NEW CONTRIBUTIONS TO SOFT TERMS

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Work in progress (with E. Dudas)

OUTLINE

- ✗ Motivation: Why consider strongly coupled high energy phase in supersymmetric models?
- ✗ Integrating out the heavy mesons - the role of the R-current
- ✗ A 5D model - supergravity with hypermultiplets
- ✗ The effective Kahler potential at low energy and implications for soft terms
- ✗ Conclusions

MOTIVATION

✗ The fermion mass hierarchy can be explained in the MSSM by a strongly coupled (nearly) conformal high energy phase

✗ FCNC's are suppressed similar to FN models

Nelson + Strassler 2000

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UV: CFT

Confinement
e.g. M_{GUT}

IR: MSSM

$$W = y(\Lambda)\ QUH + \ldots$$

$$y(\mu) = y(\Lambda)\left(\frac{\mu}{\Lambda}\right)^{\Delta_Q + \Delta_U + \Delta_H - 3}$$

$$\langle \bar{Q} Q \rangle = \frac{F_0^2}{p^2} + \sum \frac{F_n^2}{p^2 + m_n^2}$$

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Zero mode
→ MSSM

Heavy "mesons"
→ integrate out

INTEGRATING OUT MESONS

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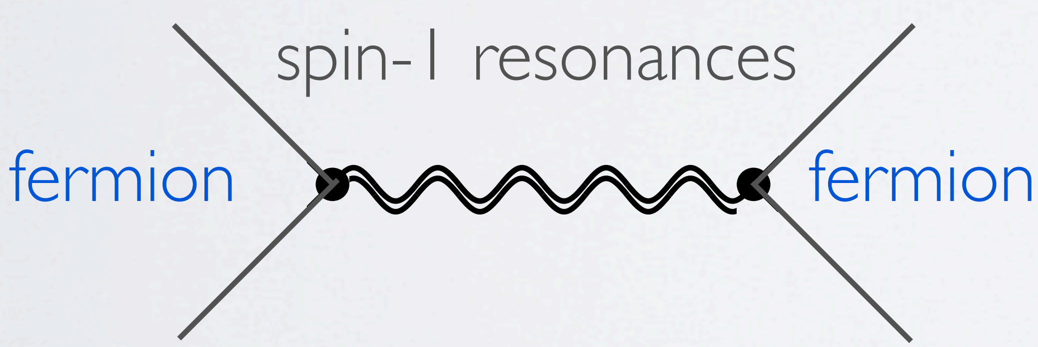

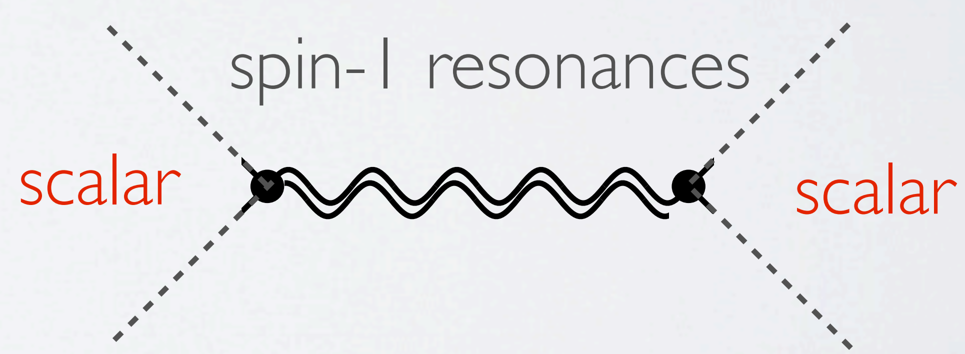

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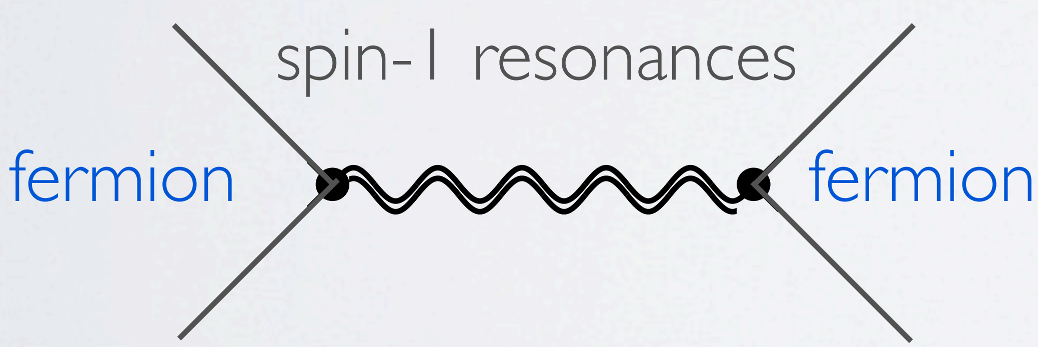

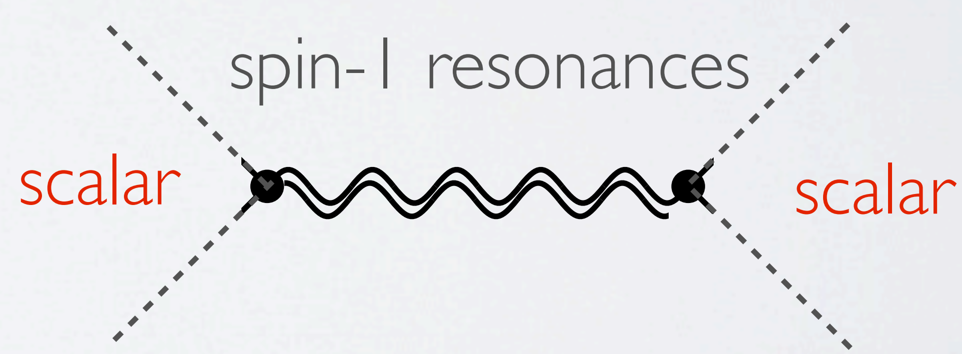

$$\mathcal{L}_{eff} \supset \left(J_\mu^{IR}\right)^2 \longrightarrow K \supset \sum_i \alpha_{ij}(\bar{\Phi}_i \Phi_i)(\bar{\Phi}_j \Phi_j)$$

SOFT TERMS?

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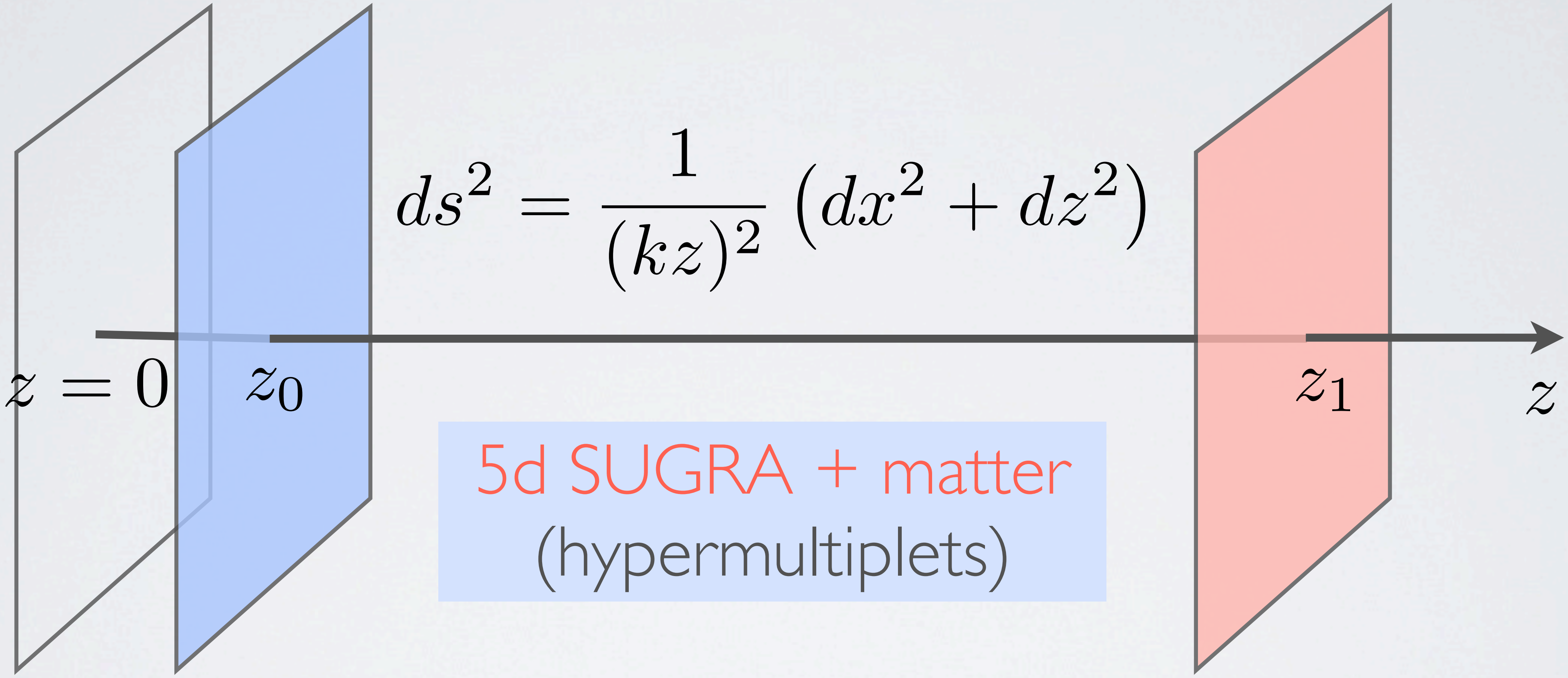
✗ SCFT's such as SQCD in conformal window possess a global abelian R symmetry under which ALL fields are charged

$$q_R = \frac{2}{3}\Delta$$

Generates IRREDUCIBLE contribution to soft terms (→ this talk)

A MODEL IN 5 DIMENSIONS

✗ AdS/CFT: Five dimensional SUGRA provides a simple computable framework for strongly coupled SUSY gauge theories.



$$ds^2 = \frac{1}{(kz)^2}\left(dx^2 + dz^2\right)$$

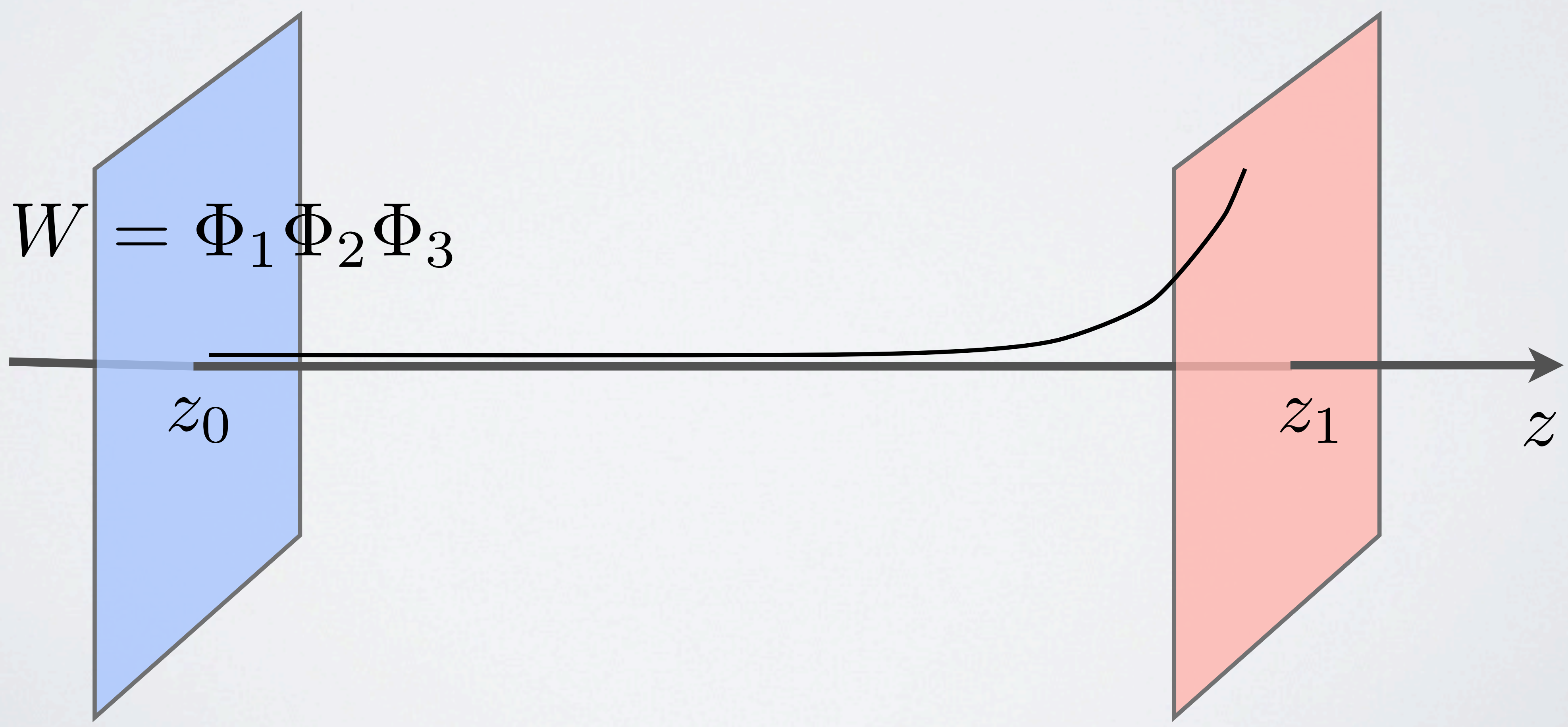
UV brane (4d gravity)

IR brane (confinement)

✗ Resulting KK Lagrangian describes mesons and their interactions

HYPERMULTIPLETS

- ✗ In 5d, minimal supersymmetry is N=2
- ✗ Matter comes in hypermultiplets = two chiral multiplets Φ, Φ_c
- ✗ Boundary conditions remove 1/2 of supersymmetries, e.g. $\Phi_c = 0$
- ✗ Zero modes are chiral $\Phi(x,z) = \phi(x)\, z^{\frac{3}{2}-c}$



5D N=2 SUGRA

Field content of 5d (minimal) SUGRA (8+8 d.o.f.):

✗ 5d metric h_{MN} (5 d.o.f.)

✗ graviphoton A_M (3 d.o.f.)

✗ gravitino ψ^i_M (8 d.o.f.)

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4d SUGRA, 2+2 d.o.f.

✗ 4d metric $h_{\mu\nu}$ (2 d.o.f.)

✗ gravitino ψ^1_μ (2 d.o.f.)

Radion, 2+2 d.o.f.

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✗ Integrate out the heavy KK modes in presence of 5d sources (5d energy-momentum tensor, 5d R-current)

✗ Properly subtract zero modes

✗ Extract quartic Kahler potential from 4-fermion terms (or, alternatively, from 2-derivative 4-scalar terms)

FERMIONIC COUPLINGS

✗ The Lagrangian containing matter fermions reads

$$\begin{aligned}\mathcal{L} &= -i\,\bar{\Psi}\gamma^M D_M\Psi - im_\Psi\,\bar{\Psi}\Psi \\ &\quad -\sqrt{\frac{3}{128\,M^3}}\,\bar{\Psi}\gamma^{AB}\Psi F_{AB} - \frac{1}{128\,M^3}\left(\bar{\Psi}\gamma_{AB}\Psi\right)^2\end{aligned}$$

$$m_\Psi = c\,k \qquad k^2 = \frac{8M^3g_R^2}{3}$$

$$D_M = \partial_M + i\,g_R\left(-\frac{2\,c}{3}\right)A_M + \Gamma_M$$

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✗ 5d R charge proportional to mass

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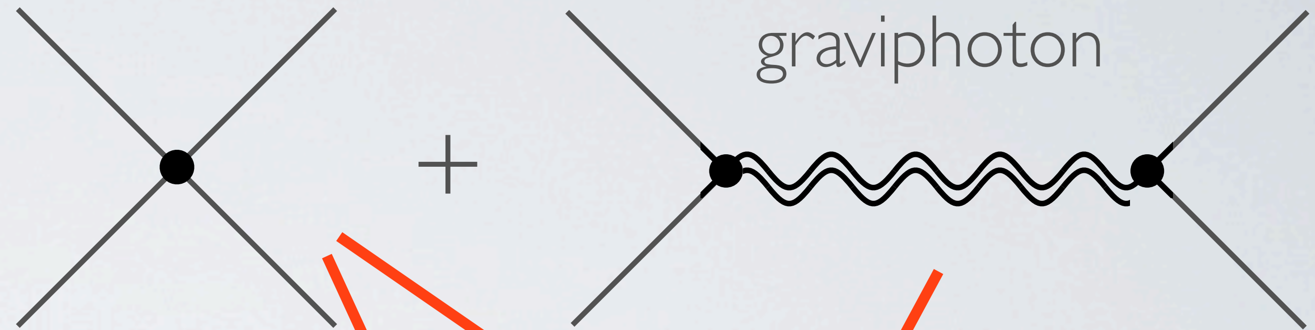
✗ 5d four-fermion term

RESULT

For 4-fermion terms just two diagrams:

✗ 5d 4-fermion term

✗ graviphoton exchange



$$K_{eff} = \underbrace{\left(\frac{1}{8M_{Pl}^2} + \frac{1}{6}\alpha_{ij} \right)}_{\text{always } > 0 \text{ !}} \bar{\Phi}_i \Phi_i \bar{\Phi}_j \Phi_j$$

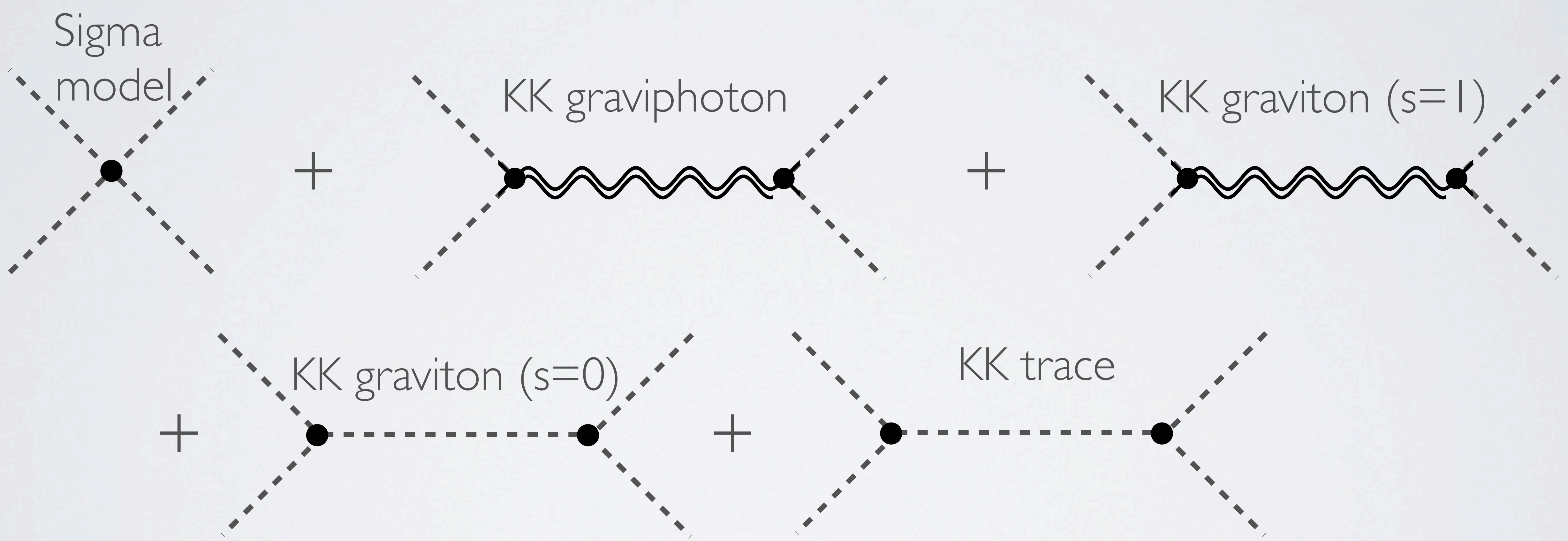
$$\begin{aligned} \alpha_{ij} \quad &= \quad -\frac{1}{8M_{Pl}^2} \frac{(3-2c_i)(3-2c_j)}{(4-2c_i-2c_j)} \\ &\quad + \frac{1}{8M_{Pl}^2 \epsilon^2} \frac{(1-2c_i)(1-2c_j)}{(4-2c_i-2c_j)} \frac{(1-\epsilon^{3-2c_i})(1-\epsilon^{3-2c_j})}{(1-\epsilon^{1-2c_i})(1-\epsilon^{1-2c_j})} \end{aligned}$$

$$\epsilon = \frac{z_0}{z_1}$$

SCALARS

✗ We can also reconstruct the quartic Kahler from dimension-6, four scalar, 2-derivative terms

✗ There are now more contributions



✗ These contributions lead to the same Kahler potential!

$$K_{eff} = \left(\frac{1}{8M_{Pl}^2} + \frac{1}{6}\alpha_{ij} \right) \bar{\Phi}_i \Phi_i \bar{\Phi}_j \Phi_j$$

“GLOBAL” LIMIT

✗ Let’s take the following limit in this expression:

$$M_{Pl} \to \infty \qquad \epsilon\, M_{Pl} \ \text{held fixed} \qquad (z_0 \to 0)$$

✗ Decouples 4d gravity (in fact the whole elementary sector)

✗ Retains only the contribution from the CFT!

$$K_{eff} = \left(\cancel{\frac{1}{8M_{Pl}^2}} + \frac{1}{6}\alpha_{ij} \right) \bar{\Phi}_i \Phi_i \bar{\Phi}_j \Phi_j$$

$$\alpha_{ij} = \begin{cases} \frac{1}{8M_{Pl}^2\epsilon^2} \frac{(1-2c_i)(1-2c_j)}{(4-2c_i-2c_j)} & c_i,\ c_j < \frac{1}{2} \\ 0 & \text{otherwise} \end{cases}$$

✗ Manifestly tachyonic soft terms!

$$\tilde{m}_i^2 = -\frac{1}{3}\alpha_{Xi}|F_X|^2$$

"COMPACTIFICATION" LIMIT

✗ Let's take the following limit in this expression:

$$\epsilon \to 1 \qquad M_{Pl} \text{ held fixed} \qquad (z_1 \to z_0)$$

$$\alpha_{ij} \to 0 \qquad K_{eff} = \frac{1}{8M_{Pl}^2}\,\bar{\Phi}_i\Phi_i\bar{\Phi}_j\Phi_j$$

✗ By looking at the scalar metric, one can also obtain the full Kahler in this case (in usual sugra conventions $2M_{Pl}^2 = 1$)

$$K_{eff} = -2\,\log\left(1 - \tfrac{1}{2}\bar{\Phi}_i\Phi_i\right)$$

✗ In SUGRA soft terms are $\tilde{m}_{i\bar{j}}^2 = (m_{\frac{3}{2}})^2 g_{i\bar{j}} + |F_X|^2\ R_{X\bar{X}i\bar{j}}$

✗ Still yields tachyonic terms (for subplanckian <X>)

SIDE REMARK ON N=2 SIGMA MODELS

✗ The N=2 hypermultiplets parametrize a nontrivial sigma model

✗ Supersymmetry fixes the curvature of these manifolds to be negative and related to the (5d) Planck mass

U model
$$\frac{U(n_H,2)}{U(n_H)\times U(2)}$$

S model
$$\frac{USp(2n_H,2)}{USp(2n_H)\times USp(2)}$$

$\xrightarrow{\text{compactify}}$

$$\frac{U(n_H,1)}{U(n_H)\times U(1)}$$

$$K = -p\,\log\left(1 - p^{-1}\bar{\Phi}_i\Phi_i\right)$$

No free parameter! $\longrightarrow$

✗ U model: $p=1$

✗ S model: $p=2$

✗ Again yields tachyonic soft masses (at subplanckian <X>)

CONCLUSIONS

✗ Have considered 5D supersymmetric models of flavor in a slice of AdS5 spacetime (SUSY-RS with potentially large IR scale).

✗ Integrating out 5D supergravity yields new contributions to the Kahler potential of chiral zero modes

✗ The se irreducible contribution gives tachyonic soft terms

✗ Via AdS/CFT: dual to the contributions of mesons excited by the R-current (FZ multiplet of currents)

✗ Possible additional contributions include

- Other global (non - R) currents (read: 5d gauge multiplets)
- Brane localized Kahler potentials
- Radion mediation
- Higher order terms in Kahler potential
- ...

BACKUP

HYPERMULTIPLETS

- ✗ Hypermultiplets describe chiral operators of the CFT
- ✗ Contains 2 chiral multiplets $\Phi, \ \Phi_c$
- ✗ Consider a hypermultiplet with bulk (fermion) mass $c\,k$

$$\Phi^c(x,z) \sim z^{\frac{3}{2}+c} J^c(x)$$

$$c < \frac{1}{2}$$

Describes chiral operator $\mathcal{O}$ with dimension $\Delta = \frac{3}{2} - c$

$$\Phi(x,z) \sim z^{\frac{3}{2}-c} J(x)$$

$$c > -\frac{1}{2}$$

Describes chiral operator $\mathcal{O}^c$ with dimension $\Delta = \frac{3}{2} + c$

EFFECTIVE LAGRANGIAN

KK modes of metric yield:

$$
\begin{aligned}
\mathcal{L}_{eff} &= +\frac{1}{8M_{Pl}^2}\int_{z_0}^{z_1} dz\ z^3\ [\Theta_{\mu\nu}(z) - \Omega_2(z)\,\Theta_{\mu\nu}(z_1)]^2 \\
&\quad -\frac{1}{32M_{Pl}^2}\int_{z_0}^{z_1} dz\ z^3\ [\Theta_{tr}(z) - \Omega_2(z)\,\Theta_{tr}(z_1)]^2 \\
&\quad +\frac{1}{4M_{Pl}^2}\left(\int_{z_0}^{z_1} dz\ z\ [\Theta_{\mu 5}(z)]^2 - \frac{2}{z_1^2 - z_0^2}\left[\int_{z_0}^{z_1} dz\ z\,\Theta_{\mu 5}(z)\right]^2\right) \\
&\quad +\frac{1}{12M_{Pl}^2}\int_{z_0}^{z_1} dz\ z^{-1}\ [\Theta_{55}(z) - \Omega_0(z)\,\Theta_{55}(z_1)]^2 \qquad (1
\end{aligned}
$$

$$
\begin{aligned}
\Theta_{\mu\nu}(z,x) &= \int_{z_0}^{z} dz'\, z'^{-3}\left[T_{\mu\nu}(z',x) - \frac{1}{4}\eta_{\mu\nu}T_{\rho\rho}(z',x)\right] \\
\Theta_{tr}(z,x) &= \int_{z_0}^{z} dz'\ z'^{-3}\,T_{\rho\rho}(z',x)\,, \\
\Theta_{55}(z,x) &= \int_{z_0}^{z} dz'\, z^{-1}\left[T_{55}(x,z') - \frac{1}{2}T_{\rho\rho}(x,z')\right], \\
\Theta_{\mu 5}(z,x) &= \int_{z_0}^{z} dz'\, z'^{-2}\,T_{\mu 5}(z',x)\,,
\end{aligned}
$$

$$
\Omega_0 = \frac{z^2 - z_0^2}{z_1^2 - z_0^2}\,,
$$

$$
\Omega_2 = \frac{z^{-2} - z_0^{-2}}{z_1^{-2} - z_0^{-2}}
$$

Similar Lagrangian can be written for the contribution of 5d gauge field. Cabrer GG, Quirós '11