Anomaly Mediation (without negative sleptons) and Radius Stabilization by Constant Boundary Superpotentials in a Warped Space

Nobuhito Maru (Kobe U)

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References

- Supersymmetry Breaking by Constant Boundary Superpotentials in Warped Space,
  N.M., N. Sakai (Tokyo Womans' Christian Univ.) and N. Uekusa (Univ. of Helsinki),
  PRD74 (2006) 045017

- Radius Stabilization by Constant Boundary Superpotentials in Warped Space,
  N.M., N. Sakai and N. Uekusa,
  PRD75 (2007) 125014

- Work in progress, with N. Sakai and N. Uekusa

Plan

①Introduction
②Model of radius stabilization
③SUSY breaking spectrum
④Summary & Discussion

Introduction

Motivations of considering Extra Dimensions:

1: (Alternative) Solution to the gauge hierarchy problem without SUSY

Large extra dimensions

Arkani-Hamed, Dimopoulos & Dvali, PLB429 (1998) 263

Warped extra dimensions

Randall & Sundrum, PRL83 (1999) 3370, 4690

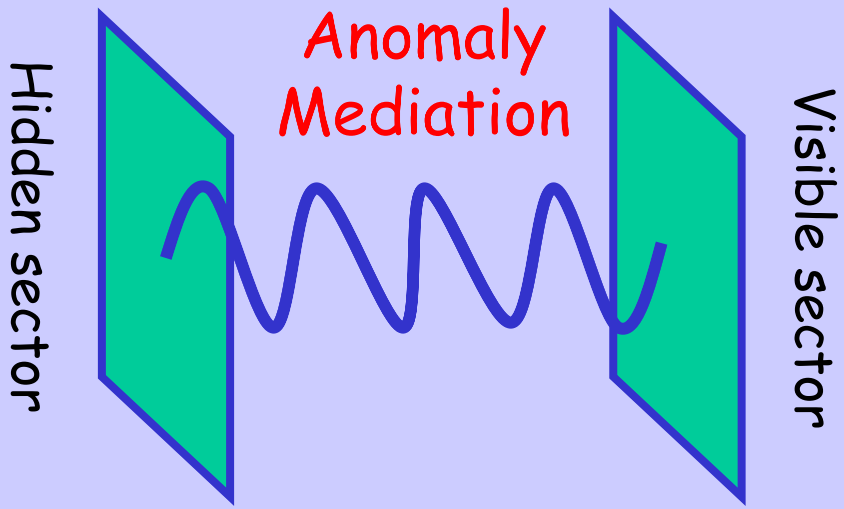
etc

Introduction

Another motivation of considering Extra Dimensions:

2: Solution to SUSY flavor problem

Randall & Sundrum, NPB557 (1999) 79
Luty & Sundrum, PRD62 (2000) 035008
Giudice, Luty, Murayama & Rattazzi, JHEP9812 (1998) 027



Direct coupling between these two sectors are suppressed geometrically

↓

Anomaly Mediation

↓

No SUSY flavor problem

Not the end of the story ⇒ "Radius Stabilization"

Phenomenological viable Brane World Scenario
= Compactification Radius should be stabilized

From PDG

Limits on Mass of Radion

This section includes limits on mass of radion, usually in context of Randall-Sundrum models. See the "Extra Dimension Review" for discussion of model dependence.

VALUE (GeV)	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[51] ABBIENDI	05	OPAL	$e^+e^- \to Z$ radion
$\gtrsim 35$	[52] MAHANTA	00		$Z \to$ radion $\ell\overline{\ell}$
>120	[53] MAHANTA	00B		$p\overline{p} \to$ radion $\to \gamma\gamma$

[51] ABBIENDI 05 use e^+e^- collisions at $\sqrt{s} = 91$ GeV and $\sqrt{s} = 189$–209 GeV to place bounds on the radion mass in the RS model. See their Fig. 5 for bounds that depend on the radion-Higgs mixing parameter ξ and on $\Lambda_W = \Lambda_\phi/\sqrt{6}$. No parameter-independent bound is obtained.

[52] MAHANTA 00 obtain bound on radion mass in the RS model. Bound is from Higgs boson search at LEP I.

[53] MAHANTA 00B uses $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV; production via gluon-gluon fusion. Authors assume a radion vacuum expectation value of 1 TeV.

Not the end of the story ⇒ "RADIUS STABILIZATION"

Phenomenological viable Brane World Scenario
= Compactification Radius should be stabilized

No radion potential in SUSY limit
since **the radion is a moduli**

⇒ Size of radius is undetermined

⇒ Once SUSY is broken,
nontrivial radion potential is generated

⇒ Only gravity multiplet does not stabilize the radius
N.M & N.Okada, hep-ph/0508113

⇒ Bulk fields should be introduced to stabilize the radius

⇒ New flavor-violating soft SUSY breaking
vs Anomaly Mediation

[For stabilization by classical SUSY background, see
N.M & Okada, PRD70 025002 (2004), Eto, N.M, Sakai, PRD70 086002 (2004)]

Model of Radius Stabilization

Model

5D SUSY model of a hypermultiplet
on the Randall-Sundrum background

$$ds^2 = e^{-2R\sigma}\eta_{\mu\nu}dx^\mu dx^\nu + R^2 dy^2,\ \sigma(y) = k|y|,\ 0 \le y \le \pi$$

Marti & Pomarol, PRD64 (2001) 105025

$$\mathcal{L}_5 = \int d^4\theta \frac{1}{2}\varphi^\dagger\varphi\left(T+T^\dagger\right)e^{-\left(T+T^\dagger\right)\sigma}\left(\Phi^\dagger\Phi + \Phi^c\Phi^{c\dagger} - 6M_5^3\right)$$
$$+\int d^2\theta\left[\varphi^3 e^{-3T\sigma}\left\{\Phi^c\left[\partial_y - \left(\frac{3}{2}-c\right)T\sigma'\right]\Phi + 2M_5^3 w_0\delta(y)\right\} + h.c.\right]$$

Bulk mass

Constant superpotential@y=0

$$\varphi = 1 + \theta^2 F_\varphi,\quad T = R + \theta^2 F_T$$

Compensator multiplet
(Auxiliary multiplet)

Radion multiplet

$\Phi^{(c)}$ even (odd)

Background solution (leading order of w_0(<<1))

$$\phi(y) = N_2 \exp\left[\left(\frac{3}{2} - c\right) Rk|y|\right]$$

$$\phi^c(y) = \hat{\varepsilon}(y)\, w_0 \left(\frac{|\phi|^2}{6M_5^3} - 1\right)^{-1} \left(\frac{|\phi|^2}{6M_5^3}\right)^{\frac{5/2-c}{3-2c}} \left[c_1 + c_2 \left(\frac{|\phi|^2}{6M_5^3}\right)^{-\frac{1-2c}{3-2c}} \left(\frac{|\phi|^2}{6M_5^3} + \frac{2}{1-2c}\right)\right] \left(c \neq \frac{1}{2}, \frac{3}{2}\right)$$

$$\hat{\varepsilon}(y) \equiv +1(0<y<\pi), -1(-\pi<y<0), \quad \hat{N} \equiv |N_2|^2 / 6M_5^3$$

$$c_1 = -\left(\frac{N_2^\dagger}{2\hat{N}^{(5-2c)/2(3-2c)}}\right) \frac{(1-2c)\hat{N}e^{2Rk\pi} + 2e^{-(1-2c)Rk\pi}}{(1-2c)\hat{N}\left(e^{2Rk\pi}-1\right) + 2\left(e^{-(1-2c)Rk\pi}-1\right)}, \quad c_2 = \left(\frac{N_2^\dagger}{2\hat{N}^{(3+2c)/2(3-2c)}}\right) \frac{(1-2c)}{(1-2c)\hat{N}\left(e^{2Rk\pi}-1\right) + 2\left(e^{-(1-2c)Rk\pi}-1\right)}$$

$W_0 = 0$ case ⇒ SUSY solution (solution of F-flatness)

3 parameters (N_2, c_1, c_2) are integration constants

2 of them (c_1, c_2) are fixed by boundary conditions @ y=0, π

1 of them (N_2) is fixed by the minimization of the potential

Potential

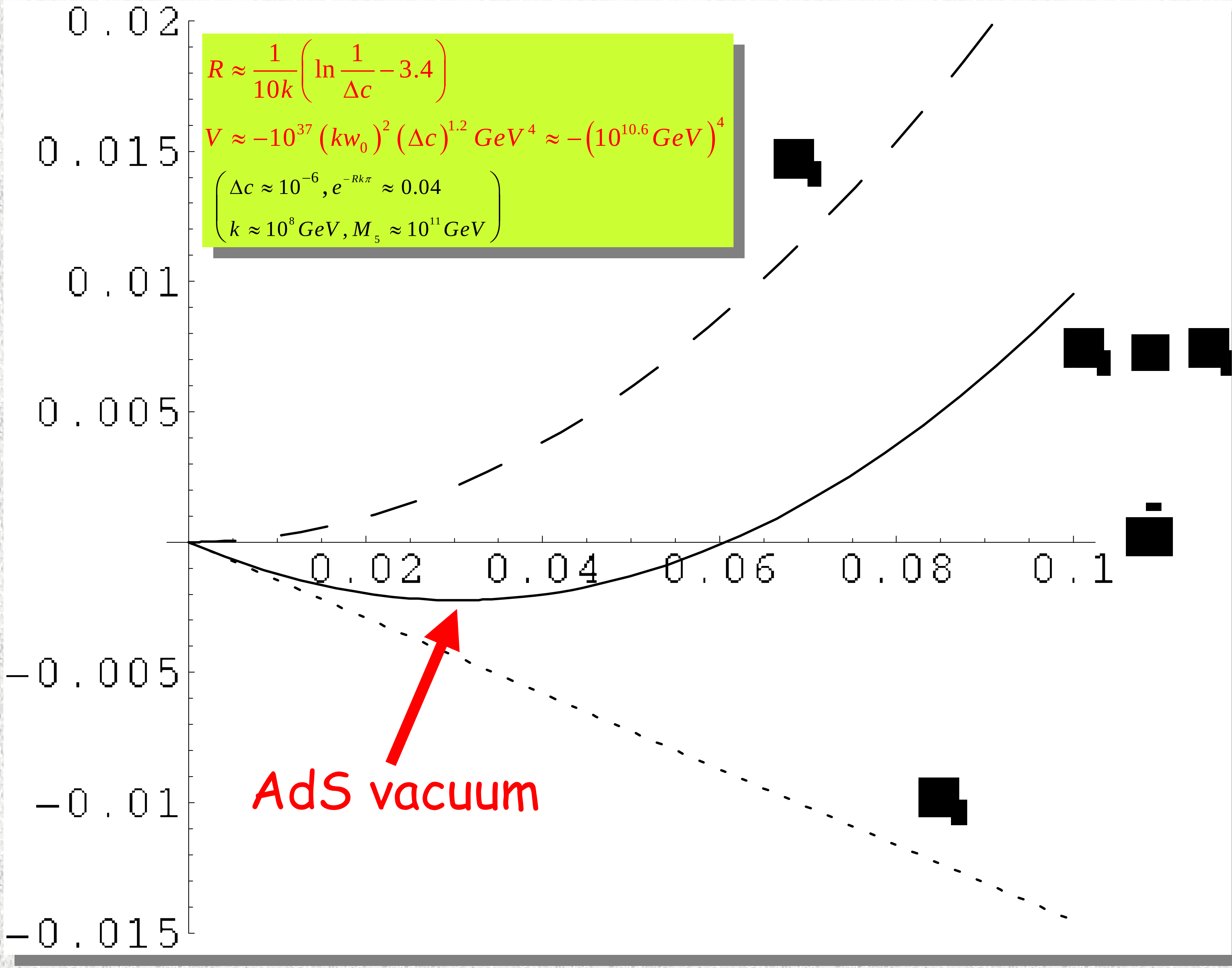
$$V=\frac{3M_5^3kw_0^2}{2}\left[\frac{-2(1-2c)}{(1-2c)\left(e^{2Rk\pi}-1\right)\hat{N}+2\left(e^{(2c-1)Rk\pi}-1\right)}\hat{N}^{4-2c-\frac{1}{3-2c}}\right.$$

$$\left.+\frac{\hat{N}}{1-\hat{N}}\left(-4c^2+12c-6+\frac{3-2c}{3\left(1-\hat{N}\right)}\right)\right]$$

$$\approx\frac{3M_5^3kw_0^2}{2}\left(\underbrace{\frac{2(2c_{cr}-1)}{3-2c_{cr}}\hat{N}^{\left(4c_{cr}^2-12c_{cr}+10\right)/\left(3-2c_{cr}\right)}}_{V_1}\underbrace{-\hat{N}\left(-8c_{cr}+\frac{34}{3}\right)\Delta c}_{V_2}\right)$$

$$\left(c=c_{cr}-\Delta c,|\Delta c|\ll 1\right)$$

We found a potential minimum with $\partial V/\partial R=\partial V/\partial\hat{N}=0$ for $c<c_{cr}\equiv\frac{17-\sqrt{109}}{12}\approx 0.546$



0.02
0.015
0.01
0.005
-0.005
-0.01
-0.015
0.02
0.04
0.06
0.08
0.1
$R \approx \frac{1}{10k}\left(\ln\frac{1}{\Delta c} - 3.4\right)$
$V \approx -10^{37}\,(kw_0)^2\,(\Delta c)^{1.2}\,GeV^4 \approx -\left(10^{10.6}\,GeV\right)^4$
$\left(\begin{array}{l}\Delta c \approx 10^{-6},\ e^{-Rk\pi} \approx 0.04 \\ k \approx 10^8\,GeV,\ M_5 \approx 10^{11}\,GeV\end{array}\right)$
AdS vacuum

Radion & Moduli Masses

$$m_{light}^2 \approx k^2 w_0^2 0.38 \left(3.4 + \ln \Delta c\right)^2 \Delta c^{1.7}$$

$$m_{heavy}^2 \approx k^2 w_0^2 0.47 \Delta c^{0.7}$$

Almost radion

Almost N2R, N2I has a same mass

We obtain for $kw_0 \sim 10^7$ GeV & $\Delta c \sim 10^{-6}$

$$m_{light} \sim 1\ \text{TeV},\ m_{heavy} \sim 100\ \text{TeV}$$

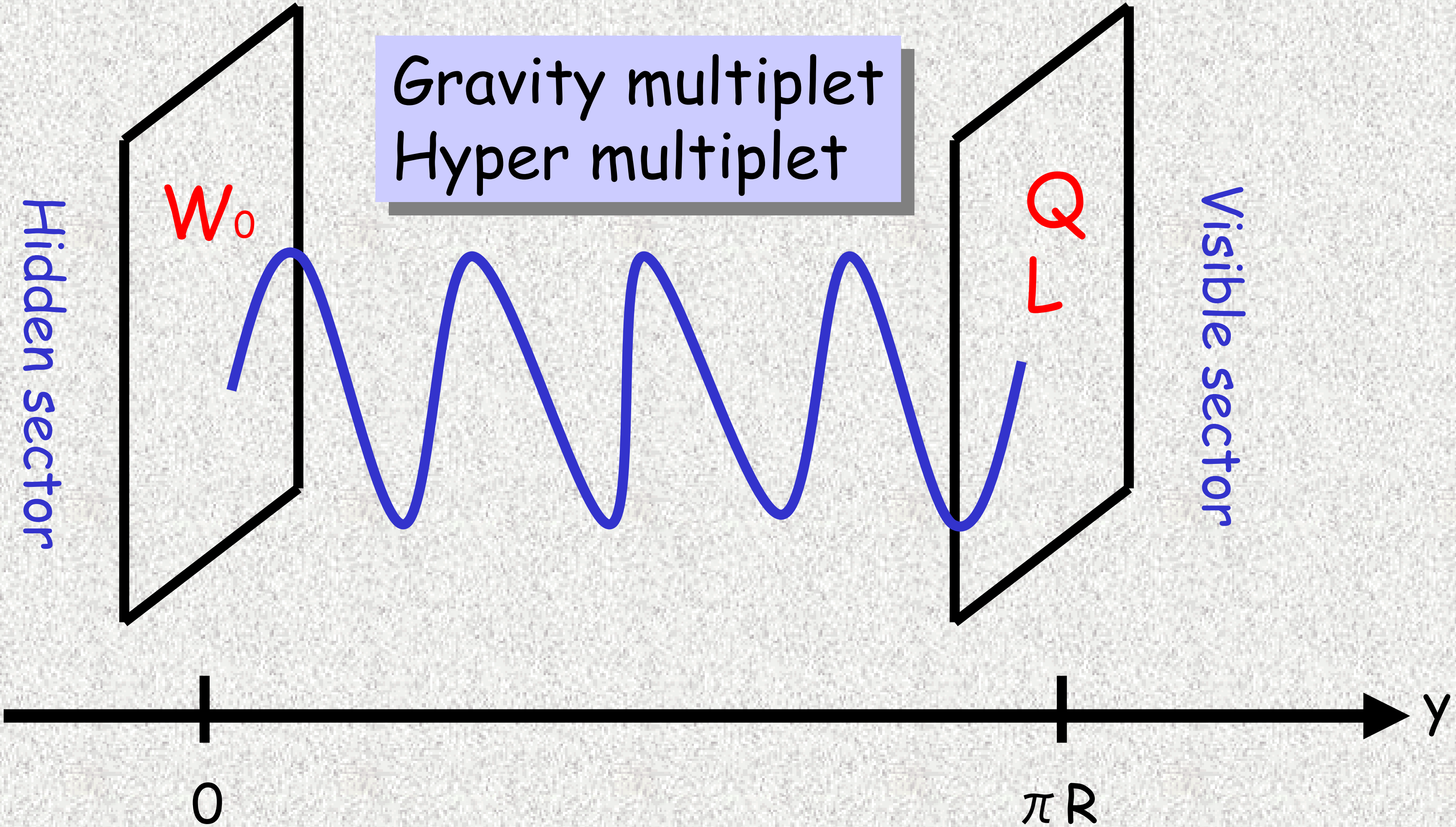
Radion

Moduli

SUSY Breaking Spectrum

SUSY breaking transmission to our world

SUSY breaking and Our world are assumed to be separated in the direction of 5^{th} dimension



Anomaly Mediation

In this setup, NO GRAVITY MEDIATION@tree level,
and we get anomaly mediated SUSY breaking spectrum
We would like to make this SUSY breaking effects dominant
because of flavor-blindness

Gaugino, Sfermion masses

Luty, PRL89 (2002) 141801

$$\tilde{m}_{AMSB} \sim \frac{g^2}{16\pi^2} \left\langle \frac{F_\omega}{\omega} \right\rangle \bigg|_{y=\pi} \sim 10^{-4} g^2 k w_0$$

$$\sim 100 GeV \left(g^2 k w_0 \sim 10^6 GeV \right)$$

$$\omega \equiv \varphi e^{-T\sigma}$$

Gravitino Mass

Gherghetta-Pomarol, NPB586 (2000) 141
Kugo-Ohashi, PTP108 (2002) 203

$$\mathcal{L} = M_5 \sqrt{-g} \left[i\bar{\Psi}^i_M \gamma^{MNP} D_N \Psi^i_P - \frac{3}{2} \sigma' \bar{\Psi}^i_M \gamma^{MN} \left(\sigma_3\right)^{ij} \Psi^i_N \right]$$
$$- 6 w_0 \delta\left(y\right) \left[\psi^1_\mu \sigma^{[\mu} \bar{\sigma}^{\nu]} \psi^1_\nu + \bar{\psi}^1_\mu \bar{\sigma}^{[\mu} \sigma^{\nu]} \bar{\psi}^1_\nu \right]$$

Boundary superpotential generates brane localized gravitino mass terms

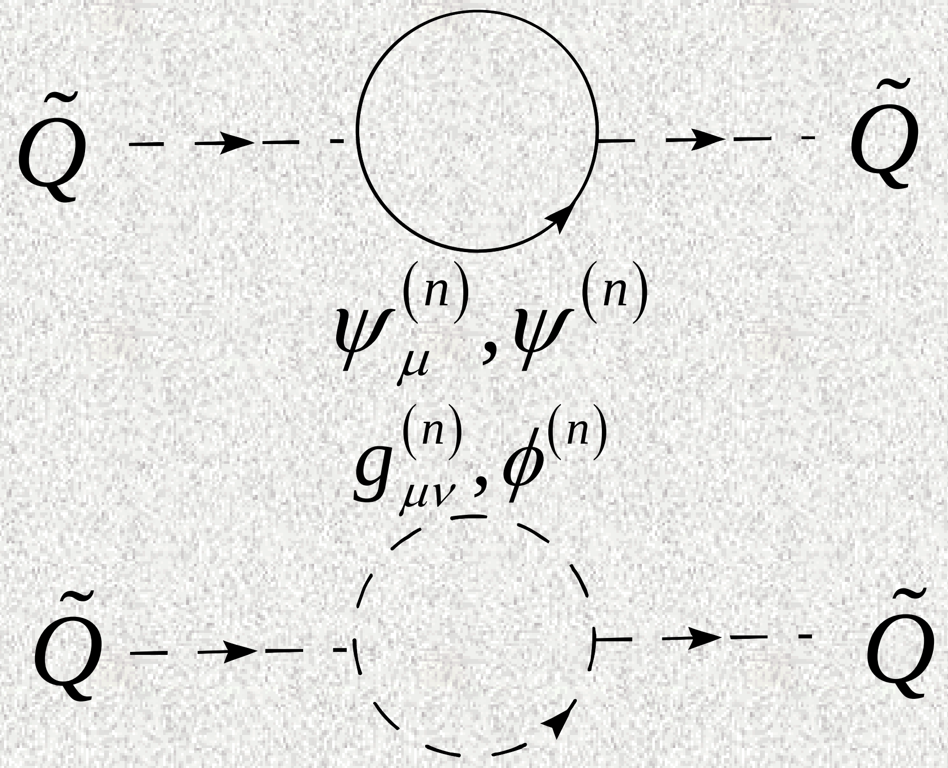
Taking the limit $\frac{m_n}{k} \ll 1, \frac{m_n}{k} e^{Rk\pi} \ll 1$, we obtain

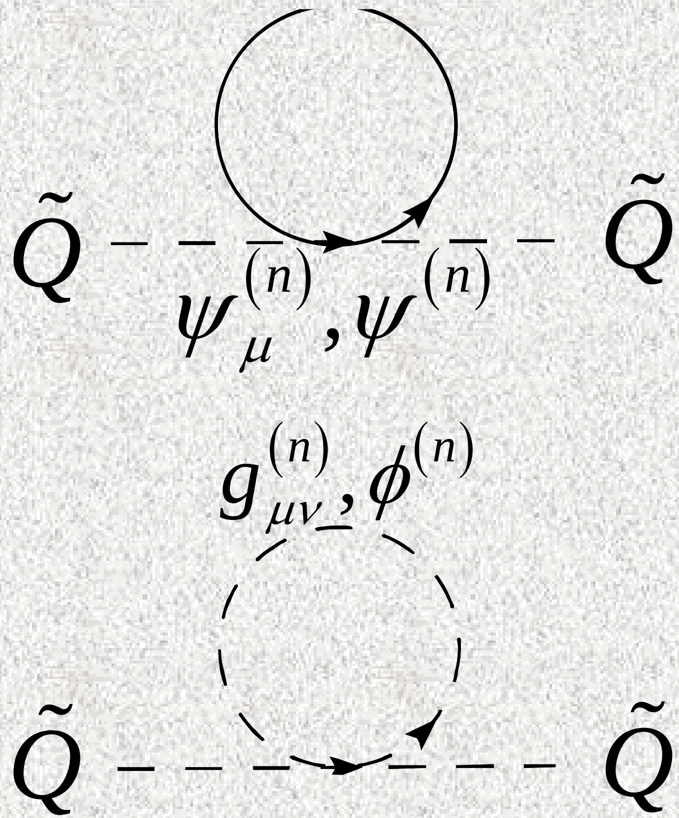
$$m_{3/2} \approx 6 w_0 k \sim 10^7 GeV$$

for $m_{AMSB} \sim 10^{-4} g^2 k w_0 \sim 100 GeV$

Mass splitting by W_0 for the gravity & hyper multiplets generate sfermion masses @1-loop

Antoniadis-Quiros, NPB505 (1997) 109





$$\tilde{m}_{KK} \sim 0.1 \frac{\Delta m^2}{M_p} \leq 10^{-5}\, GeV \ll \tilde{m}_{AMSB}$$

Canceling Cosmological Constant

The radion potential has a negative vacuum energy (~ − (10^10 GeV)^4)

⇒ should be canceled by some positive energy

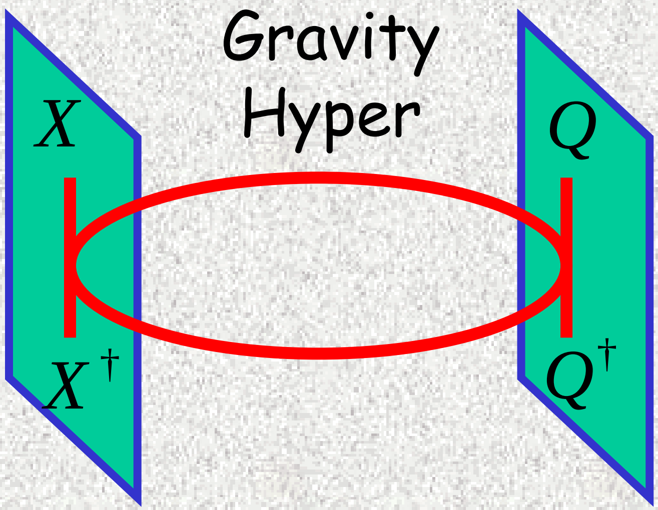
F-term cancellation

We add a SUSY breaking chiral multiplet "X"@y=0

$$\mathcal{L}_X = \delta(y)\left[\int d^4\theta \varphi^\dagger \varphi X^\dagger X + \int d^2\theta \left(\varphi^3 m^2 X + h.c.\right)\right]$$

$$\rightarrow \Delta V = \left|F_X\right|^2 = m^4 \Rightarrow \sqrt{F_X} \approx 10^{10}\, GeV$$

F_X induced sfermion masses@1-loop



"Tachyonic"

$$\Delta\tilde{m}^2_{gravity} = -\frac{k^4}{18\pi^2 M_5^6} e^{-4k\pi R} |F_X|^2$$

Gregoire, Rattazzi, Scrucca, Strumia & Trincherini, NPB720 (2005) 3

$$\Delta\tilde{m}^2_{hyper} \sim \frac{c_{ij}}{16\pi^2} \left(\frac{F_X}{\sqrt{3}M_4}\right)^2 \left(\frac{k}{M_4}\right)^2 \left(\frac{1-2c}{e^{(1-2c)Rk\pi}-1}\right) e^{(3-2c)Rk\pi}$$

Maru & Okada, PRD (2004) 025002

"Flavor dependent"

$$\Delta\tilde{m}^2_{gravity}, \Delta\tilde{m}^2_{hyper} \leq 10^{-2}\,\tilde{m}^2_{AMSB} \Rightarrow \sqrt{F_X} \leq 10^{11}\,GeV$$

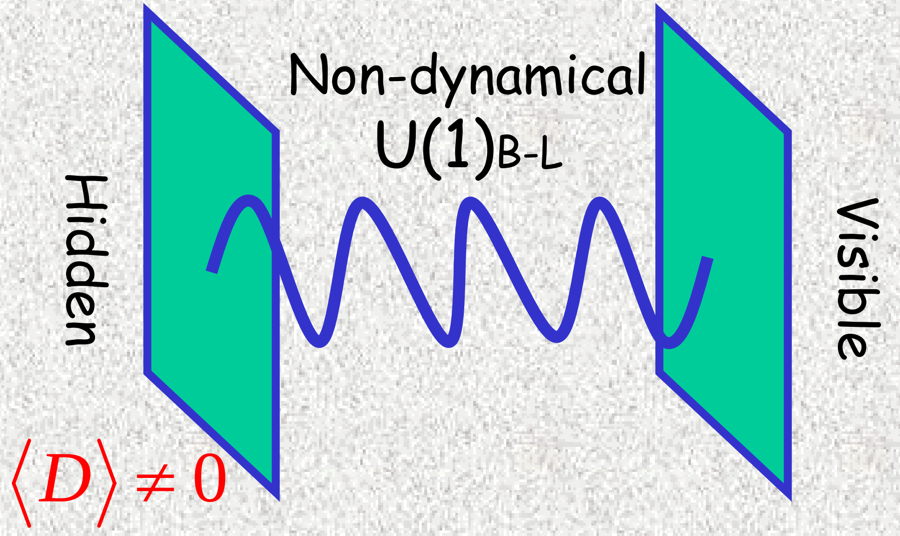
Summary & Discussion

- We have presented a simple model of
  radius stabilization & SUSY breaking
  in SUSY RS model with a hypermultiplet &
  a constant W@y=0
- Radius & the moduli are shown to be stabilized
  $\Rightarrow m_{\text{radion}} \sim 1$ TeV, $m_{\text{moduli}} \sim 100$ TeV
- SUSY breaking is dominated by anomaly mediation
  $\Rightarrow$ No SUSY flavor problem
- Gravitino mass ~ 10^4 TeV
- Cosmological constant can be canceled
  by localized F-term SUSY breaking

Issues to be addressed

- Negative slepton problem
- μ problem
- Sparticle spectroscopy, … etc

For negative slepton problem,
we are now studying whether the additional D-term solution by Arkani-Hamed, Kaplan, Murayama & Nomura is compatible without spoiling our stabilization mechanism



$U(1)_{B-L}$ & $U(1)_Y$ D-term contributions can solve the negative slepton problem

Backup Slides

Radion (R) & Moduli (N_2) masses

$$\mathcal{L}_{quadratic} = \mathcal{L}_{kin} + \mathcal{L}_{mass}$$

$$\begin{aligned}\mathcal{L}_{kin} = \sigma\left(\partial_\mu R\right)\left(\partial^\mu R\right) e^{-2R\sigma}\left(\phi^\dagger\phi + \phi^{c\dagger}\phi^c - 6M_5^3\right) \\ -\frac{1}{2}(1-2R\sigma)e^{-2R\sigma}\left(\partial_\mu R\right)\partial^\mu\left(\left|\phi\right|^2 + \left|\phi^c\right|^2\right) \\ -R\,\mathrm{e}^{-2R\sigma}\left[\left(\partial_\mu\phi^\dagger\right)\left(\partial^\mu\phi\right) + \left(\partial_\mu\phi^{c\dagger}\right)\left(\partial^\mu\phi^c\right)\right]\end{aligned}$$

$$\mathcal{L}_{mass} = -\frac{1}{2}\left(R, N_{2R}\right)\begin{pmatrix}\dfrac{\partial^2 V}{\partial R^2} & \dfrac{\partial^2 V}{\partial R\,\partial N_2} \\ \dfrac{\partial^2 V}{\partial N_2^\dagger\,\partial R} & \dfrac{\partial^2 V}{\partial N_2^\dagger\,\partial N_2}\end{pmatrix}\begin{pmatrix} R \\ N_{2R}\end{pmatrix} - \frac{1}{2}\frac{\partial^2 V}{\partial N_2^\dagger\,\partial N_2}\left(N_{2I}\right)^2$$

Note:

1: non-canonical normalization

2: mixing between R and N_{2R}

Fluctuations: $R+\tilde{R},\quad N_2+\tilde{N}_2,\quad \tilde{N}_2=\tilde{N}_{2R}+i\tilde{N}_{2I}$

$$\int_0^\pi dy\mathcal{L}_{kin}=-\left(\partial_\mu\tilde{R},\partial_\mu\tilde{N}_{2R}\right)\begin{pmatrix} f_{11} & f_{12}\\ f_{21} & f_{22}\end{pmatrix}\begin{pmatrix}\partial^\mu\tilde{R}\\ \partial^\mu\tilde{N}_{2R}\end{pmatrix}-f_{22}\partial_\mu\tilde{N}_{2I}\partial^\mu\tilde{N}_{2I}$$

$$f_{11}\equiv\frac{\left|N_2\right|^2}{(1-2c)^3R^2k}e^{(1-2c)Rk\pi}\left\{-\left(\frac{3}{2}-c\right)\left(\frac{1}{2}+c\right)(1-2c)^2\left(Rk\pi\right)^2+2(1-2c)\left(Rk\pi\right)-2+2e^{-(1-2c)Rk\pi}\right\}$$
$$+\frac{3M_5^3}{2R^2k}\left\{1-e^{-2Rk\pi}\left(1+2Rk\pi\right)\right\}$$

$$f_{12}\equiv\frac{\pi}{2}N_2^\dagger e^{(1-2c)Rk\pi}=\frac{\pi}{2}N_2e^{(1-2c)Rk\pi}=f_{21},\quad f_{22}\equiv\frac{e^{(1-2c)Rk\pi}-1}{(1-2c)k}$$

To get canonical forms, the following rotations are needed

$$\bar{N}_{2I}=\sqrt{2f_{22}}\tilde{N}_{2I},\quad\begin{pmatrix}\bar{R}\\ \bar{N}_{2R}\end{pmatrix}=\begin{pmatrix}\sqrt{\lambda_+} & \\ & \sqrt{\lambda_-}\end{pmatrix}\begin{pmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}\tilde{R}\\ \tilde{N}_{2R}\end{pmatrix}$$

$$\lambda_\pm=f_{11}+f_{22}\pm\sqrt{\left(f_{11}-f_{22}\right)^2+4f_{12}^2},\quad\tan\theta=\frac{1}{2f_{12}}\left[f_{22}-f_{11}+\sqrt{\left(f_{11}-f_{22}\right)^2+4f_{12}^2}\right]$$

Mass term:

$$\int_0^{\pi} dy \mathcal{L}_{mass} = -\frac{1}{2}\left(\bar{R}, \bar{N}_{2R}\right)\mathcal{M}^2 \begin{pmatrix} \bar{R} \\ \bar{N}_{2R} \end{pmatrix} - \frac{1}{2}\mathcal{M}_{2I}^2 \left(\bar{N}_{2I}\right)^2$$

$$\mathcal{M}_{2I}^2 = \frac{1}{2 f_{22}} \frac{\partial^2 V}{\partial N_2^{\dagger} \partial N_2}$$

$$\mathcal{M}^2 = \begin{pmatrix} 1/\sqrt{\lambda_+} & \\ & 1/\sqrt{\lambda_-} \end{pmatrix} \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \frac{\partial^2 V}{\partial R^2} & \frac{\partial^2 V}{\partial R \partial N_2} \\ \frac{\partial^2 V}{\partial N_2^{\dagger} \partial R} & \frac{\partial^2 V}{\partial N_2^{\dagger} \partial N_2} \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} 1/\sqrt{\lambda_+} & \\ & 1/\sqrt{\lambda_-} \end{pmatrix}$$

⬇

$$\mathcal{M}^2 \approx k^2 w_0^2 \begin{pmatrix} \frac{2(1-2c)^2}{3-2c}(Rk\pi)^2 e^{(-4c^2+12c-10)Rk\pi} & \frac{(2c-1)^{5/2}}{(3-2c)^2}(Rk\pi) e^{(-4c^2+11c-17/2)Rk\pi} \\ \frac{(2c-1)^{5/2}}{(3-2c)^2}(Rk\pi) e^{(-4c^2+11c-17/2)Rk\pi} & \frac{2c-1}{4}\left(-4c^2+12c-6+\frac{4(3-2c)}{3}\right) e^{(2c-3)Rk\pi} \end{pmatrix}$$

$\bar{N}_{2I}$ has a same mass squared as 22 component of the above mass squared matrix

Equations of motion for hyperscalar

$$0=\frac{W_b}{2M_5^3}\left(-2\left(\delta\left(y\right)-\delta\left(y-\pi\right)\right)h^c+\frac{\phi^\dagger}{2M_5^3}W_b+7\left(\hat{\varepsilon}\left(y\right)\right)^2 kRh^c\right)$$
$$-R^2e^{2Rk\pi}\eta^{\mu\nu}\partial_\mu\partial_\nu\phi^\dagger-e^{(5/2+c)R\sigma}\partial_y\left(e^{-(1+2c)R\sigma}\partial_y\left(e^{-(3/2-c)R\sigma}\phi^\dagger\right)\right)$$

$$0=\frac{W_b}{2M_5^3}\left(\frac{\hat{\varepsilon}\left(y\right)h^{c\dagger}}{2M_5^3}W_b+2\partial_y\phi\right)-2\left(\delta\left(y\right)-\delta\left(y-\pi\right)\right)\partial_y h^{c\dagger}$$
$$-2\left(\partial_y\delta\left(y\right)-\partial_y\delta\left(y-\pi\right)\right)h^{c\dagger}+\frac{\phi}{2M_5^3}\partial_y W_b$$
$$+\hat{\varepsilon}\left(y\right)\left[-R^2e^{2Rk\pi}\eta^{\mu\nu}\partial_\mu\partial_\nu h^{c\dagger}-e^{(5/2-c)R\sigma}\partial_y\left(e^{-(1-2c)R\sigma}\partial_y\left(e^{-(3/2+c)R\sigma}h^{c\dagger}\right)\right)\right]$$

$$W_b\equiv 2M_5^3 w_0\delta\left(y\right),\quad \phi^c\equiv\hat{\varepsilon}\left(y\right)h^c, h^c: even$$

Boundary conditions come from the cancellation conditions of δ & δ^2 terms ($\partial_y\delta$ conditions are the same as δ)

SUSY breaking by W0

Hyperscalar & gravitino obtain mass shift by W0

Hyperscalar:

$$m_n \approx k e^{-Rk\pi} \begin{cases} \left(n + \dfrac{c+1}{2}\right)\pi + \dfrac{c(1-c)}{2n\pi}\left(1 + 10^{-3}\left(\dfrac{n\pi}{w_0} e^{-Rk\pi}\right)^2\right) \\ \left(n + \dfrac{c+1}{2}\right)\pi - \dfrac{2n\pi}{c(c-1)} 10^{-3}\left(\dfrac{n\pi}{w_0} e^{-Rk\pi}\right)^2 \end{cases}, \quad m_n \approx \frac{k}{e^{Rk\pi} - 1}\left(n\pi \pm \frac{w_0}{2\sqrt{3}}\right)$$

$$\left(m_n/k \gg 1, m_n e^{Rk\pi}/k \gg 1\right)$$

$$\left(m_n/k \ll 1, m_n e^{Rk\pi}/k \gg 1\right)$$

$$m_{lightest} \approx 6 w_0 k \approx 10^7\,\mathrm{GeV} \quad \left(m_n/k \ll 1, m_n e^{Rk\pi}/k \ll 1\right)$$

Gravitino:

$$m_n \approx \begin{cases} \left(n + \dfrac{1}{4}\right)\pi k e^{-Rk\pi} & \left(\dfrac{m_n}{k} \ll 1, \dfrac{m_n}{k} e^{Rk\pi} \gg 1\right) \\ \left(n - \dfrac{3w_0}{\pi}\right)\pi k e^{-Rk\pi} & \left(\dfrac{m_n}{k} \gg 1, \dfrac{m_n}{k} e^{Rk\pi} \gg 1\right) \end{cases}$$

Mode expansion:

$$\begin{pmatrix} \phi(x,y) \\ \phi^c(x,y) \end{pmatrix} = \sum_n \sum_{I=1,2} \phi_n^I(x) \begin{pmatrix} b_n^I(y) \\ \hat{\varepsilon}(y) b_n^{cI}(y) \end{pmatrix}$$

Bulk solutions:

Gherghetta & Pomarol, NPB586 (2000) 141

$$b_n(y) = \frac{e^{2R\sigma}}{N_n}\left[J_\alpha\left(\frac{m_n}{k}e^{R\sigma}\right) + b_\alpha(m_n) Y_\alpha\left(\frac{m_n}{k}e^{R\sigma}\right)\right], \quad \alpha = \left|c + \frac{1}{2}\right|$$

$$b_n^c(y) = \frac{e^{2R\sigma}}{N_n^c}\left[J_\beta\left(\frac{m_n}{k}e^{R\sigma}\right) + b_\beta(m_n) Y_\beta\left(\frac{m_n}{k}e^{R\sigma}\right)\right], \quad \beta = \left|c - \frac{1}{2}\right|$$

BC from δ :

$$0 = -2b_n^c(0) + w_0 b_n(0), \quad 0 = b_n^c(\pi)$$

BC from δ ^2:

$$0 = \frac{7}{3} w_0 b_n^c(0) - \frac{1}{3} w_0 \left[2b_n^c(0) + \frac{m_n}{k}\frac{1}{N_n^c}\left(J'_\beta\left(\frac{m_n}{k}\right) + b_\beta(m_n) Y'_\beta\left(\frac{m_n}{k}\right)\right)\right]$$

$$-4b_n(0) + 2\left(\frac{3}{2} - c\right) b_n(0) - \frac{2m_n}{k}\left[\frac{1}{N_n}\left(J'_\alpha\left(\frac{m_n}{k}\right) + b_\alpha(m_n) Y'_\alpha\left(\frac{m_n}{k}\right)\right)\right]$$

$$0 = (1+2c) b_n(\pi) + \frac{2m_n}{k}\left[\frac{e^{3Rk\pi}}{N_n}\left(J'_\alpha\left(\frac{m_n}{k}e^{Rk\pi}\right) + b_\alpha(m_n) Y'_\alpha\left(\frac{m_n}{k}e^{Rk\pi}\right)\right)\right]$$

D-term Cancellation

Fayet-Illiopoulos model@y=0

$$\mathcal{L}_V = \delta(y)\Big[\int d^4\theta \varphi^\dagger \varphi \left(A_1^\dagger e^{eV} A_1 + A_2^\dagger e^{-eV} A_2 + 2\kappa V\right)$$

$$+\left\{\int d^2\theta \left(\frac{1}{4}\left(W^\alpha W_\alpha + \bar{W}_{\dot\alpha}\bar{W}^{\dot\alpha}\right) + \varphi^3\left(W\left(A_1, A_2\right) + h.c.\right)\right)\right\}\Big]$$

$$W\left(A_1, A_2\right) = mA_1A_2$$

$$\Delta V = \delta(y)\left[\frac{1}{2}\left(\kappa + \frac{e}{2}\left(|A_1|^2 - |A_2|^2\right)\right)^2 + \left|\frac{\partial W}{\partial A_1}\right|^2 + \left|\frac{\partial W}{\partial A_2}\right|^2 - \left\{F_\varphi\left(3W - A_1\frac{\partial W}{\partial A_1} - A_2\frac{\partial W}{\partial A_2}\right) + h.c.\right\}\right]$$

$$= \frac{1}{2}\kappa^2 \,@\, A_1 = A_2 = 0 \Rightarrow \sqrt{\kappa} \approx 10^{10}\, GeV$$

0 @minimum

Eqs. of motion unchanged

Equations of motion

$$0 = -i\bar{\sigma}^{\mu}\partial_{\mu}\psi_{\nu}^{1} + \left(\frac{1}{R}\partial_{y} - \frac{3}{2}\sigma'\right)\bar{\psi}_{\nu}^{2} - \frac{6w_{0}}{R}\delta(y)\bar{\psi}_{\nu}^{1}$$

$$0 = -i\sigma^{\mu}\partial_{\mu}\psi_{\nu}^{2} - \left(\frac{1}{R}\partial_{y} + \frac{3}{2}\sigma'\right)\psi_{\nu}^{1}$$

Up to the gauge fixing $\bar{\sigma}^{\mu}\psi_{\mu}^{1,2} = 0,\ \partial^{\mu}\psi_{\mu}^{1,2} = 0$

Boundary conditions come from δ terms
& parity property

Mode expansion:

$$\psi_{\rho}^{1,2}(x,y)=\sum_{n}\psi_{\rho}^{1,2(n)}(x)\, f^{1,2(n)}(y)$$

Bulk solution:

$$f_1^{(n)}(y)=\frac{e^{R\sigma/2}}{N_n}\left[J_2\left(\frac{m_n}{k}e^{R\sigma}\right)+b_2(m_n)Y_2\left(\frac{m_n}{k}e^{R\sigma}\right)\right]$$

$$f_2^{(n)}(y)=\hat{\varepsilon}(y)\frac{e^{R\sigma/2}}{N_n}\left[J_2\left(\frac{m_n}{k}e^{R\sigma}\right)+b_2(m_n)Y_2\left(\frac{m_n}{k}e^{R\sigma}\right)\right]$$

Boundary conditions:

$$0=\bar{\tilde{f}}_2^{(n)}(0)-3w_0 f_1^{(n)}(0)$$

$$0=\tilde{f}_2^{(n)}(\pi),\quad 0=\left(\partial_y+\frac{3}{2}R\sigma'\right)f_1^{(n)}(\pi)$$

Auxiliary field Lagrangian:

$$\mathcal{L}_{aux}=\left(\frac{1}{2}e^{-2R\sigma}\left(2RF^{\dagger}F+F_TF^{\dagger}\phi+F_T^{\dagger}F\phi^{\dagger}\right)+\left\{\frac{1}{2}e^{-2R\sigma}\left(2R\phi^{\dagger}F+F_T\left(\phi^{\dagger}\phi-3M_5^3\right)\right)\left(F_{\varphi}^{\dagger}-F_T^{\dagger}\sigma\right)+h.c.\right\}+\left(\phi\leftrightarrow\phi^c\right)\right)$$
$$+e^{-2R\sigma}R\left(\phi^{\dagger}\phi+\phi^{c\dagger}\phi^c-6M_5^3\right)\left(F_{\varphi}^{\dagger}-F_T^{\dagger}\sigma\right)\left(F_{\varphi}-F_T\sigma\right)+\left[3e^{-3R\sigma}\left(F_{\varphi}-F_T\sigma\right)\left\{\phi^c\left[\partial_y-\left(\frac{3}{2}-c\right)R\sigma'\right]\phi+W_b\right\}\right.$$
$$\left.+e^{-3R\sigma}\left\{F^c\left[\partial_y-\left(\frac{3}{2}-c\right)R\sigma'\right]\phi+\phi^c\left[\partial_y-\left(\frac{3}{2}-c\right)R\sigma'\right]F-\phi^c\left(\frac{3}{2}-c\right)F_T\sigma'\phi\right\}+h.c.\right]$$

Equations of motion for auxiliary fields:

$$F=-\frac{e^{-R\sigma}}{R}\left[-\partial_y\phi^{c\dagger}+\left(\frac{3}{2}+c\right)R\sigma'\phi^{c\dagger}+\frac{\phi}{2M_5^3}W_b+\frac{1}{6M_5^3}\phi^{\dagger}\phi\partial_y\phi^{c\dagger}+\frac{1}{3M_5^3}\phi^{c\dagger}\phi\partial_y\phi^{\dagger}-\frac{1}{6M_5^3}\phi^{\dagger}\phi\phi^{c\dagger}\left(\frac{9}{2}-c\right)R\sigma'\right]$$

$$F^c=-\frac{e^{-R\sigma}}{R}\left[\partial_y\phi^{\dagger}-\left(\frac{3}{2}-c\right)R\sigma'\phi^{\dagger}+\frac{\phi^c}{2M_5^3}W_b+\frac{1}{6M_5^3}\phi^c\phi^{\dagger}\partial_y\phi^{c\dagger}+\frac{1}{3M_5^3}\phi^{c\dagger}\phi^c\partial_y\phi^{\dagger}-\frac{1}{6M_5^3}\phi^c\phi^{\dagger}\phi^{c\dagger}\left(\frac{9}{2}-c\right)R\sigma'\right]$$

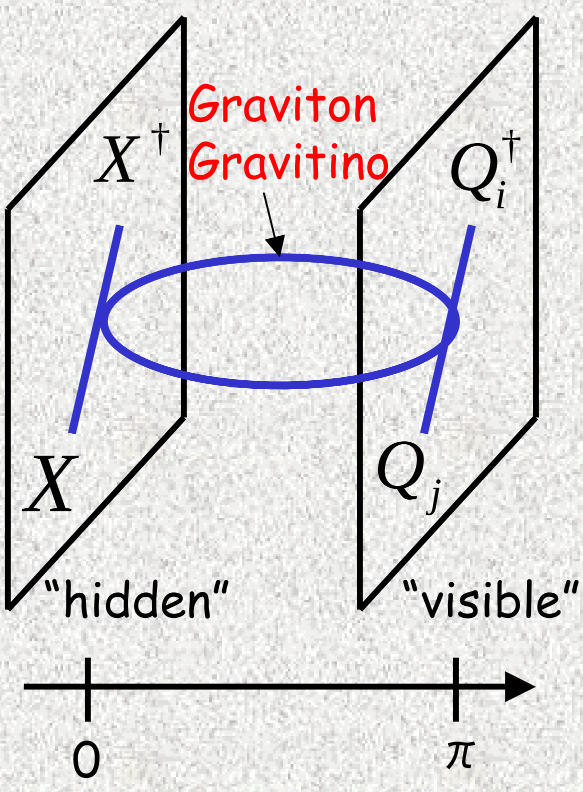
$$F_{\varphi}=-\frac{e^{-R\sigma}}{R}\left[-\frac{1}{6M_5^3}\phi^{\dagger}\partial_y\phi^{c\dagger}-\frac{1}{3M_5^3}\phi^{c\dagger}\partial_y\phi^{\dagger}+\frac{1}{6M_5^3}\phi^{\dagger}\phi^{c\dagger}\left(\frac{9}{2}-c\right)R\sigma'-\frac{1}{2M_5^3}W_b-\frac{3\left(1-2R\sigma\right)}{r}\phi^{c\dagger}\partial_y\phi^{\dagger}\right.$$
$$\left.-\frac{3\left(1-2R\sigma\right)}{r}W_b+\frac{\left(1-2R\sigma\right)}{r}\phi^{c\dagger}\phi^{\dagger}\left(\frac{3}{2}-c\right)R\sigma'\right]$$

$$F_T=-\frac{e^{-R\sigma}}{R}\left[6\phi^{c\dagger}\partial_y\phi^{\dagger}-2\phi^{c\dagger}\phi^{\dagger}\left(\frac{3}{2}-c\right)R\sigma'+6W_b\right],\quad r\equiv\phi^{\dagger}\phi+\phi^{c\dagger}\phi^c-6M_5^3$$

Scalar Masses by 1-loop Gravity Multiplet

Gherghetta-Riotto, NPB623 (2002) 97
Rattazzi-Scrucca-Strumia, NPB674 (2003) 171
Buchbinder et al. PRD70 (2004) 025008

Flavor blind but tachyonic ⇒ should be suppressed



$$\tilde{m}^2 \sim -\frac{1}{16\pi^2} m_{3/2}^2 \frac{\Lambda^2}{M_4^2}$$

$$\sim -\frac{1}{16\pi^2} |F_X|^2 \frac{\Lambda^2}{M_4^4} (4D)$$

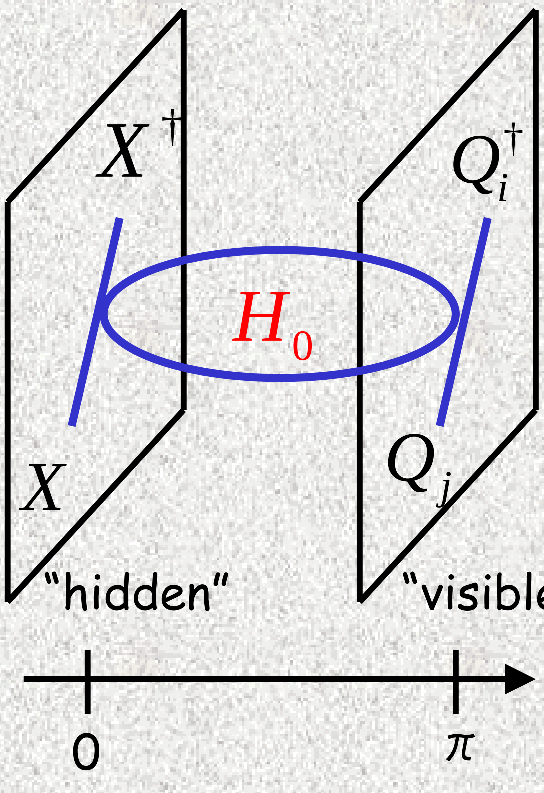
$$\tilde{m}^2 \sim -\frac{1}{16\pi^2} |F_X|^2 \frac{M_c^4}{M_5^6} (\text{5D flat})$$

$$\Rightarrow -\frac{1}{16\pi^2} |F_X|^2 \frac{k^4 e^{-4Rk\pi}}{M_5^6} (\text{5D RS})$$

Scalar Masses by 1-loop Bulk Hypermultiplet

0-mode of Φ can couple directly to both the visible & hidden sectors
⇒ flavor-violating scalar masses

$$K_{\text{hidden}} \sim \frac{1}{|N_0|^2}\int d^4\theta \frac{h_0^\dagger h_0 X^\dagger X}{M_5^3}, K_{\text{visible}} \sim c_{ij}\frac{e^{(3/2-c)(T_0+T_0^\dagger)k\pi}}{|N_0|^2}\int d^4\theta \frac{h_0^\dagger h_0 Q_i^\dagger Q_j}{M_5^3}$$



$$\left(H_0(x,y) = \frac{1}{N_0}e^{(3/2-c)T_0 k|y|}h_0(x), |N_0|^2 = \frac{e^{(1/2-c)(T_0+T_0^\dagger)k\pi}-1}{(1-2c)k}\right)$$

$$\Delta\tilde{m}_{ij}^2 \sim \frac{c_{ij}}{16\pi^2}m_{3/2}^2\left(\frac{k}{M_4}\right)^2\left(\frac{1-2c}{e^{(1/2-c)(T_0+T_0^\dagger)k\pi}-1}\right)^2 e^{(3/2-c)(T_0+T_0^\dagger)k\pi}$$

To be suppressed…

c > 3/2: H_0 localized@hidden brane

c < -1/2: H_0 localized@visible brane

c∼3/2,-1/2: $k \ll M_4$