I. Antoniadis

CERN

Gaugino masses

from

string loops

problem:

$m_{1/2} = 0$ to lowest order

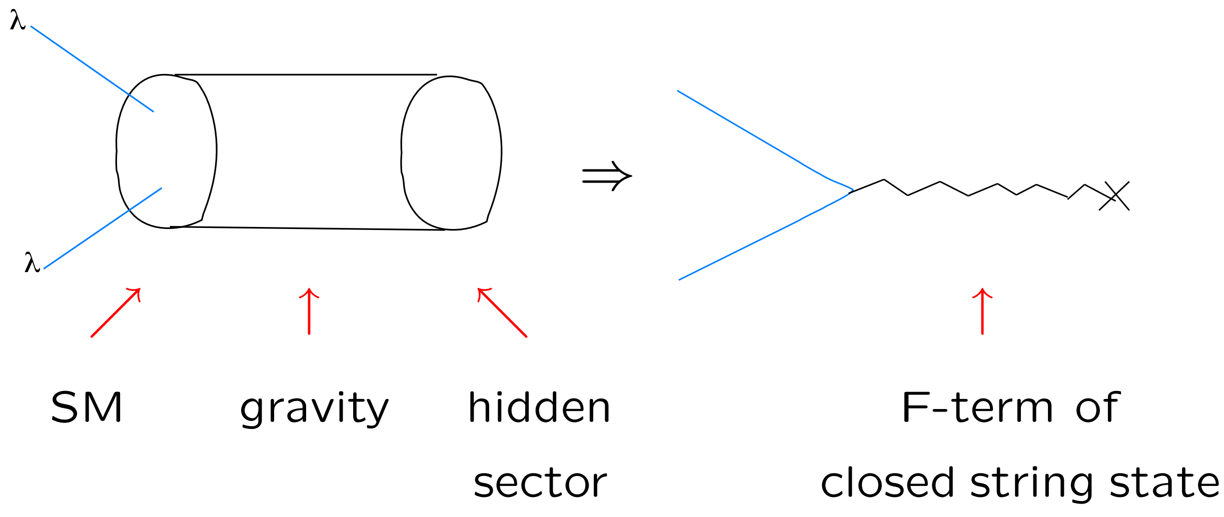
$\Rightarrow$ generated by string loop corrections

Framework: type I string theory

- effective field theory: may be still tree-level

  closed string gravity exchange $\Rightarrow$

  SUGRA tree-level



Gaugino masses: protected by R-symmetry

but broken in 4d SUGRA by the gravitino mass

Two possible ways for generating $m_{1/2}$:

(1) via gravity (brane susy) $\Rightarrow$

generate $m_{1/2}$ from $m_{3/2}$

one gravitational loop: 1 handle + 1 boundary

$$\Rightarrow m_{1/2} \sim g_s^2 \frac{m_{3/2}^3}{M_s^2}$$

I.A.-Taylor '04

(2) keep gravity subdominant $\Rightarrow$

generate $m_{1/2}$ from brane α'-corrections

two gauge loops: 3 boundaries

$$\Rightarrow m_{1/2} \sim g_s^2 \frac{m_0^4}{M_s^3}$$

I.A.-Narain-Taylor '05

gauginos: open strings

$\Rightarrow$ at least one boundary (brane) $h \geq 1$

$N = 2$ superconformal charge:

3/2 units for each (chiral) gaugino

± 1 unit for each 2d supercurrent insertion T_F

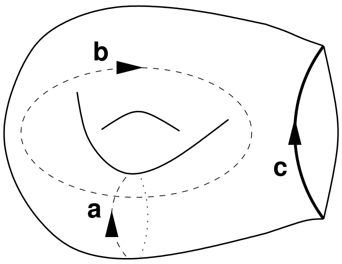
$\Rightarrow$ at least 3 T_F insertions

lowest order (effective genus): $g + h/2 = 3/2$

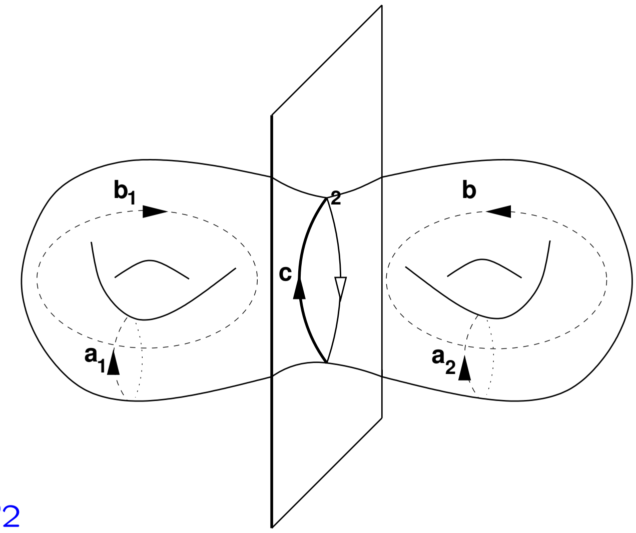
independently of the source of SUSY breaking!

Oriented case

(1) $g = 1$ $h = 1$ from mirror involution of $g = 2$



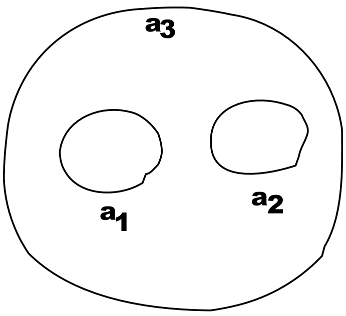
$\longleftarrow$



$a_1 \leftrightarrow a_2$

$b_1 \leftrightarrow -b_2$

(1) $g = 0$ $h = 3$ from mirror involution of $g = 2$



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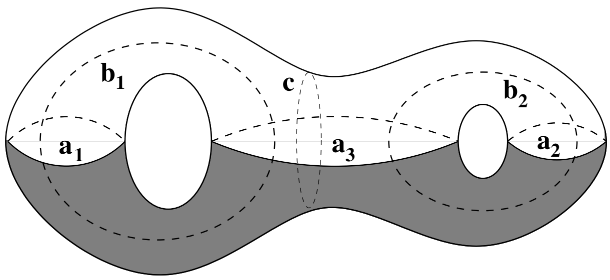


$a_i \leftrightarrow a_i$

$b_i \leftrightarrow -b_i$

Topological partition function F_g ← genus g

computes $N = 2$ SUSY F-terms

AGNT, BCOV '93

$$F_g \int d^4\theta \; W_{N=2}^{2g} \quad \rightarrow \quad F_g \, R^2 \, T^{2g-2}$$

F_g: moduli dependent function

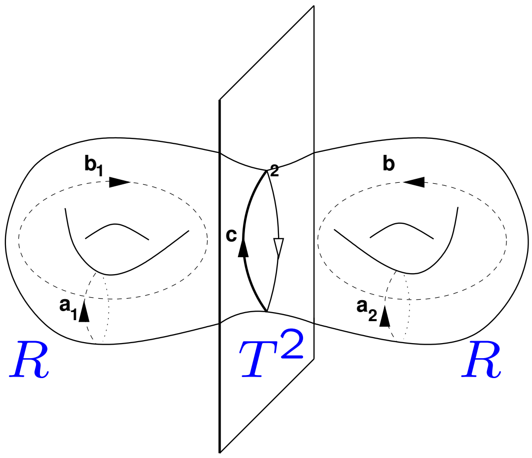
Weyl superfield: $W_{N=2} = T + \theta^2 R + \cdots$

T: graviphoton field strength

R: Riemann tensor

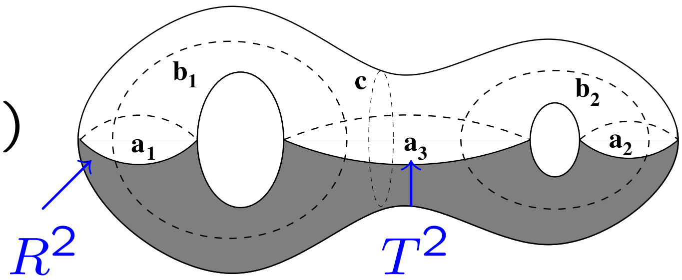
$$F_2 \int d^4\theta \; W^4_{N=2} \quad \rightarrow \quad F_2 \, R^2 \, T^2$$

- graviphoton vertex T = (gaugino)^2
- graviton vertex = (gauge field)^2

(1) 

$\Rightarrow \quad \lambda\lambda\, R$

or SUSY breaking

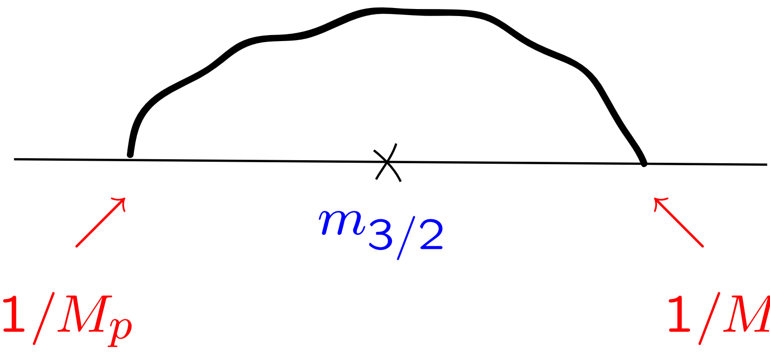
(2) 

$\Rightarrow \quad \lambda\lambda\, F^2$

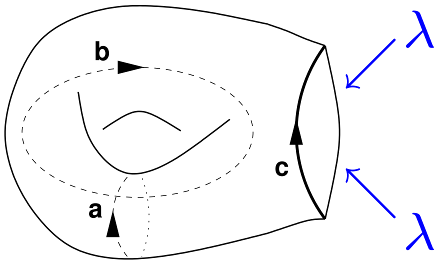
SUSY breaking: $R \rightarrow \langle$gravity auxiliary field$\rangle$

$$F \rightarrow \langle \text{D} \rangle$$

$m_{1/2}$:



$$\sim \frac{m_{3/2}}{M_p^2} \times \begin{cases} \Lambda_{\text{UV}}^2 & \text{if quadr. divergent} \\ m_{3/2}^2 & \text{if convergent} \end{cases}$$



$$\sim g_s^2 \, \frac{m_{3/2}^3}{M_s^2} \qquad g_s \sim g^2$$

but it vanishes for orbifolds

I.A.-Taylor '04

- anomaly mediation:

$$m_{1/2} \sim g^2 m_{3/2} \qquad g^2 \sim g_s$$

- power of g_s does not match

one loop correction always vanishes

by $N = 2$ superconformal charge

- two loops behave $\sim m_{3/2}^3$

- hierarchy between gaugino and scalar masses

however numerics not very good

unless every loop factor $\sim\ 10^{-2}$

Sherk-Schwarz along an interval $\perp$ branes

$\Rightarrow m_{3/2} \sim 1/R$

gravity strength $\Rightarrow R^{-1} = \frac{2}{\alpha_G^2}\frac{M_s^3}{M_p^2} \sim 10^{13}$ GeV

for $M_s \sim M_{\text{GUT}} \sim 10^{16}$ GeV

- $m_{1/2} \sim g_s^2 \frac{m_{3/2}^3}{M_s^2} \sim 1$ TeV

if every loop-factor $\sim 10^{-2}$

- $m_0 \gtrsim g_s \frac{m_{3/2}^2}{M_s} \sim 10^8$ GeV

scalar masses induced at one loop

$\Rightarrow$ split supersymmetry framework

heavy scalars, light fermions

Arkani Hamed-Dimopoulos, Giudice-Romanino '04

SUSY breaking by internal magnetic fields

or equivalently branes at angles

Effective QFT description: D-breaking

magnetic field $H \sim \langle \mathrm{D} \rangle$-term of $U(1)$ ↗ $U(N)$ brane stack

$\langle \mathrm{D} \rangle \sim m_0^2$

R-symmetry broken by string corrections

$\Rightarrow$ higher-dim effective operators:

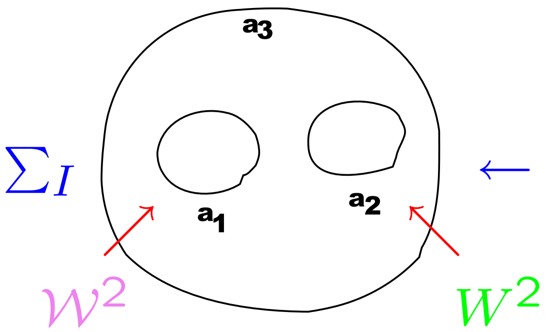
I.A.-Narain-Taylor '05

$F_{(0,3)} \int d^2\theta \mathcal{W}^2 \mathrm{Tr} W^2$ $\qquad \langle \mathcal{W} \rangle = \theta \langle \mathrm{D} \rangle$

$\Rightarrow \; m_{1/2} \sim \epsilon^2 \frac{m_0^4}{M_s^3}$ $\qquad \epsilon^2$: 2-loop factor

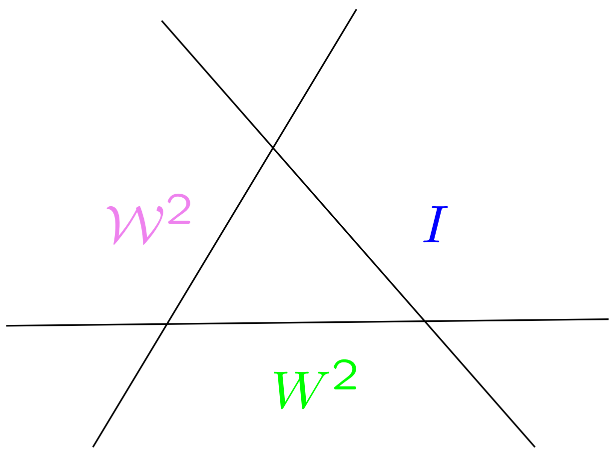
$\sim$ TeV for $m_0 \sim 10^{13} - 10^{14}$ GeV

World-sheet with 3 boundaries (2 loops)



$\leftarrow$ I: intermediate brane

T-duality $\Rightarrow$



$\neq 0$: I-brane away from the intersection

of the other two

- as gauge mediation with string scale gaugino masses

- Higgsino mass

$$\int d^2\theta \mathcal{W}^2 \bar{D}^2 \bar{H}_1 \bar{H}_2 \Rightarrow \mu \sim \epsilon \frac{m_0^4}{M_s^3} \lesssim m_{1/2}$$

$\nearrow$

$\psi_1 \psi_2$

- Simple toroidal models

gauge multiplets: $N = 4$ (or $N = 2$) SUSY

$\Rightarrow$ Dirac gaugino masses without $\not{R}$

$$\int d^2\theta \mathcal{W} \text{Tr} W A \;\Rightarrow\; m_D \sim \epsilon \frac{m_0^2}{M_s} \qquad \text{1-loop factor}$$

$N = 2$ vector $= N = 1$ vector W + chiral A

they can still be consistent with unification

in inermediate energy scales $\sim 10^7 - 10^{13}$ GeV

I.A.-Benakli-Delgado-Quirós-Tuckmantel '05

Evading the hierarchy $m_0 >> m_D$:

- SM on a SUSY brane
- gauge mediation with Dirac masses

I.A.-Benakli-Delgado-Quirós in preparation

$\not{S}$USY brane with massive hypermultiplets

in its $(N=2)$ intersection with SM brane

$(M,D) \longrightarrow \text{SM} \quad \Rightarrow \quad M_s \to M$

$$D < M < M_s \quad \Rightarrow \quad m_D^a = \frac{\alpha_a}{4\pi}\frac{D}{M}$$

- adjoint SM scalars Σ_a: one loop masses

$$m_{\Sigma_a}^2 = \frac{\alpha_a}{4\pi}\frac{D^2}{M^2}$$

- squarks and sleptons Q: two loop masses

$$m_Q^2 = 2\sum_a C_a(Q)\left(\frac{\alpha_a}{4\pi}\right)^2\frac{D^2}{M^2}$$

need $\mathrm{Tr}Y_{\text{hyp}} = 0$ to avoid $m_Q^2 \sim D$ from D_Y^2

$\nearrow$

$D_Y = D_Y^{\text{SM}} + D_Y^{\text{hyp}}$

e.g. messengers in complete $SU(5)$ reps

- Higgs sector: $N = 2$ hyper $(H_1, H_2) \Rightarrow$

$$V_H = m_1^2|H_1|^2 + m_2^2|H_2|^2 - m_3^2(H_1H_2 + h.c.)$$

$$+ \frac{1}{8}(g^2 + g'^2)(|H_1|^2 - |H_2|^2)^2 + \frac{1}{2}(g^2 + g'^2)|H_1H_2|^2$$

$\nearrow$ $\nearrow$

$N = 2$ D-term $\Rightarrow$ $N = 1$ D-term $+$ F-term $\Sigma H_1 H_2$

$\Rightarrow$

$$m_h = m_Z, \; m_H = m_A, \; m_{H^\pm}^2 = m_A^2 + 2m_W^2$$

$$g_{Zhh} = g_{Zhh}^{\text{SM}}, \quad g_{ZHH} = 0$$

$\Rightarrow$

h behaves as SM Higgs

H plays no role in EWSB

CONCUSIONS

Gaugino masses from string loops:

High string scale $\Rightarrow$ hierarchy $m_0 >> m_{1/2}$

1) Majorana masses

- gravity 'mediation' $\Rightarrow m_{1/2}^2 \sim m_0^3/M_s$

- gauge 'mediation' $\Rightarrow m_{1/2} \sim m_0^4/M_s^3$

2) Dirac masses $\Rightarrow m_D \sim m_0^2/M_s$

evading the hierarchy:

$M_s \to M_{\text{hyp}}$, $m_0^2 \to D$ in a SU$\!\!\!/$SY sector

$m_0^{\text{SM}} \sim m_D$ from 2-loops