Orientifold GUTs

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(with E. Kiritsis and M. Lennek)

NIKHEF

“GUTs in Strings”
DESY, 5 februari 2009

Alternative Title:

Guts in Strings

Guts vs. Strings

GUTs: selling points

- Beautiful!
- Unifies 3 of the 4 known interactions
- Explains family structure
- Explains charge quantization
- Predicts $\sin^2\theta_w$
- Baryogenesis?

Around 1983:

Experimental confirmation seemed imminent:

First Results from a Superconductive Detector for Moving Magnetic Monopoles

Blas Cabrera

Physics Department, Stanford University, Stanford, California 94305

(Received 5 April 1982)

Proton decay experiments were starting...

The expectations were reminiscent of those regarding SUSY at the LHC

H. Georgi,
Fourth workshop on Grand Unification
Philadelphia,1983

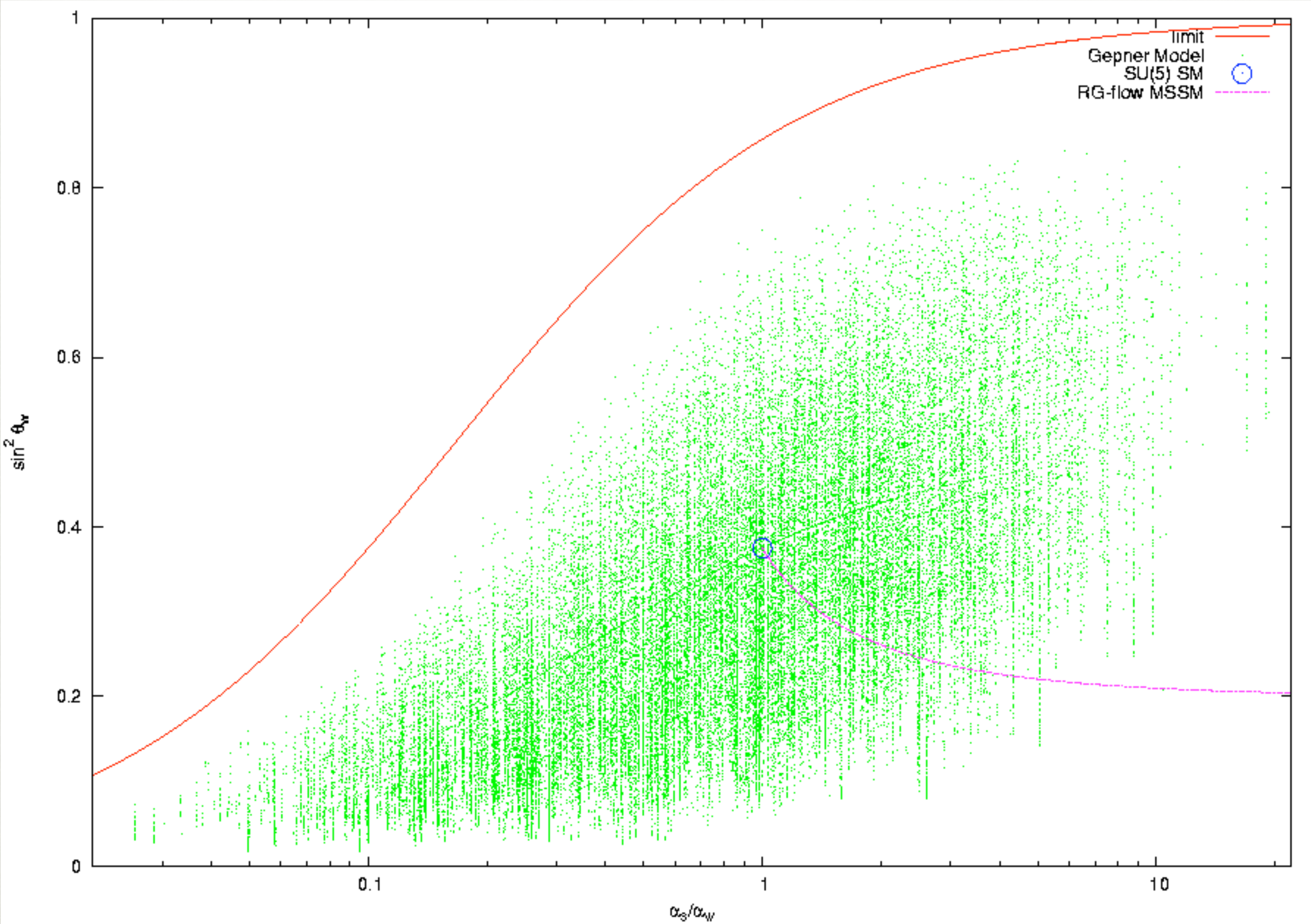
GUTs in strings?

Guts in Strings?

- Beauty: implausible selection criterion in the landscape.
- Unification of interactions: string theory not only unifies the three gauge interactions, but also gravity, without any need for GUTs.

GUTs in Strings?

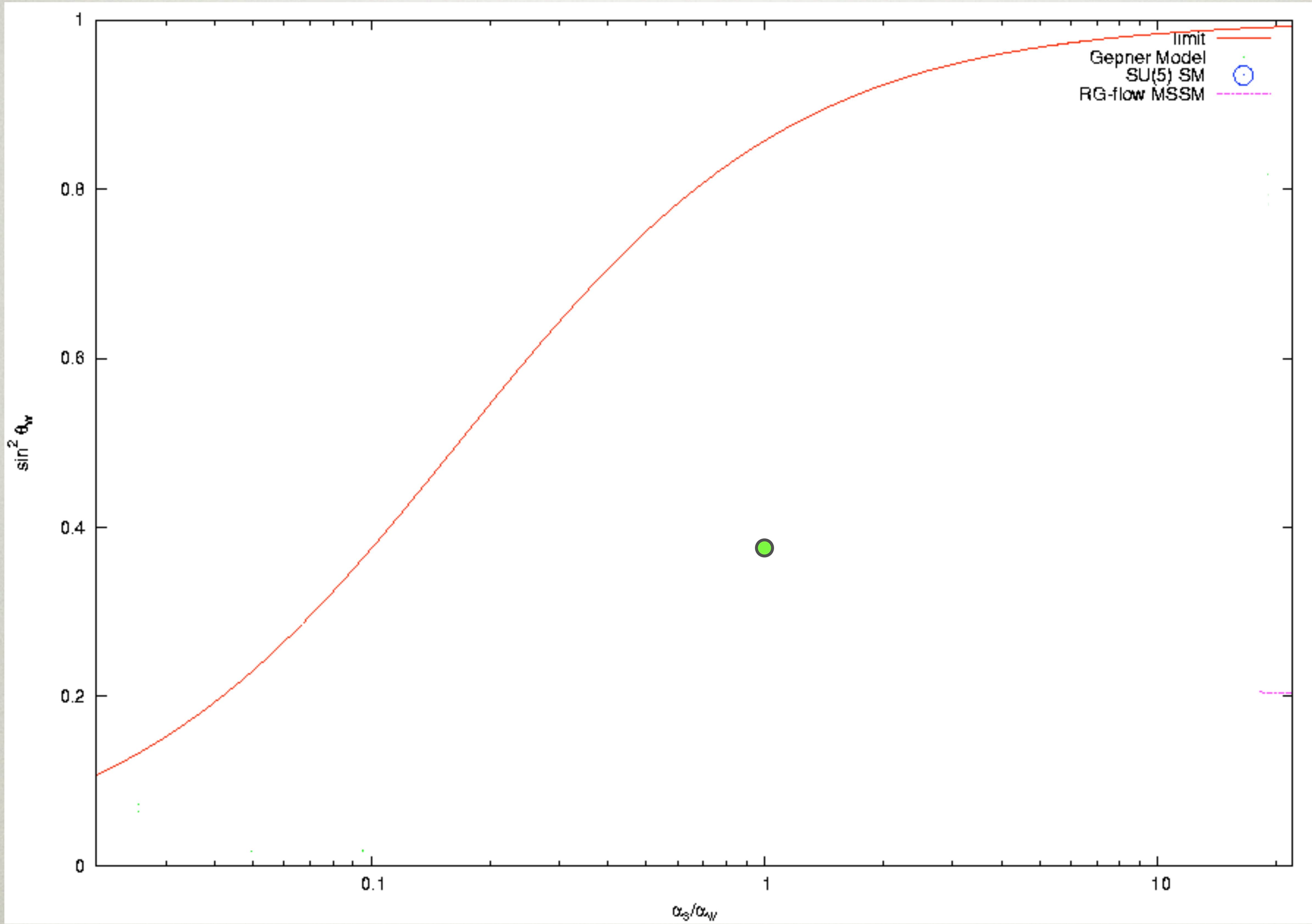
Coupling constant unification



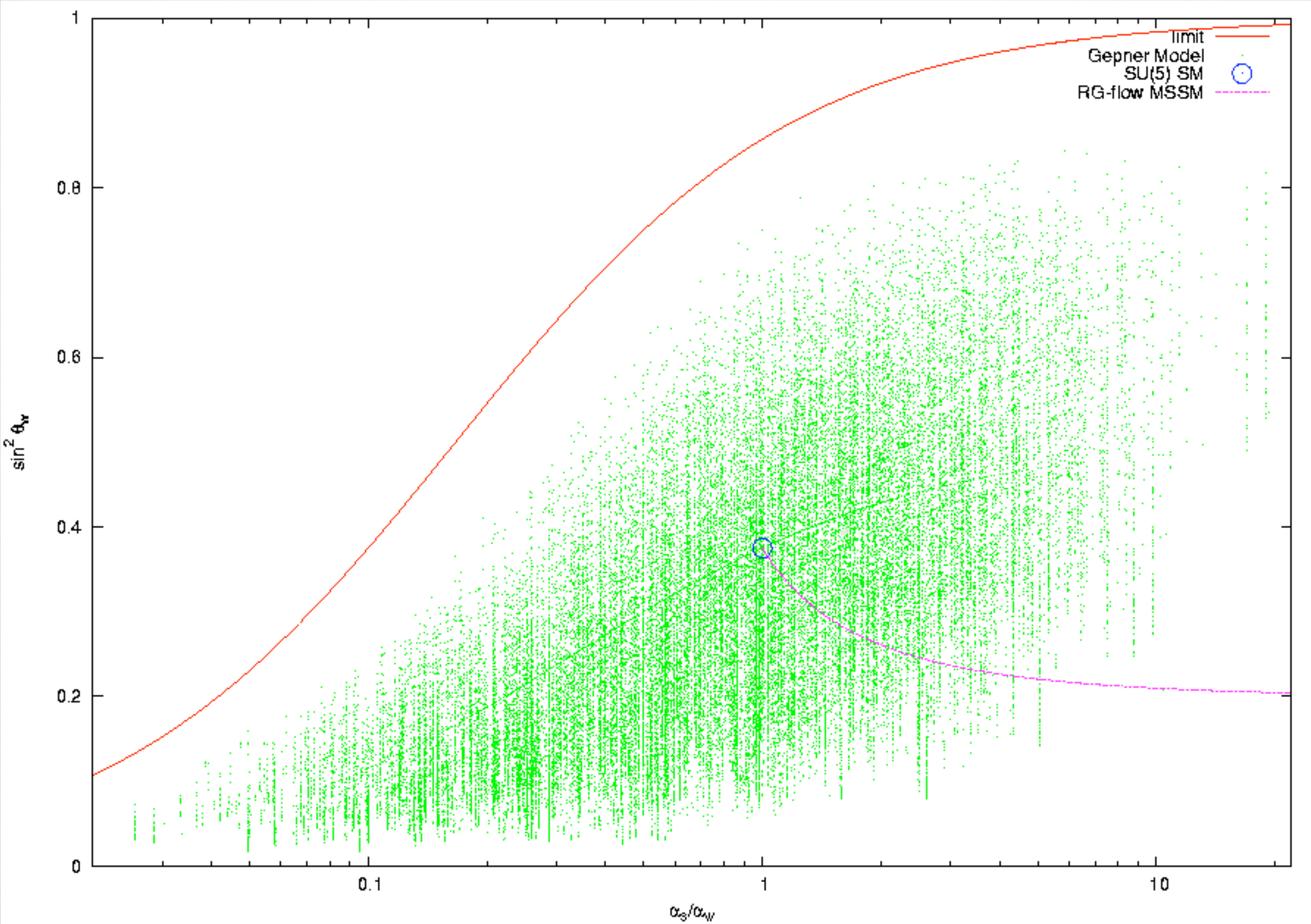
Dijkstra, Huiszoon, Schellekens, **Nucl.Phys.B710:3-57,2005**

We are using orientifolds or heterotic strings to get some idea about generic features of the landscape.

So what looks more generic:



Heterotic Strings



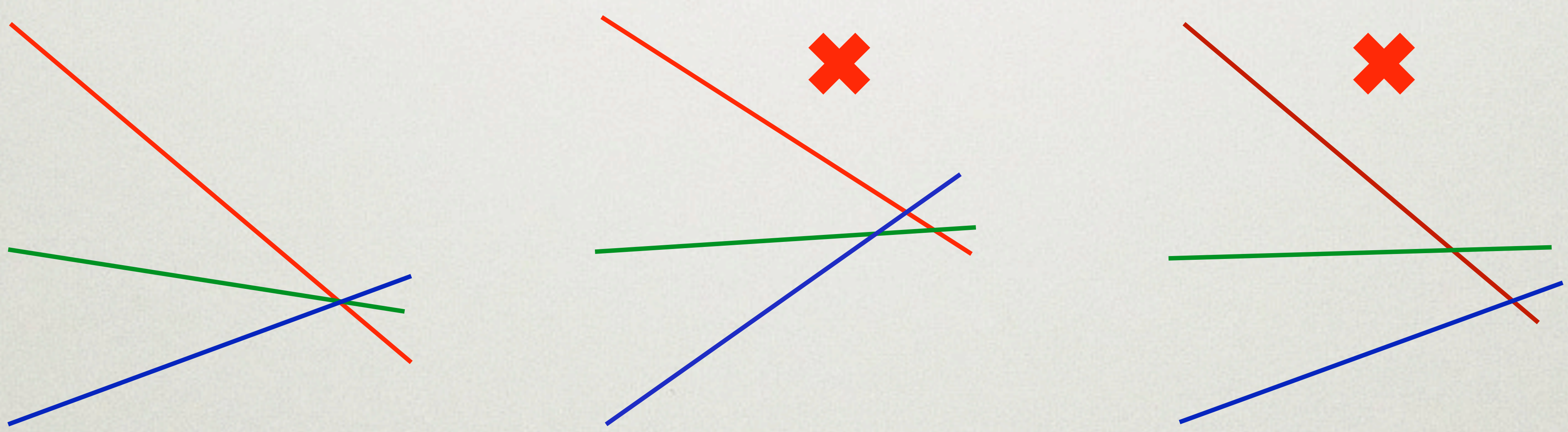
Orientifolds

Evidence for GUTs (without strings)

But not predicted by strings

(but can be “accomodated”)

Better options:



GUTs in Strings?

family structure

GUTs emerge “naturally” in compactified $E_8 \times E_8$ Heterotic strings:

- Embedding of the spin-connection in the gauge group (CHSW, 1984)
- “Bosonic string map” (LLS, 1986)

Bosonic string map*

One-to-one map of the characters of the 4-dimensional covariant NSR model to the characters of $SO(10) \times E_8$ (affine level 1)

This fact can be used to build heterotic string partition functions starting from a diagonal bosonic or type-II partition function:

$$\sum_i \bar{\chi}_i^{\mathrm{NSR}}(\bar{\tau}) \chi_i^{SO(10)\times E_8}(\tau) \times \ldots$$

Automatically yields chiral spectra with a number of (16)'s of SO(10).

This fact was exploited by Gepner in 1987.

(*) Lerche, Lüst, Schellekens (1986)

Bosonic string map

Using a simple current extension one can get E6 ⊃ SO(10)

By orbifoldings one can get subgroups of SO(10)

There is a large network* of related string theories for which the structure of one family can be traced back to the characters of the 4-D NSR models:

$$D = 4 \rightarrow SO(10) \text{ - like family structure}$$

The existence of a GUT group SO(10) at any scale is not really required.

(*) Includes the "mini-landscape"? (Talks by Ratz, Nilles, Schmidt, Schmidt-Hoberg, Ramos)

$D = 4 \rightarrow SO(10)$ - like family structure

A triumph for (heterotic) string theory!
Conceptually this is far superior to field theory GUTs:

- Dictates the choice of SO(10) (or SU(5), E6) over most other Lie algebras.
- Dictates the choice of (16)'s of SO(10) over any other anomaly free representation.
- Anomaly cancellation is not an ad-hoc constraint as it is in QFT

Even if this does not work, one may appeal to the slightly less powerful statement that the (16) of SO(10) (and its branchings) is among the few chiral representations allowed at affine level 1.

Even better:
$SU(3)_1 \times SU(2)_1 \times U(1)_{30}$
(the standard U(1) normalization for coupling constant convergence)
has a simple current extension to SU(5).

This means that any such SM realization is an orbifold of an SU(5).

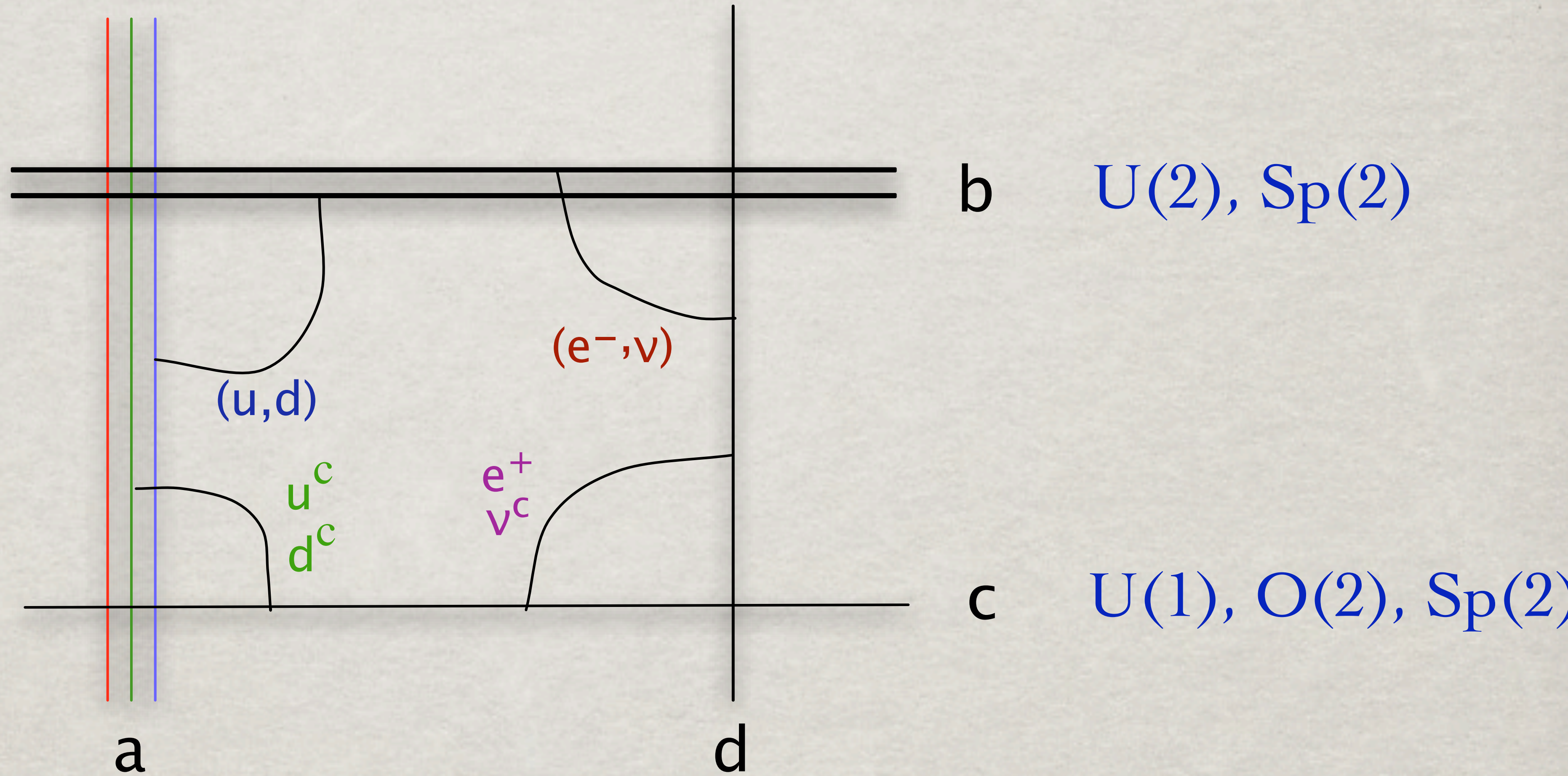
But what about other parts of the landscape?

The best studied alternative are orientifold/intersecting brane models.

(F-theory GUTs *(Vafa, Heckman)* assume GUTs *ab initio,* so there is nothing to discuss.)

Orientifolds can produce the right family structure without any apparent relation to SO(10):

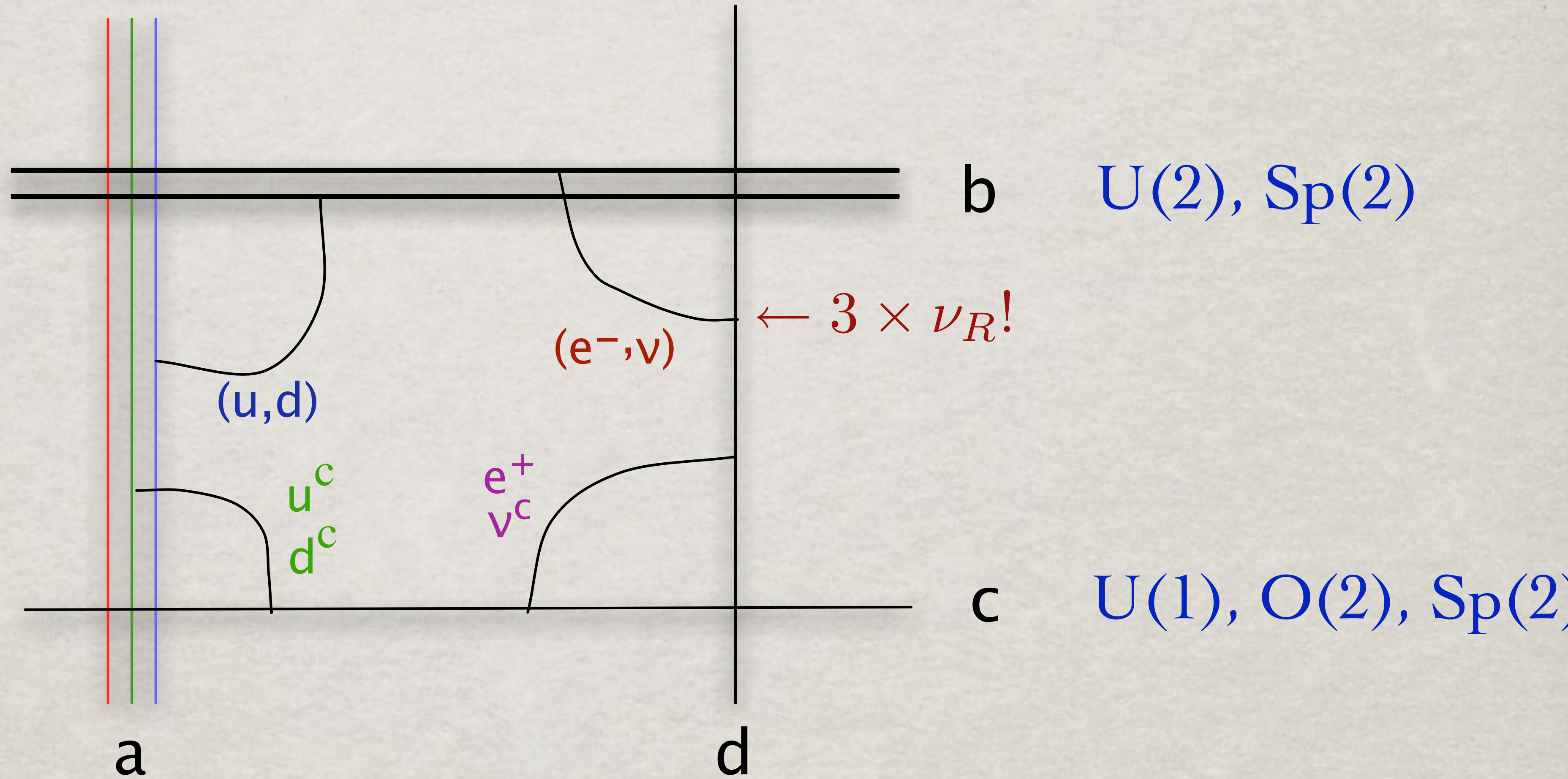
The Madrid Model*



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

(*) Ibanez, Marchesano, Rabadan (2001)
Lots of further work, reviewed in: Blumenhagen, Cvetic, Langacker, Shiu (2005)

The Madrid Model*



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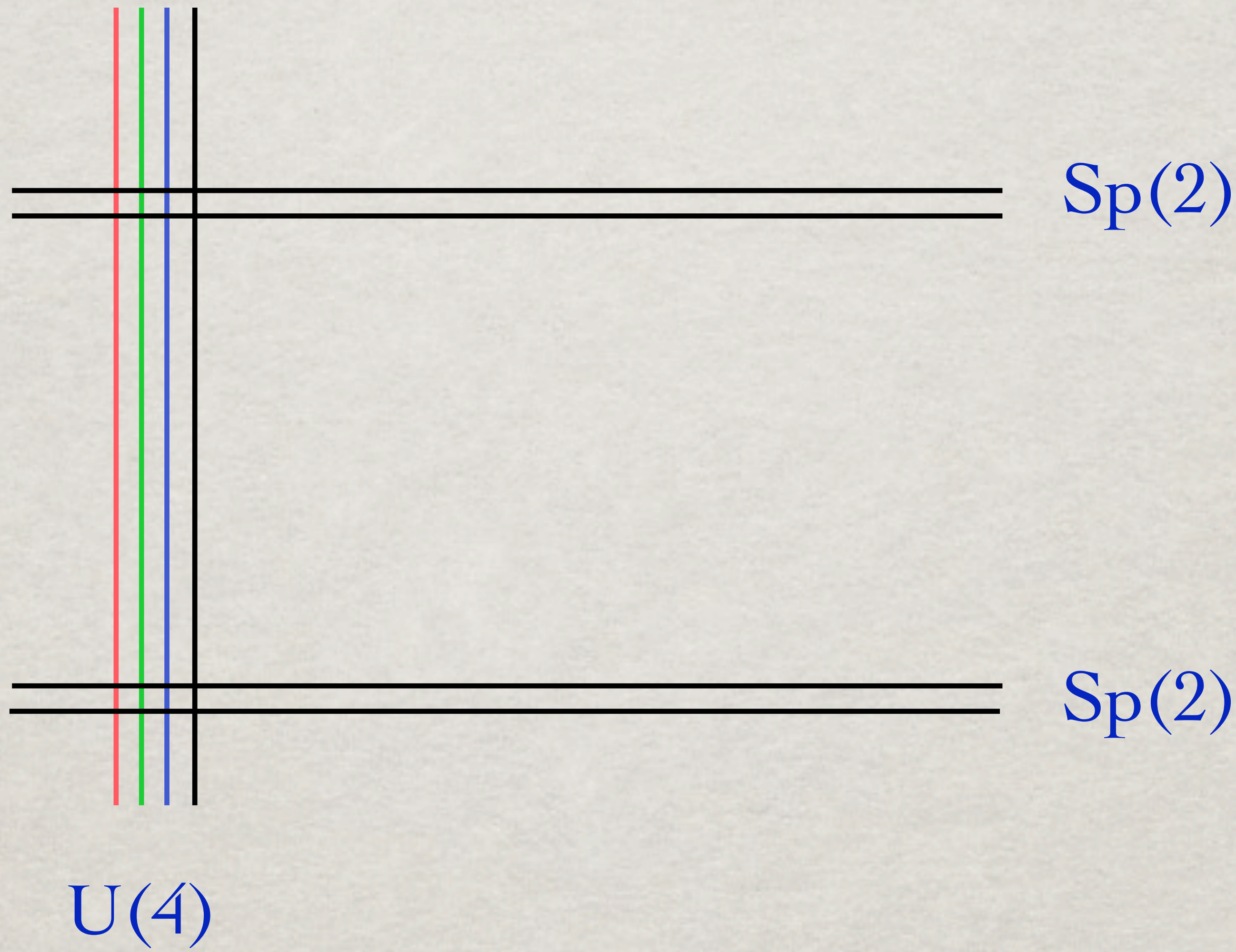
Pati-Salam model $\subset$ SO(10)



Pati-Salam model $\subset$ SO(10)

Other Orientifold realizations of the Standard Model

with Anastasopoulos, Dijkstra, Kiritsis

Search Criteria

Require only:

- U(3) from a single brane
- U(2) from a single brane
- Quarks and leptons, Y from at most four branes
- $G_{CP} \supset SU(3) \times SU(2) \times U(1)$
- Chiral G_{CP} fermions reduce to quarks, leptons (plus non-chiral particles)
- Massless Y

Chan-Paton group

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

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

$$Y = (x-\frac{1}{3})Q_a + (x-\frac{1}{2})Q_b + \underbrace{xQ_C + (x-1)Q_D}_{\text{Distributed over c and d}}$$

Allowed values for x

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

We looked for these configurations in the context of orientifolds of Gepner models.

The “branes” are realized as boundary states of the CFT.

We found a total of more than 19000* chirally distinct standard model realizations.

(*) No chiral exotics, modulo non-chiral exotics

Statistics

(Before tadpole cancellation)

Value of x	Total
0	24483441
1/2	138837612
1	30580
-1/2, 3/2	0
any	1250080

- The dominant classes x=0, 1/2 contain Pati-Salam and SU(5) models
  In this sense one could argue that the family structure is GUT-related, without having a GUT.

- SU(5) GUT models are about .01% of the total, and about .6% of the x=0 models.

Most frequent models

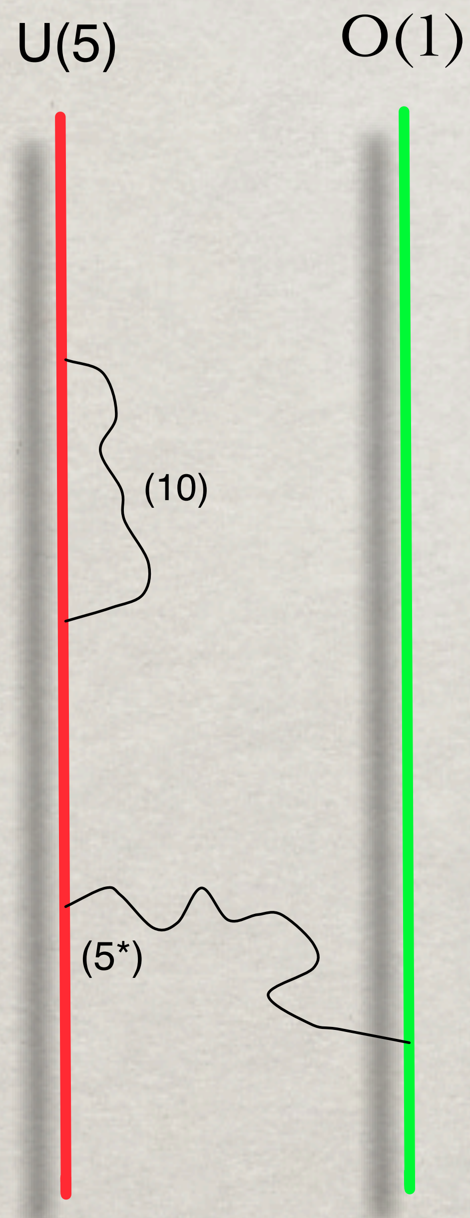
nr	Total occ.	MIPFs	Chan-Paton Group	spectrum	x	Solved
1	9801844	648	$U(3) \times Sp(2) \times Sp(6) \times U(1)$	VVVV	1/2	Y!
2	8479808(16227372)	675	$U(3) \times Sp(2) \times Sp(2) \times U(1)$	VVVV	1/2	Y!
3	5775296	821	$U(4) \times Sp(2) \times Sp(6)$	VVV	1/2	Y!
4	4810698	868	$U(4) \times Sp(2) \times Sp(2)$	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
...						

Curiosities

nr	Total occ.	MIPFs	Chan-Paton Group	Spectrum	x	Solved
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!
2624	1248	3	$U(3) \times U(2) \times U(2) \times U(3)$	VAAV	1	
2753	1136	74	$U(5) \times U(1)$	AS	0	Y
2880	1049	34	$U(5) \times U(1)$	AS	1/2	Y!
2881	1049	34	$U(5) \times U(1)$	AS	0	Y!
6580	146	18	$U(5) \times U(1)$	AS	0	
14861	12	2	$U(5) \times U(1)$	AS	0	

MODEL NR. 617

Gauge group is just SU(5)!

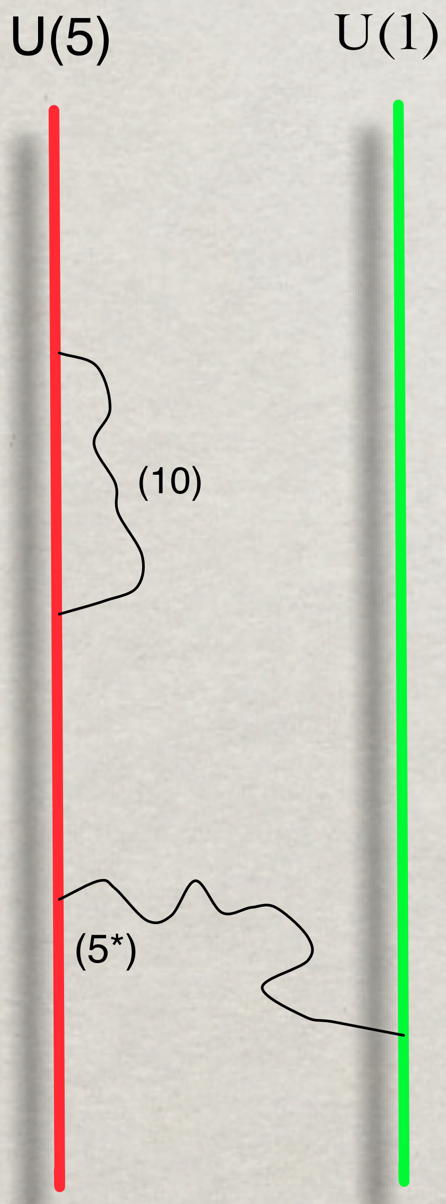


		U5	O1	O1		
3	x	(A	,0	,0	)	chirality 3
11	x	(V	,V	,0	)	chirality -3
8	x	(S	,0	,0	)	
3	x	(Ad	,0	,0	)	
1	x	(0	,A	,0	)	
3	x	(0	,V	,V	)	
8	x	(V	,0	,V	)	
2	x	(0	,S	,0	)	
4	x	(0	,0	,S	)	
4	x	(0	,0	,A	)	

Hidden sector

MODEL NR. 2880

Gauge group is SU(5) × U(1)



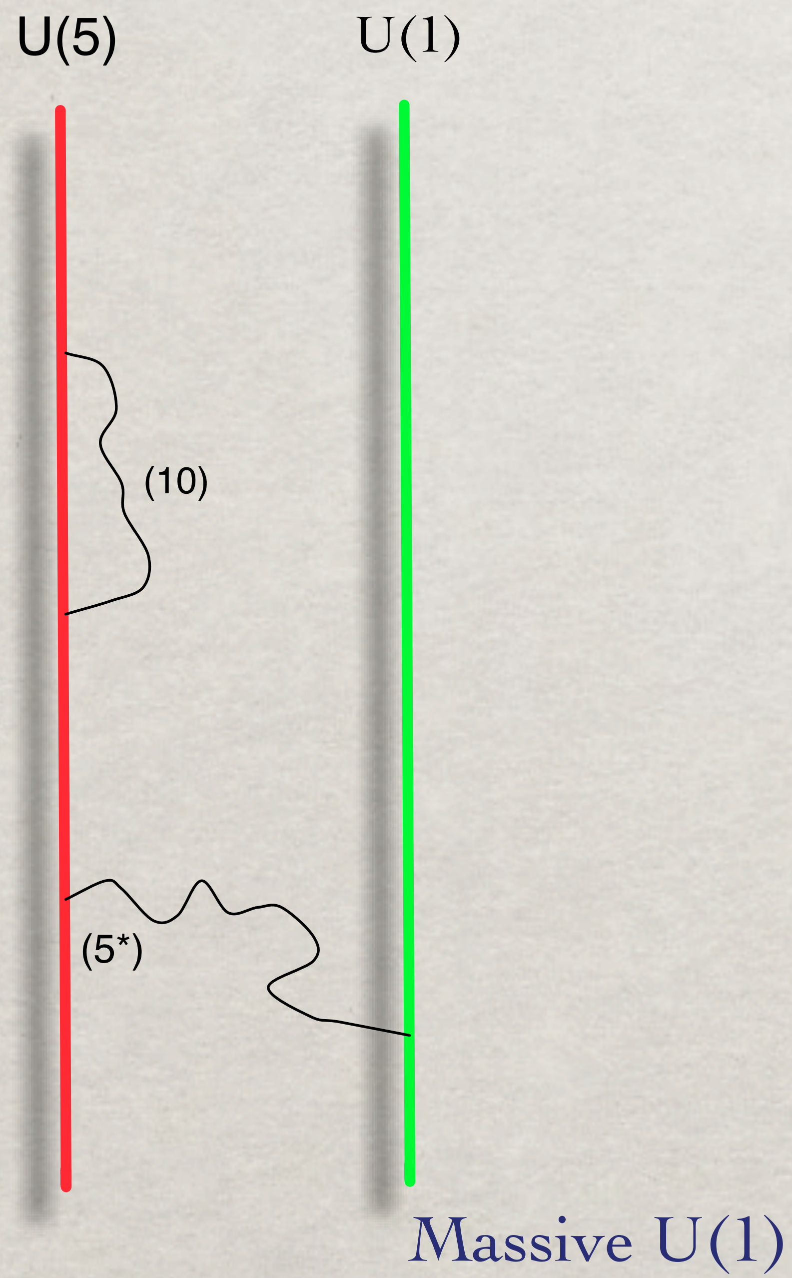
Massless U(1)
Allows flipped SU(5)

U5 U1

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

No hidden sector!

MODEL NR. 2753



	U5	U1	O2	U2	O2	U5	S4	U1	U1	
7 x	0	S	0	0	0	0	0	0	0	chirality 3
3 x	A	0	0	0	0	0	0	0	0	chirality 3
3 x	V	V	0	0	0	0	0	0	0	chirality -3
2 x	S	0	0	0	0	0	0	0	0	chirality 0
2 x	0	A	0	0	0	0	0	0	0	chirality 0
3 x	Ad	0	0	0	0	0	0	0	0	chirality 0
2 x	0	Ad	0	0	0	0	0	0	0	chirality 0
4 x	0	V	0	0	V	0	0	0	0	chirality 0
2 x	V	0	0	0	0	0	0	0	V*	chirality 0
4 x	V	0	0	0	0	0	0	0	V	chirality 0
2 x	V	0	0	0	0	V	0	0	0	chirality 0
2 x	V	0	0	0	0	0	V	0	0	chirality 0
2 x	V	0	0	0	0	0	0	V*	0	chirality 0
2 x	V	V*	0	0	0	0	0	0	0	chirality 0
2 x	0	V	0	0	0	0	0	0	V*	chirality 0
3 x	0	0	0	0	0	0	0	0	A	chirality -1
1 x	0	0	0	0	0	0	0	S	0	chirality 1
1 x	0	0	0	V	V	0	0	0	0	chirality 1
3 x	0	0	0	0	0	0	V	0	V	chirality 1
2 x	0	0	0	0	0	0	0	0	S	chirality -2
1 x	0	0	V	0	0	V	0	0	0	chirality 1
1 x	0	0	0	V	0	V	0	0	0	chirality -1
1 x	0	0	0	0	0	A	0	0	0	chirality -1
5 x	0	0	0	0	0	0	0	A	0	chirality -1
1 x	0	0	0	0	V	V	0	0	0	chirality -1
3 x	0	0	0	0	0	0	0	V	V	chirality 1
2 x	0	0	0	0	0	0	0	V	V*	chirality 2
2 x	0	0	0	0	V	0	0	0	V	chirality 2
1 x	0	0	V	0	0	0	0	V	0	chirality 1
1 x	0	0	0	V	0	0	V	0	0	chirality 1
1 x	0	0	0	V	0	0	0	V	0	chirality -1
1 x	0	0	0	0	0	V	V	0	0	chirality 1
1 x	0	0	0	0	0	V	0	V	0	chirality -1
3 x	0	0	0	0	V	0	0	V	0	chirality -3
6 x	0	0	0	0	0	0	V	V	0	chirality 0
1 x	0	0	0	0	S	0	0	0	0	chirality 0
1 x	0	0	0	0	0	0	A	0	0	chirality 0
2 x	0	0	0	0	0	0	0	Ad	0	chirality 0
2 x	0	0	0	0	0	0	0	0	Ad	chirality 0
1 x	0	0	0	0	0	0	S	0	0	chirality 0

Hidden sector

GUTs in Strings?

Charge Quantization

Standard model:

$$\frac{t}{3} + \frac{s}{2} + Y = 0 \bmod 1$$

Explained by SU(5) GUTs!

Heterotic with standard U(1) normalization:
spectrum always contains particles violating this relation*
(may be heavy or confined by other interactions).

Orientifolds with x=1/2: half-integer charges in the OH-sector (if there is a hidden sector)

Orientifolds with x=0: SM charge quantization satisfied perturbatively.

☺ True unification (higher level affine, x=0 orientifolds, SU(5) F-theory ...)

☹ Heterotic strings, most x=1/2 orientifolds

(*) X. Wen and E. Witten, Nucl.Phys.B261:651,1985
A.N Schellekens, Phys.Lett.B237:363,1990

Vacuum Selection

Could true GUTs with $M_{GUT} < M_{planck}$ be prefered over generic string vacua?

- Aesthetics: makes no sense.
- Statistics/Vacuum counting: seems unlikely.
- Cosmologically?
- Anthropically?
  - Low energy gauge couplings don't care about unification.
  - Baryogenesis might be a candidate, but does not seem to work

Guts in Strings?

- Beautiful! ✖
- Unifies 3 of the 4 known interactions ✖
- Explains family structure ~
- Explains charge quantization ✔
- Predicts $\sin^2\theta_w$ ✖

Nothing is better than GUTs!

(inspired by W. Siegel)

from:

THEORY OF MORE THAN EVERYTHING*

V. Gates, Empty Kangaroo, M. Roachcock, and W.C. Gall**

There is, in fact, a simple proof that superpea theory is superior to superstring theory in describing physics:

(1) Nothing is better than superstrings.

(2) Superpeas are better than nothing.

(3) Therefore, superpeas are better than superstrings.