Discreet Steps in the Landscape

Bert Schellekens
Nikhef, Amsterdam

CERN TH Seminar 11-4-2012

discreet |disˈkrēt|
adjective (**discreeter**, **discreetest**)
careful and circumspect in one's speech or actions, esp. in order to avoid causing offense.

ORIGIN Middle English: from Old French ***discret***, from Latin ***discretus* ‘separate,’**

usage: The words **discrete** and **discreet** are pronounced in the same way and share the same origin but they do not mean the same thing.

discrete |disˈkrēt|
adjective
individually separate and distinct.

ORIGIN late Middle English: from Latin ***discretus* ‘separate’**.

CONTENTS

- The discreet birth of the landscape
- Trouble for the discretuum?
- Discrete scans of the landscape
- Discrete symmetries in discrete orientifolds
  (with L. Ibañez, A. Uranga)

CONTENTS

- The discreet birth of the landscape
- Trouble for the discretuum?
- Discrete scans of the landscape
-

CONTENTS

Based on work with:
F. Englert, H. Nicolai, W. Lerche, D. Lüst, N. Warner, B Nilsson, S. Yankielowicz, B. Gato-Rivera, M. Kreuzer, J. Fuchs, C. Schweigert, L. Huiszoon, T. Dijkstra, J. Walcher, E. Kiritsis, M. Lennek, M. Tsulaia, R. Richter, P. Anastasopoulos, G. Leontaris, L. Ibañez, A. Uranga, M. Maio

- The discreet birth of the landscap
- Trouble for the discretuum?
- Discrete scans of the landscape
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1986: The first cracks in the "uniqueness" of string theory

Narain, December 1985

It is shown that infinitely many heterotic string theories exist...

Strominger, Februari 1986

All predictive power seems to have been lost.

Kawai, Lewellen, Tye, June 1986

in contrast to the 10-dimensional case the number of 4-dimensional chiral models is very large.

(From the long version, October 1986)

Lerche, Lüst, Schellekens, November 1986

this number is of order 10^{1500}

Antoniadis, Bachas, Kounnas, December 1986

The number of consistent four-dimensional string theories is so huge that classifying them all would be both impractical and not very illuminating.

Number of solutions related to the number of even-selfdual lattices

Lattice Dimension	Estimated Number N_{8k}	Actual Number N_{8k}	Space-Time Dimension	Number of String Theories
8	2.8×10^{-9}	1		
16	4.9×10^{-18}	2		
24	15.8×10^{-15}	24	10	8 (+1)
32	8.0×10^{7}	???		
...				
88	$\approx 10^{1500}$	???	4	???

Lower bound on the number of even self-dual lattices in $8k$ dimensions

$$N_{8k} > \sum_{\Lambda} \frac{1}{|\mathrm{Aut}(\Lambda)|} = \frac{|B_{4k}|}{8k} \prod_{j=1}^{4k-1} \frac{|B_{2j}|}{4j}$$

So the number is large, but what does that mean?

So the number is large, but what does that mean?

Strominger:

All of this points to the overwhelming need to find a dynamical principle for determining the ground state, which now appears more imperative than ever.

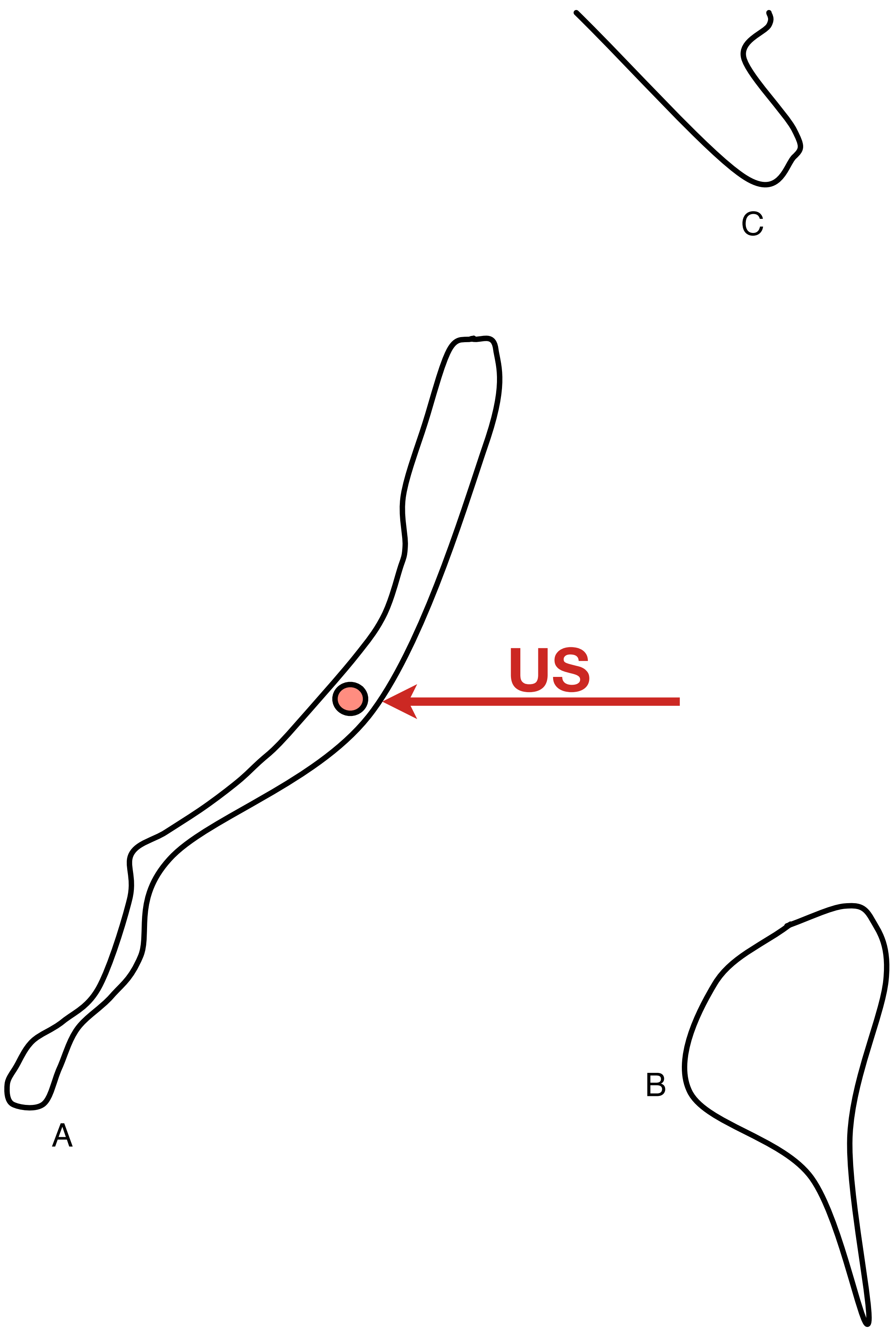
But I was not very satisfied with this point of view:
The missing “selection principle” looked like pure wishful thinking.

Two things bothered me in the beginning of 1987.

String theory was a beautiful idea, so why did it give such a strange answer?

And why did the standard model appear to be tuned to allow the existence of life? Especially the lightness of the up-quark, and the fact that this was essential to have a stable proton, was bothering me.

Amazingly, it took me a few months to put these two worries together, and understand that they cancelled each other.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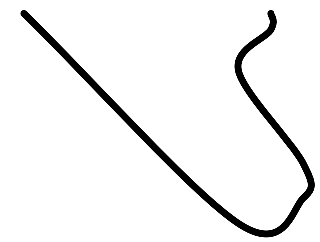
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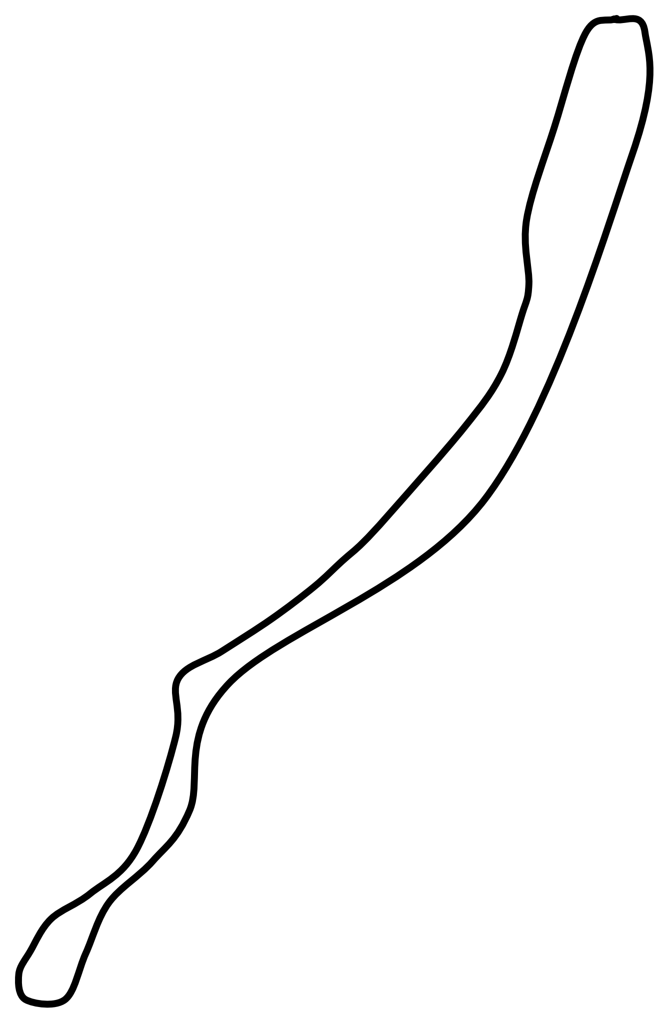
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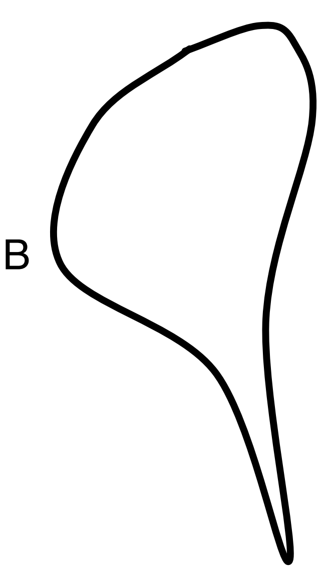
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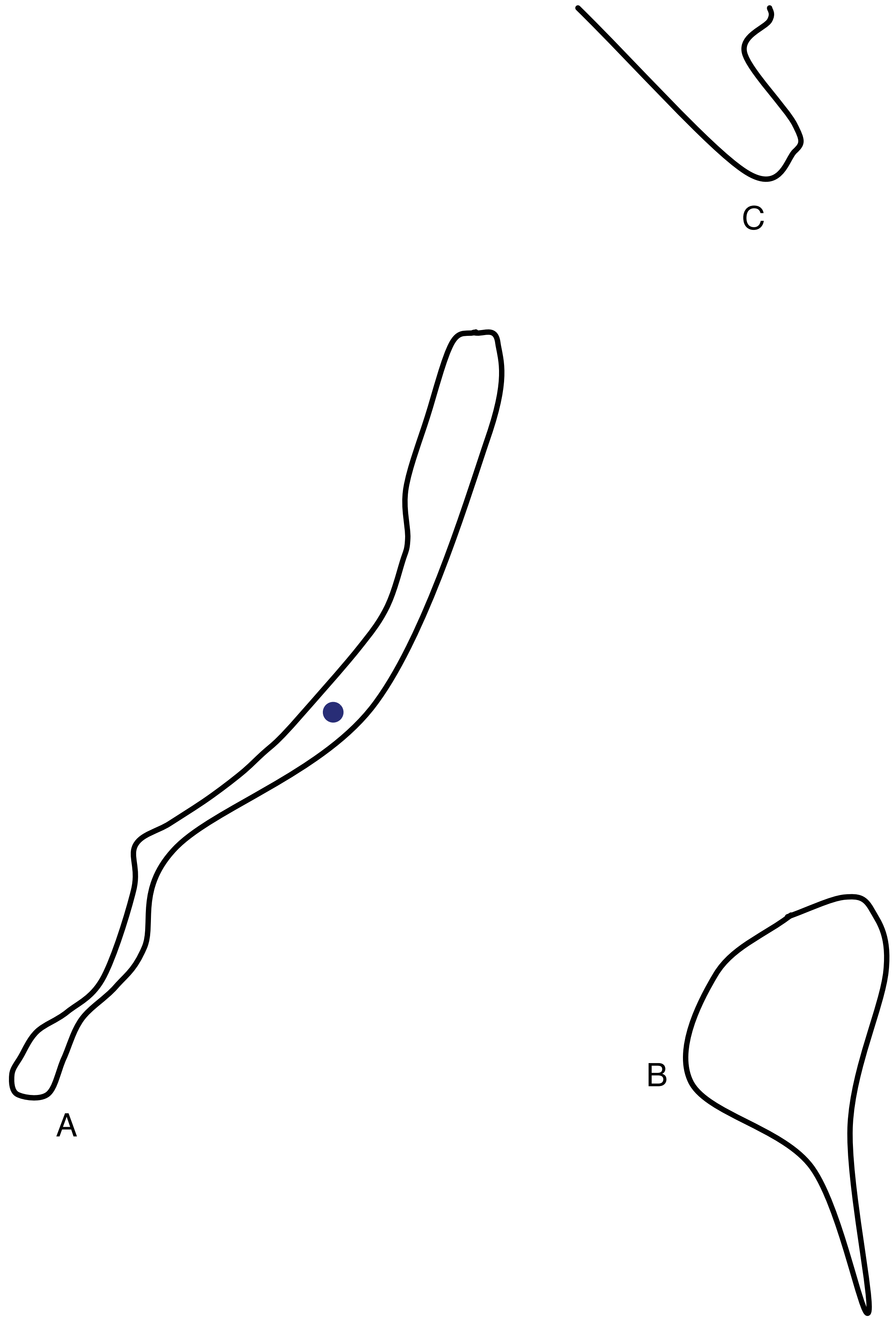
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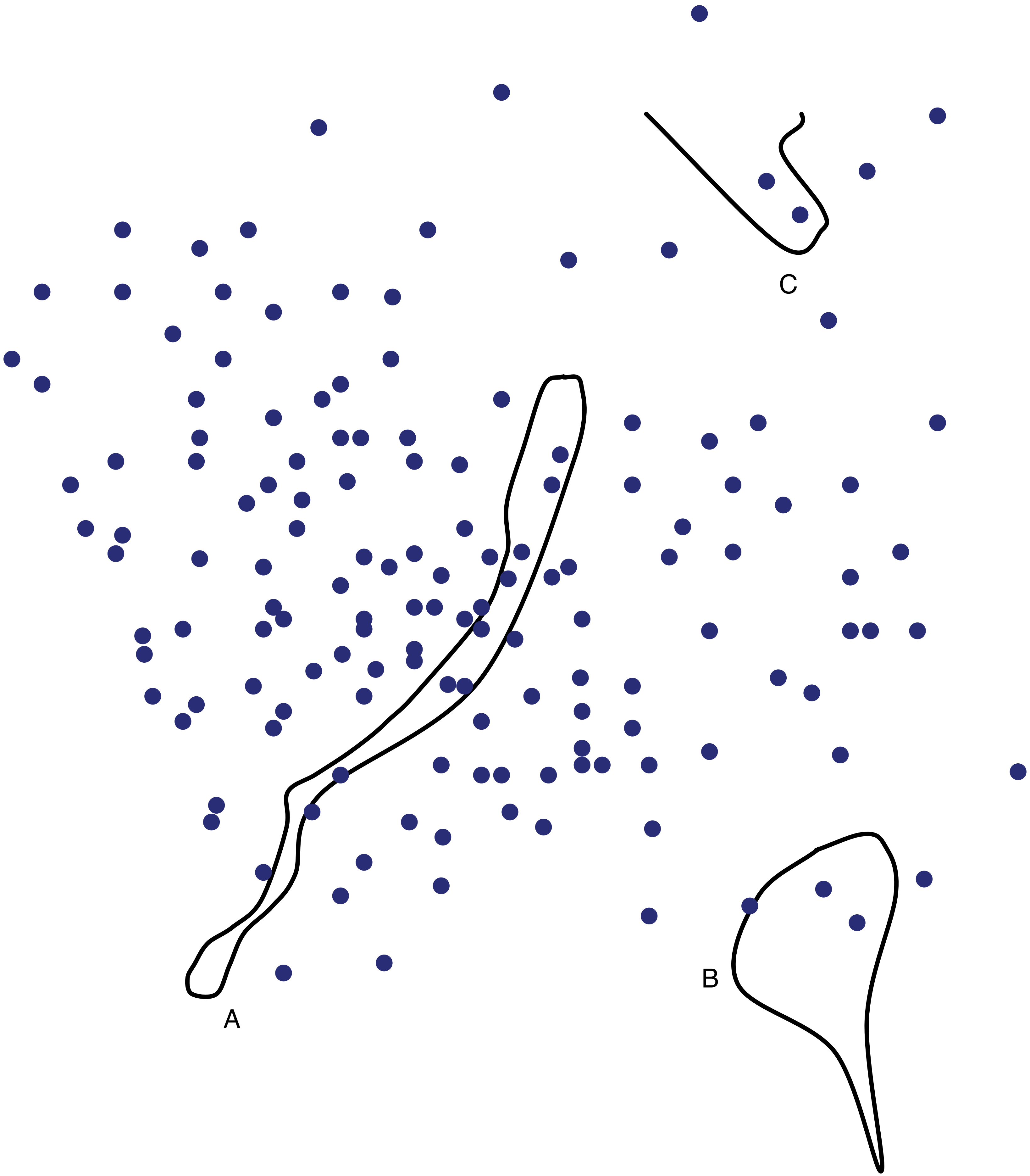
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This was of course called “The anthropic principle”, and was something one could not talk about.

I was very discreet about this, except occasionally in the CERN cafetaria.

In 2006, Lenny Susskind wrote me
“I also had been thinking these things way back, but it took me longer to come out of the closet.”

In the previous century, I managed to get my thoughts on paper just twice.

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In 1987:

A.N. Schellekens,
Contribution to the proceedings of the EPS conference, Uppsala, June 1987

The prevailing attitude seems to be that "non-perturbative string effects" will somehow select a unique vacuum. This is unreasonable and unnecessary wishful thinking. We do not know at present how to discuss such effects, and have no idea whether they impose any restrictions at all. One cannot reasonably expect that a mathematical condition will have a unique solution corresponding to the standard model with three generations and a bizarre mass matrix. It is important to realize that this quest for uniqueness is based on philosophy, not on physics. There is no logical reason why the "theory of everything" should have a unique vacuum.

... but apparently I did not dare to mention the “A-word”.

Andre Linde said it better, a year earlier:

“From this point of view, an enormously large number of possible types of compactification which exist, e.g., in the theories of superstrings should be considered not as a difficulty but as a virtue of these theories, since it increases the probability of existence of mini universes in which life of our type may appear.”

Eternally Existing Selfreproducing Chaotic Inflationary Universe. **Phys.Lett.B175:395-400,1986**

In 1998 I wrote a inauguration speech which was completely devoted to this topic, with the main conclusion that a huge “anthropic landscape” (as Susskind called it five years later) was the best possible outcome for particle physics.

But I wrote it in Dutch, and did not translate it until 2006.
(physics/0604134)

Just to put the record straight:
It is not correct that until 2003 all string theorist were promising a unique outcome.
It is true that they were very discreet about it. Anthropic arguments were never mentioned.
Most were either taking a “wait and see” or phenomenological attitude.

Consider the following quotes from Kawai, Lewellen, Tye **(Nucl.Phys. B288 (1987) 1)**

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"We should point out that the equivalence of space and color was known in Buddhism many centuries ago."

So why is this exciting?

We all hope to witness big discoveries during our career.
This looked like it could be the one.

If true, we would understand once again that we are not in the center of everything: the solar system, the galaxy or the universe.
We would understand that we are living in a multiverse, and that our standard model is just one of a huge number of possibilities, explaining its special features.

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Doesn't that sound more exciting than discovering that at a fundamental level nature needs to cancel boson and fermion loops?

Recent developments

In the beginning of this century, there were several important developments:

Flux compactifications, helping with moduli stabilization and providing a way to "neutralize" the cosmological constant. *(Bousso-Polchinski, 2000)*

$$\Lambda = \Lambda_{\text{bare}} + \frac{1}{2}\sum_{i}^{N_{\text{flux}}} n_i^2 y_i^2$$

Construction of metastable deSitter vacua *(Kachru, Kallosh,Linde,Trivedi, 2003)*

An estimate of the number of vacua: 10^{500} *(Douglas et. al. 2004)*

The first non-discreet paper on the subject:
"The Anthropic Landscape of String Theory" *(Susskind 2003)*

Many papers since then, with a wide range of conclusions.
But one thing is certain: there may be zero metastable deSitter vacua, but there is not going to be just one.

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In the space of all quantum field theories, the standard model is undoubtedly special.
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If there are other possibilities, clearly some features we are observing are environmental.
If (intelligent) life cannot exist for some other possibilities, then we are already have an “anthropic principle”.

Many of the remaining standard model problems are related to “naturalness”.
We are puzzled that some parameters take strange values.
If they can also take other values, that may be relevant when thinking about naturalness problems.
If furthermore our existence depends crucially on certain parameter values,
it is hard to see how that could ***not*** be relevant.

Consider for example the gauge hierarchy problem, because this is an interesting time to do so.

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Yet is quite clear that if we push the quark and lepton masses to the Planck scale,
life as we know it ceases to exist pretty soon, and plausibly any kind of life*).
(the strong scale is ***not*** a counter example).
So why do most people regard this fact as irrelevant?

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But this does not mean that we should jump to conclusions.

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V. Agrawal, S. Barr, J. Donoghue, D. Seckel,

"The anthropic principle and the mass scale of the Standard Model", 1998

if the Weak scale is what it is for anthropic reasons, there would be no need to invoke supersymmetry or technicolor or other structure at the Weak scale to make the fine-tuning "natural". If no such structure is found, then, it would be a point in favor of anthropic explanations; indeed, in that case there would be few if any alternatives to an anthropic explanation.

S. Weinberg, "Living in the Multiverse", 2005

If the electroweak symmetry breaking scale is anthropically fixed, then we can give up the decades long search for a natural solution of the hierarchy problem. This is a very attractive prospect, because none of the "natural" solutions that have been proposed, such as technicolor or low energy supersymmetry, were ever free of difficulties.

The usual gauge hierarchy discussion is based on two incorrect arguments:

- It is a big mystery why $\mu^2 \ll (M_{Planck})^2$

  But we already know the explanation; any additional explanation would only create a new problem. Even with low-E susy or new dynamics the explanation will be anthropic.

- We must explain that μ^2 is much smaller than its quantum corrections.

  But these are not separately observable.

However, the "technical naturalness" argument can still make sense... in the context of a landscape.

In unnatural theories with a fundamental scale M the weak scale μ^2 can be expected to be spread over a range $-M^2$ to M^2, so that the fraction of theories with small μ^2 is of order μ^2/M^2.

But to use this argument we also need to know how many unnatural theories there are in comparison to natural ones.

Douglas, Susskind, 2004:
for multiple susy breaking terms, high susy breaking scales are favored.

Definitive conclusions are hard to get.

But any statement about naturalness involves implicit assumptions about distributions of parameters.

If you don't want to think about landscapes, you are just poking around in the dark.

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Recently, anthropic ideas *have* entered the discussion

Split Susy *(Arkani-Hamed, Dimopoulos, Giudice, Romanino, 2004)*
High Susy *(Douglas, Susskind, 2004)*
No Susy *(Occam, ~1325)*
Antropic Little Hierarchy *(Giudice, Rattazzi, 2006)*

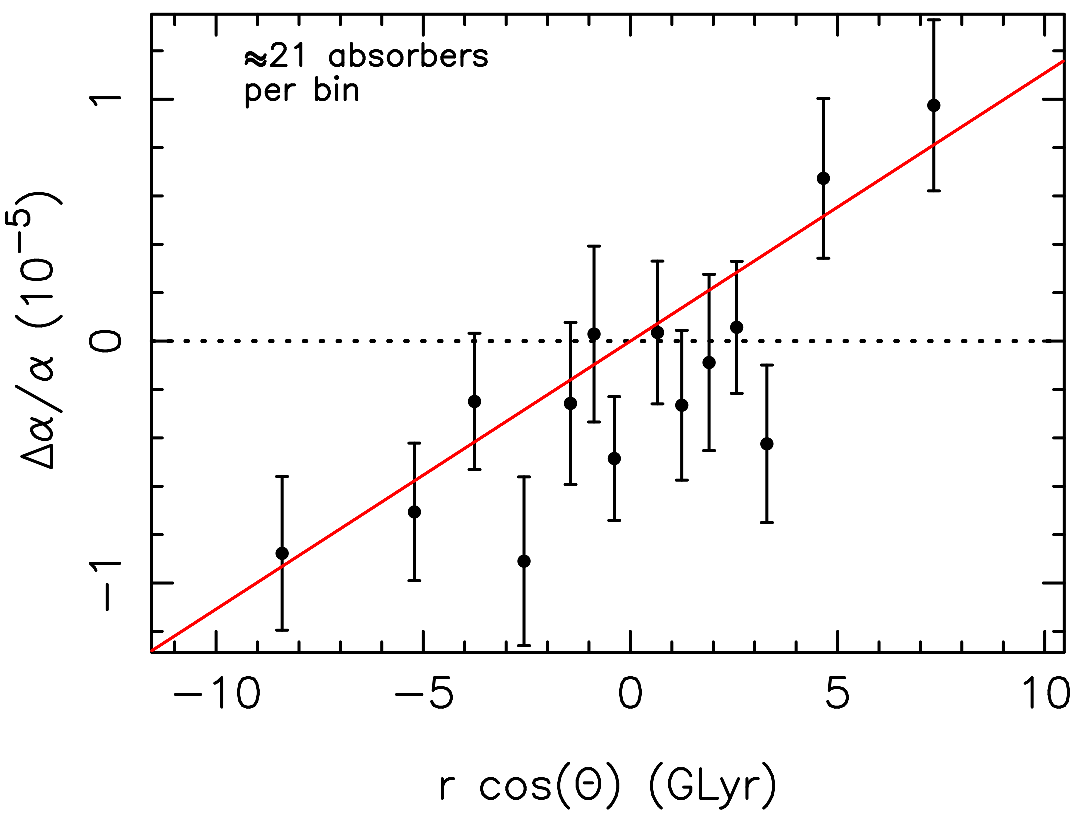
Remarkably, the high scale scenarios are already under stress....

Giudice and Strumia, Dec. 2011

Indications of a spatial variation of the fine structure constant

J. K. Webb[1], J. A. King[1], M. T. Murphy[2], V. V. Flambaum[1], R. F. Carswell[3], and M. B. Bainbridge[1]
[1]*School of Physics, University of New South Wales, Sydney, NSW 2052, Australia*
[2]*Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Mail H30, PO Box 218, Victoria 3122, Australia and*
[3]*Institute of Astronomy, Madingley Road, Cambridge, CB3 0HA, England.*
(Dated: November 2, 2011)

We previously reported Keck telescope observations suggesting a smaller value of the fine structure constant, α, at high redshift. New Very Large Telescope (VLT) data, probing a different direction in the universe, shows an inverse evolution; α increases at high redshift. Although the pattern could be due to as yet undetected systematic effects, with the systematics as presently understood the combined dataset fits a spatial dipole, significant at the 4.2σ level, in the direction right ascension 17.5 ± 0.9 hours, declination -58 ± 9 degrees. The independent VLT and Keck samples give consistent dipole directions and amplitudes, as do high and low redshift samples. A search for systematics, using observations duplicated at both telescopes, reveals none so far which emulate this result.



$$\frac{\alpha(\mathbf{x})}{\bar{\alpha}} = 1 + B_\alpha\, \hat{\mathbf{z}}_\alpha \cdot \mathbf{x}$$

$$B_\alpha = (1.10 \pm 0.25) \times 10^{-6}\ \mathrm{Glyr}^{-1}$$

Most obvious parametrization

$$\mathcal{L} = -\frac{1}{4} e^{\lambda\phi} F_{\mu\nu} F^{\mu\nu}$$

But then any shift in ϕ will not only shift α, but also generate a gigantic contribution to the cosmological constant. (Banks, Dine, Douglas, Phys.Rev.Lett. 88 (2002) 131301)

$$\left|\frac{\delta\alpha}{\alpha}\right| < 10^{-37}.$$ *(cutoff at QCD scale)*

If these observations are correct, they would falsify the Bousso-Polchinski-Susskind landscape

Most of the literature on variations of constants of nature does not even mention this.
An exception is this footnote:

Paul Langacker, hep-ph/0304093 (Int. J. Mod. Phys.)

"It was argued in [27] that a variation in α would upset the fine-tuned cancellations of radiative corrections to the cosmological constant with other contributions, with enormous effect. We take the view that such arguments are not conclusive given our lack of understanding of why Λ is so small."

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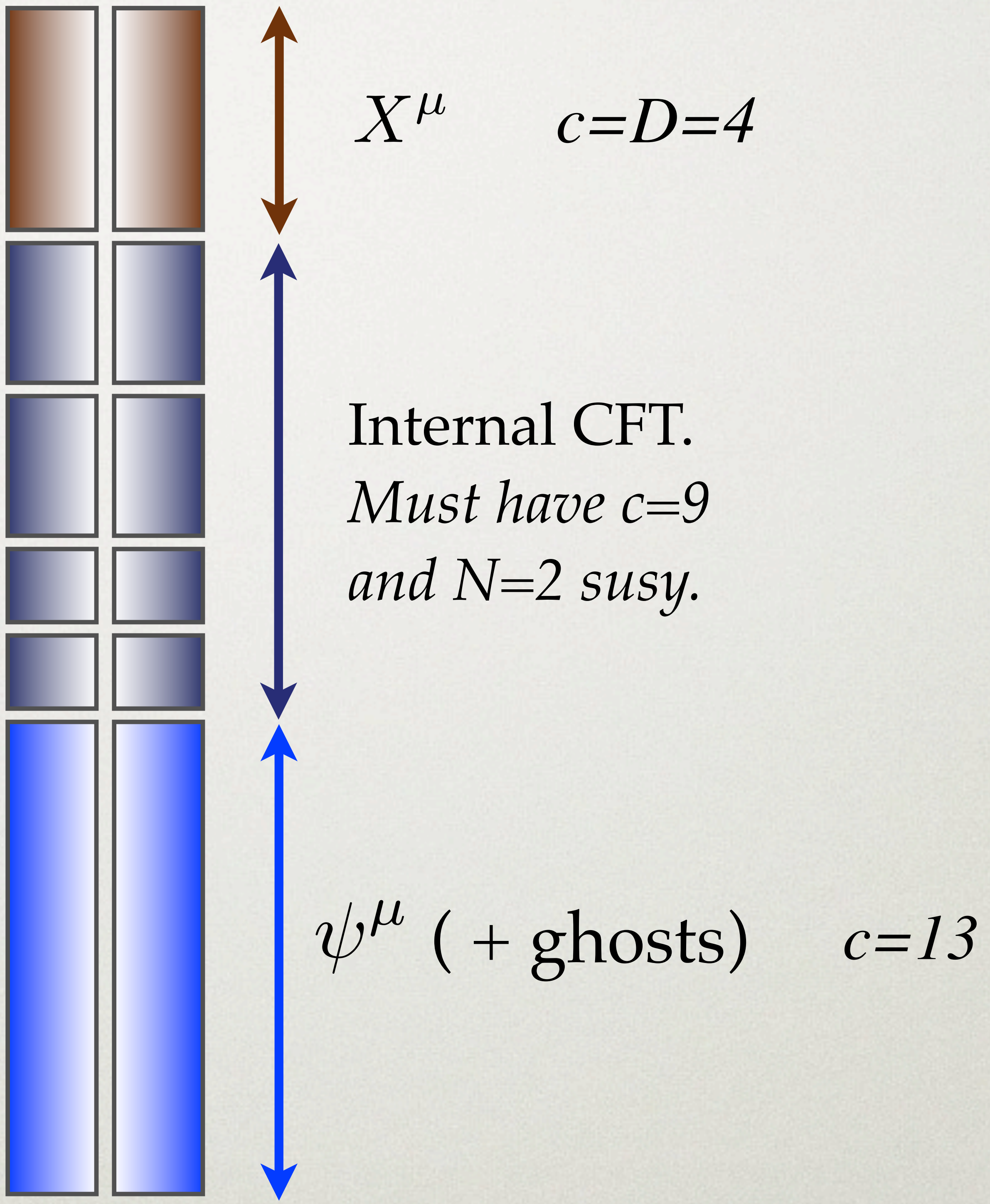
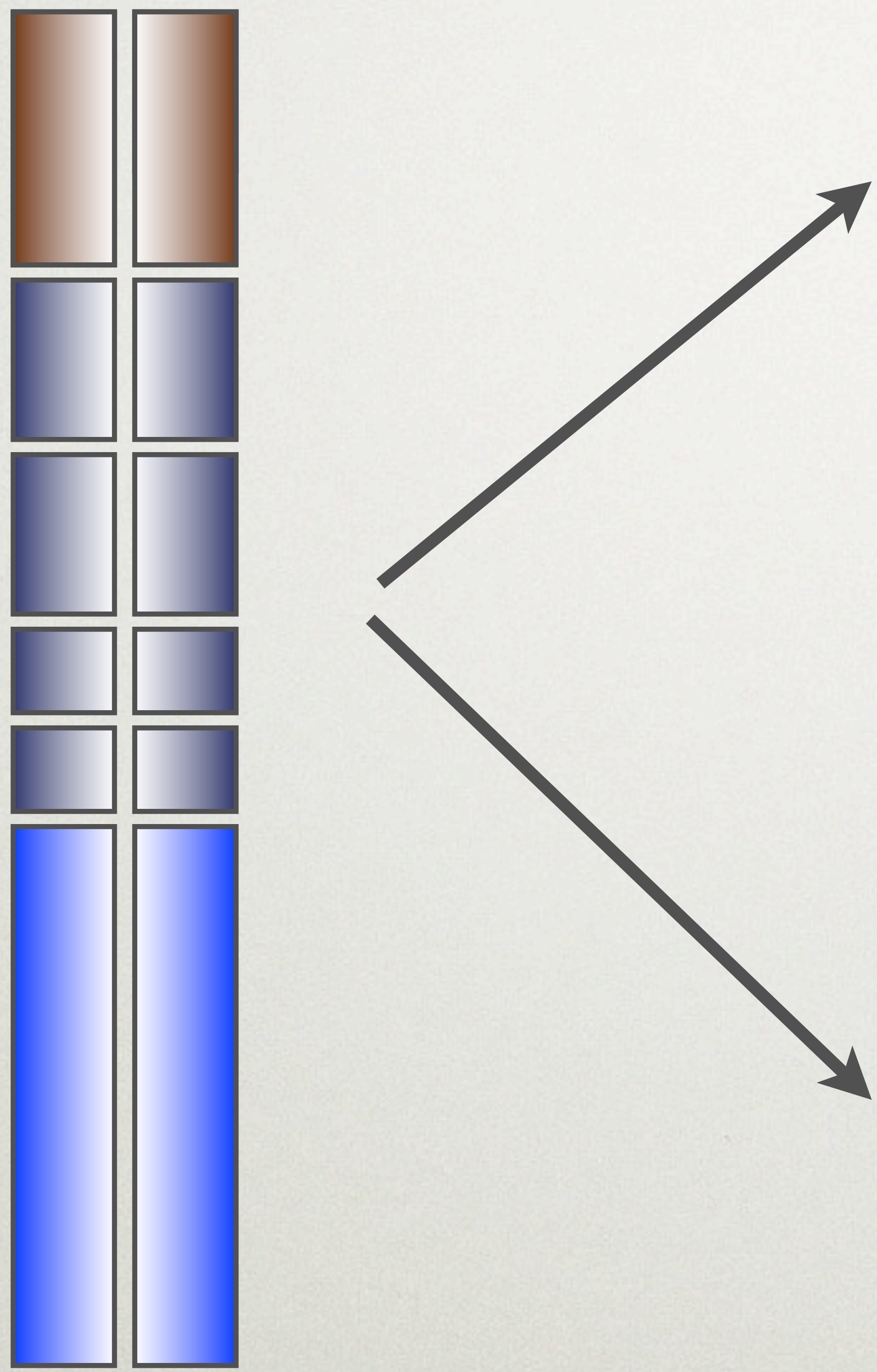
"The fact that it is infinite does not necessarily imply that one may ignore it"
(Dirac)

Discrete Scans

Type-II strings

168 combinations of minimal N=2 models





Heterotic

(Gepner, 1987)

Standard model from closed strings

Orientifolds

(Angelantonj, Bianchi, Pradisi, Sagnotti, Stanev, 1996)

Standard model from open strings

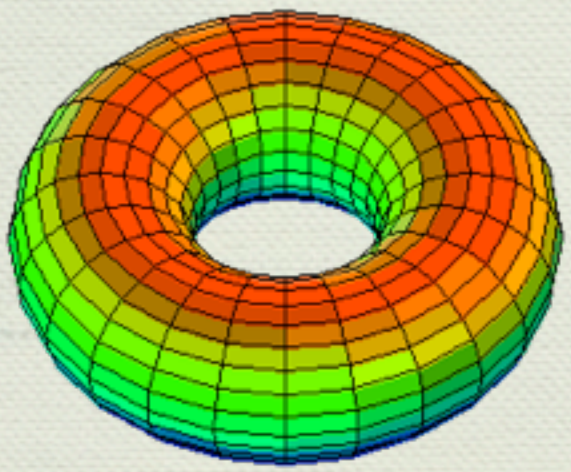
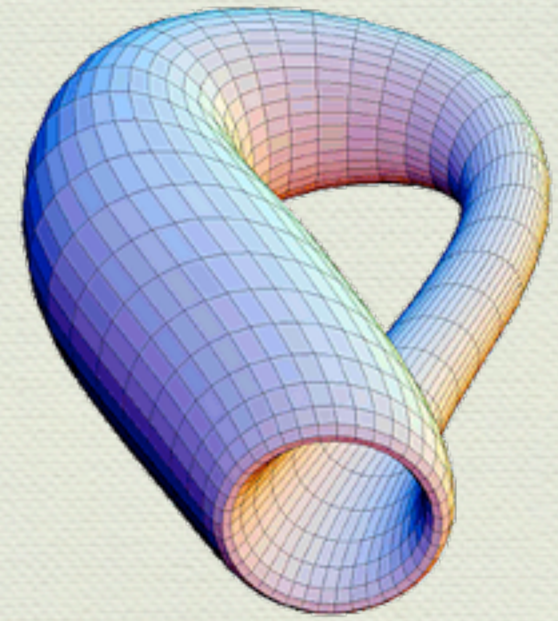
Heterotic strings:

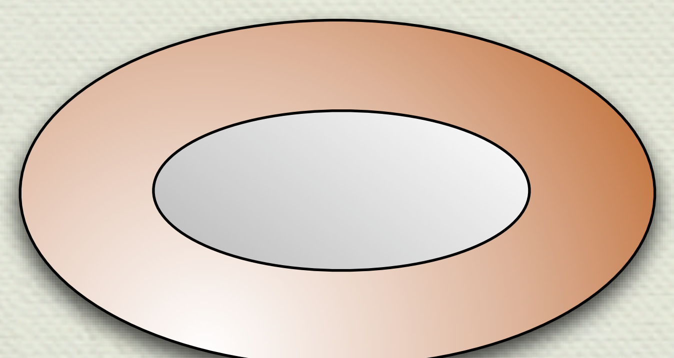
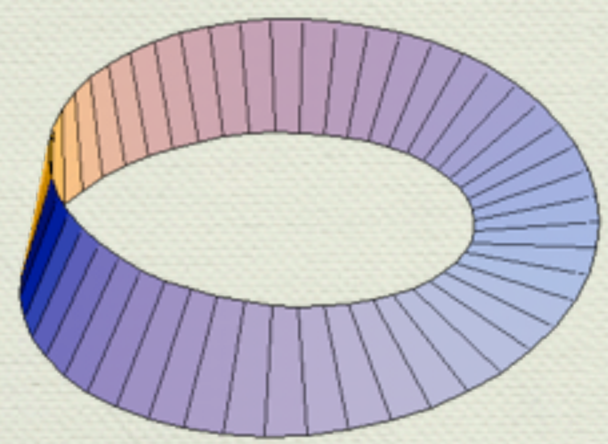
Left-moving modes should be those of the bosonic string.

Orientifolds:

We need to add boundary and crosscap states

Orientifold Partition Functions

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

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

Orientifold 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

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

i : Primary field label (finite range)

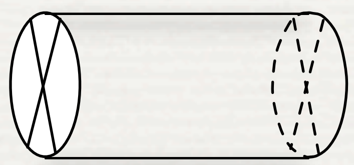
a : Boundary label (finite range)

χ_i : Character

N_a : Chan-Paton (CP) Multiplicity

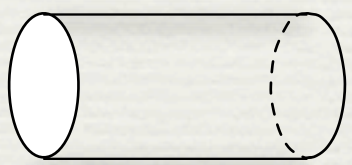
Coefficients

- Klein bottle



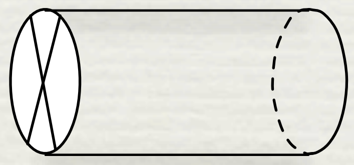
$$K^i = \sum_{m,J,J'} \frac{S^i{}_m U_{(m,J)} g^{\Omega,m}_{J,J'} U_{(m,J')}}{S_{0m}}$$

- 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



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

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

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

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

Cardy (1989)
Sagnotti, Pradisi, Stanev (~1995)
Huiszoon, Fuchs, Schellekens, Schweigert, Walcher (2000)

Intersecting branes

The ends of open strings give rise to $U(N)$, $O(N)$ or $Sp(2N)$ gauge groups.

Since each open string has two ends, matter must be in bi-fundamentals (or rank-two tensors).

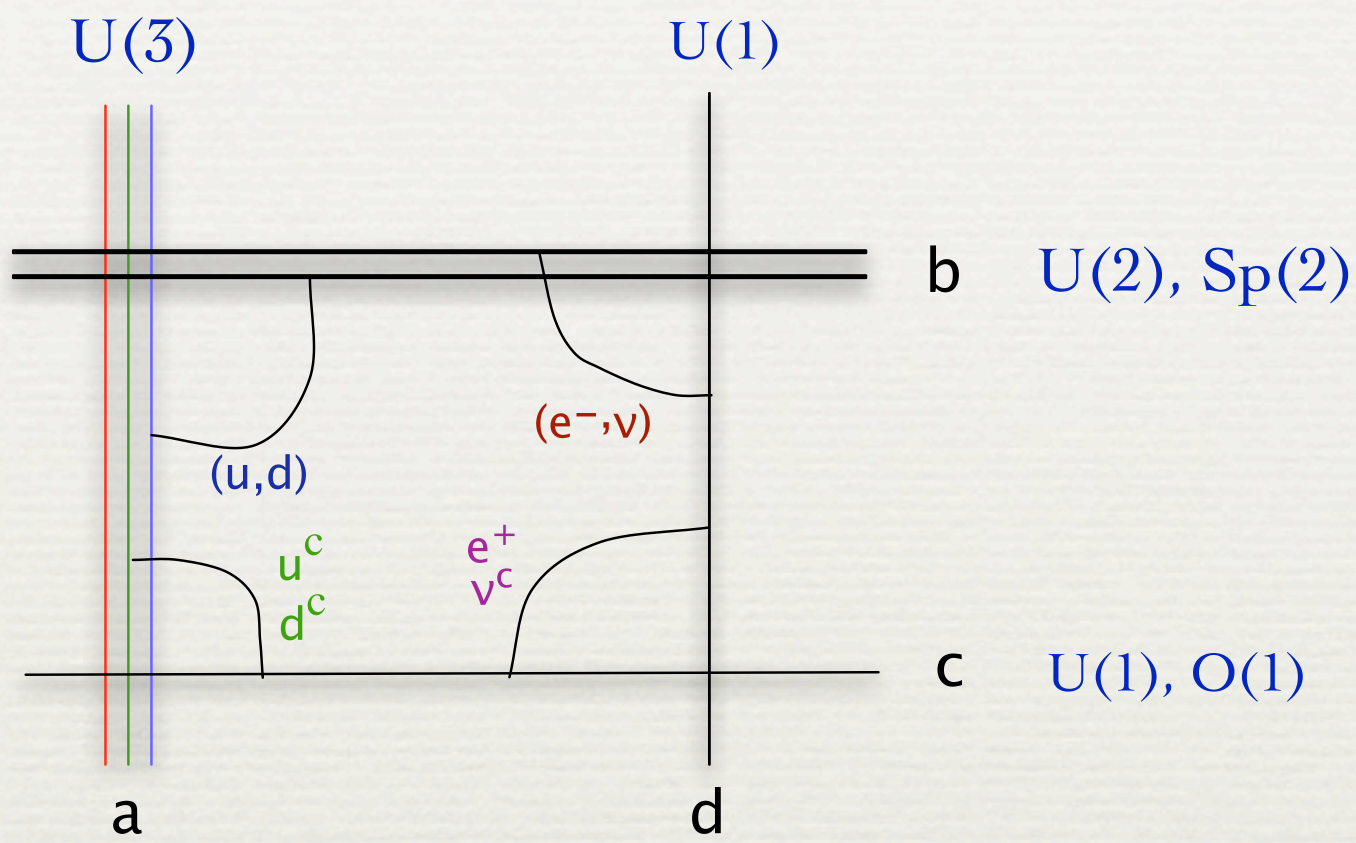
One may think of the endpoints as open strings ending on a membrane or a stack of N membranes. In CFT language, this is described by boundary states.

By considering suitable combinations of stacks of intersecting branes one may obtain the standard model.

Analogously, in CFT constructions one may look for the right combinations of boundary states.

(hundreds of papers since ~ 2000)

The Madrid Model*



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

168 Gepner Models

$\sim$ 5000 Partition functions (MIPFs)

$\sim$ 30000 Orientifolds

$\sim$ 10000 Boundaries per MIPF/Orientifold

$\sim 45 \times 10^{18}$ possibilities to investigate

(*) *Ibanez, Marchesano, Rabadan (2000)*

Gauge group: Exactly SU(3) × SU(2) × U(1)!

	U(3)	Sp(2)	U(1)	U(1)	chirality	
3 x	V	V	0	0	3	Q
3 x	V	0	V	0	-3	U*
3 x	V	0	V*	0	-3	D*
3 x	0	V	0	V	3	L
5 x	0	0	V	V	-3	E*+(E+E*)
3 x	0	0	V	V*	3	N*
18 x	0	V	V	0		Higgs
2 x	V	0	0	V		
2 x	Ad	0	0	0		
2 x	A	0	0	0		
6 x	S	0	0	0		
14 x	0	A	0	0		
6 x	0	S	0	0		
9 x	0	0	Ad	0		
6 x	0	0	A	0		
14 x	0	0	S	0		
3 x	0	0	0	Ad		
4 x	0	0	0	A		
6 x	0	0	0	S		

Dijkstra, Huiszoon, Schellekens (2004)

Gauge group: Exactly SU(3) × SU(2) × U(1)!

	U(3)	Sp(2)	U(1)	U(1)		
3 x	V	V	0	0	chirality 3	Q
3 x	V	0	V	0	chirality -3	U*
3 x	V	0	V*	0	chirality -3	D*
3 x	0	V	0	V	chirality 3	L
5 x	0	0	V	V	chirality -3	E*+(E+E*)
3 x	0	0	V	V*	chirality 3	N*
18 x	0	V	V	0		Higgs
2 x	V	0	0	V		
2 x	Ad	0	0	0		
2 x	A	0	0	0		
6 x	S	0	0	0		
14 x	0	A	0	0		
6 x	0	S	0	0		
9 x	0	0	Ad	0		
6 x	0	0	A	0		
14 x	0	0	S	0		
3 x	0	0	0	Ad		
4 x	0	0	0	A		
6 x	0	0	0	S		

Vector-like matter

V=vector

A=Anti-symm. tensor

S=Symmetric tensor

Ad=Adjoint

Dijkstra, Huiszoon, Schellekens (2004)

The discrete structure of the standard model: gauge groups and representations.

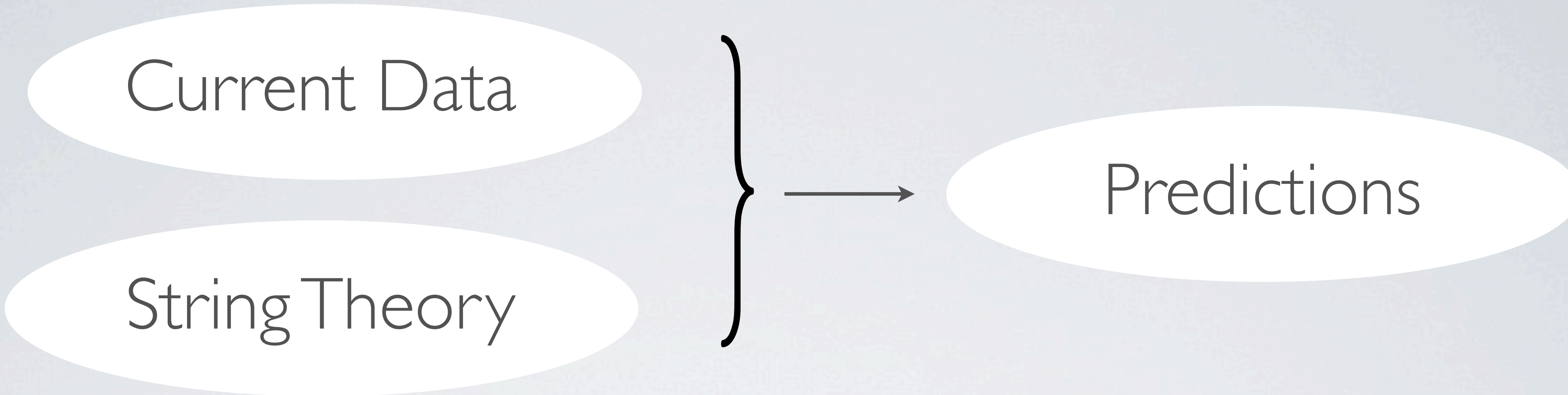
In 1984 the standard model appeared to come out automatically in heterotic string theory.

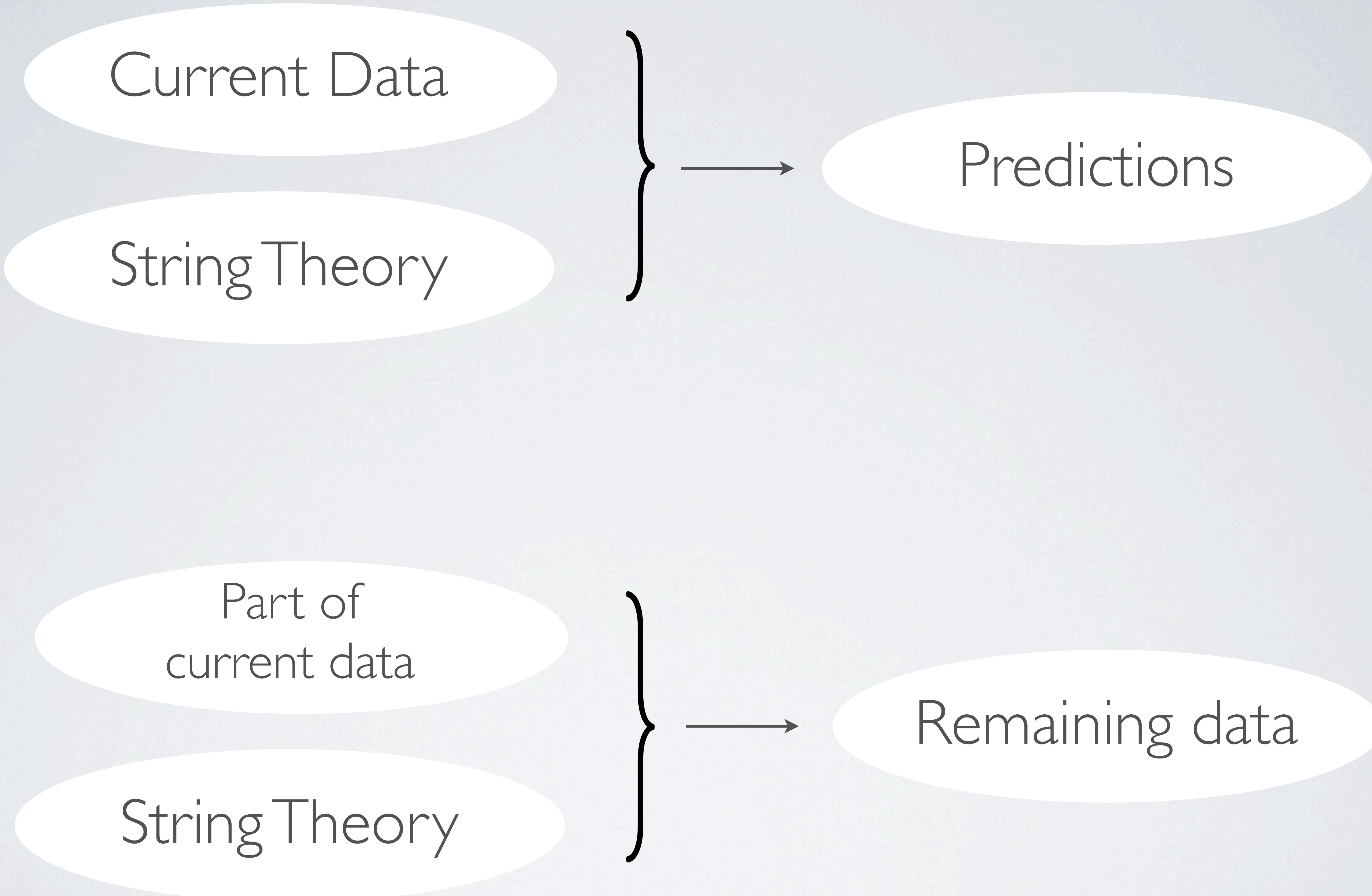
The most obvious compactification gives families of (27)'s of E6.
Even more generically, (16)'s of SO(10).

Work since then has mostly focussed on getting "exactly" SU(3)×SU(2)×U(1), with "exactly" three families.

This can indeed be done.

But can we understand the detailed structure of the standard model from string theory?

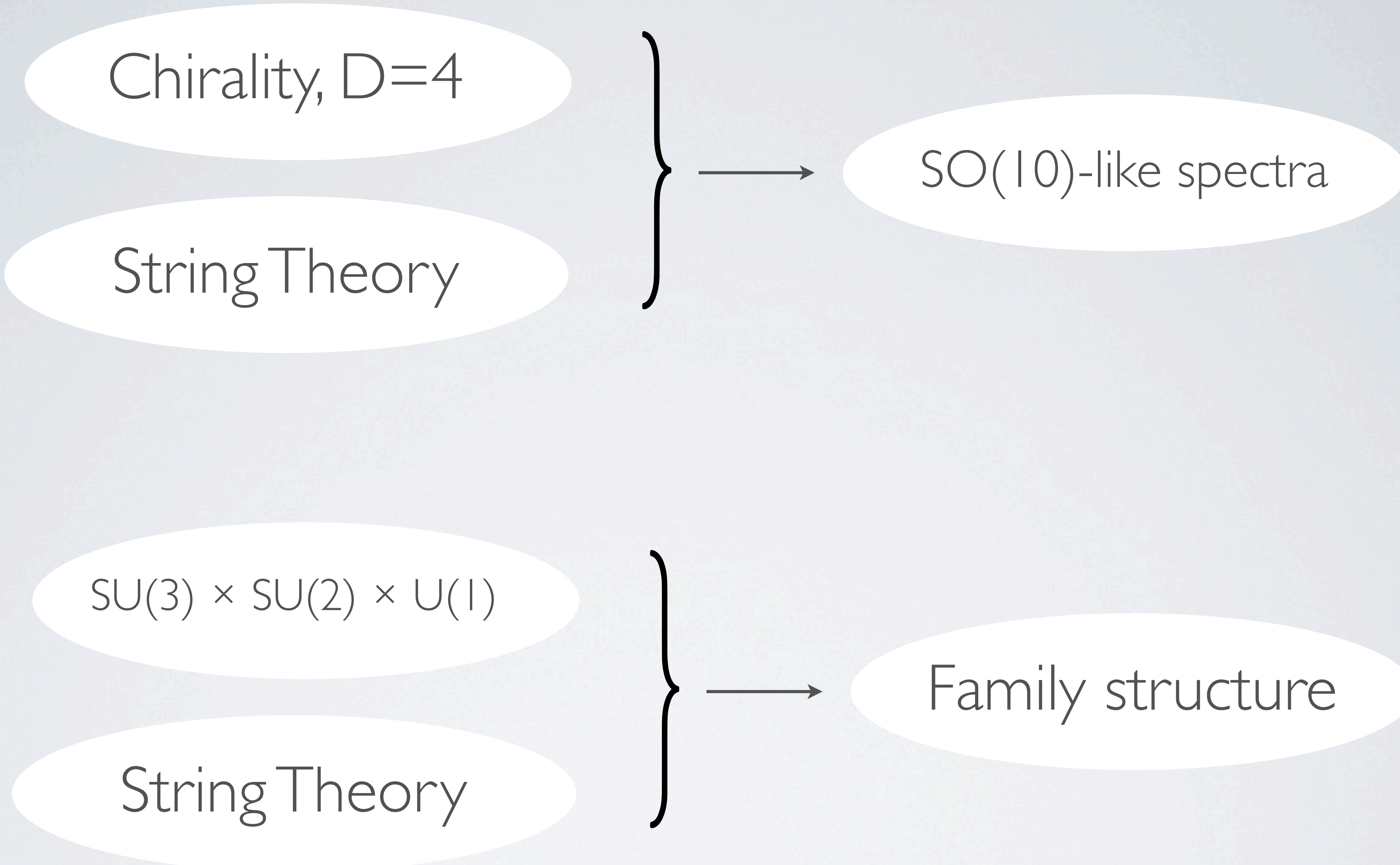

Current Data
String Theory
Predictions


Current Data
String Theory
Predictions
Part of
current data
String Theory
Remaining data

Chirality, D=4

String Theory

→ SO(10)-like spectra



Chirality, D=4
String Theory
SO(10)-like spectra
SU(3) × SU(2) × U(1)
String Theory
Family structure

SU(3) × SU(2) × U(1)
Chiral Families

String Theory

→ 3 families

SU(3) × SU(2) × U(1)
Chiral Families

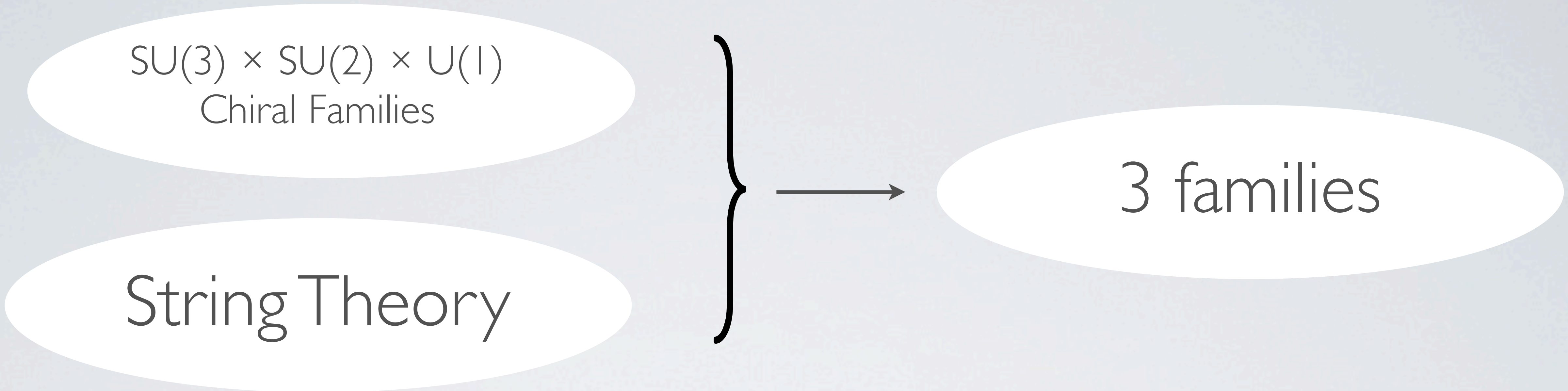
String Theory

→ 3 families

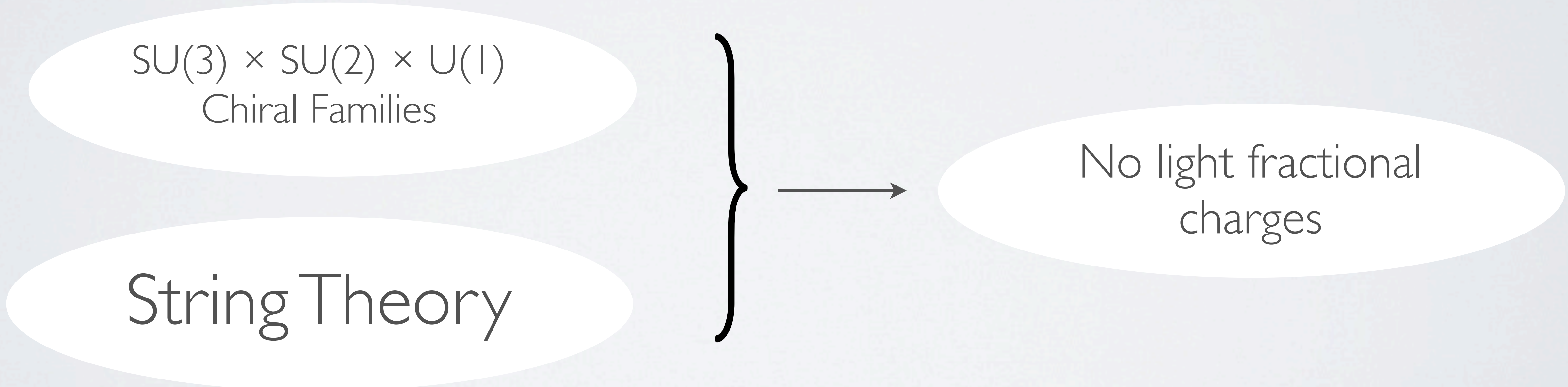
SU(3) × SU(2) × U(1)
Chiral Families

String Theory

→ No light fractional charges



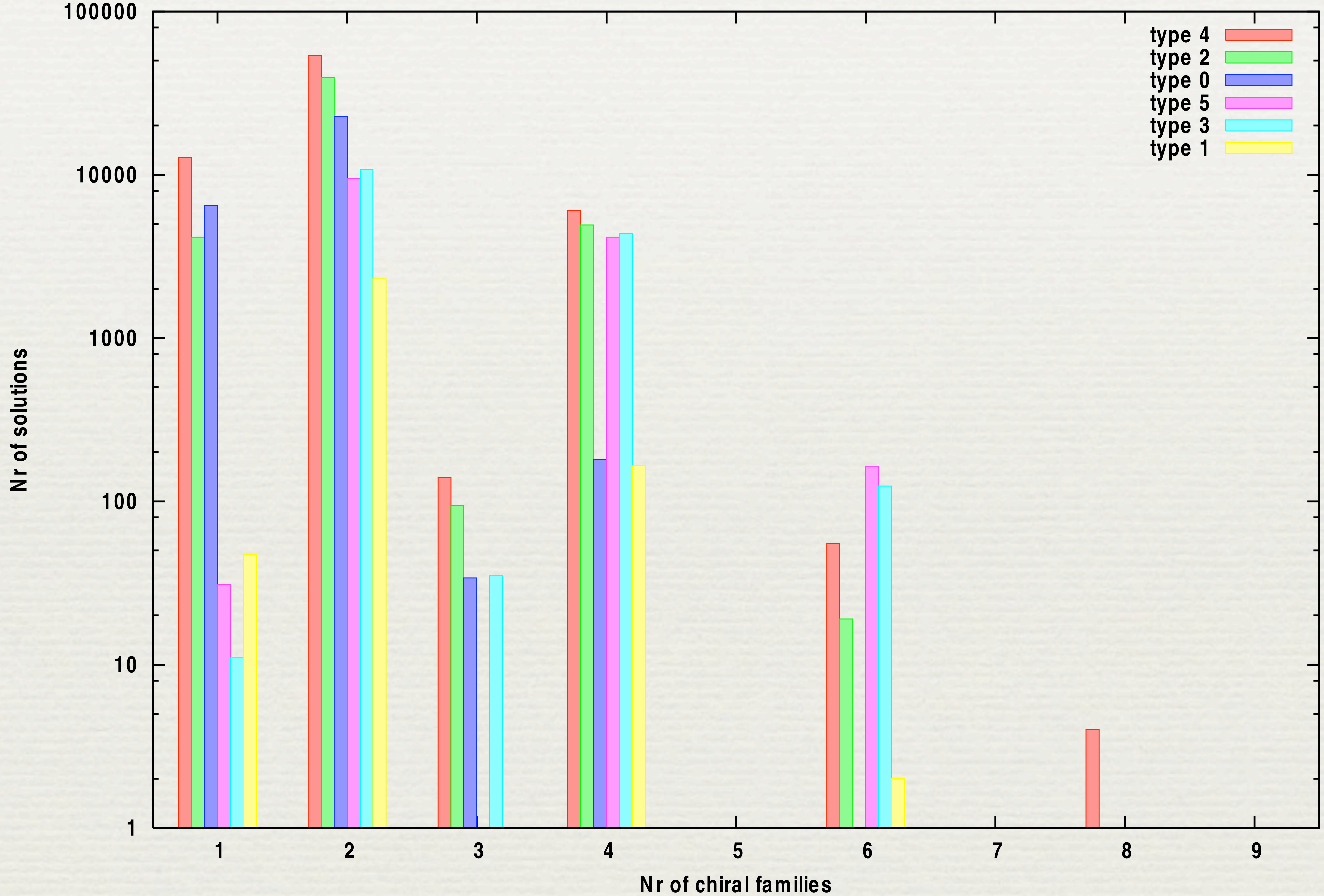
No known anthropic explanation



Anthropic explanation unlikely

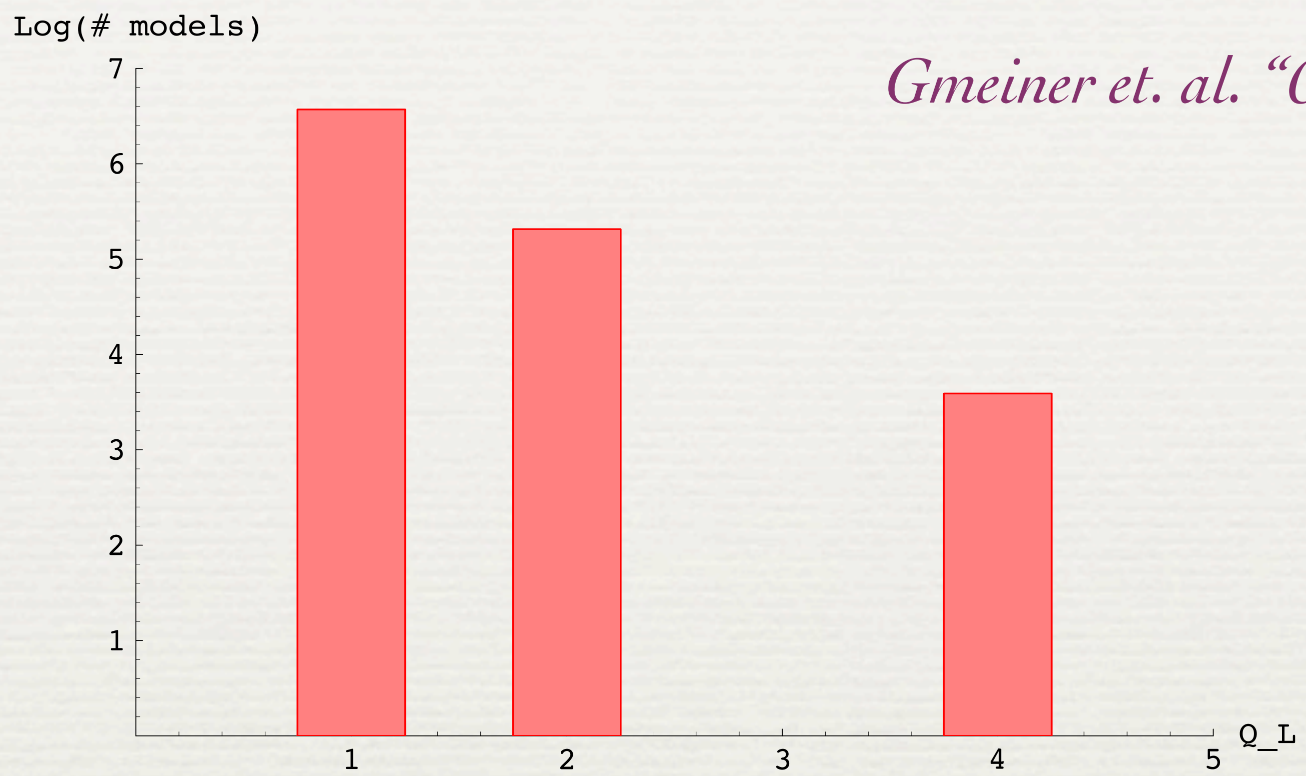
Number of families

(orientifolds)



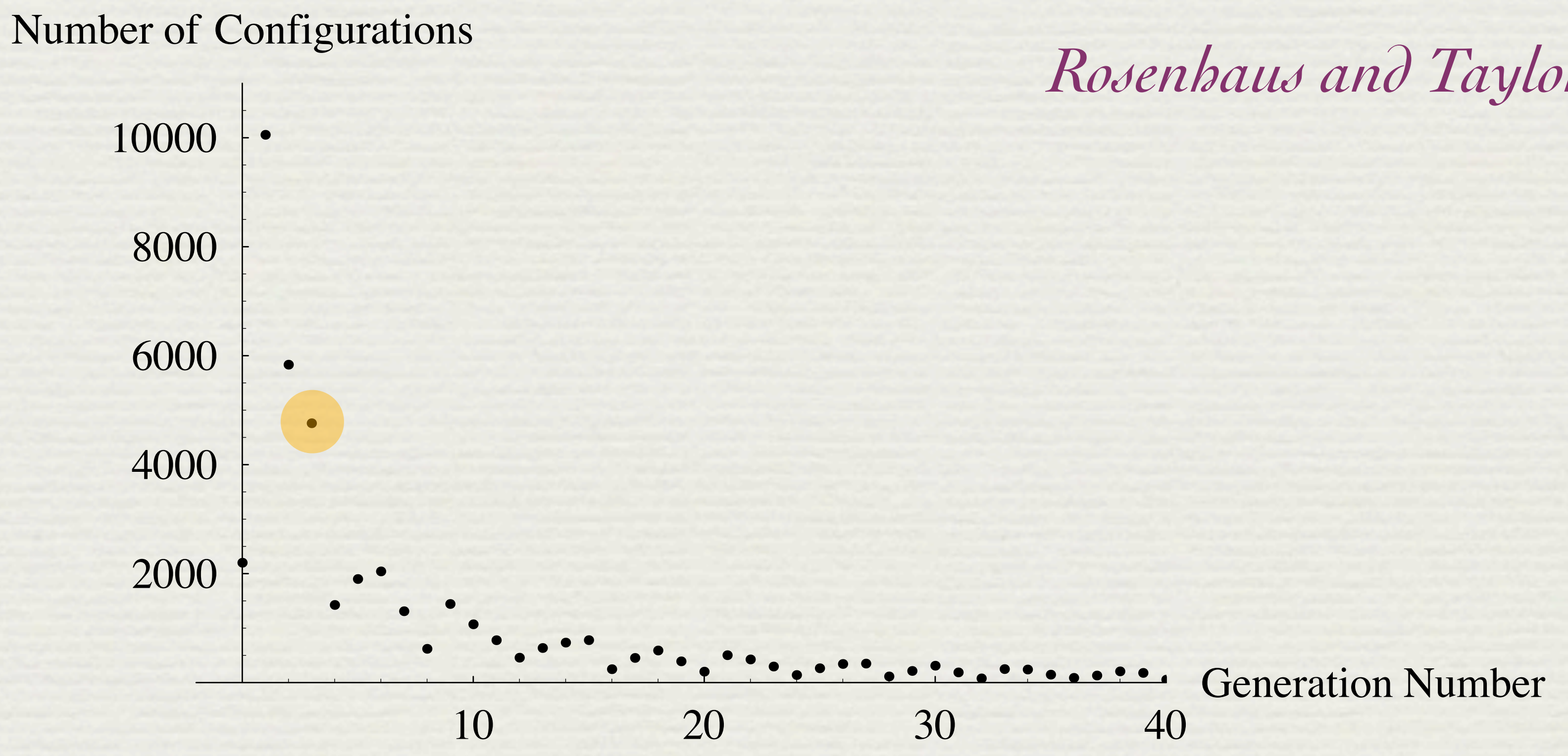
Dijkstra, Huiszoon, Schellekens (2004)

Gmeiner et. al. "One in a Billion", 2005

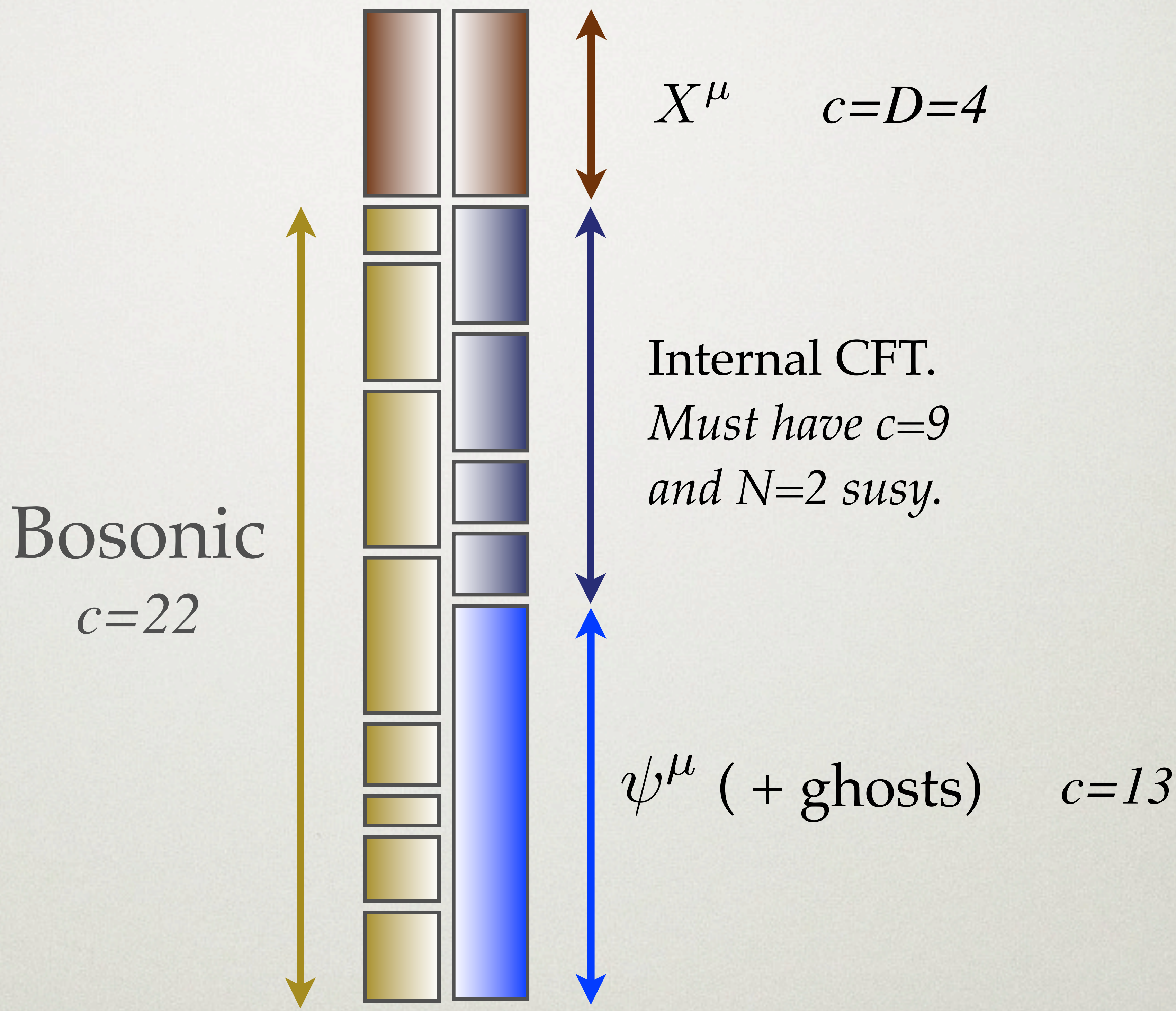


$T_6/\mathbb{Z}_2 \times \mathbb{Z}_2$

Rosenhaus and Taylor, 2009

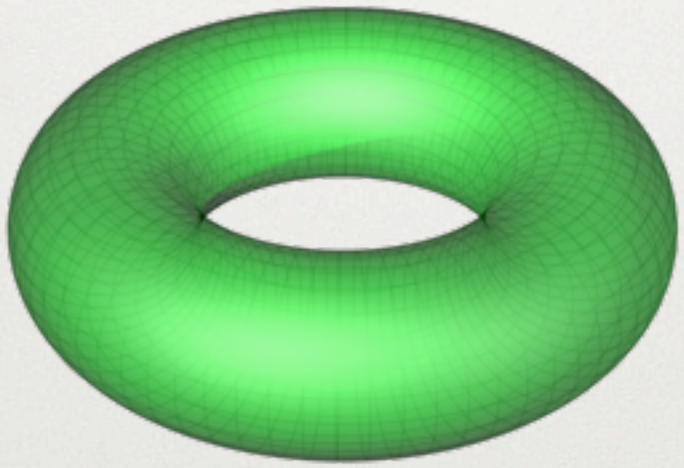


Heterotic strings



Modular invariance

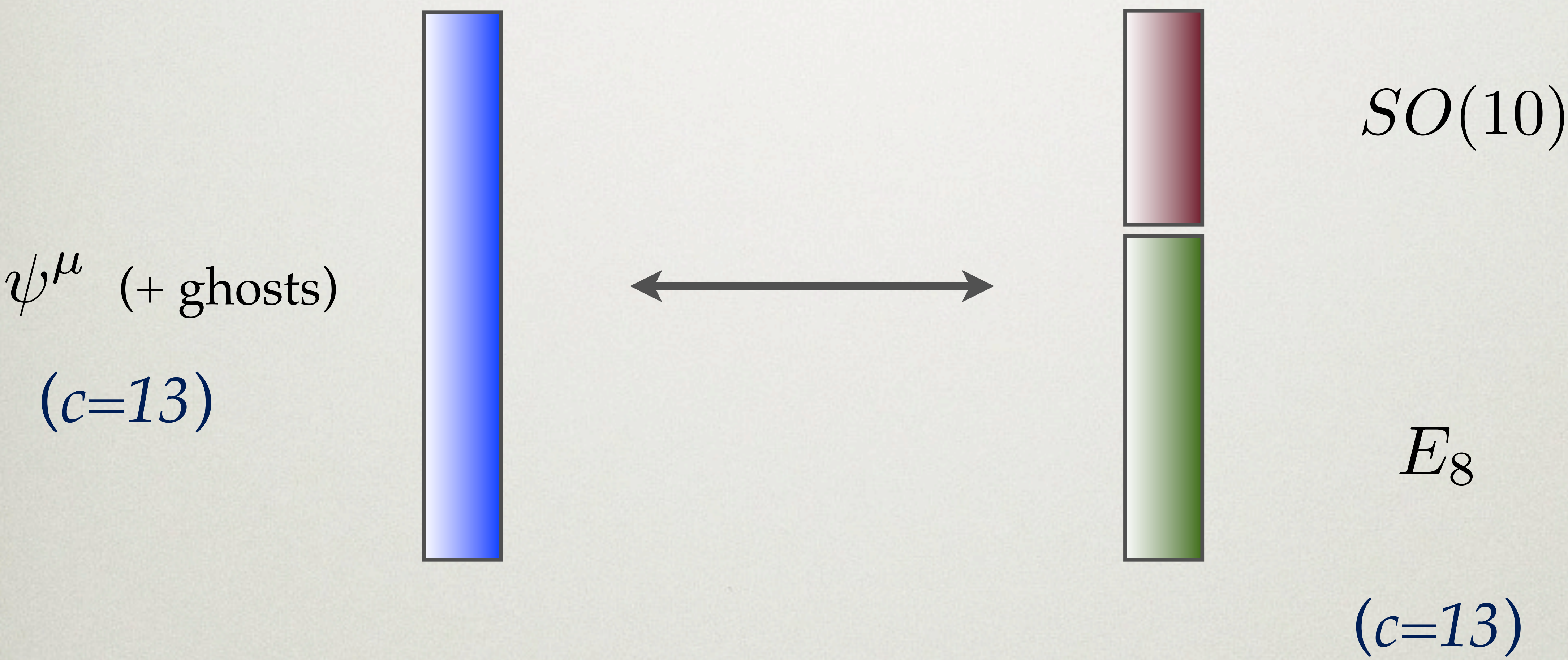
The freedom of associating left and right building blocks is severely limited by consistency of the simplest one-loop diagram, the torus ("modular invariance").



There are two classes of solutions:

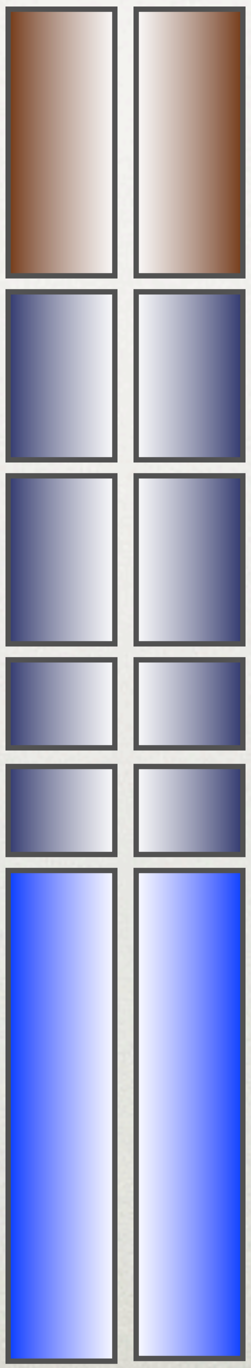
- Identical L-R building blocks
- Free 2-D field theory

The Bosonic String Map

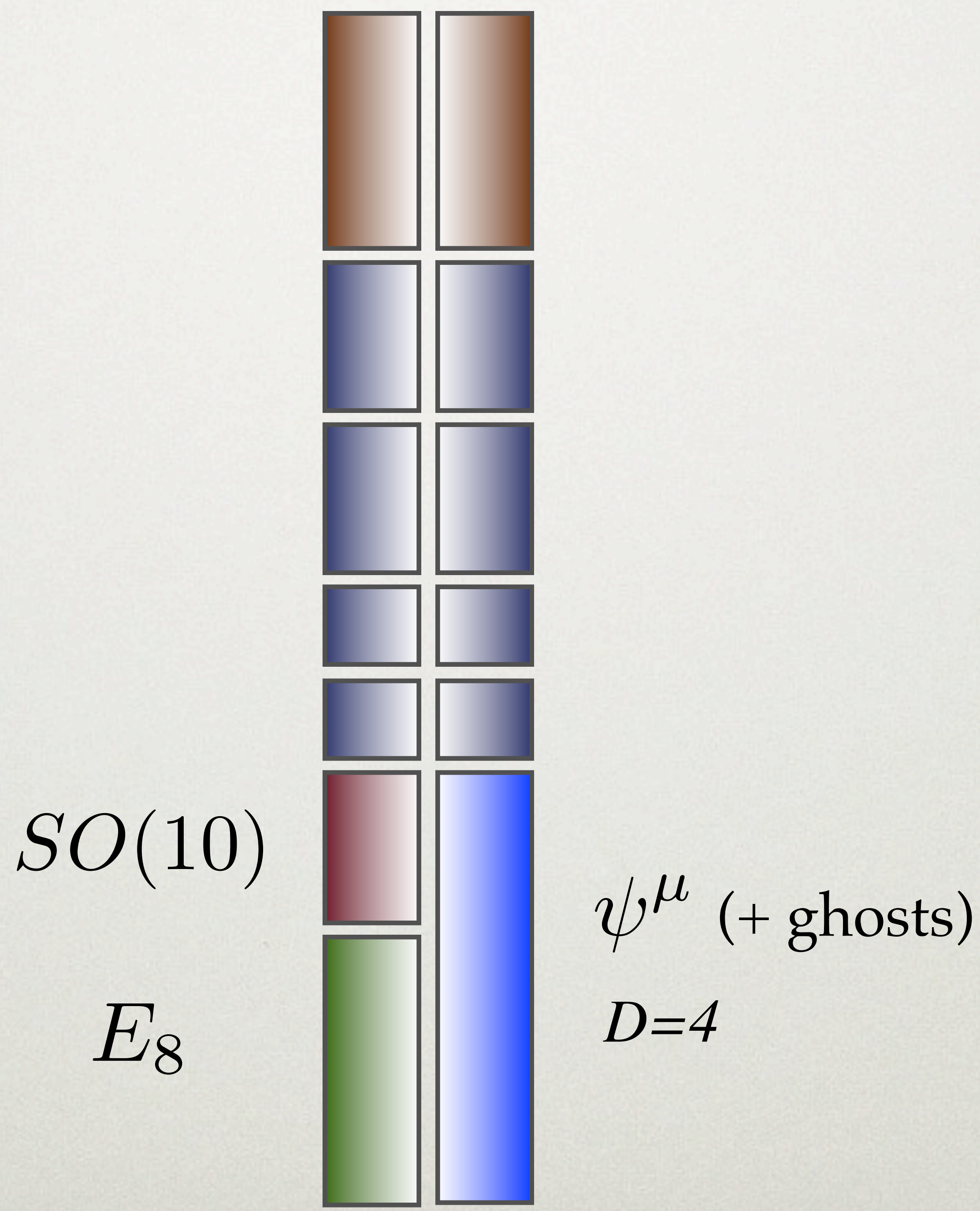


Lerche, Lüst, Schellekens (1986)

Start with a symmetric type-II string...



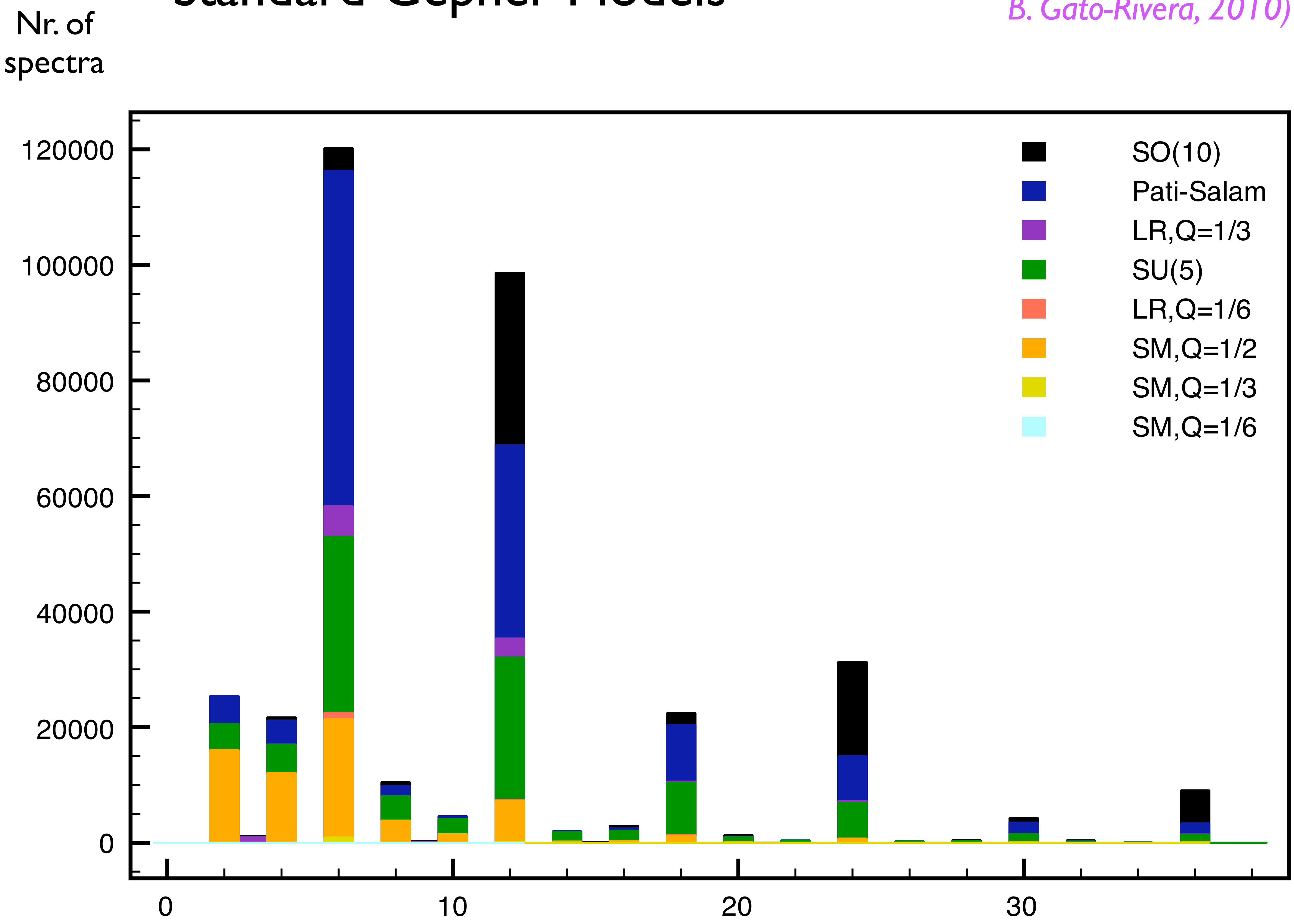
... and map it to a heterotic string



Families of (16)'s of SO(10)!

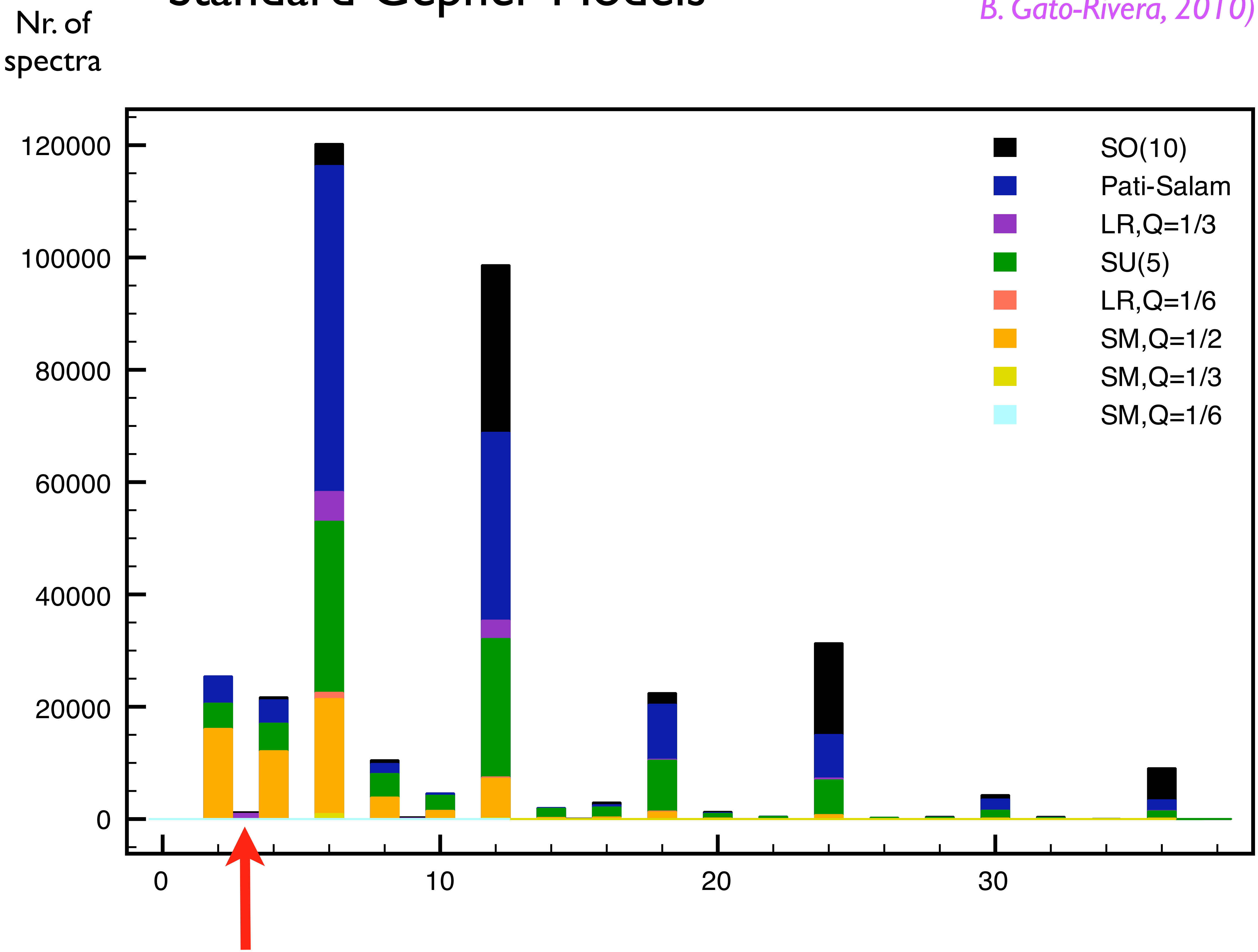
Standard Gepner Models

(with S. Yankielowicz, 1989, B. Gato-Rivera, 2010)

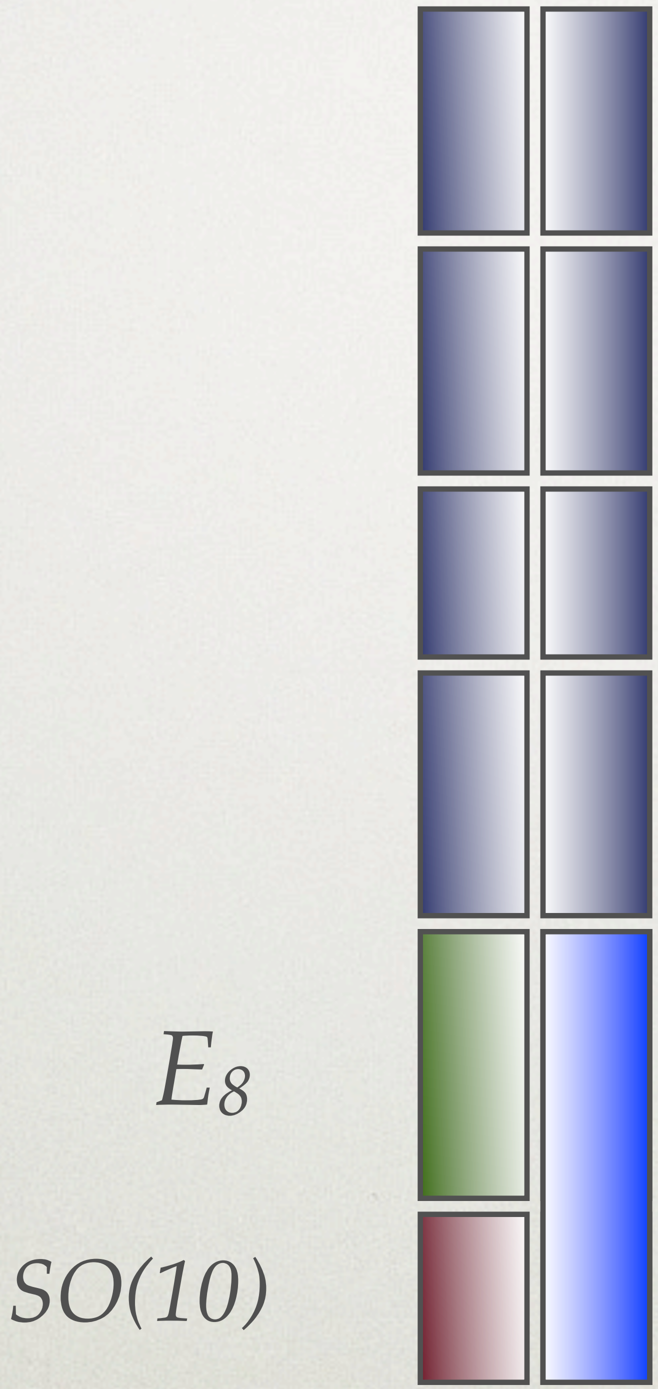


Standard Gepner Models

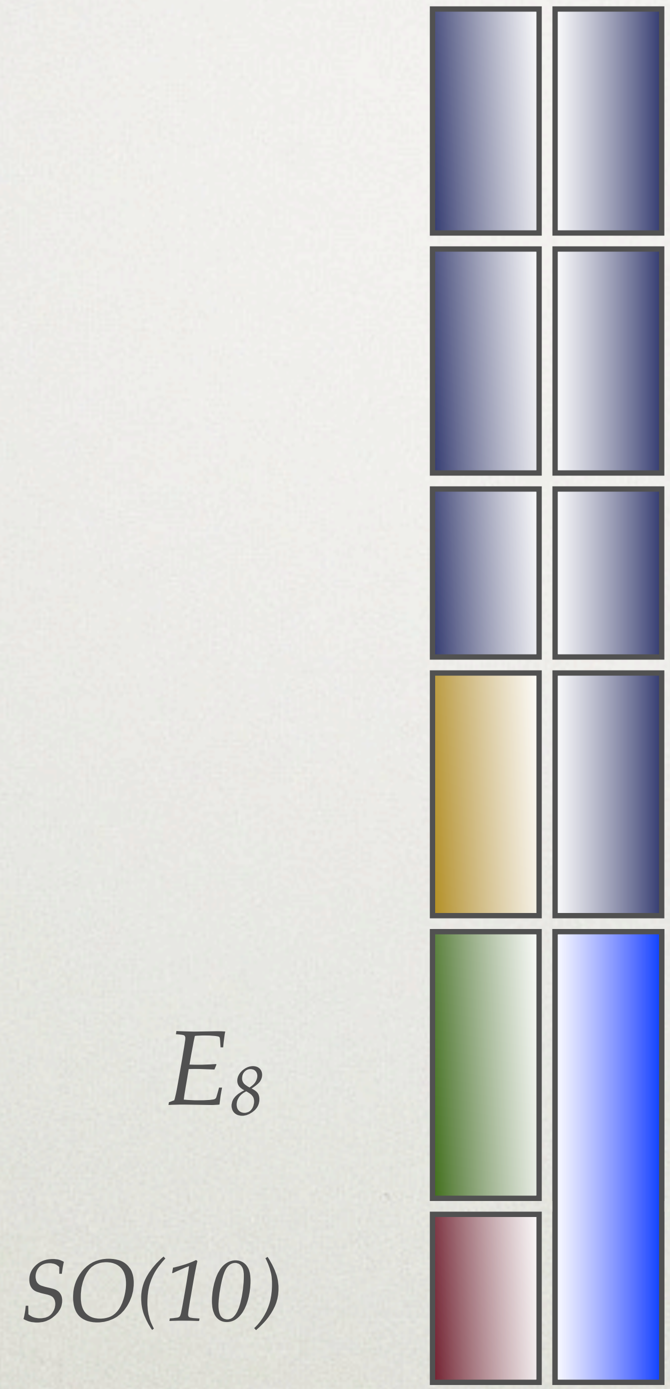
(with S.Yankielowicz, 1989, B. Gato-Rivera, 2010)



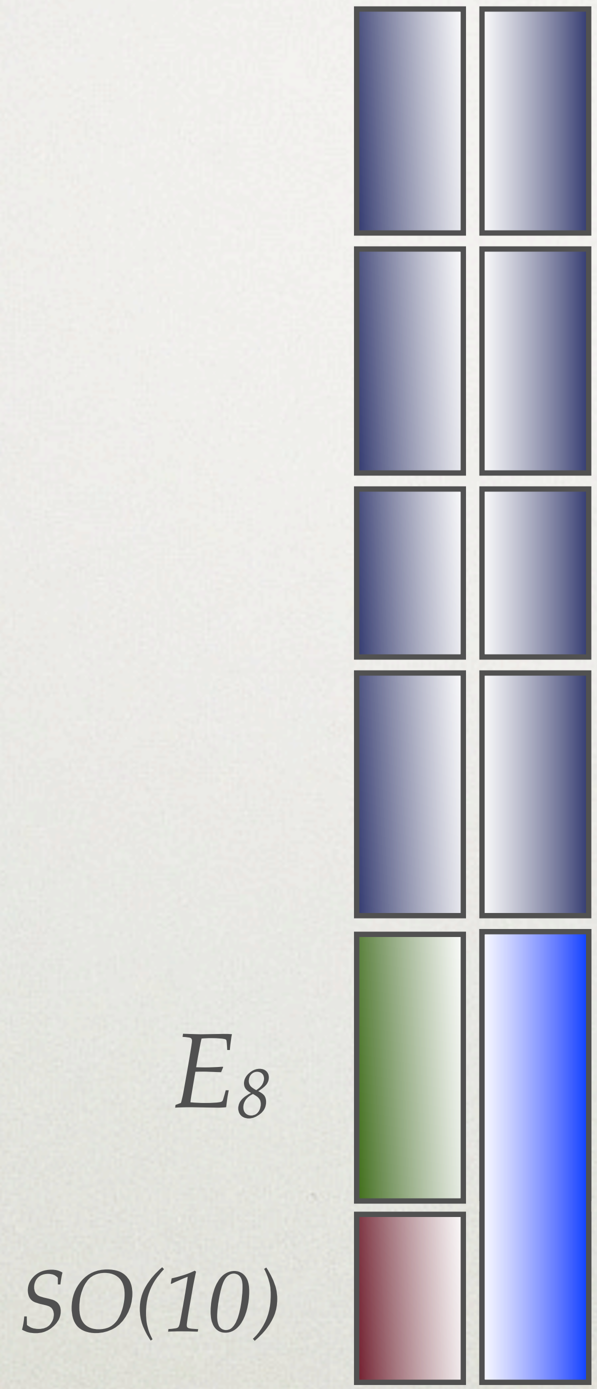
Less symmetric?



Less symmetric?

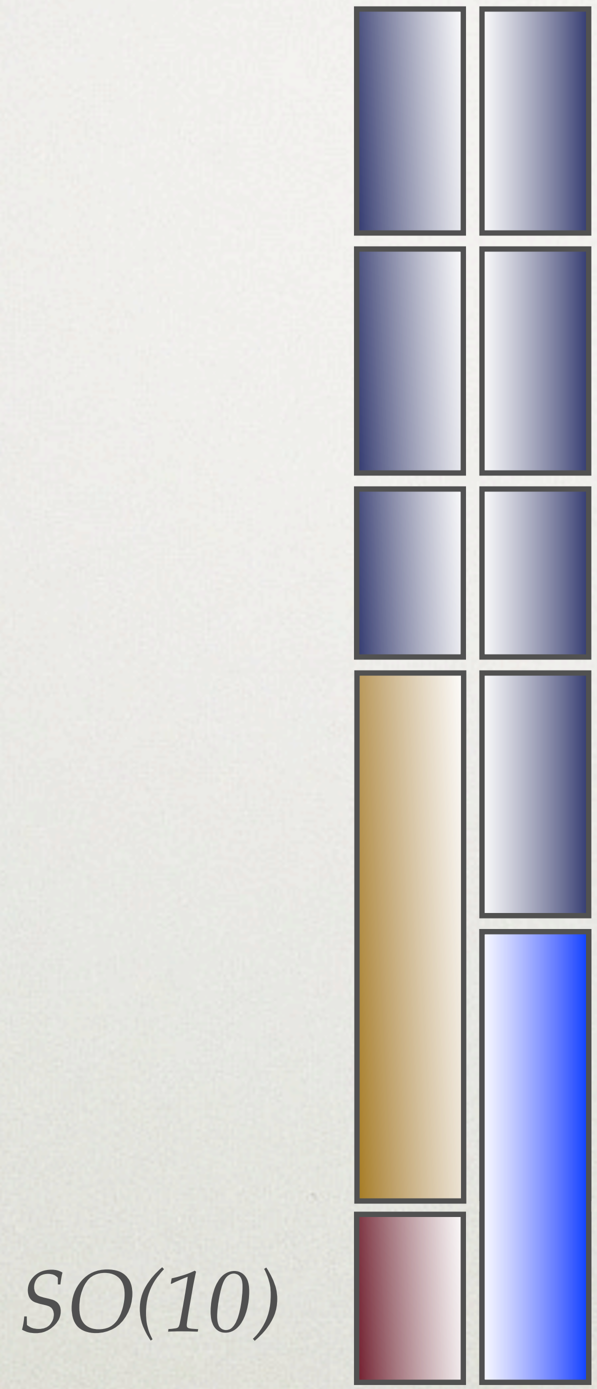


Heterotic Weight Lifting



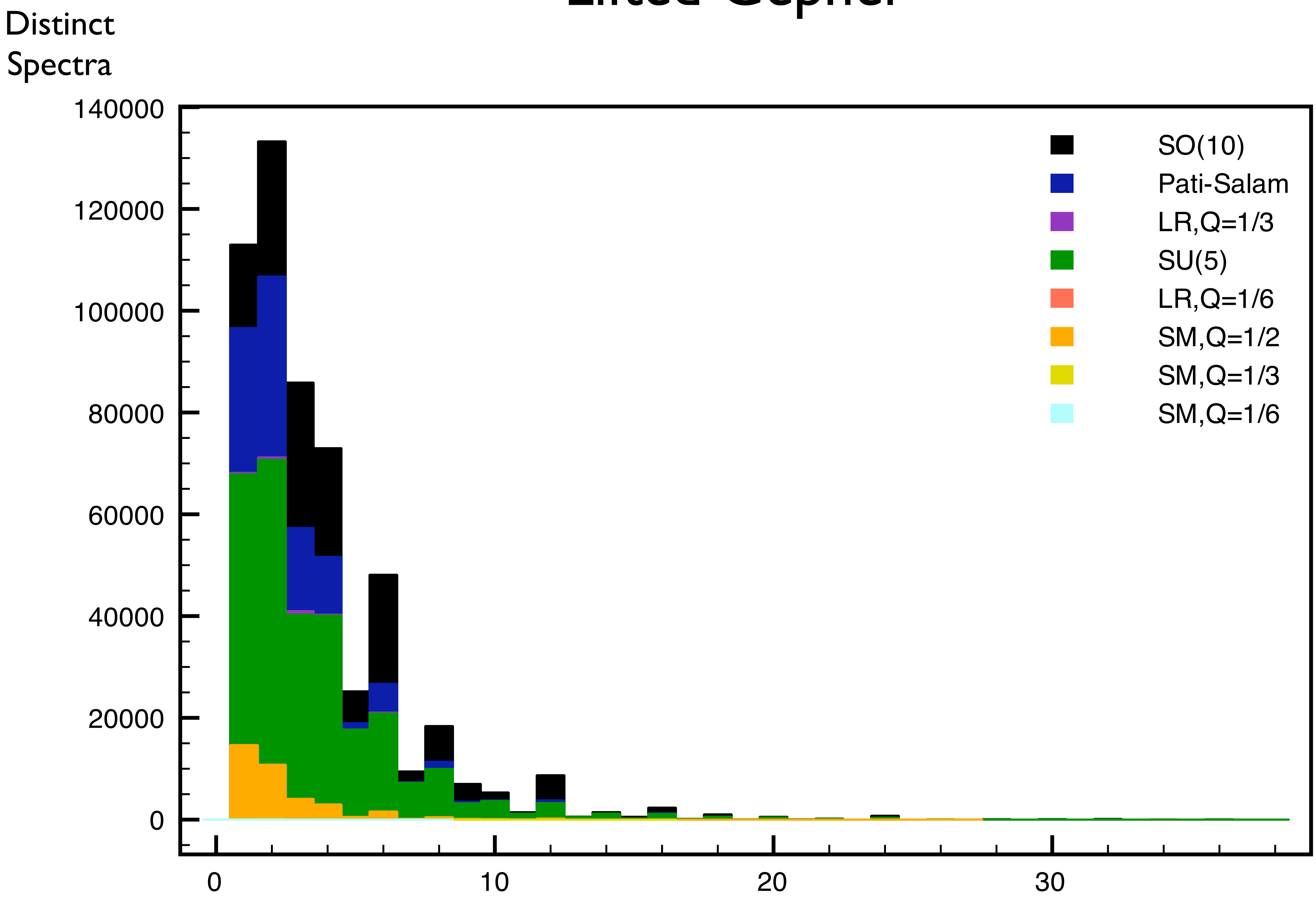
Gato-Rivera, Schellekens, 2009

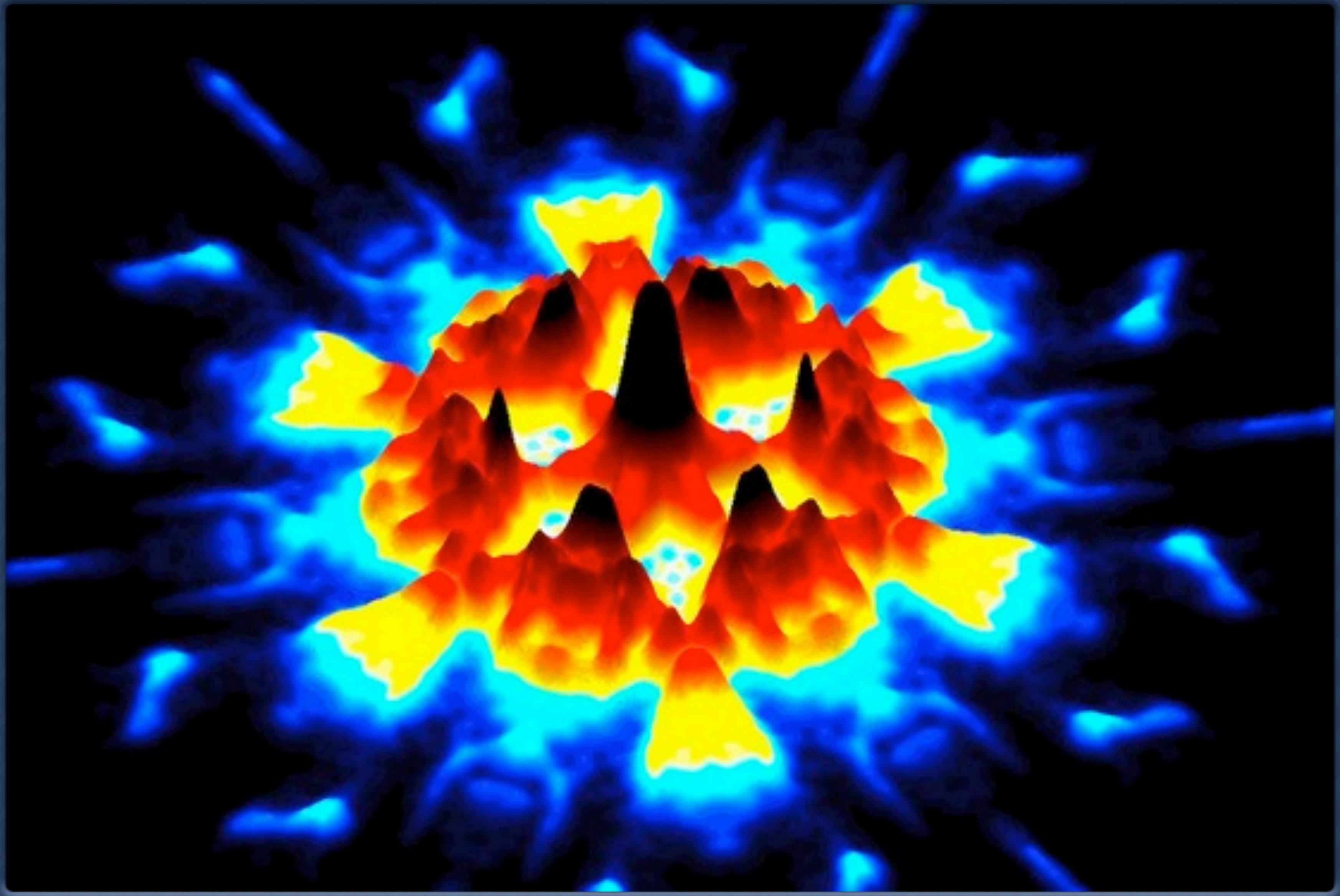
Heterotic Weight Lifting



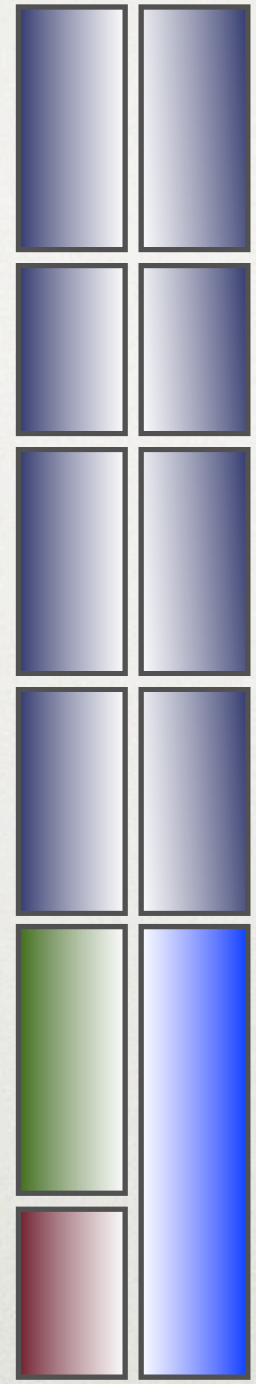
Gato-Rivera, Schellekens, 2009

Lifted Gepner

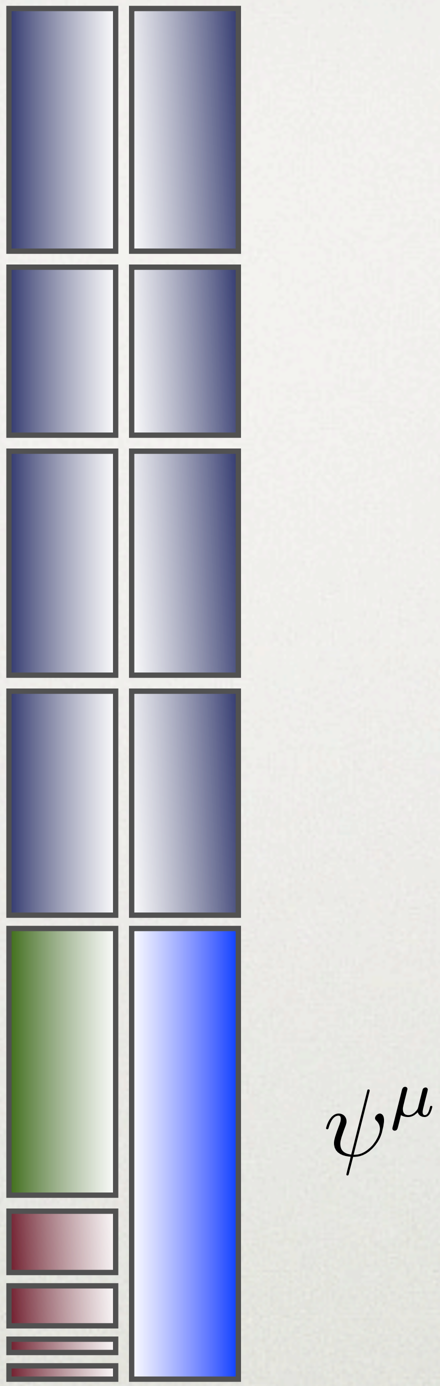




Fractional Charges



ψ^μ



SO(10) currents replaced by
operators of higher weight

Gauge group SU(3)×SU(2)×U(1)×U(1) ⊂ SO(10)

SO(10) CFT sub-algebras

	Name	Current	Order	Gauge group	Grp.	CFT
	SM, Q=1/6	$(1,1,0,0)$	1	$SU(3)\times SU(2)\times U(1)\times U(1)$	$\frac{1}{6}$	$\frac{1}{6}$
	SM, Q=1/3	$(1,2,15,0)$	2	$SU(3)\times SU(2)\times U(1)\times U(1)$	$\frac{1}{6}$	$\frac{1}{3}$
	SM, Q=1/2	$(3,1,10,0)$	3	$SU(3)\times SU(2)\times U(1)\times U(1)$	$\frac{1}{6}$	$\frac{1}{2}$
	LR, Q=1/6	$(1,1,6,4)$	5	$SU(3)\times SU(2)_L\times SU(2)_R\times U(1)$	$\frac{1}{6}$	$\frac{1}{6}$
	SU(5) GUT	$(\bar{3},2,5,0)$	6	$SU(5)\times U(1)$	1	1
	LR, Q=1/3	$(1,2,3,-8)$	10	$SU(3)\times SU(2)_L\times SU(2)_R\times U(1)$	$\frac{1}{6}$	$\frac{1}{3}$
	Pati-Salam	$(\bar{3},0,2,8)$	15	$SU(4)\times SU(2)_L\times SU(2)_R$	$\frac{1}{2}$	$\frac{1}{2}$
	SO(10) GUT	$(3,2,1,4)$	30	$SO(10)$	1	1

Fractional Electric Charges

Fractional Electric Charge

Half-integer or third-integer charges can be avoided by clever choices of the CFT, but not simultaneously.

Absence of fractional charges ⇔ Extension to **unbroken** SU(5) GUT

(A.N. Schellekens, Phys. Lett. B237, 363, 1990).
Similar results: Wen and Witten, Nucl. Phys. B261, 651 (1985); Athanasiu, Atick, Dine, Fischler, Phys. Lett. B214, 55 (1988)

Ways out:
fractional charges could be massive, vector-like (and liftable) or confined by some additional gauge group.

Fractional Charge Summary (all constructions)

Type	Chiral Exotics	GUT	Non-chiral	$N > 0$ fam.	No frac.
Standard*	37.4%	32.7%	20.5 %	9.3%	0
Standard, perm.	29.7%	33.4 %	27.9 %	8.9%	0
Free fermionic	1.5%	2.9%	94.4%	1.1%	0.072%
Lifted	28.3%	18.7%	51.9%	1.1%	0.00051%
Lifted, perm.	26.8%	8.9%	62.7 %	1.6%	0.00078%
$(\text{B-L})^*_{\text{Type-A}}$	21.3%	28.0%	50.4 %	0.3%	0.00017%
$(\text{B-L})_{\text{Type-A}}$, perm.	22.8%	8.1 %	69.1 %	0.03%	0
$(\text{B-L})^*_{\text{Type-B}}$	38.5%	8.7%	52.1%	0.6%	0
$(\text{B-L})_{\text{Type-B}}$, perm.	27.6%	7.3 %	65.0 %	0.1%	0

Vector-like Exotics

No Exotics

No-exotics models have an even number of families
For three-family examples see

Assel, Christodoulides, Faraggi, Kounnas and Rizos (2010) *[Free fermions]*

Blaszczyk, Nibbelink, Ratz, Ruehle, Trapletti, Vaudrevange (2010) *[Freely acting symmetries]*

Fractional charges in Orientifold models

SM-realizations with at most four branes*

Non-orientable "x=½"

Half-integer charges in hidden sector (if present)

Non-orientable "x=0"

Only integer charges in perturbative spectrum

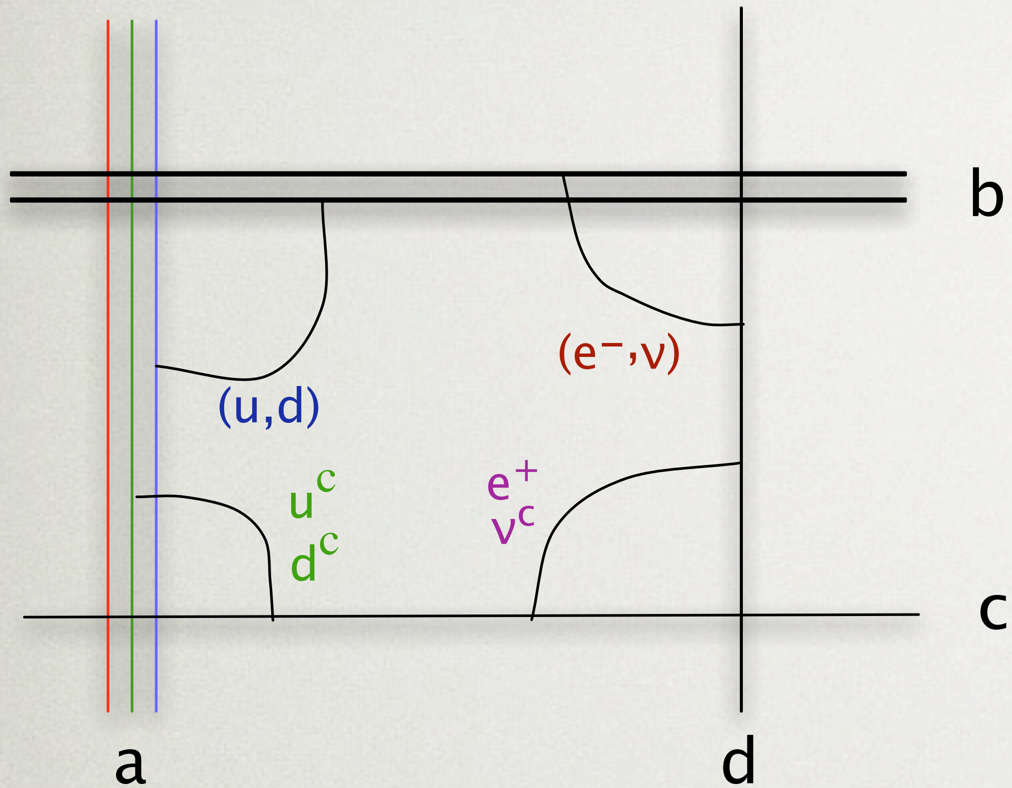
Orientable

±x integer charges in hidden sector (if present)

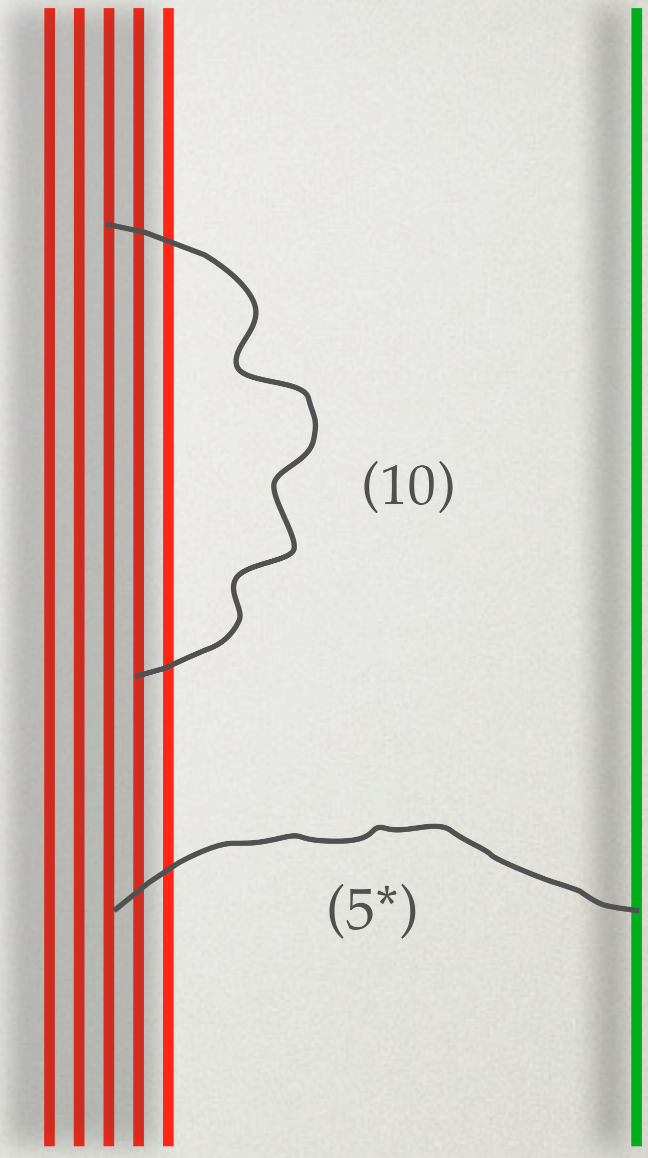
No fractional charges in SM-realizations with few branes.
But: higher rank tensors not automatically absent, unlike heterotic string.

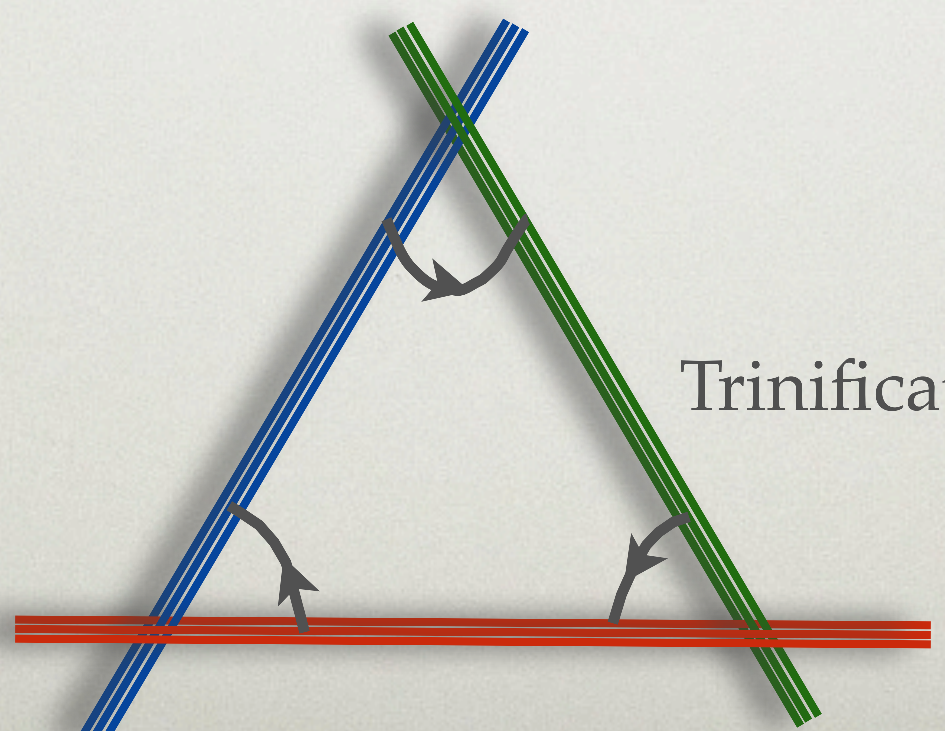
(*) Anastasopoulos, Dijkstra, Kiritsis, Schellekens

“Madrid Model”



SU(5)





Trinification

Conclusions

- We need a fundamental theory with a landscape.
- For the moment, string theory is the only game in town.
- Some string landscape ideas are already under stress.
- Three families not really a problem.
- The structure of a standard model family is problematic (generically):

In heterotic strings: Fractional charges typically occur.

In orientifolds: Higher rank representations typically occur.
(cf. Cvetic, Papadimitriou, Shiu, 2002)

Just “fitting the data” hides all these problem

(look elsewhere effect)