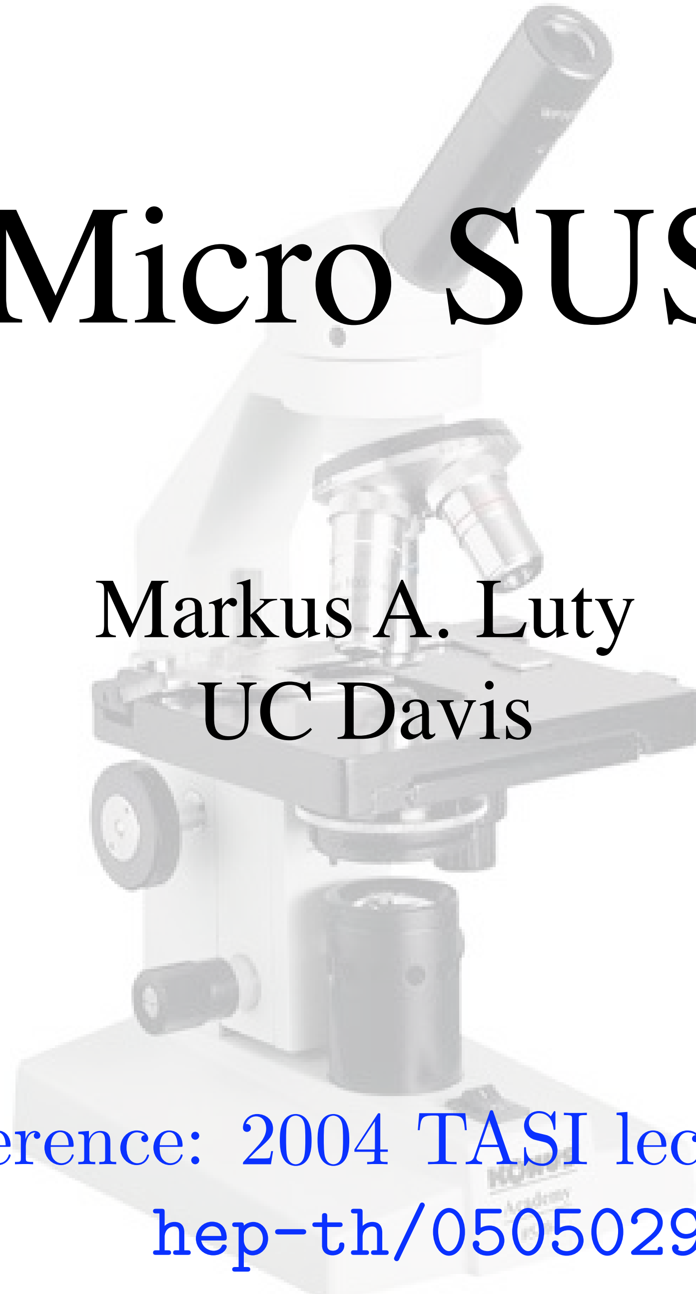
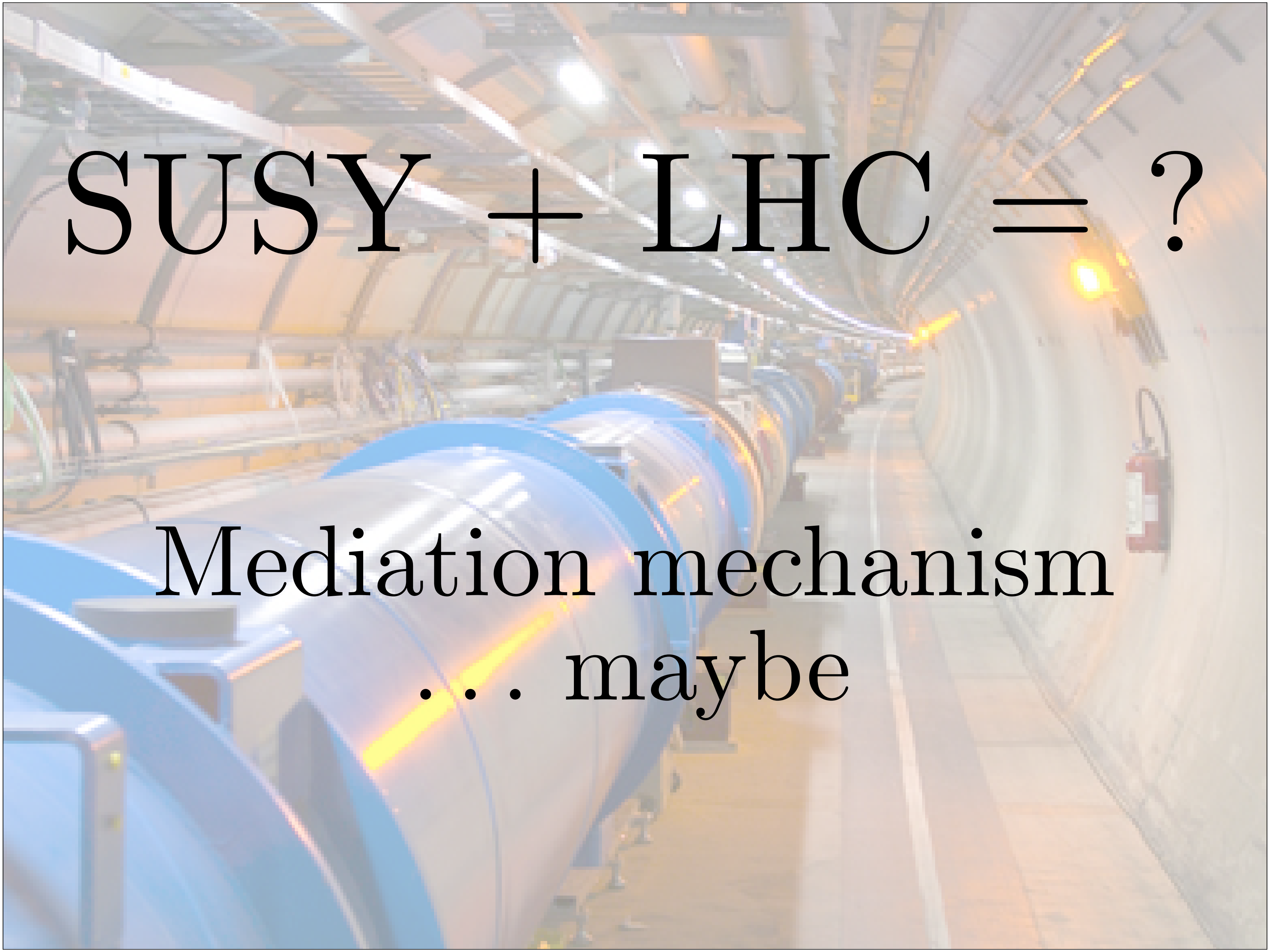


“Micro SUSY”

Markus A. Luty
UC Davis

Reference: 2004 TASI lectures
hep-th/0505029



SUSY + LHC = ?

Mediation mechanism

. . . maybe

Uncertainty principle:

$$\text{depth} \times \text{breadth} \leq 2 \text{ lectures}$$

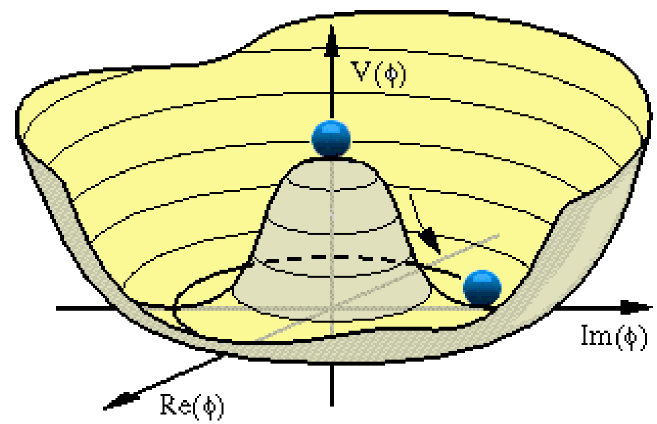
(Note sign!)

Help me saturate it: Ask questions!

Outline

- Direct SUSY breaking
- "UV mediation"
- SUSY flavor problem
- Gauge mediation
- Anomaly mediation
- High-scale SUSY breaking

Can we find the "Higgs" of SUSY breaking at LHC?



- $\langle F_\Phi \rangle \sim 100$ GeV
- Couple Φ to MSSM via renormalizable operators (no $1/M$ suppression)

Problems

- Gaugino masses too small

$$\Delta\mathcal{L} = \sqrt{2}\, g \langle H \rangle^\dagger \lambda \tilde{H} + \text{h.c.}$$

$$\Rightarrow M_{1,2} \sim M_{W,Z}$$

$$M_3 = 0$$

- Scalar masses too small

$$\Delta W = y Q \langle H \rangle u^c \qquad \Rightarrow m_{\tilde{q}} = m_q$$

$$\Delta\mathcal{L} = y \tilde{Q} \langle F_H \rangle \tilde{u}^c + \text{h.c.}$$

$$\Delta V_D = g^2 \langle D_3 \rangle \tilde{Q}^\dagger T_3 \tilde{Q} \qquad \Rightarrow \pm\,\text{eigenvalues}$$

$\Rightarrow m_{\tilde{q}} \leq m_u$ at tree level (Dimopoulos, Georgi)

Solutions

SUSY breaking mediated by

- Non-renormalizable interactions (UV physics)
- Loops
- Supergravity

UV Mediation

SUSY broken by $\langle F_X \rangle \neq 0$

UV physics at M_{P} couples to visible sector

$$\mathcal{L}_{\mathrm{eff}} \sim \int d^4\theta \, \frac{1}{M_{\mathrm{P}}^2} X^\dagger X Q^\dagger Q$$

$$+ \int d^2\theta \, \frac{1}{M_{\mathrm{P}}} X W^\alpha W_\alpha + \mathrm{h.c.}$$

$$+ \int d^2\theta \, \frac{1}{M_{\mathrm{P}}} X Q H u^c + \mathrm{h.c.}$$

$$+ \cdots$$

$$\Rightarrow \Delta\mathcal{L}_{\text{eff}} \sim \frac{\langle F_X \rangle^2}{M_{\text{P}}^2} \tilde{Q}^\dagger \tilde{Q}$$ scalar masses

$$+ \frac{\langle F_X \rangle}{M_{\text{P}}} \lambda^\alpha \lambda_\alpha + \text{h.c.}$$ gaugino masses

$$+ \frac{\langle F_X \rangle}{M_{\text{P}}} \tilde{Q} H \tilde{u}^c + \text{h.c.}$$ A terms

$$+ \cdots$$

All SUSY breaking masses of order

$$M_{\text{SUSY}} \sim \frac{\langle F_X \rangle}{M_{\text{P}}}$$

Even μ and $B\mu$ terms:

$$\Delta\mathcal{L}_{\text{eff}} \sim \int d^4\theta \, \frac{1}{M_{\text{P}}} X^\dagger H_u H_d + \text{h.c.}$$

$$+ \int d^4\theta \, \frac{1}{M_{\text{P}}^2} X^\dagger X H_u H_d + \text{h.c.}$$

$$\Rightarrow \Delta\mathcal{L}_{\text{eff}} \sim \int d^2\theta \, \frac{\langle F_X \rangle}{M_{\text{P}}} H_u H_d + \text{h.c.} \qquad \mu \text{ term}$$

$$+ \frac{\langle F_X \rangle^2}{M_{\text{P}}^2} H_u H_d + \text{h.c.} \qquad B\mu \text{ term}$$

Exercise

At sufficiently high order, all possible SUSY breaking terms are generated. Estimate the size of the difference between the fermion and scalar kinetic terms.

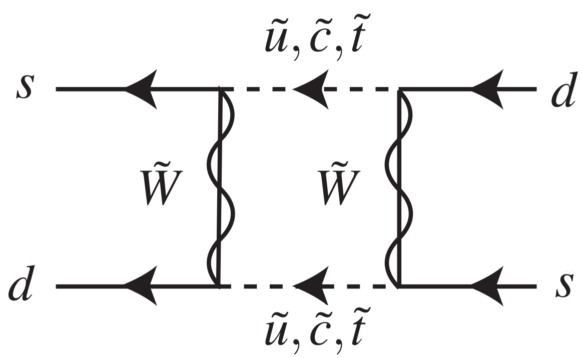
SUSY Flavor Problem

Flavor dependence of scalar masses:

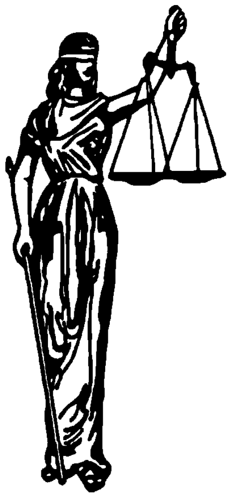
$$\Delta\mathcal{L}_{\text{eff}} = \int d^4\theta \, \frac{c^i{}_j}{M_{\text{P}}^2} X^\dagger X Q_i^\dagger Q^j$$

$$\Rightarrow (m^2_{\tilde{Q}})^i{}_j = \frac{c^i{}_j}{M_{\text{P}}^2} \langle F_X \rangle^2$$

E.g. K^0–$\bar{K}^0$ mixing



$$\Rightarrow \frac{m^2_{\tilde{d}\tilde{s}}}{m^2_{\tilde{s}}} \lesssim 10^{-3} \left(\frac{m_{\tilde{s}}}{\text{TeV}} \right)$$



Isn't gravity flavor-blind?

IR: gravitons couple via equivalence principle

$\Rightarrow$ flavor-blind

UV: string/M theory

$\Rightarrow$ UV states carry flavor

$\Rightarrow$ flavor-violating effective operators

A Popular Ansatz

At $\mu = M_{\rm P}$:

m_0^2 = common scalar mass

$m_{1/2}$ = common gaugino mass

A terms $A_{ij} = A_0 y_{ij}$

μ, $B\mu$ terms

Fix $\langle H \rangle = 256$ GeV $\Rightarrow$ 4 free parameters

$\sim 10^4$ papers

"Minimal SUGRA"

Hidden Sector Running

(Cohen, Roy, Schmaltz 2006)

$$\mathcal{L}_{\text{eff}} = \int d^4\theta \, \frac{A_i}{M_{\text{P}}^2} X^\dagger X Q^\dagger Q + \int d^4\theta \sum_{a=1}^{3} \frac{B_a}{M_{\text{P}}} X W_a^\alpha W_{\alpha a} + \text{h.c.}$$

$$m_i^2 = \frac{A_i}{M_{\text{P}}^2} \langle F_X \rangle^2 \qquad M_a = \frac{B_a}{M_{\text{P}}} \langle F_X \rangle$$

$X =$ dynamical field

$$\frac{dM_a}{dt} = \frac{b_a}{8\pi^2} g_a^2 M_a - \tfrac{1}{2} \gamma_X M_a \qquad \gamma_X = \frac{d \ln Z_X}{dt}$$

$$\frac{dm_i^2}{dt} = \sum_{a=1}^{3} \frac{C_{ai}}{2\pi^2} g_a^2 M_a^2 - \gamma_X m_i^2 \qquad t = \ln \mu$$

$\Rightarrow$ weak scale masses depend on γ_X

Gaugino masses:

$$M_a(t) = \hat{M}_a(t) \exp\left\{-\frac{1}{2}\int_0^t dt'\,\gamma_X(t')\right\}$$

where $\hat{M}_a(t) = M_a(0) \exp\left\{-\int_0^t dt'\,\frac{b_a}{8\pi^2}\,g_a^2(t')\right\}$

$= \text{solution without hidden sector running}$

$\Rightarrow$ absorb hidden sector effects in overall scale

Scalar masses:

$$m_i^2(t) = -\sum_{a=1}^{3} \frac{C_{ai}}{2\pi^2} \int_0^t dt'\, g_a^2(t') M_a^2(t') \exp\left\{-\int_{t'}^t dt''\,\gamma_X(t'')\right\}$$
$$- \, m_i^2(0) \exp\left\{-\int_0^t dt'\,\gamma_X(t')\right\}$$

$\Rightarrow$ nontrivial hidden sector effects

Predictions independent of hidden sector:

$$S = \sum_i a_i m_i^2$$

such that $\sum_i a_i C_{ia} = 0, \quad a = 1, 2, 3$

$$\Rightarrow \frac{dS}{dt} = -\gamma_X S$$

$$S(t=0) = 0 \qquad \Rightarrow S(t) \equiv 0$$

$$e.g. \quad m_{\tilde{Q}}^2 - 2m_{\tilde{u}}^2 + m_{\tilde{d}}^2 - m_{\tilde{L}}^2 + m_{\tilde{e}}^2 = 0$$

Natural Flavor

$m^2_{\tilde{Q}},\ m^2_{\tilde{u}},\ m^2_{\tilde{d}} \simeq$ diagonal

in basis that diagonalizes $m_u,\ m_d$

- $m^2_{\tilde{Q}},\ m^2_{\tilde{u}},\ m^2_{\tilde{d}} \propto$ identity
- Special flavor structure

  (*e.g.* Nir, Seiberg 1993)

Focus on first possibility

Requires flavor-blind messenger interaction

Gauge Mediation

Standard model gauge interactions flavor-blind

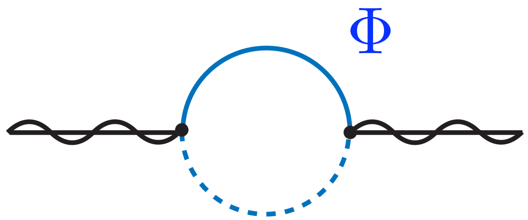
$\Rightarrow$ natural messenger interaction

Messenger fields:

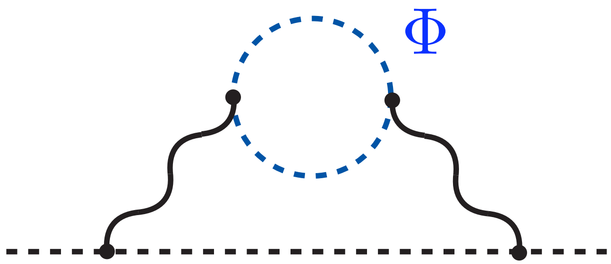
Φ, $\tilde{\Phi}$ = vectorlike representation of standard model gauge group

$$\Delta\mathcal{L} = \int d^2\theta\, \lambda X \tilde{\Phi}\Phi + \text{h.c.}$$

$$\langle X \rangle \neq 0, \qquad \langle F_X \rangle \neq 0$$

$m_{1/2} \sim$ 

$\sim \dfrac{g^2}{16\pi^2}\dfrac{F_X}{X}$

$m_0^2 \sim$ 

$\sim \left(\dfrac{g^2}{16\pi^2}\right)^2 \underbrace{\left|\dfrac{F_X}{X}\right|^2}_{U(1)_R \text{ invariant}}$

- Independent of λ

$\Rightarrow$ masses fixed by gauge quantum numbers, F_X/X

- $\dfrac{F_X}{X} \sim 10$ TeV
- $m_0 \sim m_{1/2}$

But: sign of m_0^2? Predictions?

Calculation of Masses

Use SUSY effective theory (Giudice, Rattazzi 1997)

$M \to \mathcal{M} = M + \theta^2 F =$ chiral superfield

How does effective theory below M depend on $\mathcal{M}$?

$$\mathcal{L}_{\text{eff}} = \int d^4\theta \, Z Q^\dagger e^V Q \; + \left(\int d^2\theta \, \tau W^\alpha W_\alpha + \text{h.c.} \right)$$

$$+ \text{ higher-dimension operators}$$

Z, τ depend logarithmically on M via RG

$$\tau \sim \frac{g^2}{16\pi^2} \ln M \qquad \Rightarrow [\tau]_{\theta^2} \neq 0 \qquad \Rightarrow m_{1/2} \neq 0$$

$$Z \sim \frac{g^2}{16\pi^2} \ln M \qquad \Rightarrow [Z]_{\theta^4} \neq 0 \qquad \Rightarrow m_0^2 \neq 0$$

Gaugino mass:

$$\tau = \frac{1}{2g^2} + \theta^2 \frac{m_{1/2}}{g^2} = \text{chiral} \quad \Rightarrow m_{1/2} = g^2 [\tau]_{\theta^2}$$

Matching and running:

$$\tau(\mathcal{M}) = \tau'(\mathcal{M})$$

$$\Rightarrow \tau(\mu) = \tau_0 + \frac{b'}{16\pi^2} \ln \frac{\mathcal{M}}{\Lambda} + \frac{b}{16\pi^2} \ln \frac{\mu}{\mathcal{M}}$$

$$b - b' = N = \text{number of messengers}$$

$$\Rightarrow m_{1/2} = -\frac{g^2 N}{16\pi^2} \frac{F}{M}$$

Scalar mass:

$$\frac{d \ln Z}{d \ln \mu} = \frac{C}{4\pi^2} g^2$$

$$\Rightarrow \ln Z(\mu) = \ln Z_0 + \frac{2C}{b'} \ln \frac{g_0'^2}{g'^2(M)} + \frac{2C}{b} \frac{g^2(M)}{g^2(\mu)}$$

$$Z = \text{real}$$

$$\Rightarrow M \to |\mathcal{M}|,$$

$$g^2 \to \frac{1}{\tau + \tau^\dagger}$$

(independent of $\Theta \propto \mathrm{Im}(\tau)$)

$$\Rightarrow m^2(\mu = M) = \frac{g^4(M)}{(8\pi^2)^2} CN \left| \frac{F}{M} \right|^2 > 0$$

Finite 2-loop calculation done with 1-loop RG!

Exercise

Find effective operators that give corrections to the gaugino and scalar masses of order

$$\Delta m_{1/2} \sim \frac{F}{M} \times \frac{F^2}{M^4}$$

$$\Delta m_0^2 \sim \frac{F^2}{M^2} \times \frac{F^2}{M^4}$$

These are subleading for $F \ll M$

Exercise

Derive the formulas for the gaugino and scalar mass. Note that it is a bit surprising in this approach that the scalar mass comes in at two loops, since the anomalous dimension is one loop. Explain this.

Phenomenology

- $\dfrac{m_{\tilde{q}}}{m_{\tilde{e}}} \sim \sqrt{N_\mathrm{c}}\,\dfrac{g_3^2}{g_1^2} \sim 10$

  $m_{\tilde{e}} \gtrsim 100$ GeV $\;\Rightarrow\;$ $m_{\tilde{q}} \gtrsim 1$ TeV

  Good: $m_{h^0} > 114$ GeV   Bad: tuned!

- Gravitino LSP

  $$m_{3/2} \sim \frac{F_0}{M_\mathrm{P}} \sim 100 \text{ GeV} \left(\frac{\sqrt{F_0}}{10^{10} \text{ GeV}} \right)^2$$

  $F_0 =$ *fundamental* scale of SUSY breaking $\gtrsim F$

  Gravitino couplings suppressed by $1/F_0$ at low energies

  $\Rightarrow$ NLSP long-lived, can decay in detector

  e.g. $\chi^0 \to \gamma \tilde{G}$ or $\tilde{\tau}_R \to \tau \tilde{\Gamma}$

- Dark matter: super-WIMP scenario

  NLSP freezes out,

  late decay converts energy to gravitino

  $\Rightarrow$ no direct detection

Anomaly Mediation

Gravity is flavor-blind

. . . in IR

Motivates SUSY breaking by auxiliary fields of SUGRA

Part of graviton multiplet, couplings dictated by super-covariance

“Need-to-know” SUGRA

$\mathcal{N} = 1$ SUGRA multiplet: $(g_{\mu\nu}, \psi_\mu, A_\mu, F_\phi)$

$\Rightarrow$ SUSY breaking by $\langle F_\phi \rangle \neq 0$

Rules for F_ϕ couplings:

$U(1)_R \times$ scale transformations

$\subset$ superconformal gauge symmetry

$$\phi = \underbrace{1}_{\text{superconformal gauge choice}} + \theta^2 F_\phi = \text{chiral}$$

$=$ “superconformal compensator”

Ordinary matter, gauge multiplets have $R = 0$, $d = 0$

$$R(\phi) = \frac{2}{3}, \quad d(\phi) = 1$$

$$\begin{aligned} \Rightarrow \mathcal{L} = &\int d^4\theta\, \phi^\dagger \phi\, K(Q, \ldots) \\ &+ \int d^2\theta\, \phi^3\, W(Q, \ldots) + \text{h.c.} \\ &+ \int d^2\theta\, \tau\, W^\alpha W_\alpha + \text{h.c.} \end{aligned}$$

Integrating out ϕ gives SUGRA potential

Renormalizable theory:

$$\mathcal{L} = \int d^4\theta\, \phi^\dagger \phi\, Q^\dagger Q$$
$$+ \int d^2\theta\, \phi^3 \left(m Q^2 + \lambda Q^3 \right) + \text{h.c.}$$

Define $\hat{Q} = \phi Q$

$$\Rightarrow \mathcal{L} = \int d^4\theta\, \hat{Q}^\dagger \hat{Q}$$
$$+ \int d^2\theta \left(\underbrace{\phi m \hat{Q}}^2 + \lambda \hat{Q}^3 \right) + \text{h.c.}$$

SUSY breaking $\leftrightarrow$ scale symmetry breaking

Looks unpromising phenomenologically:

- $m_{1/2} = 0$
- μ term = only scale breaking

  $\Rightarrow$ only H_u, H_d feel SUSY breaking

Loop corrections?

- scale symmetry broken

  $\Rightarrow$ all SUSY breaking terms generated
- μ = SUSY breaking effect

Regulate:

$$\mathcal{L} = \int d^4\theta \, \hat{Q}^\dagger \left(1 + \frac{\partial^2}{\Lambda^2 \phi^\dagger \phi} \right) \hat{Q} \qquad d(\partial_\mu) = 1$$

$$+ \int d^2\theta \, \lambda \hat{Q}^3 + \text{h.c.}$$

$$Z_0 = Z(\mu) + \frac{\lambda^2}{16\pi^2} \ln \frac{\mu}{\Lambda} + \cdots$$

$$\to Z\left(\frac{\mu}{|\phi|} \right) + \frac{\lambda^2}{16\pi^2} \ln \frac{\mu}{\Lambda |\phi|} + \cdots$$

Z_0 independent of μ, $\phi \Leftrightarrow$ no UV SUSY breaking

$$\Rightarrow \ \mu \to \frac{\mu}{|\phi|}$$

$$m_{1/2} = -\frac{\beta_g}{g} F_\phi$$

$$m_0^2 = -\frac{1}{4} \frac{d\gamma}{d\ln\mu} |F_\phi|^2$$

$$A = \frac{1}{\lambda} \frac{\beta_\lambda}{\lambda} F_\phi$$

Defines renormalization group trajectory

$\Rightarrow$ SUSY breaking independent of UV physics

Exercise

Show that

$$\ln\mu \to \ln\mu - \tfrac{1}{2}\left(\theta^2 F_\phi + \text{h.c.}\right). \quad \text{(no } \theta^4 \text{ component)}$$

Show that this implies that anomaly mediated masses are 2-loop.

Verify the formulas for the anomaly mediated soft breaking terms.

UV Insensitivity

Prediction independent of SUSY thresholds

$$\frac{1}{g^2(\mu)} = \frac{1}{g_0^2} + \frac{b'}{8\pi^2} \ln \frac{M}{\Lambda} + \frac{b}{8\pi^2} \ln \frac{\mu}{M}$$

$\Lambda \to \Lambda\phi, \quad M \to M\phi \qquad\qquad \Lambda,\ M = \text{chiral}$

$$\Rightarrow \tau(\mu) = \tau_0 + \frac{b'}{16\pi^2} \ln \frac{M}{\Lambda} + \frac{b}{16\pi^2} \ln \frac{\mu}{M\phi}$$

SUSY breaking still equivalent to $\mu \to \dfrac{\mu}{\phi}$

Same for scalar mass.

Can anomaly mediation dominate?

$$\text{SUGRA} \Rightarrow \langle F_\phi \rangle \lesssim \frac{F_0}{M_\text{P}}$$

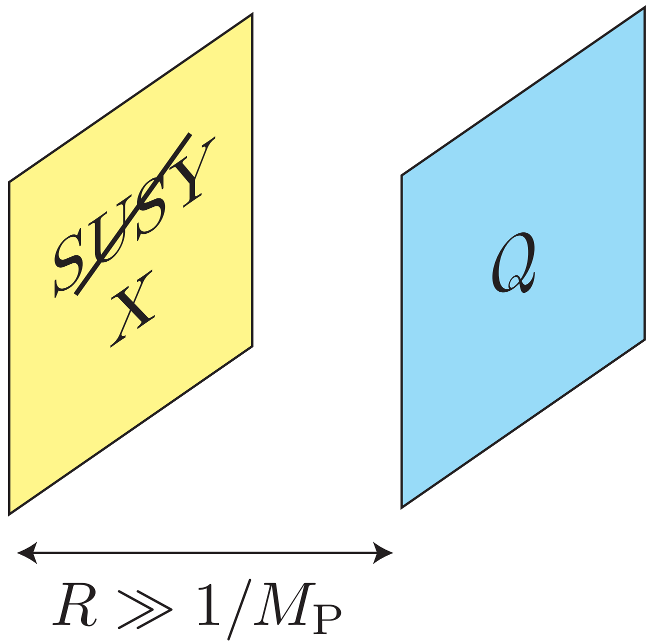
$$\Delta\mathcal{L}_\text{eff} \sim \int d^4\theta \, \frac{1}{M_\text{P}^2} X^\dagger X Q^\dagger Q$$

$$\Rightarrow \; \Delta m_0^2 \sim \left(\frac{F_0}{M_\text{P}} \right)^2 \gg \text{AMSB contribution}$$

Must forbid direct couplings to SUSY breaking

“sequestering”

Brane-localized fields in extra dimensions

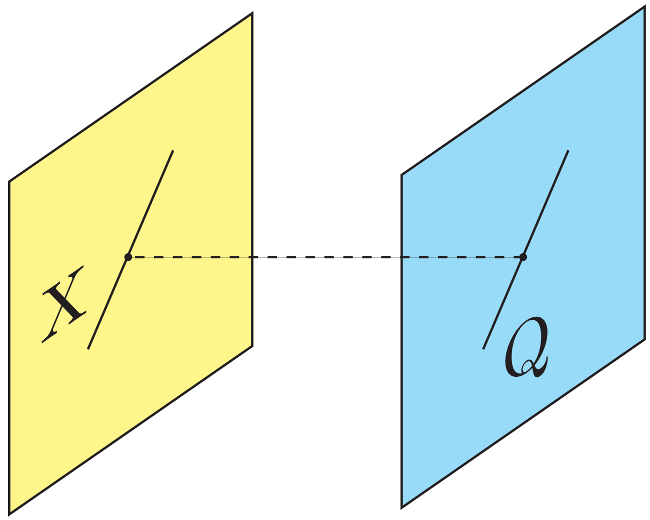


$\Rightarrow$ Higher-dimensional theory cannot contain

$$\int d^4\theta \, X^\dagger X Q^\dagger Q$$

4D effective theory: must forbid generation of

$\int d^4\theta \, X^\dagger X Q^\dagger Q$ from exchange of bulk fields

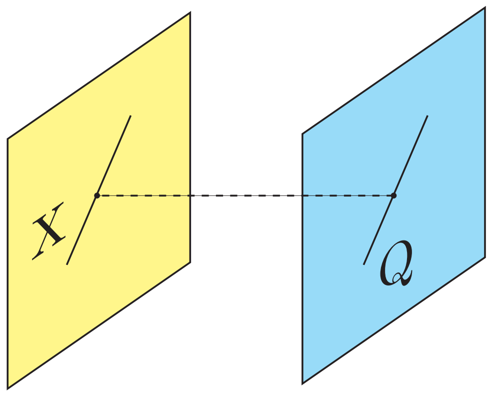


Bulk state has mass $M \gtrsim M_\mathrm{P}$

$\Rightarrow$ suppressed by $e^{-R/M} \ll 1$

Only light states ($M \lesssim 1/R$) contribute

Integrate out SUGRA KK modes: $\quad M_{\mathrm{KK}} \sim \dfrac{1}{R}$



$$\Rightarrow \Delta\mathcal{L}_4 \overset{?}{\sim} \underbrace{\frac{1}{M_5^3}\frac{1}{R}}_{\sim \frac{1}{M_{\mathrm{P}}^2}} \int d^4\theta\, X^\dagger X Q^\dagger Q$$

In fact, in 4D effective theory $1/M_{\mathrm{P}}^2$ contact terms are *required* by $\mathcal{N} = 1$ SUGRA

(Similar to D-term potential in gauge theory.)

Minimal model:

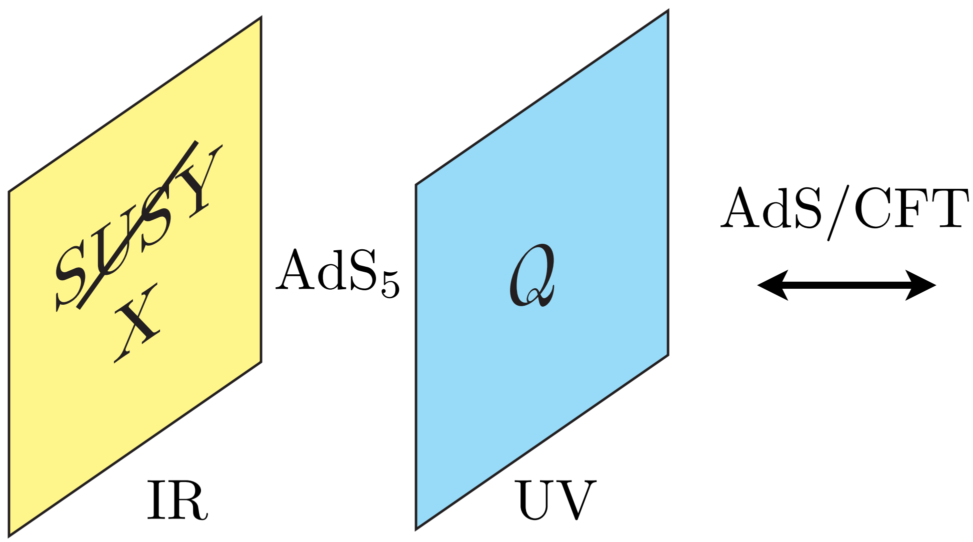
- 5D, minimal SUGRA in bulk
- Radion stabilized (crucial!)

Explicit calculation $\Rightarrow$ sequestered Kähler potential

(Luty, Sundrum 1999)

Also, conformal sequestering:

(Luty, Sundrum 2001, 2002)



CFT_4 for $\Lambda_{IR} < \mu < \Lambda_{UV}$

Coefficient of $\int d^4\theta\, X^\dagger X Q^\dagger Q$

suppressed by large

anomalous dimension

Is it Viable?

Sign of scalar mass:

$$\gamma = \frac{d \ln Z}{d \ln \mu} \sim +g^2 - y^2$$

$$m_0^2 \sim -\frac{d\gamma}{d \ln \mu} \sim -g\beta_g + y\beta_y$$

$$\Rightarrow m_0^2 > 0 \text{ requires } \beta_g < 0 \text{ or } \beta_y > 0$$

MSSM: $SU(2)_W$ and $U(1)_Y$ not asymptotically free, no large Yukawa couplings for first two generations

$$\Rightarrow m_{\tilde{L}}^2, m_{\tilde{e}}^2 < 0!$$

“Gaugomaly” Mediation

(Pomarol, Rattazzi 1998)

Not all massive thresholds are supersymmetric

$$\mathcal{M} = M + \theta^2 F, \qquad F \neq M F_\phi = \text{result of } M \to M\phi$$

Example: (Nelson, Weiner 2002)

$$\Delta\mathcal{L} = \int d^4\theta \, c \, \phi^\dagger \phi^{-1} \tilde{\Phi}\Phi + \text{h.c.} \qquad (\Phi,\ \tilde{\Phi} = \text{canonical})$$

$$= \int d^2\theta \, (c\, F_\phi) \phi^{-1} \tilde{\Phi}\Phi + \text{h.c.}$$

$c \sim 1 \Rightarrow M = cF_\phi \sim 10$ TeV

$F = -MF_\phi \quad \Rightarrow \Phi,\ \tilde{\Phi}$ act as gauge messengers

Minimal model: $m_0^2 =$ anomaly-mediated at M

Non-minimal model OK (Hsieh, Luty 2007)

Exercise

Suppose we add to the visible sector

$$\Delta\mathcal{L} = \int d^4\theta\, X^\dagger X + \int d^2\theta \left[\lambda X\tilde{\Phi}\Phi + \frac{1}{M^{n-3}}X^n\right] + \text{h.c.}$$

Here Φ and $\tilde{\Phi}$ are in a vector-like representation of the standard model gauge group, and X is a singlet Show that X effectively has a chiral superfield mass

$$\mathcal{M} = M + \theta^2 F$$

Compute M and F, and verify that $F \sim MF_\phi$, but $F \neq MF_\phi$. (Pomarol, Rattazzi 1998)

Phenomenology

- Spectrum depends on type of "gaugomaly" model
- $m_{3/2} \sim F_\phi \sim 10$ TeV
  $\Rightarrow$ conventional dark matter

Accidental SUSY

(Goh, Luty, Ng, 2003)

IR can have more symmetry than UV if all symmetry-breaking operators are irrelevant

"Accidental symmetry"
(*e.g.* baryon number in standard model)

Can "fundamental" symmetries (like Lorentz invariance or SUSY) be accidental? (Nielsen)

What about SUSY?

- Weak coupling $\Rightarrow$ scalar mass relevant

  $\Rightarrow$ need strong coupling

- Coupling must stay strong over a large range of scales for approximate SUSY

  (We want to solve hierarchy problem!)

  $\Rightarrow$ CFT

Does such a theory exist?

Existence

- Example: $\mathcal{N} = 4$ SYM with $N_c \gg 1$, $g^2 N_c \gg 1$

  $\leftrightarrow$ string theory on $\mathrm{AdS}_5 \times S_5$

  $d(\phi^\dagger \phi) \sim (g^2 N_c)^{1/4}$ $\quad$ ($\phi^\dagger \phi \leftrightarrow$ string mode)

  All relevant operators can be forbidden by $SO(6)$

- Another possible example (less SUSY)

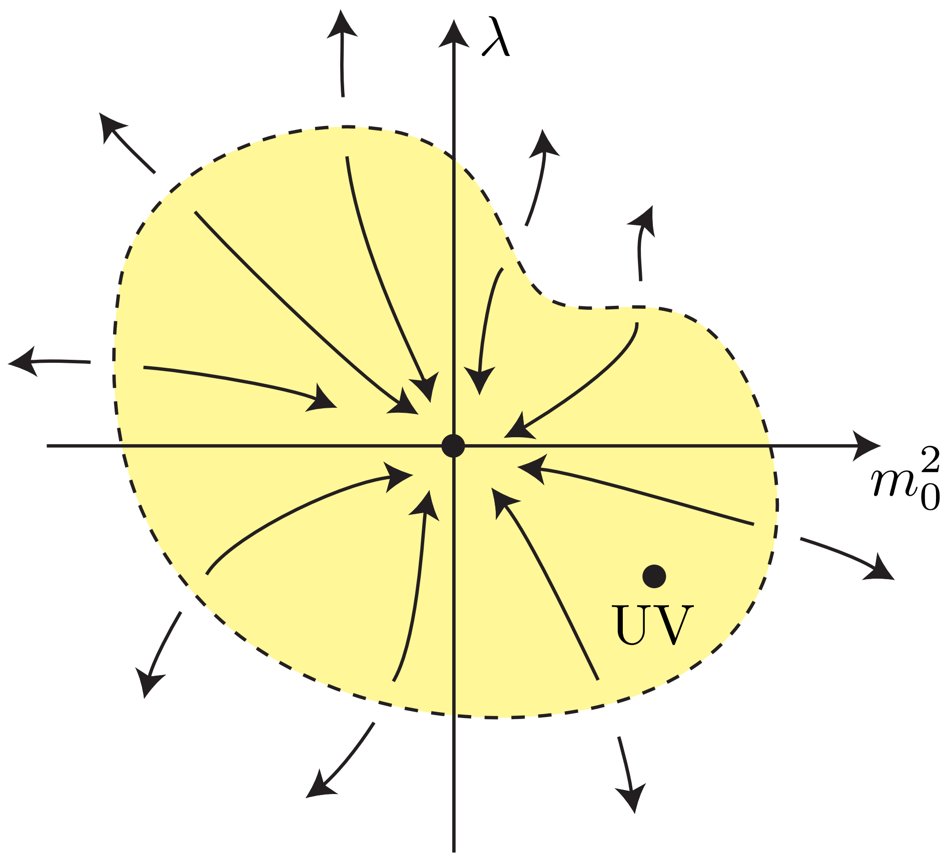
  $\mathcal{N} = 1$ SUSY QCD with $N_c \sim N_f$

  $\rightarrow$ strongly coupled CFT in IR

  $d(\phi^\dagger \phi) > 2$ $\quad$ (Luty, Rattazzi 1999)

  $d(\phi^\dagger \phi) > 4\,?$

Coupling constant flow:

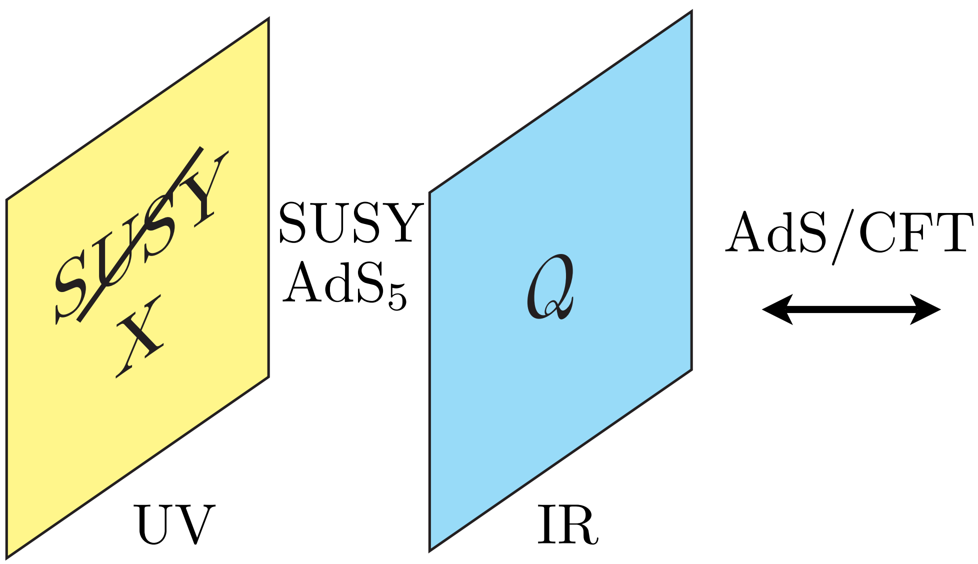


Realistic model must break conformal symmetry at low energies ($\gtrsim$ TeV)

$\Rightarrow$ SUSY also broken

Fixed point never reached

Concrete realization in RS model:



CFT$_4$ for $\Lambda_{\rm IR} < \mu < \Lambda_{\rm UV}$

SUSY broken at $\Lambda_{\rm UV}$

Accidental SUSY for $\mu < \Lambda_{\rm UV}$

Q = composite at $\Lambda_{\rm IR}$

Dilaton Potential

Exact IR SUSY $\Rightarrow$ Flat dilaton potential

(AdS radion $\leftrightarrow$ CFT dilaton)

$\Rightarrow$ Get small dilaton potential from irrelevant SUSY breaking operators

$\sigma =$ dilaton $\qquad \langle\sigma\rangle = \Lambda_{\rm IR}$

$$\Delta\mathcal{L}_{\rm CFT} = \lambda\mathcal{O}_d \quad \Rightarrow V_{\rm eff} \sim \sigma^4 f\left(\frac{\lambda}{\sigma^{4-d}}\right)$$

$f(0) = 0 \quad$ (SUSY limit)

$$\Rightarrow V_{\rm eff} \sim \sigma^d + \sigma^{2d-4} + \cdots$$

$V_{\text{eff}} \sim c_1 \sigma^{d_1} + c_2 \sigma^{d_2}$

$\Rightarrow$ metastable minimum

$\langle \sigma \rangle \ll \Lambda_{\text{UV}}$ for $d_1 \simeq d_2$ (log tuning)

SUSY is not exact in IR

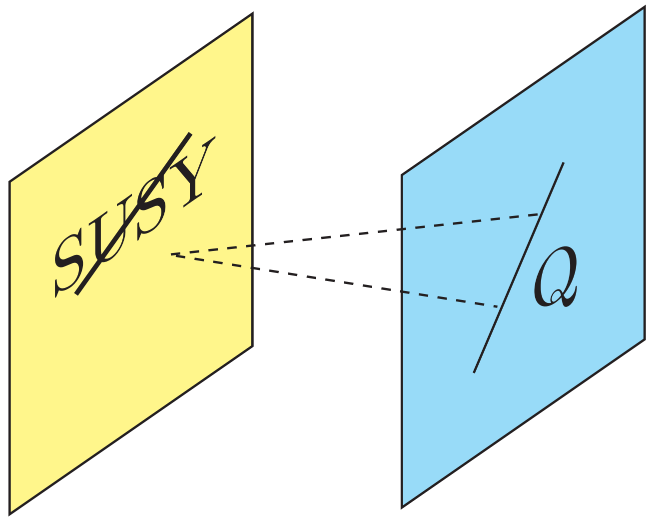
$\frac{F_\sigma}{\sigma} \neq 0 \Rightarrow$ anomaly mediated SUSY breaking!

$$\text{RS} \Rightarrow \frac{F_\sigma}{\sigma} \sim \left(\frac{\Lambda_{\text{IR}}}{\Lambda_{\text{UV}}} \right)^{d_1 - 4} \Lambda_{\text{IR}} \qquad (d_1 < d_2)$$

Model independent?

Gravity Loops

SUSY breaking from gravity loops



AdS/CFT ⟷ Cut off by strong CFT dynamics

$$\Delta m_0^2 \sim \frac{1}{16\pi^2} \frac{1}{M_{\mathrm{P}}^2} \Lambda_{\mathrm{IR}}^4 \qquad \Rightarrow \Lambda_{\mathrm{IR}} \lesssim 10^{11}\ \mathrm{GeV}$$

Standard model fields composite below M_{GUT}!

Low scale unification?

Conclusions

- SUSY flavor problem has elegant solutions

  Gauge mediation, anomaly mediation, ...

- Predictions clouded by model-dependence

  Predicting superpartner spectrum

  $\stackrel{?}{\leftrightarrow}$ postdicting fermion mass spectrum

- Look for new ideas