A holographic approach to general gauge mediation

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with

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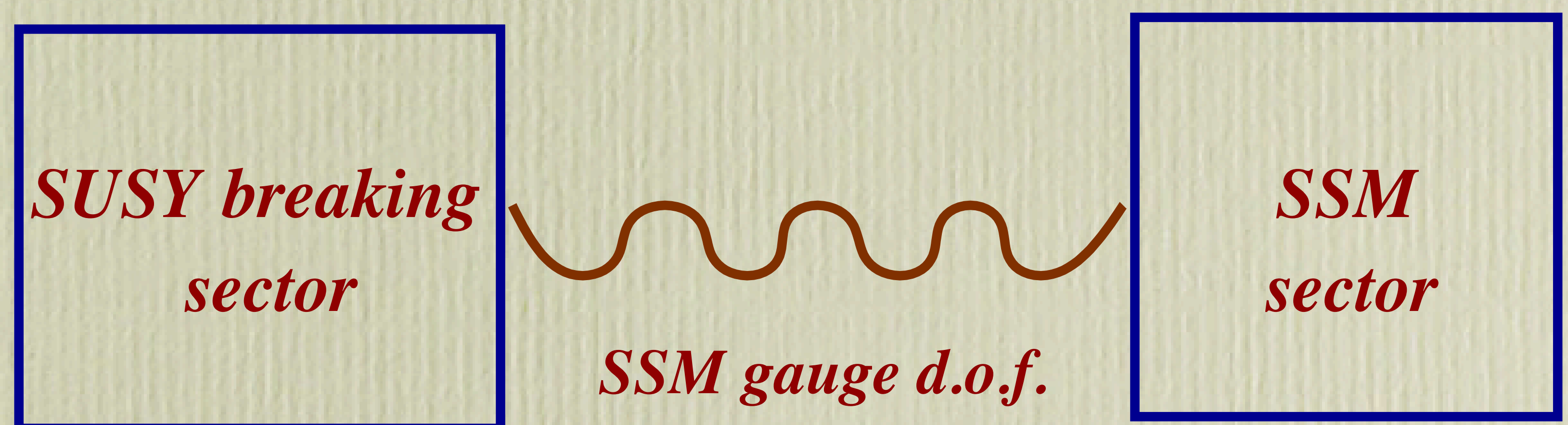
Supersymmetry is (still) the most compelling scenario for physics BSM. But, if at all realized in Nature, we have to understand how it is broken at low energy.

Gauge mediation is one of the two most popular frameworks where to study SUSY breaking, and its communication to the SSM.



$$\mathcal{L} = \mathcal{L}_{\mathbf{SSM}} + \int \mathbf{d^4}\theta\, \mathbf{g V} \mathcal{J} + \mathcal{O}(\mathbf{g^2})$$

where $\mathcal{J} = \mathbf{J} + \mathbf{i}\theta^\alpha \mathbf{j}_\alpha - \mathbf{i}\bar{\theta}_{\dot{\alpha}} \bar{\mathbf{j}}^{\dot{\alpha}} - \theta\sigma^{\mathbf{i}}\bar{\theta}\mathbf{j_i} + \ldots$ is hidden sector current superfield, $\mathbf{D^2}\mathcal{J} = \mathbf{0}$.

Using formalism of General Gauge Mediation, one can show that in gauge mediation soft masses can be expressed as follows

[Meade et al '08]

- Sfermion masses

$$\mathbf{m_{\tilde{f}}^2 = -g^4 \int \frac{d^4k}{(2\pi)^4} \frac{1}{k^2} \left[C_0(k^2) - 4C_{1/2}(k^2) + 3C_1(k^2)\right]}$$

- Gaugino masses

$$\mathbf{m_{\tilde{g}} = g^2 B_{1/2}(0)}$$

where

$$\langle \mathbf{J(k)J(-k)} \rangle = \mathbf{C_0(k^2)}$$

$$\langle \mathbf{j}_\alpha \mathbf{(k)} \bar{\mathbf{j}}_{\dot\alpha} \mathbf{(-k)} \rangle = -\sigma^{\mathbf{i}}_{\alpha\dot\alpha} \mathbf{k_i C_{1/2}(k^2)}$$

$$\langle \mathbf{j_i(k) j_j(-k)} \rangle = \mathbf{(k_i k_j} - \eta_{\mathbf{ij}} \mathbf{k^2) C_1(k^2)}$$

$$\langle \mathbf{j}_\alpha \mathbf{(k) j}_\beta \mathbf{(-k)} \rangle = \epsilon_{\alpha\beta} \mathbf{B_{1/2}(k^2)}$$

How to compute C_s and $B_{1/2}$ in strongly coupled hidden sector?

Holography!

Basic idea: describe hidden sector holographically via SUSY breaking 5D background, and compute soft spectrum evaluating GGM correlators via AdS/CFT techniques.

[see also Benini et al '09, McGuirk et al '10 & '11, Skenderis-Taylor '12]

Holographic General Gauge Mediation

Philosophy: understand relations between geometrical properties of gravitational bg and structure of the SSM soft spectrum, exploring GGM parameter space at *strong coupling*.

HGGM: a three steps process

- Find a 5D SUSY breaking background (typically, it will have metric and scalars non-trivial profiles).

- Take the **bulk multiplet** dual to the current multiplet $\mathcal{J}$ and evaluate its action $\mathcal{S}_2$ at quadratic order and solve EOM in the gravitational background.

- Compute 2-point functions of the current multiplet using AdS/CFT: $\langle \mathcal{J}\mathcal{J}\rangle \sim \delta^2 \mathcal{S}_2^{\text{ren}}/\delta \text{source}^2$, where $\mathcal{S}_2^{\text{ren}}$ is holographycally renormalized on-shell boundary action.

In what follows, we make two simplifications:

- Focus on AAdS backgrounds

$$\mathbf{ds^2 = \frac{1}{z^2}\left(dz^2 + F(z)d\bar{x}^2\right)} \quad \text{where} \quad \mathbf{F(z) \underset{z\to 0}{\simeq} 1}$$

- Supercurrent $\mathcal{J}$ related to global symmetry of hidden sector, hence to gauge symmetry in the bulk.

Boundary Operators			Bulk fields	
$\mathbf{j_i(x)}$	$\mathbf{\Delta = 3}$	$\Rightarrow$	$\mathbf{A_\mu(z,x)}$	$\mathbf{m_A = 0}$
$\mathbf{j_\alpha(x)}$	$\mathbf{\Delta = 5/2}$	$\Rightarrow$	$\mathbf{\lambda(z,x)}$	$\mathbf{\lvert m_\lambda \rvert = 1/2}$
$\mathbf{J(x)}$	$\mathbf{\Delta = 2}$	$\Rightarrow$	$\mathbf{D(z,x)}$	$\mathbf{m_D^2 = -4}$

We take just $\mathbf{U(1)}$ SM gauge group, so we need just one bulk vector superfield.

- Top-down models -

Work at the level of N=2 consistent truncations: can be uplifted to 10D IIB SUGRA and have a UV completion.

What are minimal ingredients? N=2 5D gauged SUGRA coupled to one hypermultiplet and one vector multiplet.

graviton multiplet: $\left(\mathbf{G}_{\mu\nu}, \mathbf{A}^{\mathbf{R}}_{\mu}\right.$ + gravitini $\left.\right)$

hypermultiplet: $\left(\mathbf{C_0} + \mathbf{i}\mathbf{e}^{-\phi}, \eta\mathbf{e}^{\mathbf{i}\alpha}\right.$ + hyperini $\left.\right)$

vector multiplet: $(\mathbf{A}_{\mu}, \mathbf{D}, \lambda)$

There exist gauged N=2 SUGRA consistent truncations of N=8 SUGRA with such (super)field content! [Ceresole et al '01]

Note: gauging fixes couplings, masses (hence charges and dimension of dual operators), and scalar potential.

Step 1: starting from $\mathcal{L}_{\mathbf{bulk}} = \mathcal{L}_{\mathbf{bulk}}(\mathbf{Grav}, \mathbf{Hyper}, \mathbf{Vec})$ find a (AAdS) SUSY breaking bg having non-trivial profile for metric and scalars, solving EOM from the reduced Lagrangian (gauge fixed as $\mathbf{C_0} = \alpha = \mathbf{0}$)

$$\mathcal{L}_{\mathbf{bg}} = -\frac{\mathbf{1}}{\mathbf{2}}\mathbf{R} + \partial_\mu \eta \partial^\mu \eta + \frac{\cosh^{\mathbf{2}}(\eta)}{\mathbf{4}} \partial_\mu \phi \partial^\mu \phi + \\ + \frac{\mathbf{3}}{\mathbf{4}}\left(\cosh^{\mathbf{2}}(\mathbf{2}\eta) - \mathbf{4}\cosh(\mathbf{2}\eta) - \mathbf{5}\right)$$

Step 2: consider fluctuations of bulk vector multiplet at quadratic order in the SUSY breaking background

$$\mathcal{L}_{\mathbf{quad}} = \frac{\mathbf{1}}{\mathbf{4}}\mathbf{F}_{\mu\nu}\mathbf{F}^{\mu\nu} + \bar{\lambda}\not{\mathbf{D}}\lambda - \frac{\mathbf{1}}{\mathbf{2}}\bar{\lambda}\lambda + \frac{\mathbf{1}}{\mathbf{2}}(\mathbf{G}^{\mu\nu}\partial_\mu \mathbf{D} \partial_\nu \mathbf{D} - \mathbf{4}\mathbf{D}^{\mathbf{2}}) + \mathcal{L}_{\mathbf{int}}$$

and solve its EOM. $\mathcal{L}_{\mathbf{int}}$ contains coupling between vector multiplet and hypers and vanishes when $\eta = \mathbf{0}$.

Step 3: compute 2-point functions of the current multiplet from $\langle \mathcal{J}\mathcal{J} \rangle \sim \delta^2 \mathcal{S}^{\mathbf{ren}} / \delta \mathbf{source}^2$, where

$$\mathbf{D}(\mathbf{z},\mathbf{k}) = \mathbf{z}^2 \left(\mathbf{d_0}(\mathbf{k}) \ln(\mathbf{z}\boldsymbol{\Lambda}) + \tilde{\mathbf{d}}_\mathbf{0}(\mathbf{k}) \right) + \mathcal{O}(\mathbf{z}^4)$$

$$\mathbf{A_i}(\mathbf{z},\mathbf{k}) = \mathbf{a_{i0}} + \mathbf{z}^2 \left(\tilde{\mathbf{a}}_\mathbf{i2}(\mathbf{k}) + \ln(\mathbf{z}\boldsymbol{\Lambda}) \mathbf{a_{i2}}(\mathbf{k}) \right) + \mathcal{O}(\mathbf{z}^4)$$

$$\chi(\mathbf{z},\mathbf{k}) = \mathbf{z}^{5/2} \left(\tilde{\chi}_\mathbf{1}(\mathbf{k}) + \ln(\mathbf{z}\boldsymbol{\Lambda}) \chi_\mathbf{1}(\mathbf{k}) + \mathcal{O}(\mathbf{z}^2) \right)$$

$$\bar{\xi}(\mathbf{z},\mathbf{k}) = \mathbf{z}^{3/2} \left[\bar{\xi}_\mathbf{0}(\mathbf{k}) + \mathbf{z}^2 \left(\bar{\tilde{\xi}}_\mathbf{2}(\mathbf{k}) + \ln(\mathbf{z}\boldsymbol{\Lambda}) \bar{\eta}_\mathbf{2}(\mathbf{k}) \right) + \mathcal{O}(\mathbf{z}^4) \right]$$

are leading asymptotic at AdS boundary, we use $\lambda = \begin{pmatrix} \chi_\alpha \\ \bar{\xi}^{\dot{\alpha}} \end{pmatrix}$, and

$$\mathcal{S}_\mathbf{2}^{\mathbf{ren}} = \frac{\mathbf{N}^2}{8\pi^2} \int \frac{\mathbf{d}^4\mathbf{k}}{(2\pi)^4} \left[\mathbf{d_0}\tilde{\mathbf{d}}_\mathbf{0} - 2\mathbf{a}_\mathbf{0}^\mathbf{i} \tilde{\mathbf{a}}_\mathbf{i2} - \frac{1}{2} \mathbf{a}_\mathbf{0}^\mathbf{i} \mathbf{k}^2 \mathbf{a_{i0}} + \xi_\mathbf{0} \tilde{\chi}_\mathbf{1} + \bar{\tilde{\chi}}_\mathbf{1} \bar{\xi}_\mathbf{0} \right]$$

is the renormalized boundary action. Note: structure of 2p-functions depends on bg which determines dependence of sub-leading modes from the sources. E.g.: $\mathbf{B}_{1/2} \neq \mathbf{0}$ only if $\eta \neq \mathbf{0}$.

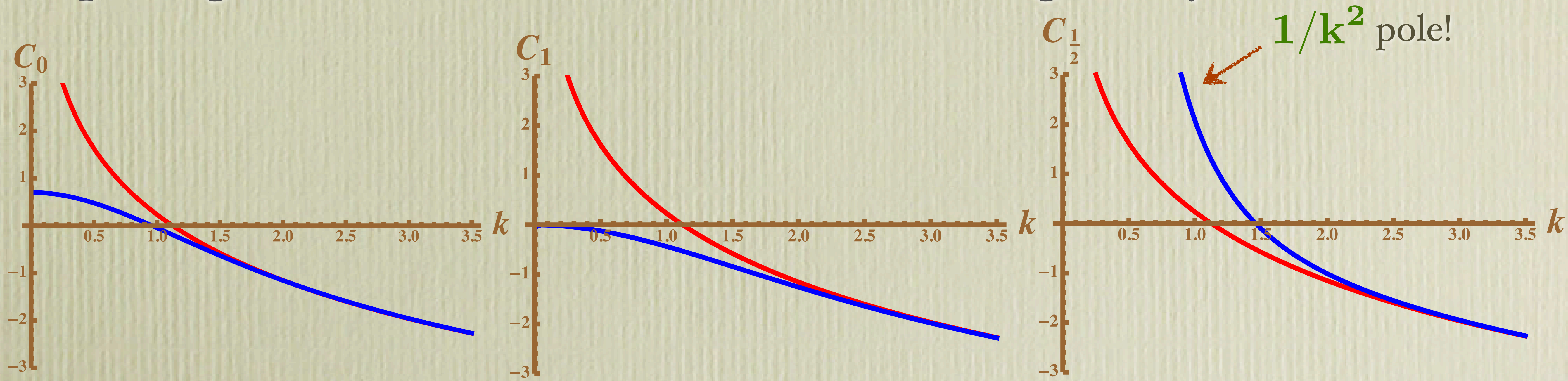
Example 1: dilaton domain wall

[Gubser et al '99]

$$\mathbf{ds^2} = \frac{\mathbf{1}}{\mathbf{z^2}}\left(\mathbf{dz^2} + \sqrt{\mathbf{1} - \mu^8\mathbf{z^8}}\,\mathbf{d\bar{x}^2}\right)$$

$$\phi(\mathbf{z}) = \phi_\infty + \sqrt{\mathbf{6}}\,\mathrm{arctanh}\,\mu^4\mathbf{z^4}$$

Background breaks SUSY and conformal invariance, but preserves $\mathbf{U(1)} \times \mathbf{U(1)_R}$ symmetry and has a naked singularity at $\mathbf{z} = \mathbf{1}/\mu$. Boundary conditions for vector superfield fixed by requiring fluctuations to be finite at the singularity.



Note: no b.c. exist which can avoid pole in fermionic correlator!

Pole in $\mathbf{C_{1/2}}$ implies there are (composite) massless fermions in hidden sector: 't Hooft fermions of preserved $\mathbf{U(1)_R}$ symmetry, which mix with fermionic $\mathbf{U(1)}$ current.

Note: this can happen only if R-symmetry is preserved, hence for backgrounds with vanishing η (implying $\mathbf{B_{1/2} = 0}$).

Phenomenological consequence: gauginos acquire Dirac mass, which arises from coupling $\sim \mathbf{g\, j^\alpha \psi_{\tilde{g}_\alpha}}$ in the Lagrangian.

[Buican-Komargodski '09, Intriligator-Sudano '10]

Pole in $\mathbf{C_{1/2}}$ saturates sfermion mass formula, and hence SSM soft spectrum looks similar to gaugino mediation:

$$\mathbf{m_{\psi_{\tilde{g}}} = gM}$$

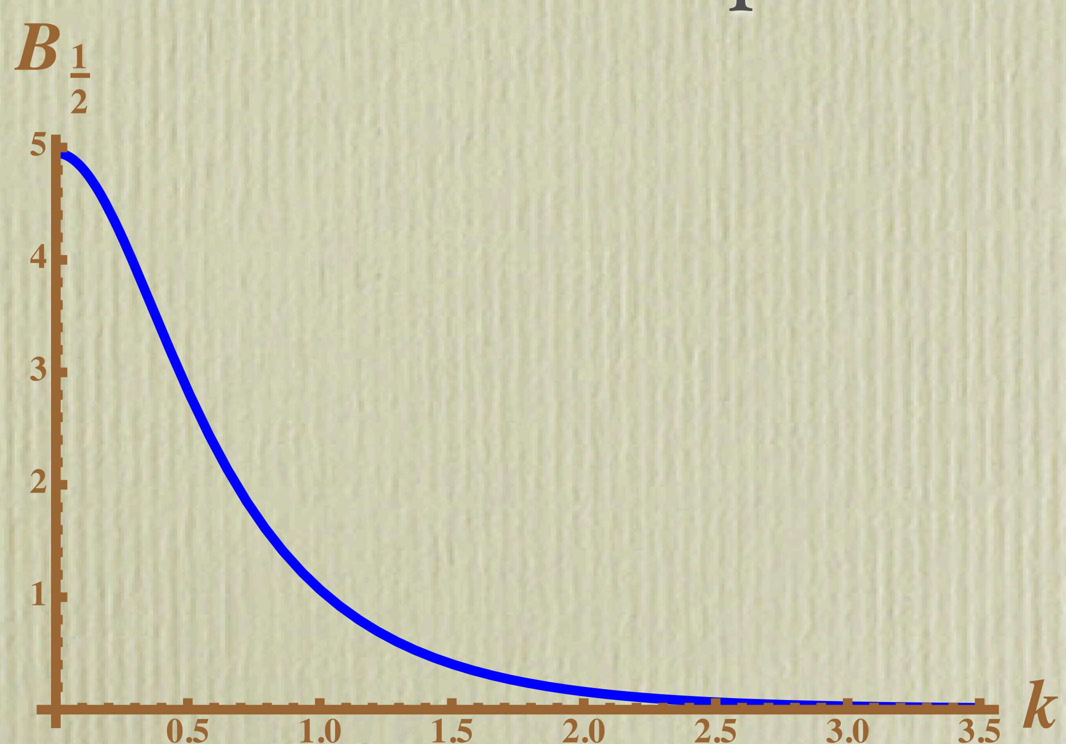
residue of the pole

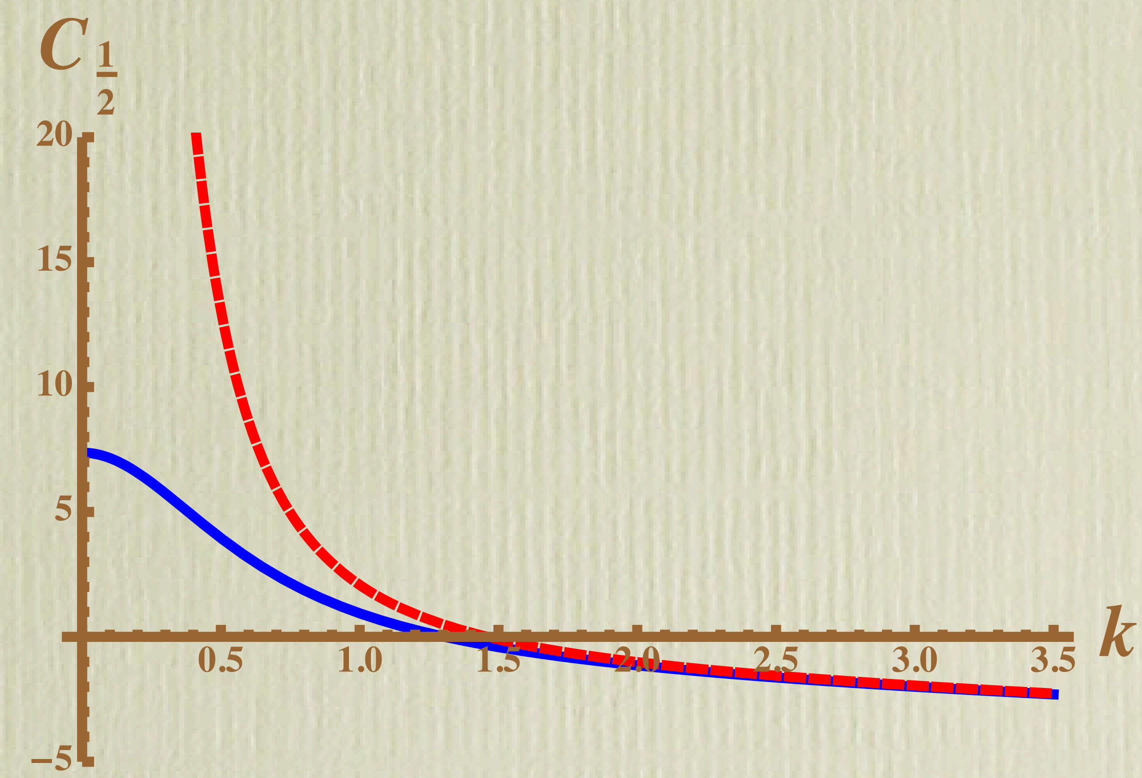
$$\mathbf{m^2_{sf}} = -\mathbf{g^2} \int \frac{\mathbf{d^4k}}{(\mathbf{2}\pi)^\mathbf{4}} \frac{\mathbf{1}}{\mathbf{k^2 + m^2_{\psi_{\tilde{g}}}}} = \frac{\mathbf{g^2}}{(\mathbf{4}\pi)^\mathbf{2}} \mathbf{m^2_{\psi_{\tilde{g}}}} \log \frac{\mathbf{1}}{\mathbf{g^2}} + \ldots$$

Example 2: dilaton/squashing mode domain wall

We now consider R-breaking bg, taking $\eta \neq \mathbf{0}$. Turning on a linearized η over the dilaton domain wall, its EOM can be solved exactly.

Repeating previous steps, we get non-vanishing $\mathbf{B_{1/2}}$, as expected. And (remarkably!), pole in $\mathbf{C_{1/2}}$ disappears, in perfect agreement with FT expectations!





Note: can move from gaugino mediation-like spectrum down to a minimal gauge mediation-like one.

General lesson, so far:

- Pure dilatonic backgrounds describe SUSY breaking sectors where gauginos are Dirac and provide a spectrum similar to gaugino mediation models.
- Backgrounds with non-trivial profiles for R-charged scalars generate gaugino Majorana mass terms, and a soft spectrum which can interpolate down to MGM.

Question: Are these results generic or depend on the specific model? More generally, how large portion of GGM parameter space can holographic models cover?

- Bottom-up models -

Philosophy: give-up a clear UV completion but gain flexibility and analytic power. Test holography with less constraints.

We focus on Hard Wall models: a slice of AdS with a sharp IR cut-off at $\mathbf{z = 1/\mu}$.

The background acts as a spectator. Behaviour of correlators mostly depends on boundary conditions at the IR cut-off:

$$\mathbf{D(z,k) + \rho_0 z \partial_z D(z,k)|_{z=1/\mu} = 0}$$

$$\mathbf{A_i(z,k) + \rho_1 z \partial_z A_i(z,k)|_{z=1/\mu} = 0}$$

$$\bar{\xi}\mathbf{(z,k) + \rho_{1/2} z \partial_z} \bar{\xi}\mathbf{(z,k)|_{z=1/\mu} = 0}$$

Now we get exact solutions of EOM (in terms of Bessel functions) and hence full analytic expressions for $\mathbf{C_s}$ and $\mathbf{B_{1/2}}$.

Basic properties of correlators:

- For *any* choice of the parameters, correct SUSY behaviour is recovered at large momenta.

- At low momenta, for *generic* values of parameters both $\mathbf{C_1}$ and $\mathbf{C_{1/2}}$ have $\mathbf{1/k^2}$ poles

$$\mathbf{C_1(k^2) \simeq \frac{4}{1+2\rho_1}\frac{\mu^2}{k^2}}\,,\quad \mathbf{C_{1/2}(k^2) \simeq 4\frac{2+3\rho_{1/2}}{2+7\rho_{1/2}}\frac{\mu^2}{k^2}}$$

- Regardless the values of $\rho_\mathbf{s}$'s, the $\mathbf{B_{1/2}}$ correlator vanishes: no Majorana mass for gauginos.

- To allow for different behaviours, one should add non-homogeneous terms in the b.c. at the IR wall.

Basic phenomenology:

- For *generic* ρ_s's the global symmetry is broken $\longrightarrow$ soft spectrum as gauge messengers mediation scenario.
- *Tuning* some ρ_s's one can eliminate both poles and obtain a situation like GGM (as far as sfermions!) or, if eliminating only $\mathbf{C_1}$ pole, like gaugino mediation.
- Allowing non-homogeneous b.c. (2 more parameters), one can cover *all* GGM parameter space (those for fermions provide $\mathbf{B_{1/2} \neq 0}$, i.e. Majorana gaugino mass).

Note: adding a squashing mode, already at linear order one recovers some of above results, i.e. generation of gaugino mass and concomitant disappearance of pole in $\mathbf{C_{1/2}}$... dynamically!

- Conclusions... -

- We have set-up a machinery to compute GGM functions holographically. Focus was on AAdS spaces, but similar approach can be applied to other SUSY breaking backgrounds.

- Bottom-up approach shows that holography can cover (though non-generically) all of GGM parameter space. Top-down models are much more constrained.

- Hard Wall models might look as rather non-dynamical way of implementing diverse phenomenologies. In same calculable set-up, one could try being more dynamical (adding a squashing mode is one such examples).

- ... and outlook -

- Three obvious further directions:

1. Work at full non-linear level in η.
2. Look for non-AAdS bg (more realistic dual FT's).
3. Enlarge rank of SM gauge group (add D7-branes).

- Computations of current correlators can have other uses than GGM. E.g.:

1. Considering FZ and R-multiplets, can learn more about (SUSY breaking) dynamics of strongly coupled theories;

2. In models where fields of visible sector couple to composite $\mathcal{O}$, like ED scenarios and (partially) composite models;

3. Can compute glueball spectra of confining theories.