	1/2	Y
13	2253928	669	$U(6) \times Sp(2) \times Sp(2)$	VVV	1/2	Y!
14	1803909	519	$U(6) \times Sp(2) \times O(2)$	VVV	1/2	Y!
15	1676493	517	$U(8) \times Sp(2) \times Sp(6)$	VVV	1/2	Y
16	1674416	384	$U(3) \times Sp(2) \times O(6) \times U(3)$	VVVV	1/2	Y
17	1654086	340	$U(3) \times Sp(2) \times U(3) \times U(1)$	VVVV	1/2	Y
18	1654086	340	$U(3) \times Sp(2) \times U(3) \times U(1)$	VVVV	1/2	Y
19	1642669	360	$U(3) \times Sp(2) \times Sp(6) \times U(5)$	VVVV	1/2	Y
20	1486664	346	$U(3) \times Sp(2) \times O(2) \times U(3)$	VVVV	1/2	Y!
21	1323363	476	$U(8) \times Sp(2) \times O(6)$	VVV	1/2	Y
22	1135702	350	$U(3) \times Sp(2) \times Sp(2) \times U(5)$	VVVV	1/2	Y!
23	1050764	532	$U(8) \times Sp(2) \times Sp(2)$	VVV	1/2	Y
24	956980	421	$U(8) \times Sp(2) \times O(2)$	VVV	1/2	Y
25	950003	449	$U(10) \times Sp(2) \times Sp(6)$	VVV	1/2	Y
26	910132	51	$U(3) \times U(2) \times Sp(2) \times O(1)$	AAVV	0	Y
...						
34	869428(1096682)	246	$U(3) \times Sp(2) \times U(1) \times U(1)$	VVVV	1/2	Y!
153	115466	335	$U(4) \times U(2) \times U(2)$	VVV	1/2	Y
225	71328	167	$U(3) \times U(3) \times U(3)$	VVV	1/3	

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13	2253928	669	$U(6) \times Sp(2) \times Sp(2)$	VVV	1/2	Y!
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17	1654086	340	$U(3) \times Sp(2) \times U(3) \times U(1)$	VVVV	1/2	Y
18	1654086	340	$U(3) \times Sp(2) \times U(3) \times U(1)$	VVVV	1/2	Y
19	1642669	360	$U(3) \times Sp(2) \times Sp(6) \times U(5)$	VVVV	1/2	Y
20	1486664	346	$U(3) \times Sp(2) \times O(2) \times U(3)$	VVVV	1/2	Y!
21	1323363	476	$U(8) \times Sp(2) \times O(6)$	VVV	1/2	Y
22	1135702	350	$U(3) \times Sp(2) \times Sp(2) \times U(5)$	VVVV	1/2	Y!
23	1050764	532	$U(8) \times Sp(2) \times Sp(2)$	VVV	1/2	Y
24	956980	421	$U(8) \times Sp(2) \times O(2)$	VVV	1/2	Y
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...						
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225	71328	167	$U(3) \times U(3) \times U(3)$	VVV	1/3	

Curiosities

nr	Total occ.	MIPFs	Chan-Paton Group	Spectrum	x	Solved
411	31000	17	$U(3) \times U(2) \times U(1) \times U(1)$	AAVA	0	Y
417	30396	26	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	Y
495	23544	14	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	
509	22156	17	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	Y
519	21468	13	$U(3) \times U(2) \times U(1) \times U(1)$	AAVA	0	Y
543	20176(*)	38	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
617	16845	296	$U(5) \times O(1)$	AV	0	Y
671	14744(*)	29	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	
761	12067	26	$U(3) \times U(2) \times U(1)$	AAS	1/2	Y!
762	12067	26	$U(3) \times U(2) \times U(1)$	AAS	0	Y!
1024	7466	7	$U(3) \times U(2) \times U(2) \times U(1)$	VAAV	1	
1125	6432	87	$U(3) \times U(3) \times U(3)$	VVV	*	Y
1201	5764(*)	20	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	
1356	5856(*)	10	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
1725	2864	14	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
1886	2381	115	$U(6) \times Sp(2)$	AV	1/2	Y!
1887	2381	115	$U(6) \times Sp(2)$	AV	0	Y!
1888	2381	115	$U(6) \times Sp(2)$	AV	1/2	Y!
17055	4	1	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	*	
19345	1	1	$U(5) \times U(2) \times O(3)$	ATV	0	

Curiosities

nr	Total occ.	MIPFs	Chan-Paton Group	Spectrum	x	Solved
411	31000	17	$U(3) \times U(2) \times U(1) \times U(1)$	AAVA	0	Y
417	30396	26	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	Y
495	23544	14	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	
509	22156	17	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	Y
519	21468	13	$U(3) \times U(2) \times U(1) \times U(1)$	AAVA	0	Y
543	20176(*)	38	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
617	16845	296	$U(5) \times O(1)$	AV	0	Y
671	14744(*)	29	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	
761	12067	26	$U(3) \times U(2) \times U(1)$	AAS	1/2	Y!
762	12067	26	$U(3) \times U(2) \times U(1)$	AAS	0	Y!
1024	7466	7	$U(3) \times U(2) \times U(2) \times U(1)$	VAAV	1	
1125	6432	87	$U(3) \times U(3) \times U(3)$	VVV	*	Y
1201	5764(*)	20	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	
1356	5856(*)	10	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
1725	2864	14	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
1886	2381	115	$U(6) \times Sp(2)$	AV	1/2	Y!
1887	2381	115	$U(6) \times Sp(2)$	AV	0	Y!
1888	2381	115	$U(6) \times Sp(2)$	AV	1/2	Y!
17055	4	1	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	*	
19345	1	1	$U(5) \times U(2) \times O(3)$	ATV	0	

Curiosities

nr	Total occ.	MIPFs	Chan-Paton Group	Spectrum	x	Solved
411	31000	17	$U(3) \times U(2) \times U(1) \times U(1)$	AAVA	0	Y
417	30396	26	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	Y
495	23544	14	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	
509	22156	17	$U(3) \times U(2) \times U(1) \times U(1)$	AAVS	0	Y
519	21468	13	$U(3) \times U(2) \times U(1) \times U(1)$	AAVA	0	Y
543	20176(*)	38	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
617	16845	296	$U(5) \times O(1)$	AV	0	Y
671	14744(*)	29	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	
761	12067	26	$U(3) \times U(2) \times U(1)$	AAS	1/2	Y!
762	12067	26	$U(3) \times U(2) \times U(1)$	AAS	0	Y!
1024	7466	7	$U(3) \times U(2) \times U(2) \times U(1)$	VAAV	1	
1125	6432	87	$U(3) \times U(3) \times U(3)$	VVV	*	Y
1201	5764(*)	20	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	
1356	5856(*)	10	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
1725	2864	14	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	1/2	Y
1886	2381	115	$U(6) \times Sp(2)$	AV	1/2	Y!
1887	2381	115	$U(6) \times Sp(2)$	AV	0	Y!
1888	2381	115	$U(6) \times Sp(2)$	AV	1/2	Y!

17055	4	1	$U(3) \times U(2) \times U(1) \times U(1)$	VVVV	*	
19345	1	1	$U(5) \times U(2) \times O(3)$	ATV	0	

Pati-Salam

```
Type:          U   S   S
Dimension      4   2   2
      5 x ( V ,0 ,V ) chirality -3
      3 x ( V ,V ,0 ) chirality 3
      2 x ( Ad,0 ,0 ) chirality 0
      2 x ( 0 ,A ,0 ) chirality 0
      7 x ( 0 ,0 ,A ) chirality 0
      4 x ( A ,0 ,0 ) chirality 0
      2 x ( 0 ,S ,0 ) chirality 0
      5 x ( 0 ,0 ,S ) chirality 0
      7 x ( 0 ,V ,V ) chirality 0
```

Pati-Salam (2)

```
Type:         U   U   U   U   U   S   U   O   U   O
Dimension     4   2   2   6   2   2   2   2   2   2
       4 x (  V  ,V  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 2
       1 x (  V  ,V*,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 1
       1 x (  V  ,0  ,V*,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality -1
       2 x (  V  ,0  ,V  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality -2
       2 x (  0  ,V  ,V*,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality -2
       2 x (  V  ,0  ,0  ,0  ,V*,0  ,0  ,0  ,0  ,0  ) chirality 0
       4 x (  V  ,0  ,0  ,0  ,0  ,V  ,0  ,0  ,0  ,0  ) chirality 0
       2 x (  0  ,S  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 0
       2 x (  A  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 0
       1 x (  Ad,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 0
       2 x (  V  ,0  ,0  ,0  ,V  ,0  ,0  ,0  ,0  ,0  ) chirality 0
       2 x (  0  ,0  ,S  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 0
       4 x (  0  ,V  ,0  ,0  ,0  ,0  ,V*,0  ,0  ,0  ) chirality 0
       2 x (  0  ,V  ,0  ,0  ,0  ,0  ,V  ,0  ,0  ,0  ) chirality 0
       2 x (  0  ,0  ,V  ,0  ,0  ,0  ,V*,0  ,0  ,0  ) chirality 0
       1 x (  0  ,Ad,0  ,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 0
       2 x (  V  ,0  ,0  ,0  ,0  ,0  ,V*,0  ,0  ,0  ) chirality 0
       2 x (  V  ,0  ,0  ,0  ,0  ,0  ,V  ,0  ,0  ,0  ) chirality 0
       1 x (  0  ,0  ,Ad,0  ,0  ,0  ,0  ,0  ,0  ,0  ) chirality 0
       2 x (  0  ,V  ,0  ,0  ,0  ,0  ,0  ,0  ,V*,0  ) chirality 0
       2 x (  0  ,0  ,V  ,0  ,0  ,0  ,0  ,0  ,V  ,0  ) chirality 0
```

Pati-Salam (2)

Type:	U	U	U	U	U	S	U	O	U	O	
Dimension	4	2	2	6	2	2	2	2	2	2	
4 x	V	V	0	0	0	0	0	0	0	0	chirality 2
1 x	V	V*	0	0	0	0	0	0	0	0	chirality 1
1 x	V	0	V*	0	0	0	0	0	0	0	chirality -1
2 x	V	0	V	0	0	0	0	0	0	0	chirality -2
2 x	0	V	V*	0	0	0	0	0	0	0	chirality -2
2 x	V	0	0	0	V*	0	0	0	0	0	chirality 0
4 x	V	0	0	0	0	V	0	0	0	0	chirality 0
2 x	0	S	0	0	0	0	0	0	0	0	chirality 0
2 x	A	0	0	0	0	0	0	0	0	0	chirality 0
1 x	Ad	0	0	0	0	0	0	0	0	0	chirality 0
2 x	V	0	0	0	V	0	0	0	0	0	chirality 0
2 x	0	0	S	0	0	0	0	0	0	0	chirality 0
4 x	0	V	0	0	0	0	V*	0	0	0	chirality 0
2 x	0	V	0	0	0	0	V	0	0	0	chirality 0
2 x	0	0	V	0	0	0	V*	0	0	0	chirality 0
1 x	0	Ad	0	0	0	0	0	0	0	0	chirality 0
2 x	V	0	0	0	0	0	V*	0	0	0	chirality 0
2 x	V	0	0	0	0	0	V	0	0	0	chirality 0
1 x	0	0	Ad	0	0	0	0	0	0	0	chirality 0
2 x	0	V	0	0	0	0	0	0	V*	0	chirality 0
2 x	0	0	V	0	0	0	0	0	V	0	chirality 0

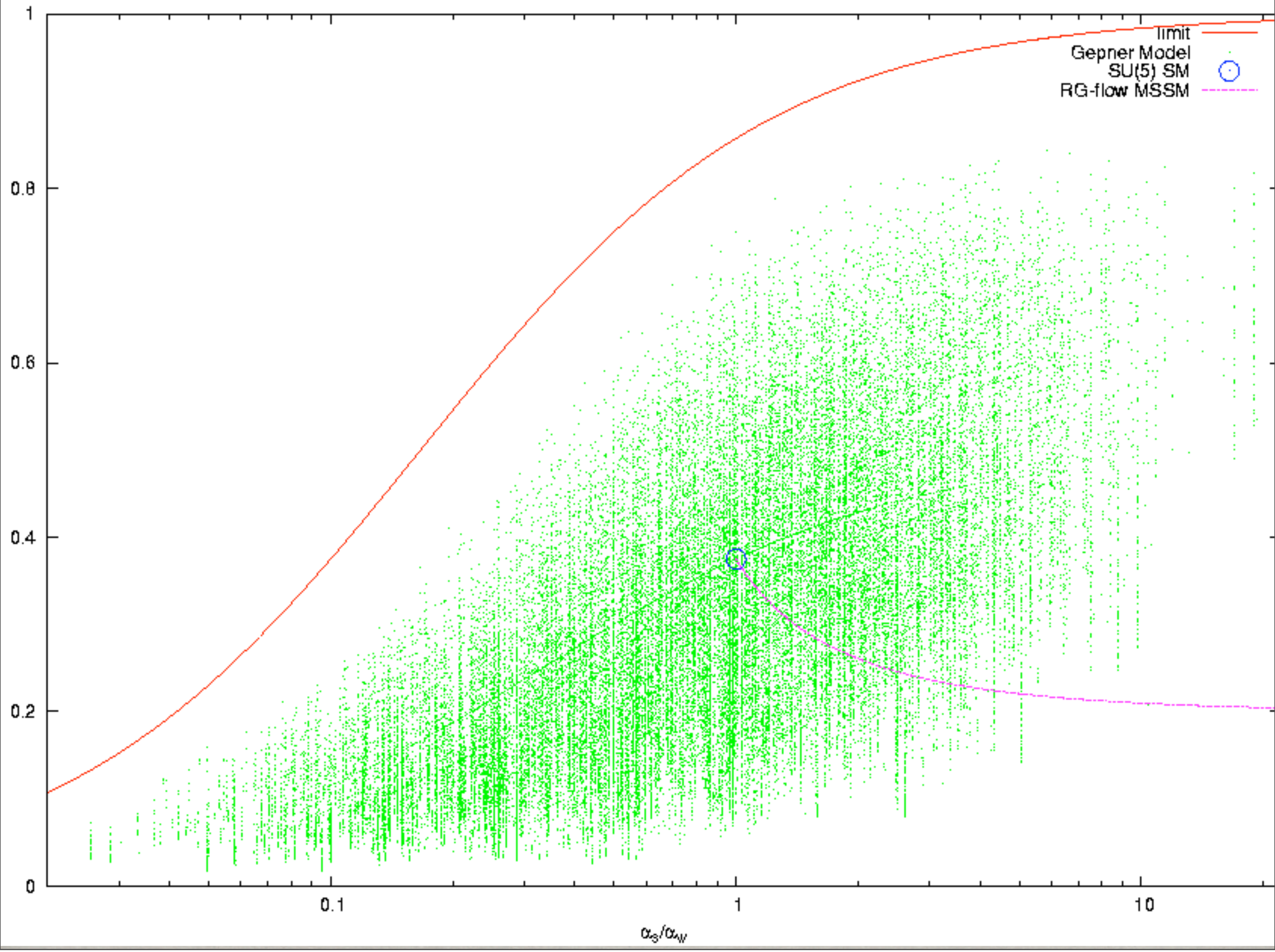
Trinification

```
         U   U   U   O   O   U   U   O   U   O
         3   3   3   4   2   6  12  12  12   4
3 x  (V ,V ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ) chirality 3
3 x  (V ,0 ,V ,0 ,0 ,0 ,0 ,0 ,0 ,0 ) chirality -3
3 x  (0 ,V ,V*,0 ,0 ,0 ,0 ,0 ,0 ,0 ) chirality -3
1 x  (0 ,0 ,0 ,V ,0 ,V ,0 ,0 ,0 ,0 ) chirality -1
1 x  (0 ,0 ,0 ,0 ,0 ,S ,0 ,0 ,0 ,0 ) chirality 1
5 x  (0 ,0 ,0 ,0 ,0 ,0 ,0 ,V ,V ,0 ) chirality 1
3 x  (0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,S ,0 ) chirality 1
1 x  (0 ,0 ,0 ,0 ,0 ,A ,0 ,0 ,0 ,0 ) chirality -1
2 x  (0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,A ,0 ) chirality -2
1 x  (0 ,0 ,0 ,V ,0 ,0 ,0 ,0 ,V ,0 ) chirality 1
1 x  (0 ,0 ,0 ,0 ,V ,0 ,0 ,0 ,V ,0 ) chirality 1
1 x  (0 ,0 ,0 ,0 ,0 ,V ,0 ,V ,0 ,0 ) chirality 1
1 x  (0 ,0 ,0 ,0 ,0 ,V ,0 ,0 ,V ,0 ) chirality -1
1 x  (0 ,0 ,0 ,0 ,0 ,0 ,V ,V ,0 ,0 ) chirality 1
1 x  (0 ,0 ,0 ,0 ,0 ,0 ,V ,0 ,V ,0 ) chirality -1
1 x  (0 ,0 ,0 ,0 ,0 ,V ,0 ,0 ,0 ,V ) chirality -1
1 x  (0 ,0 ,0 ,V ,V ,0 ,0 ,0 ,0 ,0 ) chirality 0
1 x  (0 ,0 ,0 ,0 ,S ,0 ,0 ,0 ,0 ,0 ) chirality 0
1 x  (0 ,0 ,0 ,0 ,0 ,Ad,0 ,0 ,0 ,0 ) chirality 0
1 x  (0 ,0 ,0 ,0 ,0 ,0 ,Ad,0 ,0 ,0 ) chirality 0
3 x  (0 ,0 ,0 ,0 ,0 ,0 ,0 ,S ,0 ,0 ) chirality 0
3 x  (0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,Ad,0 ) chirality 0
1 x  (0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,0 ,S ) chirality 0
2 x  (0 ,0 ,0 ,0 ,V ,V ,0 ,0 ,0 ,0 ) chirality 0
1 x  (0 ,0 ,0 ,0 ,V ,0 ,0 ,V ,0 ,0 ) chirality 0
2 x  (0 ,0 ,0 ,0 ,0 ,V ,0 ,0 ,V*,0 ) chirality 0
2 x  (0 ,0 ,0 ,0 ,0 ,0 ,V ,0 ,V*,0 ) chirality 0
1 x  (0 ,0 ,0 ,0 ,V ,0 ,0 ,0 ,0 ,V ) chirality 0
1 x  (0 ,0 ,0 ,0 ,0 ,0 ,0 ,V ,0 ,V ) chirality 0
```

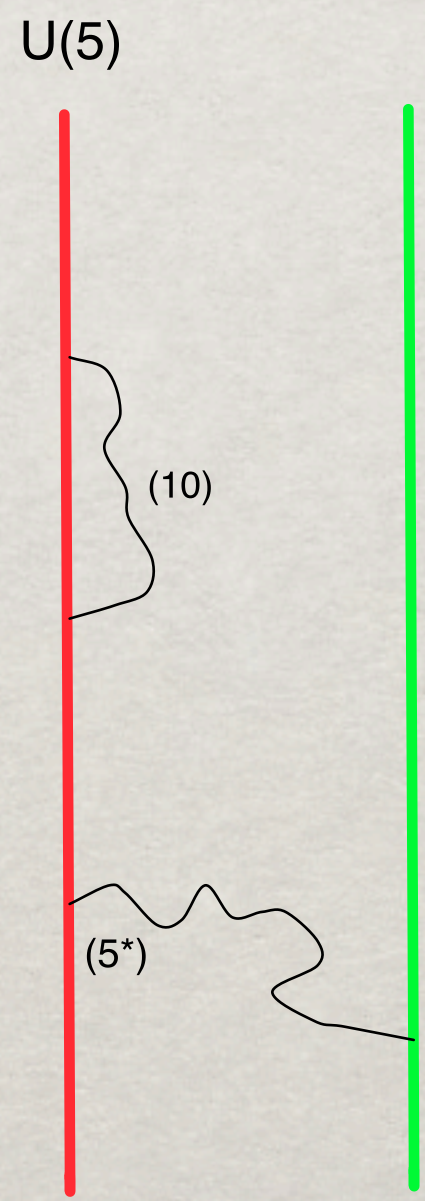
Trinification

		U	U	U	O	O	U	U	O	U	O	
		3	3	3	4	2	6	12	12	12	4	
3	x	(V	V	0	0	0	0	0	0	0	0)	chirality 3
3	x	(V	0	V	0	0	0	0	0	0	0)	chirality -3
3	x	(0	V	V*	0	0	0	0	0	0	0)	chirality -3
1	x	(0	0	0	V	0	V	0	0	0	0)	chirality -1
1	x	(0	0	0	0	0	S	0	0	0	0)	chirality 1
5	x	(0	0	0	0	0	0	0	V	V	0)	chirality 1
3	x	(0	0	0	0	0	0	0	0	S	0)	chirality 1
1	x	(0	0	0	0	0	A	0	0	0	0)	chirality -1
2	x	(0	0	0	0	0	0	0	0	A	0)	chirality -2
1	x	(0	0	0	V	0	0	0	0	V	0)	chirality 1
1	x	(0	0	0	0	V	0	0	0	V	0)	chirality 1
1	x	(0	0	0	0	0	V	0	V	0	0)	chirality 1
1	x	(0	0	0	0	0	V	0	0	V	0)	chirality -1
1	x	(0	0	0	0	0	0	V	V	0	0)	chirality 1
1	x	(0	0	0	0	0	0	V	0	V	0)	chirality -1
1	x	(0	0	0	0	0	V	0	0	0	V)	chirality -1
1	x	(0	0	0	V	V	0	0	0	0	0)	chirality 0
1	x	(0	0	0	0	S	0	0	0	0	0)	chirality 0
1	x	(0	0	0	0	0	Ad	0	0	0	0)	chirality 0
1	x	(0	0	0	0	0	0	Ad	0	0	0)	chirality 0
3	x	(0	0	0	0	0	0	0	S	0	0)	chirality 0
3	x	(0	0	0	0	0	0	0	0	Ad	0)	chirality 0
1	x	(0	0	0	0	0	0	0	0	0	S)	chirality 0
2	x	(0	0	0	0	V	V	0	0	0	0)	chirality 0
1	x	(0	0	0	0	V	0	0	V	0	0)	chirality 0
2	x	(0	0	0	0	0	V	0	0	V*	0)	chirality 0
2	x	(0	0	0	0	0	0	V	0	V*	0)	chirality 0
1	x	(0	0	0	0	V	0	0	0	0	V)	chirality 0
1	x	(0	0	0	0	0	0	0	V	0	V)	chirality 0

Unification


limit
Gepner Model
SU(5) SM
RG-flow MSSM
0
0.2
0.4
0.6
0.8
1
0.1
1
10
α_S/α_W

SU(5) models



(FLIPPED) SU(5) MODELS

M. Cvetic, I. Papadimitriou and G. Shiu, *"Supersymmetric three family SU(5) grand unified models from type IIA orientifolds with intersecting D6-branes,"* Nucl. Phys. B **659** (2003) 193 [Erratum-ibid. B **696** (2004) 298] [ArXiv:hep-th/0212177].

C. M. Chen, T. Li and D. V. Nanopoulos, *"Flipped and unflipped SU(5) as type IIA flux vacua,"* [ArXiv:hep-th/0604107].

R. Blumenhagen, B. Kors, D. Lust and T. Ott, *"The standard model from stable intersecting brane world orbifolds,"* Nucl. Phys. B **616** (2001) 3 [ArXiv:hep-th/0107138].

J. R. Ellis, P. Kanti and D. V. Nanopoulos, *"Intersecting branes flip SU(5),"* Nucl. Phys. B **647** (2002) 235 [ArXiv:hep-th/0206087].

M. Axenides, E. Floratos and C. Kokorelis, *"SU(5) unified theories from intersecting branes,"* JHEP **0310** (2003) 006 [ArXiv:hep-th/0307255].

C. M. Chen, G. V. Kraniotis, V. E. Mayes, D. V. Nanopoulos and J. W. Walker, *"A K-theory anomaly free supersymmetric flipped SU(5) model from intersecting branes,"* Phys. Lett. B **625** (2005) 96 [ArXiv:hep-th/0507232].

SU(5)

```
Type:            U   O   O
Dimension        5   1   1
          3 x  (A ,0 ,0 ) chirality 3
         11 x  (V ,V ,0 ) chirality -3
          8 x  (S ,0 ,0 ) chirality 0
          3 x  (Ad,0 ,0 ) chirality 0
          1 x  (0 ,A ,0 ) chirality 0
          3 x  (0 ,V ,V ) chirality 0
          8 x  (V ,0 ,V ) chirality 0
          2 x  (0 ,S ,0 ) chirality 0
          4 x  (0 ,0 ,S ) chirality 0
          4 x  (0 ,0 ,A ) chirality 0
```

Note: gauge group is just SU(5)!

Flipped SU(5)

```
Type:          U   U
Dimension      5   1
     11 x  (0 ,S ) chirality 3
      3 x  (A ,0 ) chirality 3
      5 x  (V ,V ) chirality -3
      8 x  (S ,0 ) chirality 0
      9 x  (Ad,0 ) chirality 0
      5 x  (0 ,Ad) chirality 0
      4 x  (0 ,A ) chirality 0
     12 x  (V ,V*) chirality 0
```

$$Y = \frac{1}{6}Q_a + \frac{1}{2}Q_c$$

Flipped SU(5)

```
Type:          U   U
Dimension      5   1
    11 x  (0 ,S ) chirality 3
     3 x  (A ,0 ) chirality 3
     5 x  (V ,V ) chirality -3
     8 x  (S ,0 ) chirality 0
     9 x  (Ad,0 ) chirality 0
     5 x  (0 ,Ad) chirality 0
     4 x  (0 ,A ) chirality 0
    12 x  (V ,V*) chirality 0
```

$$Y = \frac{1}{6} Q_a + \frac{1}{2} Q_c$$

Non-trivial U(1) anomaly cancellation!

SU(5) x U(1)

```
Type:          U   U
Dimension      5   1
     11 x  (0 ,S ) chirality 3
      3 x  (A ,0 ) chirality 3
      5 x  (V ,V ) chirality -3
      8 x  (S ,0 ) chirality 0
      9 x  (Ad,0 ) chirality 0
      5 x  (0 ,Ad) chirality 0
      4 x  (0 ,A ) chirality 0
     12 x  (V ,V*) chirality 0
```

$$Y = -\frac{2}{3}Q_a + \frac{1}{2}Q_b$$

Yukawa couplings

Standard SU(5) couplings

$$\mathcal{O}_1 \sim (\bar{\psi}^c)_\alpha \psi^{\alpha\beta} H_\beta \quad , \quad \mathcal{O}_2 \sim \epsilon_{\alpha\beta\gamma\delta\epsilon} (\bar{\psi}^c)^{\alpha\beta} \psi^{\gamma\delta} H^\epsilon$$

U(5) brane charges

1-2+1=0 -2-2-1=5

SU(5): no u,c,t couplings
flipped SU(5): no d,s,b coupings

Possible ways out:

* Higher dimension operators
* Composite condensate with charge 5
* Instantons

Requires additional and implausible dynamics

The unification dilemma

- Data suggest: Coupling unification*, no fractional charges
- Heterotic string: Wrong scale, fractional charges
- $x = \frac{1}{2}$ brane models: No unification, fractional charges
  No prediction for scale
- U(5) brane models: Unification, no fractional charges
  No prediction for scale
  No (u,c,t) Yukawa's

* assuming gauginos

Calabi-Yau dependence (1)

Tensor product	MIPF	h_{11}	h_{12}	Scalars	$x=0$	$x=\frac{1}{2}$	$x=*$	Success rate
(1,1,1,1,7,16)	30	11	35	207	1698	388	0	2.1×10^{-3}
(1,1,1,1,7,16)	31	5	29	207	890	451	0	1.35×10^{-3}
(1,4,4,4,4)	53	20	20	150	2386746	250776	0	4.27×10^{-4}
(1,4,4,4,4)	54	3	51	213	5400	5328	4248	3.92×10^{-4}
(6,6,6,6)	37	3	59	223	0	946432	0	2.79×10^{-4}
(1,1,1,1,10,10)	50	12	24	183	1504	508	36	2.63×10^{-4}
(1,1,1,1,10,10)	56	4	40	219	244	82	0	2.01×10^{-4}
(1,1,1,1,8,13)	5	20	20	140	328	27	0	1.93×10^{-4}
(1,1,1,1,7,16)	26	20	20	140	157	14	0	1.72×10^{-4}
(1,1,7,7,7)	9	7	55	276	7163	860	0	1.59×10^{-4}
(1,1,1,1,7,16)	32	23	23	217	135	20	0	1.56×10^{-4}
(1,4,4,4,4)	52	3	51	253	110493	8303	0	1.02×10^{-4}
(1,4,4,4,4)	13	3	51	250	238464	168156	0	1.01×10^{-4}
(1,1,1,2,4,10)	44	12	24	225	704	248	0	1.01×10^{-4}
(1,1,1,1,1,2,10)	21	20	20	142	2	1	0	1.00×10^{-4}
(1,1,1,1,1,4,4)	124	0	0	78	729	0	0	9.8×10^{-5}
(4,4,10,10)	79	7	43	215	0	57924	0	9.39×10^{-5}
(4,4,10,10)	77	5	53	232	0	1068926	0	8.29×10^{-5}
(1,4,4,4,4)	77	3	63	248	0	1024	0	8.12×10^{-5}
(4,4,10,10)	74	9	57	249	0	1480812	0	8.06×10^{-5}
(1,1,1,1,1,2,10)	24	20	20	142	0	0	6	7.87×10^{-5}

Calabi-Yau dependence (2)

(1,1,7,7,7)	17	10	46	220	1662	624	108	4.76×10^{-5}
(2,2,2,6,6)	106	3	51	235	0	201728	0	4.74×10^{-5}
(1,1,1,16,22)	7	20	20	140	244	19	0	4.67×10^{-5}
(1,2,4,4,10)	65	6	30	196	0	1386	0	4.41×10^{-5}
(4,4,10,10)	66	6	48	223	0	61568	0	4.33×10^{-5}
(1,4,4,4,4)	57	4	40	252	0	266328	58320	4.19×10^{-5}
(1,4,4,4,4)	80	7	37	200	0	1968	1408	4.15×10^{-5}
(6,6,6,6)	58	3	43	207	0	190464	0	3.93×10^{-5}
(1,1,1,1,10,10)	36	20	20	140	266	26	6	3.82×10^{-5}
(1,1,1,4,4,4)	125	12	24	214	351	0	0	3.62×10^{-5}
(4,4,10,10)	14	4	46	219	0	114702	0	3.3×10^{-5}
(1,1,1,1,10,10)	33	20	20	140	47	5	0	3.21×10^{-5}
...								...
(3,3,3,3,3)	6	21	17	234	0	192	0	6.54×10^{-6}
...								...
(3,3,3,3,3)	4	5	49	258	0	24	0	8.17×10^{-7}
...								...
(3,3,3,3,3)	2	49	5	258	6	27	6	1.65×10^{-9}
...								...

Conclusions

Conclusions

- Classification and construction of bottom-up models

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- Huge number of bottom-up possibilities

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- Huge number of bottom-up possibilities
- Huge number of top-down models

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- Huge number of top-down models
- Still, only small fraction of bottom-up options realized

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- Huge number of top-down models
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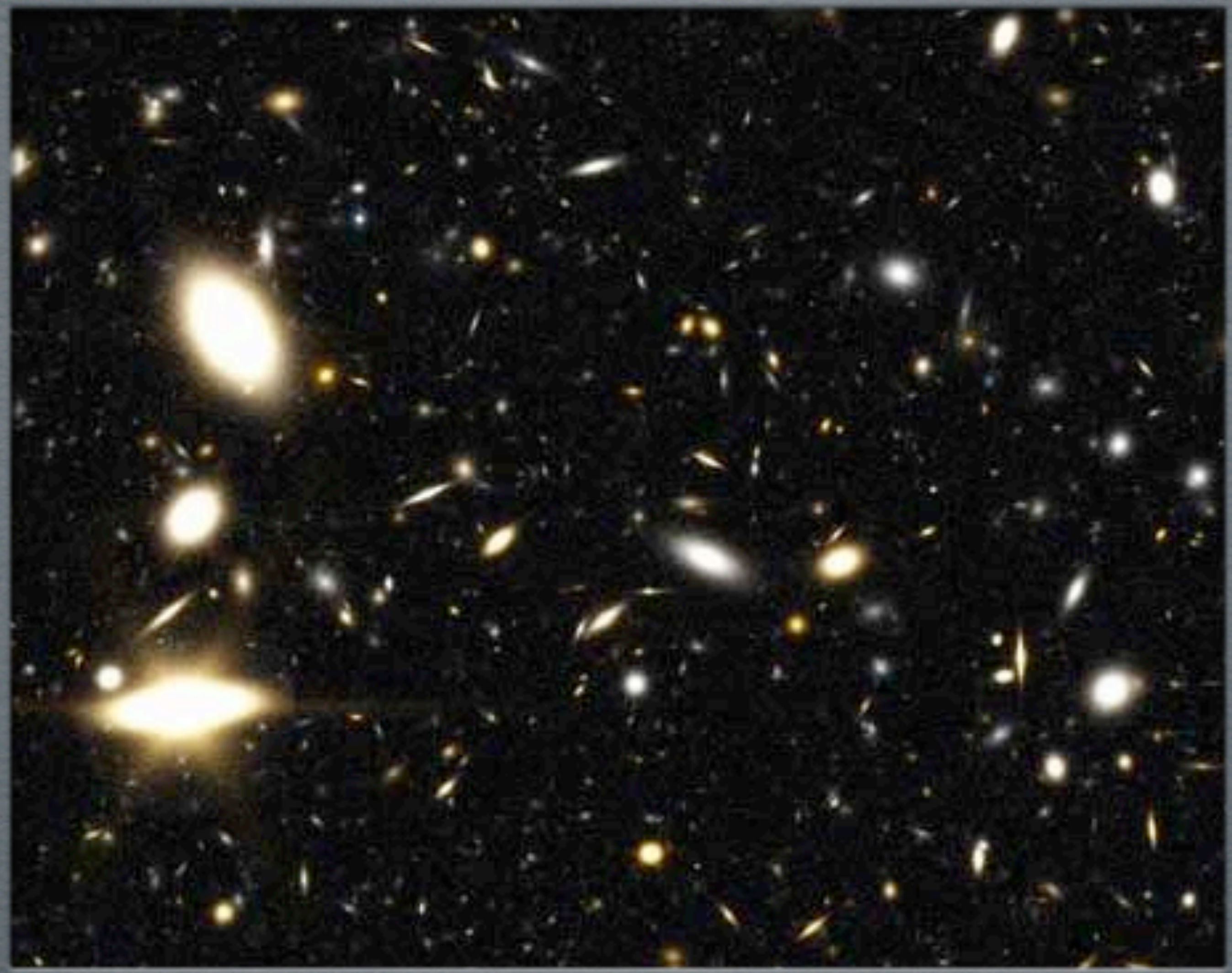
- Results dominated by $x=1/2$

Conclusions

- Classification and construction of bottom-up models
- Huge number of bottom-up possibilities
- Huge number of top-down models
- Still, only small fraction of bottom-up options realized
- Results dominated by x=1/2
- Very clean SU(5)'s....

Conclusions

- Classification and construction of bottom-up models
- Huge number of bottom-up possibilities
- Huge number of top-down models
- Still, only small fraction of bottom-up options realized
- Results dominated by x=1/2
- Very clean SU(5)'s....
- ....But are they good for anything?



It's just one small step:
874 Hodge numbers scanned
at least 30000 known (M. Kreuzer)