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

\[
\begin{align*}
\text{SM} & \quad \text{gravity} & \text{hidden} & \text{sector} & \quad \text{F-term of} \\
& & & \text{closed string state}
\end{align*}
\]
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) ⇒

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 ⇒

generate $m_{1/2}$ from brane $\alpha'$-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

⇒ 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 $T_F$

⇒ 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 $g = 2$

\begin{align*}
\text{a}_1 & \leftrightarrow \text{a}_2 \\
\text{b}_1 & \leftrightarrow -\text{b}_2 
\end{align*}

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

\begin{align*}
\text{a}_i & \leftrightarrow \text{a}_i \\
\text{b}_i & \leftrightarrow -\text{b}_i 
\end{align*}
Topological partition function $F_g$ computes $N = 2$ SUSY F-terms

$$F_g \int d^4 \theta \ W^2_{N=2} \quad \rightarrow \quad F_g R^2 T^{2g-2}$$

$F_g$: moduli dependent function

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

$T$: graviphoton field strength

$R$: Riemann tensor
\[ F_2 \int d^4 \theta \, W_{N=2}^4 \rightarrow F_2 R^2 T^2 \]

- graviphoton vertex \( T = (\text{gaugino})^2 \)
- graviton vertex = (gauge field)^2

\[
\begin{align*}
(1) & \quad \Ra{1}R^2 T^2 R \quad \Rightarrow \quad \lambda \lambda R \\
(2) & \quad \Ra{2}R^2 T^2 \quad \Rightarrow \quad \lambda \lambda F^2
\end{align*}
\]

SUSY breaking: \( R \rightarrow \langle \text{gravity auxiliary field} \rangle \)

\( F \rightarrow \langle D \rangle \)
\( m_{1/2} : \)

\[
\begin{array}{c}
\rightarrow \quad m_{3/2} \quad \rightarrow
\end{array}
\]

\( \frac{1}{M_p} \quad \frac{1}{M_p} \)

\[
\sim \frac{m_{3/2}}{M_p^2} \times \left\{ \begin{array}{ll}
\Lambda_{\text{UV}}^2 & \text{if quadr. divergent} \\
m_{3/2}^2 & \text{if convergent}
\end{array} \right.
\]

\[
\sim g_s^2 \frac{m_{3/2}^3}{M_s^2} \quad g_s \sim g^2
\]

but it vanishes for orbifolds

I.A.-Taylor '04
- anomaly mediation:

\[ m_{1/2} \sim g^2 m_{3/2} \quad g^2 \sim g_s \]

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

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

- $m_{1/2} \sim g_s^2 \frac{m_{3/2} m^3_s}{M_s^2} \sim 1$ 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 $H \sim \langle D \rangle$-term of $U(1)$

$\langle D \rangle \sim m_0^2$  
$U(N)$ brane stack

R-symmetry broken by string corrections

$\Rightarrow$ higher-dim effective operators:

I.A.-Narain-Taylor ’05

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

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

$$\sim \text{TeV} \quad \text{for} \ m_0 \sim 10^{13} - 10^{14} \ \text{GeV}$$
World-sheet with 3 boundaries (2 loops)

\[ \sum_I \]

$\mathcal{W}^2 \quad W^2$

$\leftarrow I$: intermediate brane

T-duality $\Rightarrow$

$\mathcal{W}^2 \quad I$

$W^2$

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

- as gauge mediation with string scale gaugino masses
• Higgsino mass

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

\psi_1 \psi_2

• Simple toroidal models

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

\[ \Rightarrow \] Dirac gaugino masses without \( \mathbb{R} \)

\[ \int d^2 \theta W \text{Tr} WA \Rightarrow m_D \sim \epsilon \frac{m_0^2}{M_s} \quad \text{1-loop factor} \]

\( N = 2 \) vector = \( N = 1 \) vector \( W + \text{chiral} \ A \)

they can still be consistent with unification in intermediate 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

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

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

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

- adjoint SM scalars $\Sigma_a$: one loop masses
  $$m_{\Sigma_a}^2 = \frac{\alpha_a D^2}{4\pi M^2}$$

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

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

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

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

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

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

$N = 2$ D-term $\Rightarrow$ $N = 1$ D-term $+$ F-term $\Sigma H_1H_2$

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

$\Rightarrow$

$$g_{Zh} = g_{Zh}^{\text{SM}}, \ \ g_{ZH} = 0$$

$h$ behaves as SM Higgs

$\Rightarrow$

$H$ plays no role in EWSB
CONCLUSIONS

Gaugino masses from string loops:

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

1) Majorana masses

- gravity ‘mediation’ ⇒ $m_{1/2}^2 \sim m_0^3/M_s$
- gauge ‘mediation’ ⇒ $m_{1/2}^4 \sim m_0^4/M_s^3$

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

  evading the hierarchy:

$M_s \rightarrow M_{hyp}, \quad m_0^2 \rightarrow D \quad$ in a SUSY sector

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