THE SECOND STRING (PHENOMENOLOGY) REVOLUTION

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Strings 99 - Potsdam
July 1999

String revolutions : 1985, 1995, ...

String (phen.) revolutions: 1988, 1998, ...

(3 years = time it takes to construct explicit $D=4$, $N=1$ string vacua)

→ Progress is (sometimes) realizing what we do not know

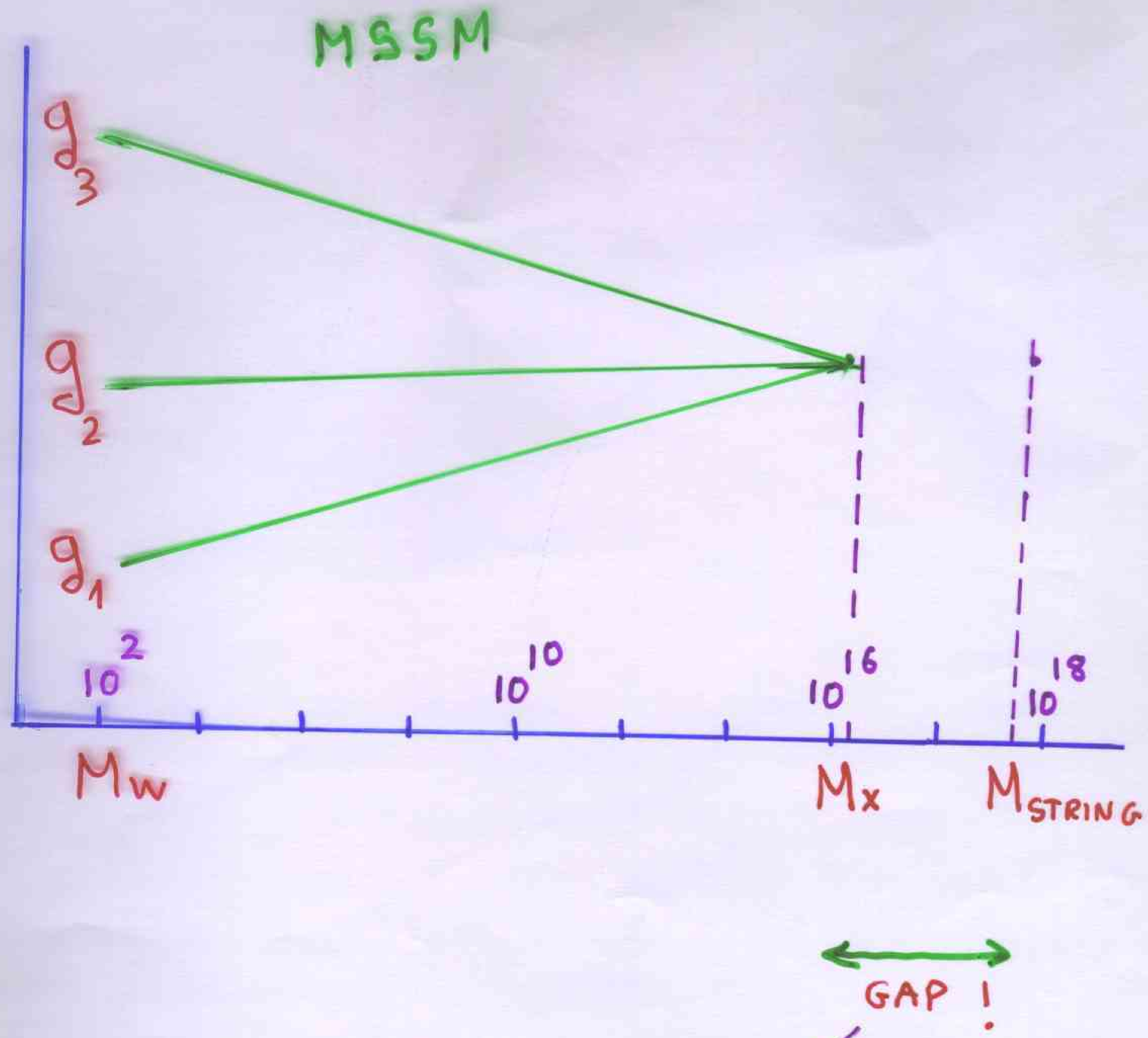
→ e.g. Now we know that we do not even know what is the fundamental scale of the theory, M_{string} !

String Phenomenology $\equiv$ How is $SU(3) \times SU(2) \times U(1)$ MODEL EMBEDDED INTO STRING THEORY

Pre-1995 Orthodoxy:

* Only heterotic, mostly $E_8 \times E_8$
* $M_{STRING} = g\, M_{PLANCK}$ (no other choice)
* M_{WEAK} SCALE GENERATED BY GAUGINO CONDENSATION $\langle \lambda\lambda \rangle \neq 0$
* Gauge coupling constants nicely unify at $M_X \simeq 2 \times 10^{16}$ GeV. M_X / M_{string} GAP problem
* Some nice examples of 3 quark-lepton generations string vacua: Z_N orbifolds, Fermionic constructions, CY's.
* (dilaton/moduli stabilization, susy-breaking, vacuum degeneracy, problems...)

LEP DATA EXTRAPOLATION:



- LARGE THRESHOLD CORRECTIONS ?
- EXTRA FIELDS BEYOND MSSM ?

AFTER 95-98 :

* Type I, Type II, F-th, M-th provide for new $D=4$, $N=1$ string vacua (end of heterotic monopoly)

* number of extra dimensions felt by gauge fields and gravity fields may be in general different

* M_{STRING} UNKNOWN

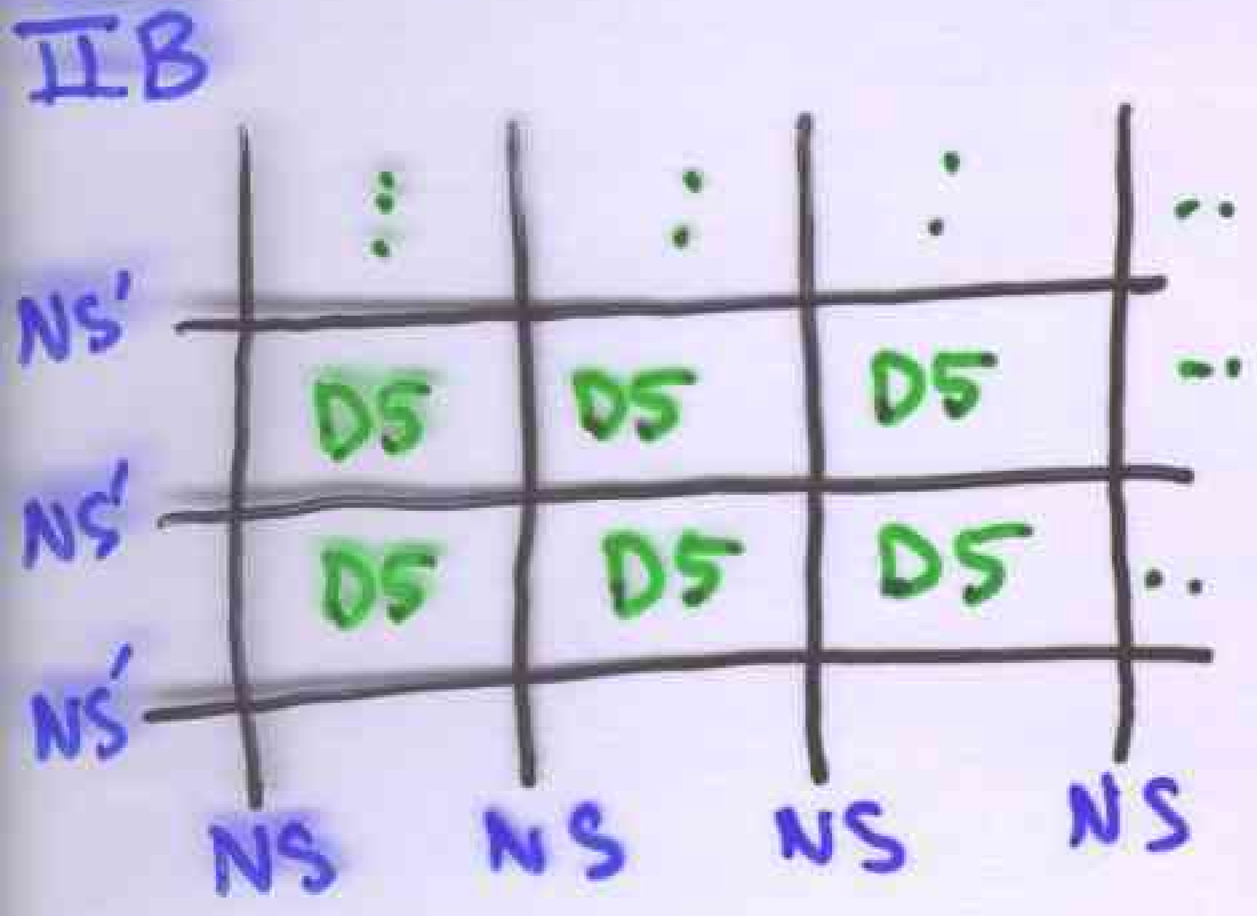
  phen. : $M_s \gtrsim 1$ TeV

NEW D=4, N=1 STRING VACUA

i) **F-THEORY** on 4-folds. Important do develup further. Complicated to extract detailed information (e.g. $U(1)$ charges, couplings, etc.)

ii) **Brane arrays** (a. la Hanany-Witten, ...)

e.g. brane boxes



Hanany-Zaffaroni
Hanany-Uranga
⋮

$N=1$, $D=4$ Type IIB vacua

(T-DUAL TO D3-brans at Z_N singularity)

BUT THESE ARE NON-COMPACT MODELS, NO USE AS UNIFIED THEORIES .... ?

iii) **M-th on $CY \times S^1/Z_2$** (see Ovrut's talk)

iv) **Type I = COMPACT TYPE IIB, $D=4$, $N=1$ ORIENTIFOLDS**

- Explicit, perturbative string vacua
- Show already many new features (like $M_s << M_{Pl}$, large gauge groups multiple anomalous $U(1)$'s etc.)

$D=4$, $N=1$, IIB ORIENTIFOLDS WITH 9,5-branes

Sagnotti et al.
Kakushadze, Tye, Shiu
Berkooz-Leigh.
Aldazabal et al.
Zwart
Lykken, Poppitz, Triv.

$$\text{IIB on } T^6 / \left\{ \begin{matrix} \mathbb{Z}_N \\ \mathbb{Z}_N \times \mathbb{Z}_M \end{matrix} , \Omega \right\}$$

$\Omega \longrightarrow$ 9-branes

if N even $\longrightarrow$ 5-branes

e.g. $\mathbb{Z}_N$: $\theta(z_1, z_2, z_3) = (e^{iV_1} z_1, e^{iV_2} z_2, e^{iV_3} z_3)$

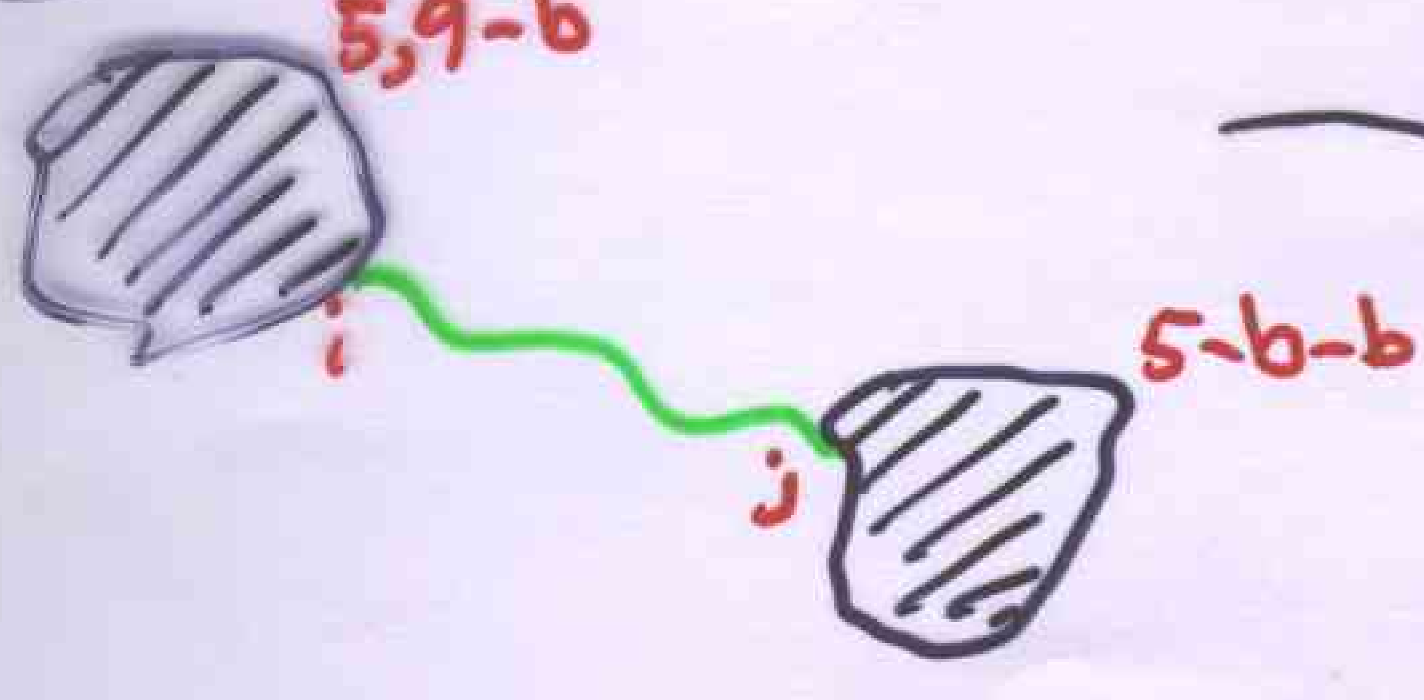
$$\bar{V} = \frac{1}{N}(a, b, c) \ , \qquad a+b+c = 0 \mod N$$

(*) CLOSED STRINGS :

 $\longrightarrow$ GRAVITY + UNTWISTED + TWISTED SINGLETS

(analogous to those in (2,2) heterotic compactifications)

(*) OPEN STRINGS



$\longrightarrow \lambda_{ij} \, \psi^{\mu}_{-1/2} |0\rangle$

$\hookrightarrow$ CP matrix (orthogonal in these models)

TWIST : $\theta^n \longrightarrow \gamma_{\theta^n}$ unitary acting on CP

unbroken group : $\lambda_{ij} = \gamma_\theta \, \lambda \, \gamma_\theta^{-1}$;

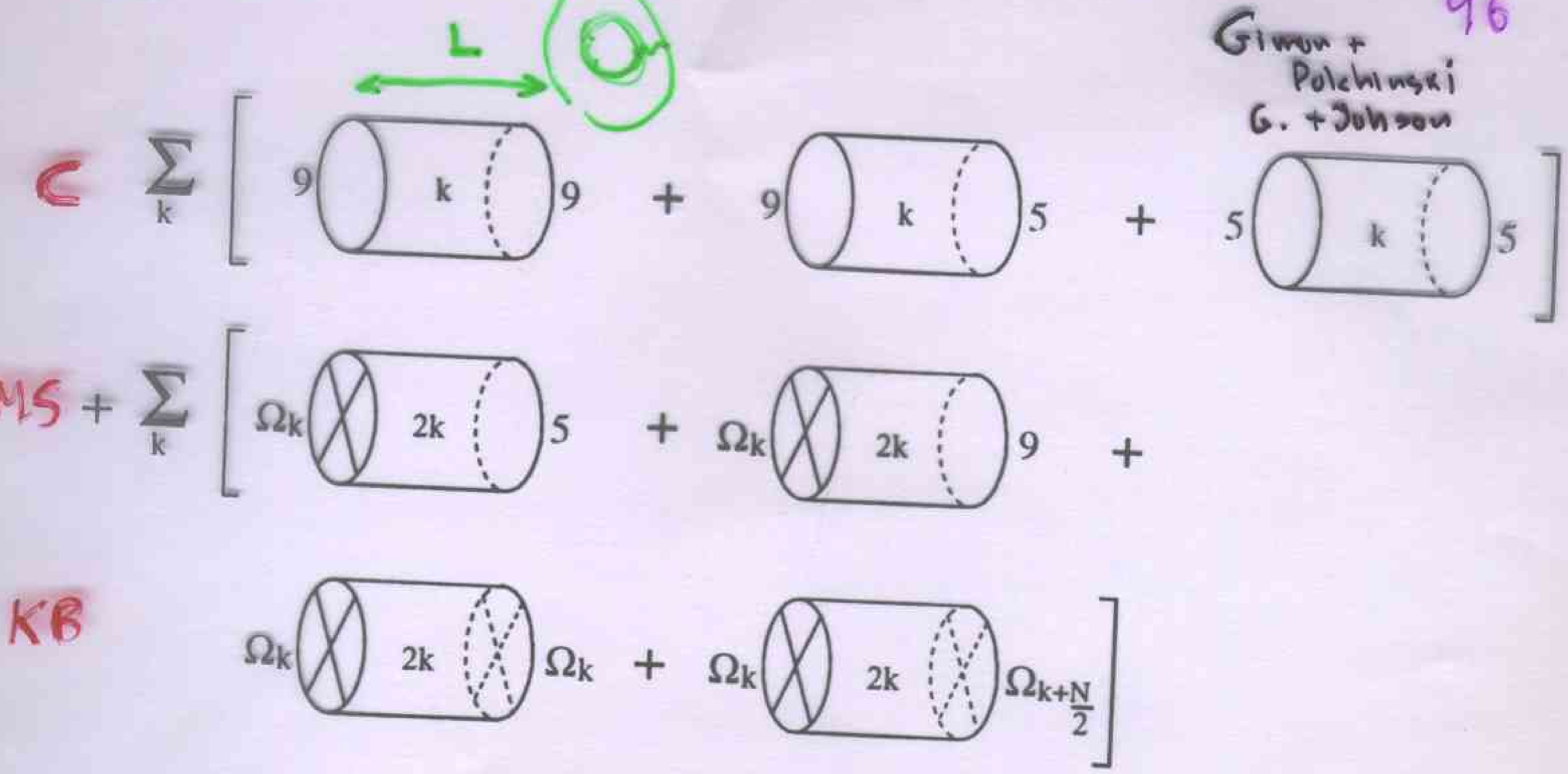
charged matter : $\lambda^{(a)} = e^{iV_a} \gamma_\theta \, \lambda \, \gamma_\theta^{-1}$

etc.

⊛ CONSISTENCY : TADPOLE CANCELATIONS

VACUUM AMPLITUDE DIVERGENCES
AS $L \to \infty$

96
Gimon + Polchinski
G. + Johnson



⊛ CANCELATION REQUIRES:

⋇ 9-b = 32
⋇ 5-b = 32
of each type

IN ADDITION, STRONG CONSTRAINTS ON γ_θ^n

Sagnotti et al. 96 e.g., Z_3 orientifold $\longrightarrow$ $\boxed{\mathrm{Tr}\,\gamma_\theta = -4}$

SOMETIMES
⊛ ALMOST UNIQUELY FIXES GAUGE GROUP AND MATTER FIELDS (MODULO WILSON LINES B_{MN} backgrounds etc.)

(*) UNLIKE WHAT HAPPENS IN HETERUTIC ORBIFOLDS THERE ARE CASES WITH NO CONSISTENT GAUGE EMBEDDING:

th-9804026

G. Aldazabal + A. Font, L. Ibáñez, G. Violero 98
G. Zwart

(*) $\mathbb{Z}_4, \mathbb{Z}_8, \mathbb{Z}_8', \mathbb{Z}_{12}$
$\mathbb{Z}_2 \times \mathbb{Z}_4, \mathbb{Z}_4 \times \mathbb{Z}_4$ } TADPOLES DO NOT CANCEL (INCONSISTENT)

(*) TADPOLES CANCEL FOR:

- $\mathbb{Z}_3, \mathbb{Z}_3 \times \mathbb{Z}_3, \mathbb{Z}_7$ — no 5-b
- $\mathbb{Z}_6, \mathbb{Z}_6', \mathbb{Z}_{12}'$, $\mathbb{Z}_3 \times \mathbb{Z}_6$ — 32 9-b + 32 5-b
- $\mathbb{Z}_2 \times \mathbb{Z}_2, \mathbb{Z}_2 \times \mathbb{Z}_6$, $\mathbb{Z}_2 \times \mathbb{Z}_6'$ — 32 9-b + 3×32 5-b

* "Semirealistic examples"

$\mathbb{Z}_3$ 3 gen SU(5) Lykken et al. 98

$\mathbb{Z}_6$ 3 gen SU(4) × SU(2) × U(1) Kakushadze + Tye 98

(*) D3-branes models are chiral only if they sit at orbifold singularities !

⇒ "MSSM is close to a singularity"

SOME Z_N, $Z_N \times Z_M$ IIB, D=4, N=1 ORIENTIFOLDS

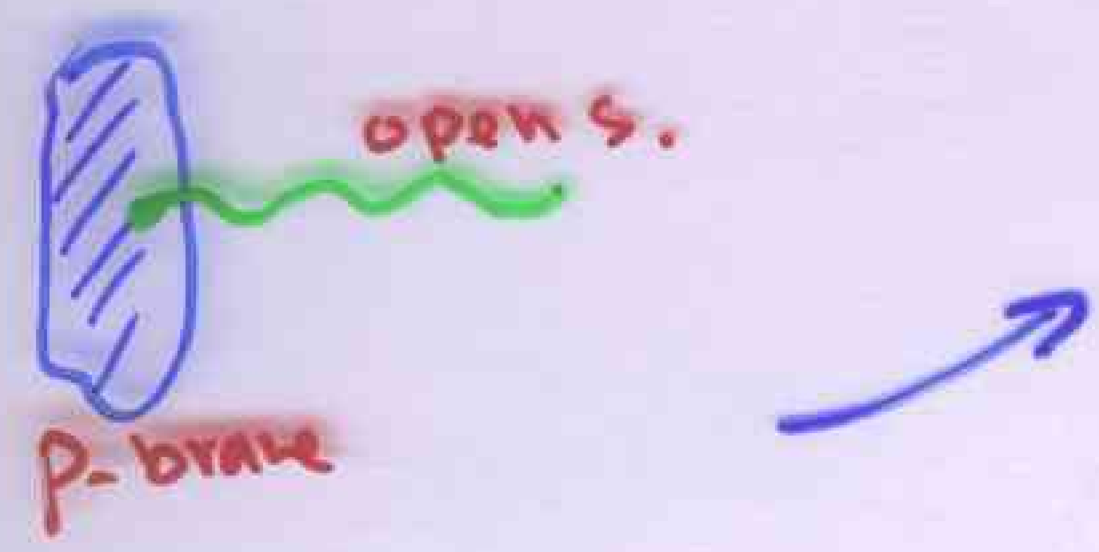
Twist Group Gauge Group	(99)/(55) matter	(95) matter
Z_3 $U(12) \times SO(8)$	$3(12,8) + 3(\overline{66},1)$	-
$Z_3 \times Z_3$ $U(4)^3 \times SO(8)$	$(\underline{4,1,1},8_v) + (\underline{\overline{4},\overline{4},1},1) + (\underline{6,1,1,1},1)$	-
Z_7 $U(4)^3 \times SO(8)$	$(\underline{4,1,1},8_v) + (\underline{\overline{4},\overline{4},1},1) + (\underline{6,1,1,1},1)$	-
Z_6 $(U(4)^2 \times U(8))^2$	$(4,1,8) + (1,\overline{4},\overline{8}) + (\underline{6,1},1)+$ $(\overline{4},1,8) + (1,4,\overline{8}) + (4,\overline{4},1)$ $+(1,1,28) + (1,1,28) + (4,4,1) + (\overline{4},\overline{4},1)$	$(4,1,1;4,1,1) + (1,\overline{4},1;1,\overline{4},1)+$ $+(1,4,1;1,1,8) + (1,1,8;1,4,1)+$ $(\overline{4},1,1;1,1,\overline{8}) + (1,1,\overline{8};\overline{4},1,1)$
Z_6' $(U(6)^2 \times U(4))^2$	$2(15,1,) + 2(1,\overline{15},1) + 2(1,6,4)+$ $2(\overline{6},1,4) + (1,6,\overline{4}) + (6,\overline{6},1)$ $+(\overline{6},1,4)$	$(6,1,1;6,1,1) + (1,\overline{6},1;1,\overline{6},1)+$ $(1,6,1;1,1,4) + (1,1,4;1,6,1)+$ $(\overline{6},1,1;1,1,\overline{4}) + (1,1,\overline{4};\overline{6},1,1)$
$Z_3 \times Z_6'$ $(U(2)^6 \times U(4)^2)^2$	$(2,2,1^5) + (1^2,2,2,1^3) + (1^4,2,2,1)$ $(1^4,2,1,4) + (1^5,2,\overline{4}) + 4(1^7) + (2,1^5,4)$ $+(1^2,2,1^3,\overline{4}) + (2,1^4,2,1) + (1^2,2,1,2,1^2)+$ $+(1,2,1^4,\overline{4}) + (1^3,2,1^2,4)$	$(2,1^6;1,2,1^5) + (1^2,2,1^4;1^3,2,1^3)+$ $(1^4,2,1^2;1^5,2,1)(1^4,2,1^2;1^6,4)+$ $(1^5,2,1;1^6,\overline{4})$ + same with groups reversed
Z_{12} $(U(3)^4 \times U(2)^2)^2$	$(\underline{\overline{3},1},\underline{\overline{3},1},1,1) + (\underline{3,1,1,1},2,1)$ $+2(1,3,1,1,2,1) + 2(3,1,1,1,1,2)$ $+2(1,1,1,3,2,1) + 2(1,1,3,1,1,2)$ $+(\underline{3,1,1,1},1,1)$	$(\overline{3},1^5;1^2,\overline{3},1^3) + (1,3,1^4;1^4,2,1)+$ $+(3,1^5;1^5,2) + (1^3,3,1^2;1^4,2,1)$ $+(1,\overline{3},1^4;1^3,\overline{3},1^2) + (1^2,3,1^3;1^5,2)$ + same with groups reversed

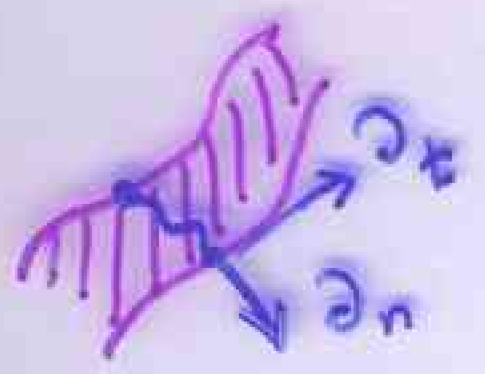
Table 1: Gauge group and charged chiral multiplets in some Z_N and $Z_N \times Z_M$ $D=4$, $N=1$ Type IIB orientifolds with GP-like projection. Only models with at most one set of fivebranes are shown. All fivebranes are supossed to sit at the same fixed point so that in models with fivebranes the spectrum is explicitely T-dual.

Sagnotti et al
Kakushadze, Shiu ; Tye
Zwart
Aldazabal, Font, L. I., Violero

D-p-brane : $\nearrow$ (P+1) dim. have Neumann boundry conditions

$\searrow$ 10−(P+1) dim. have Dirichlet b.c.





$$R_i \longleftrightarrow \frac{\alpha'}{R_i}$$

Neumann $\longleftrightarrow$ Dirichlet

Neumann: $\partial_n X^\mu = 0$, $\partial_t X^\mu \neq 0$

Dirichlet: $\partial_t X^\mu = 0$, $\partial_n X^\mu \neq 0$

T-DUALITIES

	9	5_1	5_2	5_3
$R_1 \longrightarrow \frac{\alpha'}{R_1}$	7_1	3	7_3	7_2
$R_2 \longrightarrow \frac{\alpha'}{R_2}$	5_3	5_2	5_1	9
$R_3 \longrightarrow \frac{\alpha'}{R_3}$	3	7_1	7_2	7_3

So the same model may be described in terms of different p-brane background

GAUGE COUPLING UNIFICATION IN TYPE I

$$D=10 \quad S = \int dx^{10}\sqrt{g}\left(\frac{M_I^8}{\lambda_I^2}R + \frac{M_I^6}{\lambda_I}F_{(9)}^2 + \dots\right)$$

Witten

$$\Big\downarrow \text{COMPACT VOLUME } V = M_c^{-6}$$

$$D=4 \quad S = \int dx^4\sqrt{g}\left(\frac{M_I^8}{M_c^6\lambda_I^2}R + \frac{M_I^6}{M_c^6\lambda_I}F_{(9)}^2 + \right.$$

$$\left. + \sum_{j=1}^{3}\frac{M_I^4}{M_c^4\lambda_I}F_{(7_j)}^2 + \sum_{i=1}^{3}\frac{M_I^2}{M_c^2\lambda_I}F_{(5_i)}^2 + \frac{1}{\lambda_I}F_{(3)}^2\right)$$

$$\left[M_{Planck}^2 = \frac{8}{\lambda_I^2}\frac{M_I^8}{M_c^6}\right] \; ; \; \left[\alpha_p = \frac{\lambda_I}{2}\left(\frac{M_c}{M_I}\right)^{p-3} \quad p = 9, 7, 5, 3\right]$$

$$2\times 10^{17}\,\text{GeV} = \left[\frac{\alpha_p M_{Planck}}{\sqrt{2}} = \frac{M_I^{(7-p)}}{M_c^{(6-p)}}\right]$$

Witten 96

$$\left(\text{in heterotic} \quad \frac{\alpha' M_{Planck}}{2} = M_I\right)$$

e.g., SM $\in$ 3-branes $(p=3)$

$$\boxed{M_s^4 = \frac{\alpha}{\sqrt{2}} M_c^3 M_{PLANCK}}$$

M_s MAY BE ARBITRARILY LOW BY LOWERING M_c

Lykken, 96

Antoniadis, 98

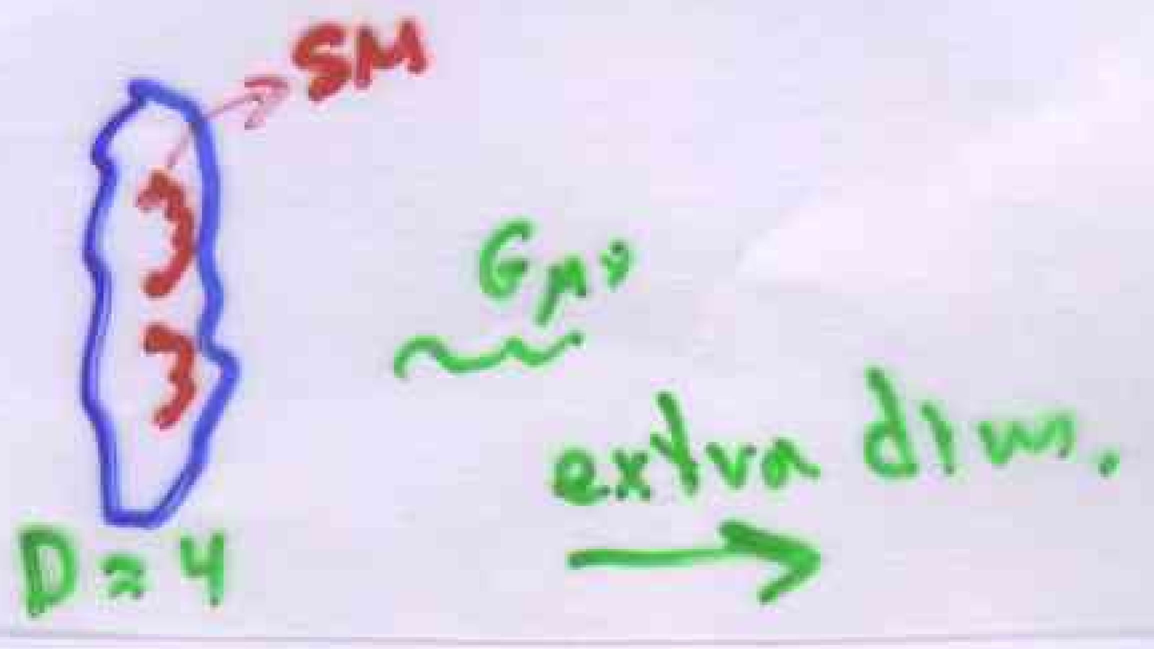
Arkani-Hamed, Dimopoulos

Dvali

PHENOMENOLOGICALLY: $M_s \gtrsim 1\ TeV$

BUT $M_c \ll 1\ TeV$ ALLOWED !!

- (*) BECAUSE CHARGED FIELDS LIVE ONLY IN FOUR DIMENSIONS (IRRESPECTIVE OF M_c)
- (*) CHARGED FIELDS DO NOT HAVE KK EXCITATIONS, ONLY GRAVITATIONAL SECTOR HAS, BECAUSE OPEN STRINGS HAVE TO END ON 3-BRANES.



What is

Ms ?

M_S ONLY CONSTRAINED BY PHENOMENOLOGICAL CONSIDERATIONS !!

SOME PHYSICALLY MOTIVATED OPTIONS:

(0)

(i) $M_s \simeq M_{GUT}$ = gauge coupling unification mass 2×10^{16} GeV

Witten

(ii) $M_s \simeq 1\,\mathrm{TeV}$

Antoniadis, Arkani-Hamed, Dimopoulos, Dvali

(iii) $M_s \simeq \sqrt{M_W M_{PLANCK}} \simeq 10^{11}$ GeV

Benakli

Burgess, L.I., Quevedo

(i) $\left[M_s = M_X \simeq 2 \times 10^{16}\ \mathrm{GeV} \right]$?

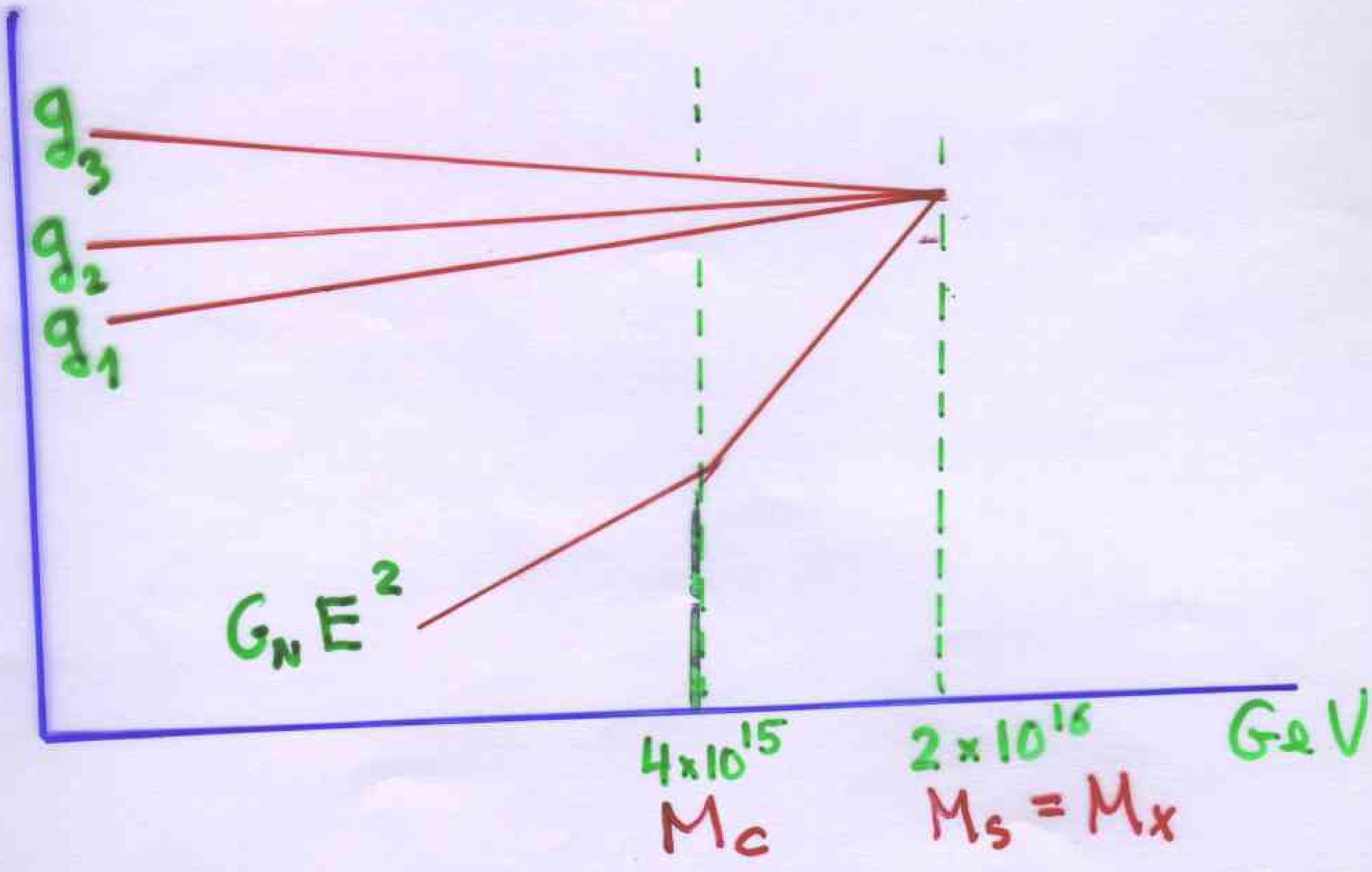
"GRAND UNIFICATION" MASS

e.g. MSSM $\in$ 3-branes :

$$M_s^{\,4} = \frac{\alpha}{\sqrt{2}}\, M_c^{\,3}\, M_{PLANCK}$$

enough to assume $M_c \simeq \frac{1}{5} M_X \simeq 4 \times 10^{15}\ \mathrm{GeV}$

(*) Solves the unification "GAP" problem: Witten 96

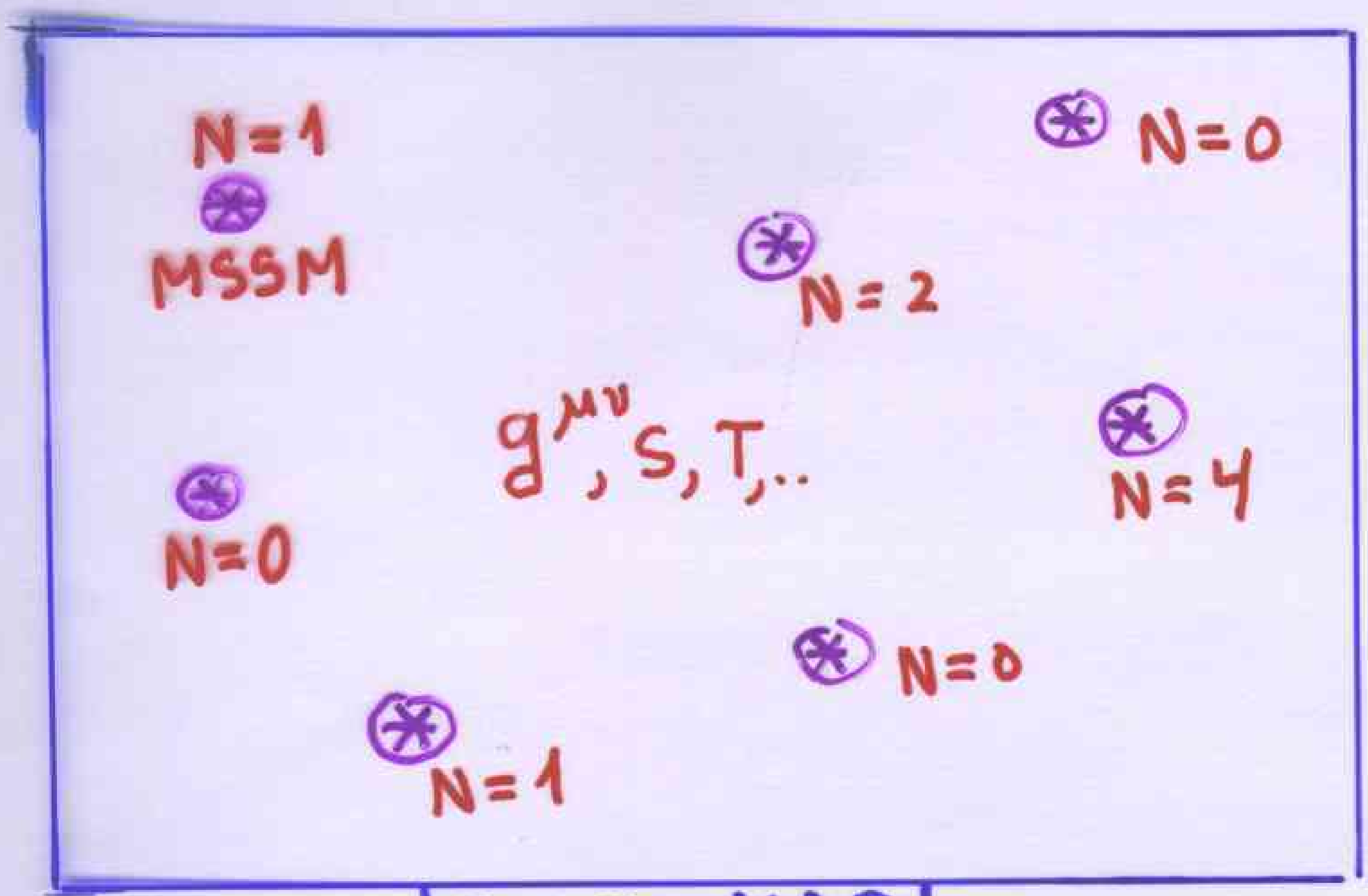


(*) what is the origin of the M_W / M_{PLANCK} hierarchy ?

ARGUE ASSUMING $M_S \lesssim \sqrt{M_{Weak}\, M_{PLANCK}} \simeq 10^{11}\ GeV$

MIGHT BE PHENOMENOLOGICALLY SAFER !

* BULK OF 6 COMPACT DIMENSIONS : L.J, Munoz, Rigolin 98



BULK MAP

⊛ = 3-brane stacks

⊛ N=0 , NON-SUSY BRANES

EXPECT : $m_{3/2} \simeq \dfrac{F_{SB}}{M_{PLANCK}} \simeq \dfrac{M_S^2}{M_{PLANCK}}$

In our N=1 branes:

$$M_W \simeq M_{\tilde{g}}, M_{\tilde{q}}, M_{\tilde{\ell}} \simeq m_{3/2}$$

$$\Longrightarrow \quad M_S \simeq \sqrt{m_{3/2}\, M_{PLANCK}} \lesssim \sqrt{M_W\, M_{PLANCK}} \simeq 10^{11}\ GeV$$

[BETTER TO HAVE $M_S \lesssim 10^{11}$ GeV TO AVOID TOO BIG SUSY-BREAKING EFFECTS FROM GENERIC N=0 BRANE SECTORS]

HOW SMALL COULD M_S BE ?

* One can go as low as :

$$\left[M_s \simeq 1\text{-}10 \text{ TeV} \right]$$

WITHOUT ANY EXP. CONTRADICTION

(Antoniadis, Arkani-Hamed, Dimopoulos, Dvali 98)

by taking:

$$\begin{cases} M_c \simeq 10^{-5} M_s & \text{(ISOTROPIC COMP.)} \\ M_c \simeq 10^{-15} M_s & \text{(ONLY 2 LARGE DIM)} \end{cases}$$

REPLACE THE INFAMOUS $M_W / M_P \simeq 10^{-15}$ HIERARCHY PROBLEM

* IF LUCKY, quantum gravity could be checked at LHC

Challenges

- P-stability : only supressed by $\frac{1}{(M_s)^n}$
  (need symmetries !)
- Coupling unification : running stops at 1 TeV !
- Cosmology, ν-masses, FCNC, ..

(Antoniadis talk)

(Also : Dienes et al, Sundrum, Shiu and Tye 98; Kakushadze + Tye 98, Bachas, Randall + Sundrum 99)

(iii) $\left[M_s \simeq \sqrt{M_W M_{PLANCK}} \simeq 10^{11}\,\text{GeV} \right]$

Benakli

Burgess, Quevedo, L.I. 98

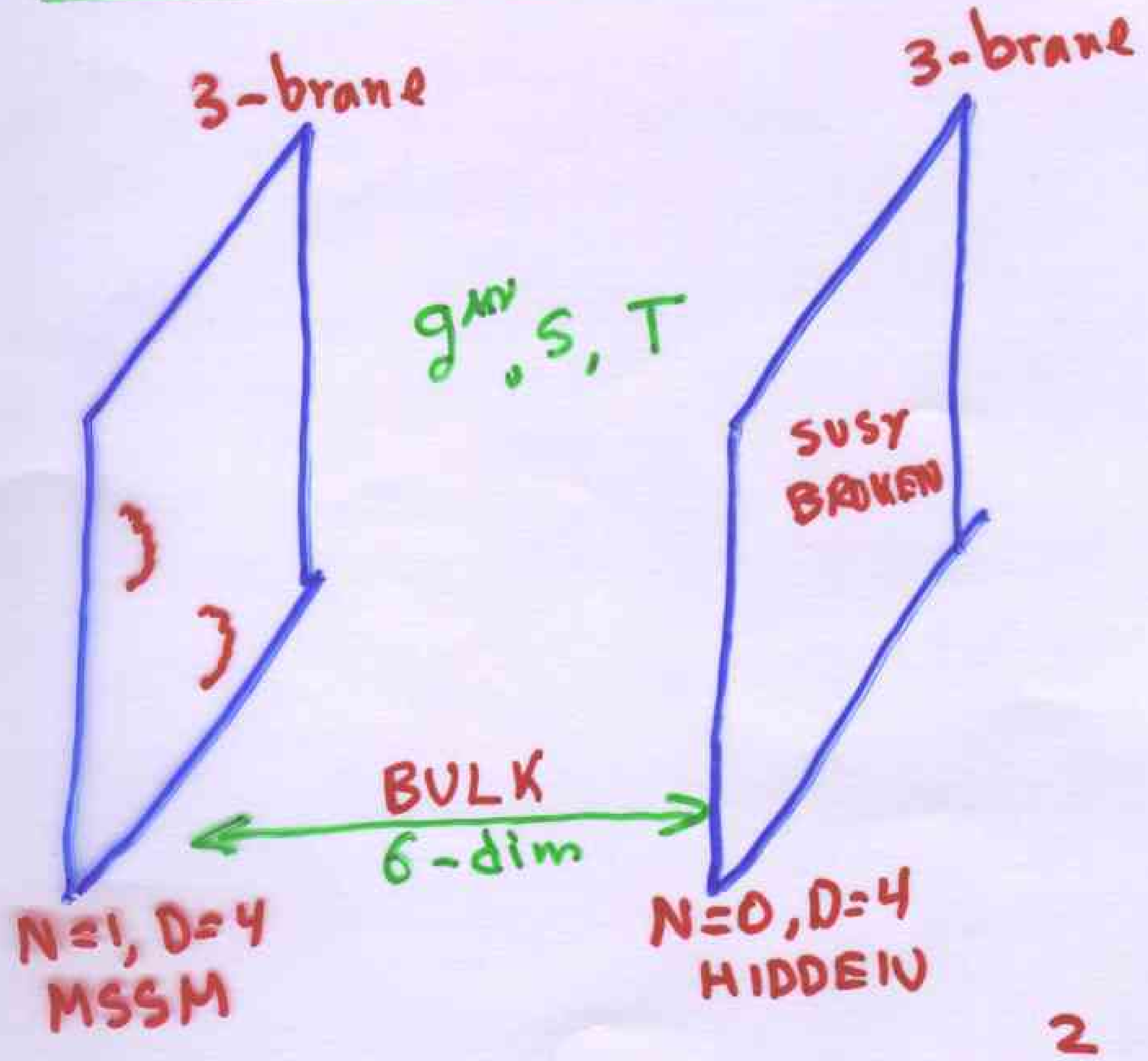
VIRTUES:

(a) — Generation of M_W/M_P hierarchy

(b) — Strong CP problem

(c) — Gauge coupling unification?

(a) The M_W/M_{PLANCK} hierarchy



$$m_{3/2} \simeq \frac{F_{SB}}{M_{PLANCK}} \simeq \frac{M_S^2}{M_{PLANCK}}$$

expect $M_W \sim M_{3/2} \Rightarrow M_S \sim \sqrt{M_W M_{PLANCK}}$

$$M_W \simeq \frac{M_s^2}{M_{PLANCK}} \equiv \frac{\alpha}{\sqrt{2}} \frac{M_c^3}{M_s^2}$$

$$M_{PLANCK} = \frac{\sqrt{2}}{\alpha} \frac{M_s^4}{M_c^3}$$

$$\Longrightarrow \quad \boxed{\frac{M_W}{M_{PLANCK}} = \frac{\alpha^2}{2}\left(\frac{M_c}{M_s}\right)^6}$$

Burgess, Quevedo, L.I. 98

ONE CAN UNDERSTAND THE M_W / M_{PLANCK} HIERARCH IN TERMS OF A MUCH MORE MODEST HIERARCHY!

$$\frac{M_c}{M_s} \sim 10^{-2} \qquad \sim \alpha$$

(NO NEED FOR ANY EXTRA HIERARCHY-GENERATING MECHANISM LIKE GAUGINO CONDENSATION)

(b) Strong CP problem

Axion-like fields $\mathrm{Im}\, M$ (from R-R twisted sectors)

$$\frac{\mathrm{Im}\, M}{M_s} F_{QCD} \wedge F_{QCD}$$

(*) Cosmological and astrophysical bounds on axion decay constant $f_a \sim M_s$

$$10^{12}\,\mathrm{GeV} \gtrsim f_a \gtrsim 10^{11}\,\mathrm{GeV}$$

$$f_a = M_s$$

↪ just in the right place

(c) ν-masses

Expected operators:

$$\frac{a}{M_s} L L \bar{H} \bar{H} \longrightarrow L L \frac{\langle \bar{H} \rangle^2}{M_s} a$$

$$\left[\, m_\nu \sim a\, 10^{-2}\,\mathrm{eV} \,\right]$$

about correct size for atmospheric ν's ...

General questions for any model with $M_s << M_{PLANCK}$

(i) GAUGE COUPLING UNIFICATION.

AMAZING SUCCESS OF MSSM RESTS ON THE EXISTENCE OF A FIELD THEORY DESERT BETWEEN M_W AND $M_X \simeq 10^{16}$ GeV.

How is that compatible with e.g. $M_S = 10$ TeV or 10^{11} GeV ?

(ii) p-stability.

(i) Requires detail knowledge of gauge kinetic functions $f_a = S + ?$

(ii) Symmetries required

U(1) ANOMALOUS SYMMETRIES RELEVANT FOR BOTH QUESTIONS

PROPERTIES OF U(1)'s $(D=4, N=1)$

HETEROTIC

ONLY ONE ANOMALOUS U(1)

GS-MECHANISM BY EXCHANGE OF S (DILATON)

MIXED $U(1) \times G^{a\,2}$ ANOMALIES ARE IN THE RATIO OF KM-LEVELS:

$$A_i : A_j = k_i : k_j$$

Anomalous U(1)'s have mass $\sim g M_s$

Anomalous U(1) does not survive as global symmetry (matter fields break it)

IIB-ORIENTIFOLDS

MULTIPLE

MULTIPLE GS-MECH BY EXCHANGE OF TWISTED M_a FIELDS

NOT CONSTRAINED IN SOME Z_3 examp. even

$$A_i : A_j = \beta_i : \beta_j$$

All U(1)'s have mass $\sim M_s$

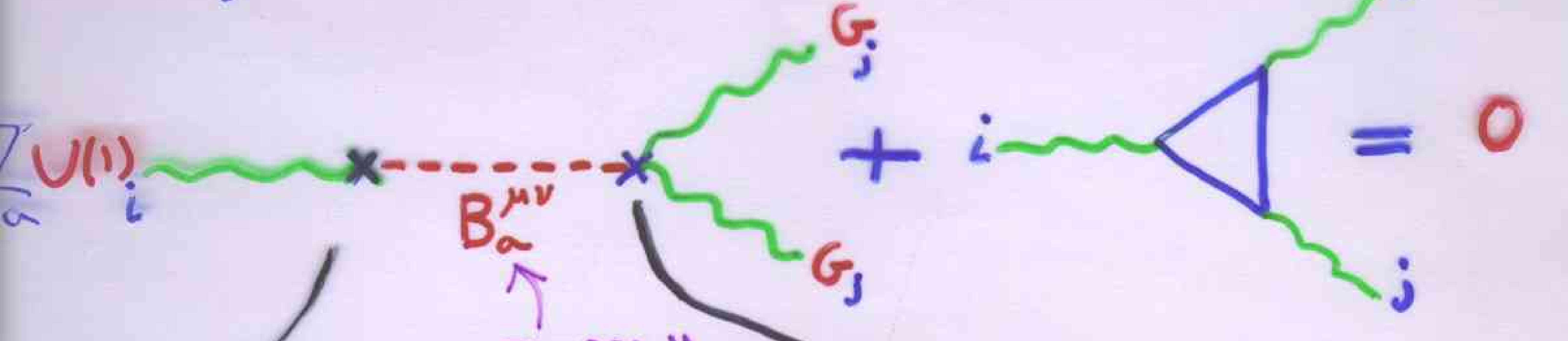
U(1)'s remain as global symmetries

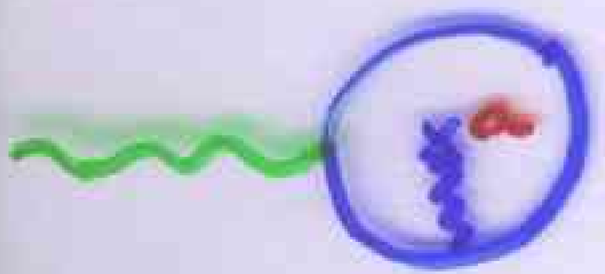
MULTIPLE ANOMALOUS U(1) CANCELLATION

IIB / $\{Z_N, \Omega\}$ ORIENTIFOLDS
$Z_N \times Z_M$

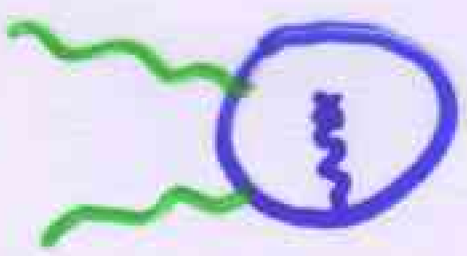
L. I. + R. Rabadan + A. Uranga 98

$$G = \prod_i U(1)_i \otimes \prod_j G_j$$





$$\simeq \underbrace{T_r(\gamma_\theta^a \lambda_i)}_{\substack{\shortparallel \\ Q_{ia}}} B_a \wedge F_i$$



$$\simeq \overbrace{T_r(\gamma_\theta^a \lambda_j^2)}^{\substack{P_{aj} \\ \shortparallel}} \eta_a F_j \wedge F_j$$

(dual to $B_a^{\mu\nu}$)

$$\left[\sum_a Q_{ia} P_{aj} + \underbrace{A_{ij}}_{\text{triangle anomaly}} = 0 \right]$$

sum over all RR scalars $\Longrightarrow$ **ONLY TWISTED CONTRIBUTE:**

$$T_r(\lambda_i) = 0$$

in these orientifolds

L.I, Rabadan, Uranga 98

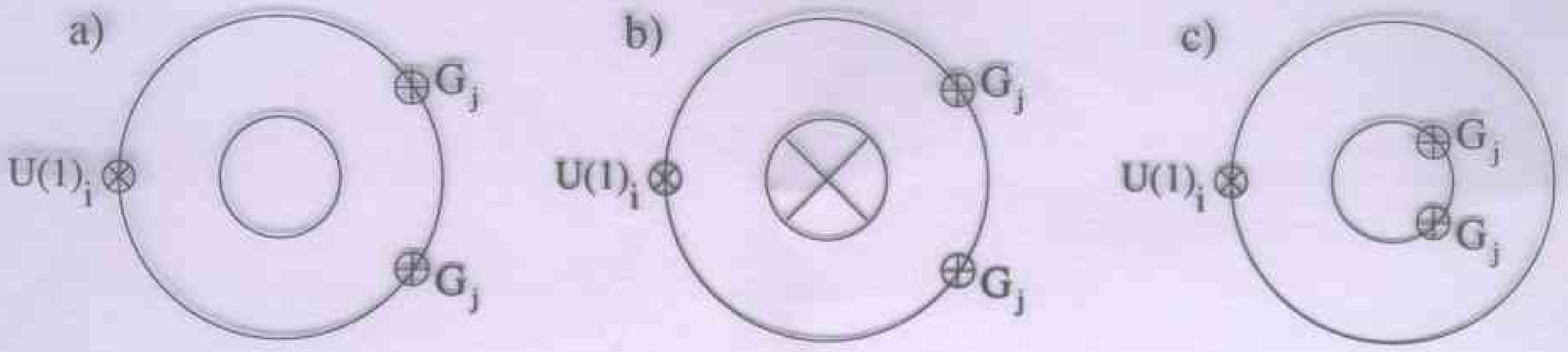


Figure 1: Figure 1: The three graphs contributing to the mixed $U(1)_i \times G_j^2$ mixed anomaly. The first two, the annulus (a) and Moebius strip (b), give the usual triangle anomaly of field theory. The last diagram (c), the non-planar annulus, cancels the contribution from the first two.

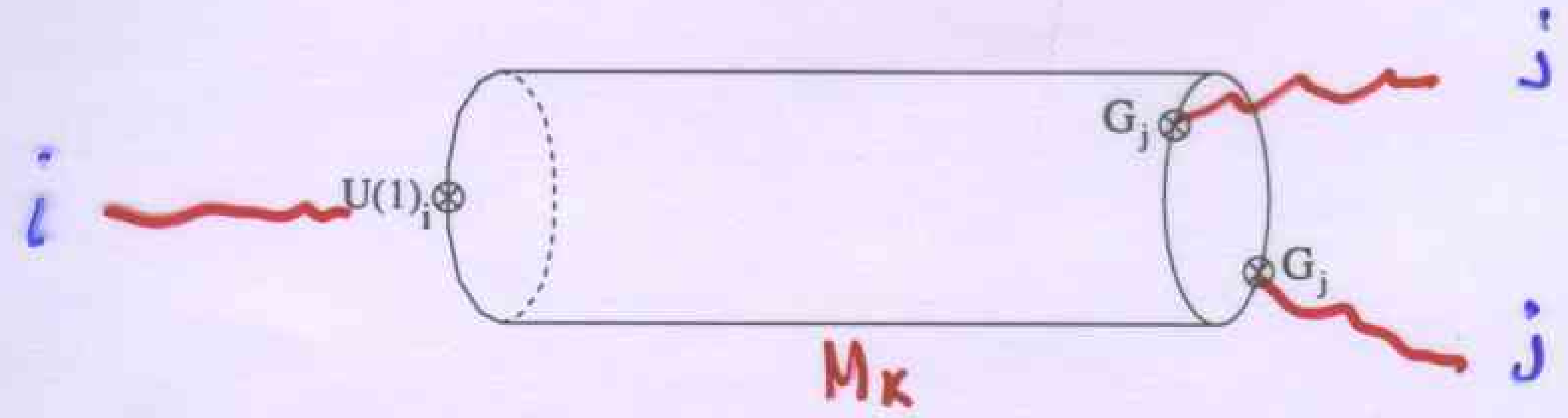


Figure 2: The annulus diagram of Figure 1c in the closed string channel. Twisted RR fields propagating along the cylinder provide the contribution that cancels the anomaly.

$$A^{pq}_{ij} = \frac{1}{N}\sum_{k=1}^{N-1} C_k^{pq}(v)\; w_i^p \sin 2\pi k V_i^p \; \cos 2\pi k V_j^p \cdots$$

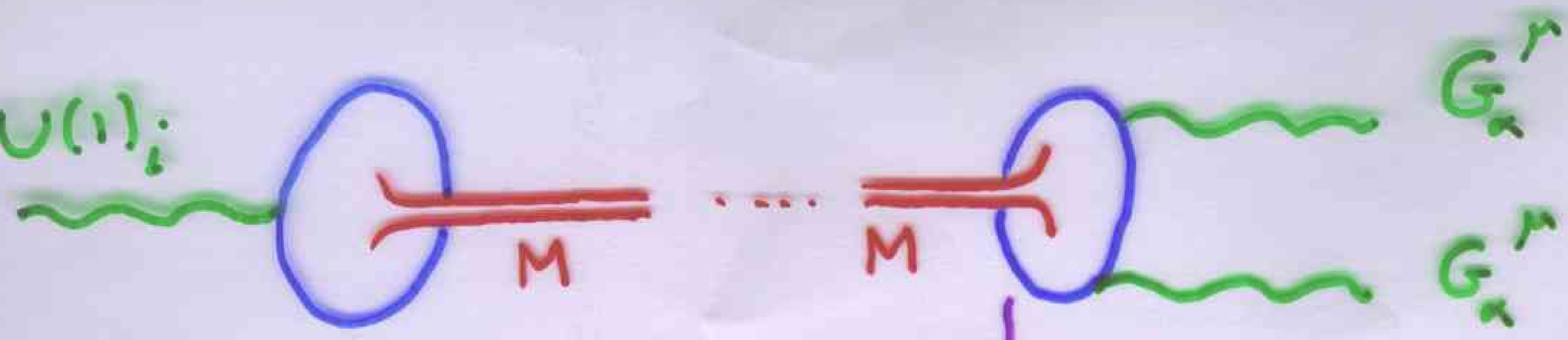
$$\mathrm{Tr}(\gamma_\theta^{k}\lambda_i) \qquad \mathrm{Tr}(\gamma_\theta^{-k}\lambda_j^2)$$

$$C_k^{pp} = \prod_{a=1}^{3} 2\sin\pi k v_a \qquad p,q = 9,5$$

$$C_k^{95} = 2\sin\pi k v_3$$

We checked in many examples: $Z_3, Z_7, Z_6, Z_6', Z_{12}$ ...

(Recently confirmed by Antoniadis, Bachas, Dudas)



$B \wedge F^{i}_{U(1)}$

$\updownarrow$

U(1) MASS $\simeq M_S$

Poppitz, 98

$\updownarrow$

FI-term: $\xi_i = \langle \mathrm{Re}\, M \rangle$

Douglas - Moore 96

$$\left[f_\alpha = S + s_\alpha M \right]$$

L.I, Uranga
Rabadan 98

Boundary values of gauge couplings at M_s
depend on :

(i) $\langle \mathrm{Re}\, M \rangle$ (is a modulus ....)

(ii) value of s_α's

L.I, Munoz, Rigolin 98

$$f_\alpha = S + s_\alpha M \quad ; \quad \langle \mathrm{Re}\, M \rangle = \gamma \log(T+T^*)$$

$$\frac{8\pi^2}{g_\alpha^2(M_s)} = \mathrm{Re}\, S + s_\alpha \gamma \log(T+T^*) - \underbrace{\frac{b_\alpha}{2} \log(T+T^*)}_{} =$$

FROM RESCALING OF FIELDS TO CANONIC. BASE. Kaplunovsky Louis 94 Antoniadis et al. 99

$$= \mathrm{Re}\, S + \frac{b_\alpha}{2} \underbrace{\left(\frac{2 s_\alpha \gamma}{b_\alpha} - 1\right)}_{\equiv\, r_\alpha} \mathrm{Log}(T+T^*)$$

As long as one can write $s_\alpha = x\, b_\alpha + y$, we would have at one loop

$$\frac{8\pi^2}{g_\alpha^2(Q^2)} = \mathrm{Re}\, S + \frac{b_\alpha}{2} \mathrm{Log}\left(\frac{M_x^2}{Q^2}\right)$$

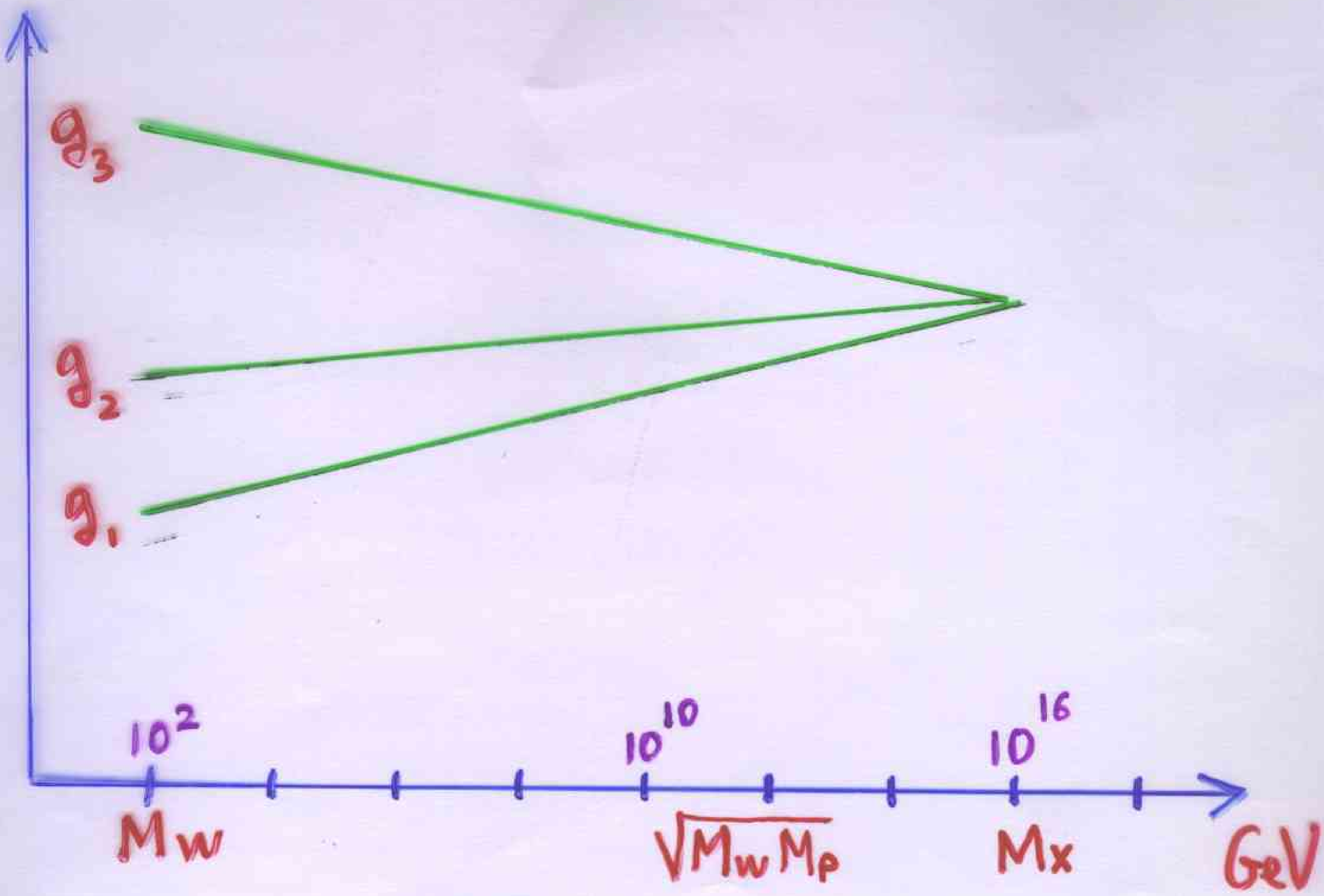
with: $\left[M_x \equiv (T+T^*)^{r/2} M_s \equiv \left(\frac{2}{\alpha}\right)^{r/2} \frac{M_s^{(2r+1)}}{M_c^{2r}} \right]$

$r \equiv 2x\gamma - 1$

L.I. 99

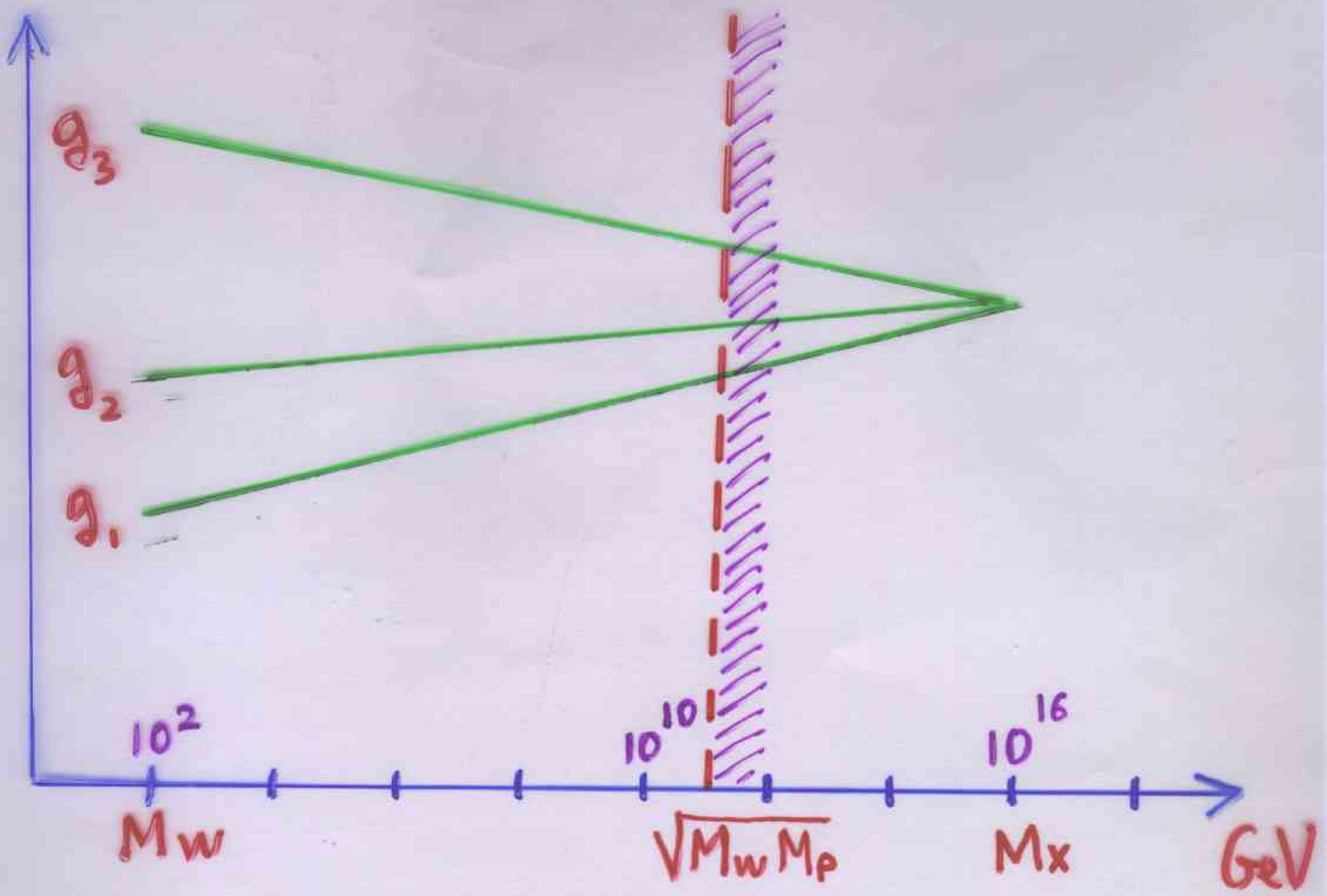
M_x = effective unification scale

(for $r > 0$, $M_x \gg M_s$ as long as $M_c \ll M_s$)



"MIRAGE UNIFICATION"

e.g. $M_S = \sqrt{M_W M_P}$



Imposing:

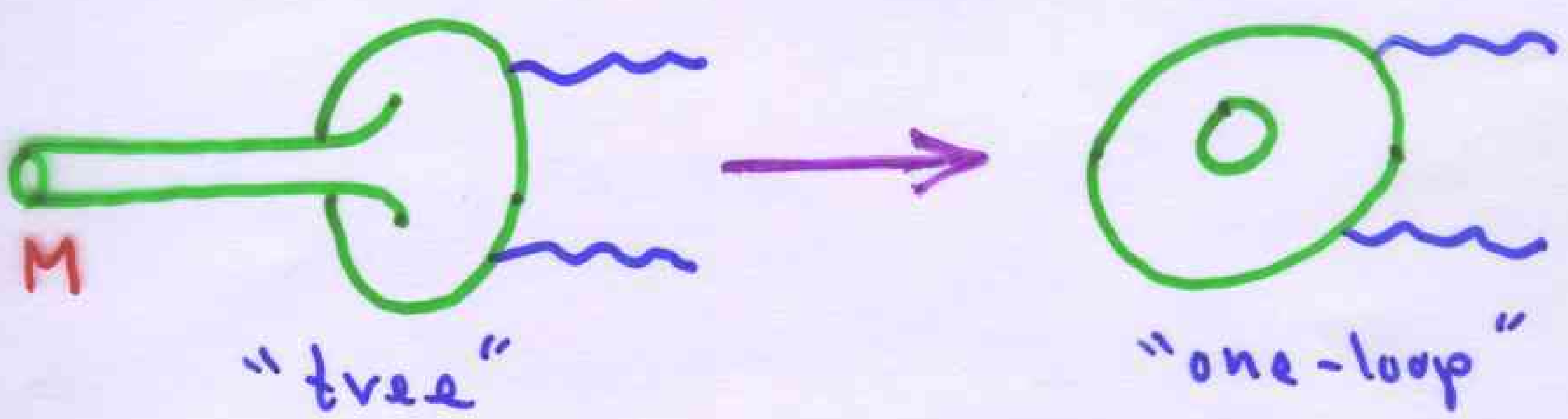
$$\left. \begin{array}{l} M_S = \sqrt{M_W M_P} \\ M_X = 2 \times 10^{16}\ \mathrm{GeV} \end{array} \right\} \longrightarrow \begin{array}{c} r \simeq 1 \\ M_c \simeq 10^9\ \mathrm{GeV} \end{array}$$

"MIRAGE UNIFICATION"

Caution : $f_\alpha = S + s_\alpha M$

— The existence or not of this "mirage" effect depends on the detailed mechanism which fixes $\langle \mathrm{Re}\, M \rangle$ and also on whether $s_\alpha = x\, b_\alpha + y$.
↳ (always true for 2 groups !)

⊛ In fact, for Z_N, N-odd orientifolds also one has: $s_\alpha = \frac{b_\alpha}{2}$!
(N=1 SUSY)



⊛ However, in those orientifolds, setting $\langle \Phi_i \rangle = 0$ sets $\gamma = 1 \Rightarrow r = 0$
↳ charged fields

$\Longrightarrow M_x = M_s$, no mirage effect
(Antoniadis, Bachas, Dudas 99)

⊛ Need to find explicit models in which the mechanism could take place

ANOMALOUS U(1)'S : SOME PHENOMENOLOGY

MOST GENERAL FLAVOUR-INDEPENDENT U(1) ALLOWING FOR USUAL YUKAWA COUPLINGS:

L. I, F. Quevedo to appear

$SU(3) \times SU(2) \times U(1)_Y \times U(1)_X$

	Q	u	d	L	e	H	$\bar{H}$	
R	0	-1	1	0	1	-1	1	$\to$ B-L
A	0	0	-1	-1	0	1	0	$\to$ PQ.
L	0	0	0	-1	1	0	0	$\to$ L
Q_X	0	-m	m-n	-n-p	m+p	-m+n	m	

Table 1: $U(1)_X$ symmetries of the SUSY standard model.

$$Q_X = mR + nA + pL$$

ANOMALIES:

$$A_3 = -n\frac{N_g}{2} = \delta_{GS}\, s_3$$

$$A_2 = -n\frac{N_g}{2} + n\frac{N_D}{2} - p\frac{N_g}{2} = \delta_{GS}\, s_2$$

$$A_1 = -n\frac{5N_g}{2} + n\frac{N_D}{2} + p\frac{N_g}{2} = \delta_{GS}\, s_1$$

$$f_a = S + s_a M \quad ; \quad \mathrm{Im}\, M \longrightarrow \mathrm{Im}\, M - \delta_{GS}\, \Lambda_X(x)$$

⊛ UNLIKE HETEROTIC CASE, THE MIXED ANOMALIES ARE NOT EQUAL, THEY ARE IN THE RATIOS OF THE s_a COEFFICIENTS.

$\Longrightarrow$ MANY MORE POSSIBILITIES

* Forbidding the Higgs mass (mu-term) $\mu H\bar{H}$ requires $n \neq 0$ $\Rightarrow$ (gauging a PQ sym.)

* Generically, as long as $n \neq 0$ all dimension = 3, 4, 5 B and L - violating operators forbidden. Automatically

  Could be usefull to supress p-decay in low string scale models.

* In heterotic models anomalous $U(1)$'s had phenomenological applications to:
  - p-stability
  - quark-lepton mass-matrices
  - cosmology

Type I still to be studied . . .

CONCLUSIONS

(i) Our view of how to embed the SM inside strings has radically changed in the last two years

(ii) Heterotics lost the monopoly. New vacua with new features have emerged.

(iii) $D=4$, $N=1$ IIB orientifolds good testing grounds of new properties:

(iv) We do not know what M_s is !!!

(v) Gauge kinetic functions relevant for unification depend on twisted moduli $\langle \mathrm{Re}\, M \rangle$. Under some conditions this could mimic one-loop unification at scales $M_X \gg M_s$.

M_s	hierarchy required	SAFE FROM N=0 BRANES	COUPLING UNIFICATION	STRONG CP	ν masses	P-stability (dim op.)
10^{16} GeV	10^{-15}	?	✓	?	✓	4-5
10^{11} GeV	$10^{-2} \sim \alpha$	✓	?	✓	✓	4-8
1 TeV	$10^{-5} - 10^{-15}$	✓	?	?	in the bulk	4-16

$\langle \mu_c \rangle << \langle \mu_c \rangle$