Anatomy of new SUSY-breaking holographic RG-flows

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Based on:

Collaboration with Bertolini, Di Pietro, Musso, Porri and Redigolo

- to appear AMR
- work in progress ABMPR
- see also arXiv:1205.4709 [hep-th], arXiv:1208.3615 [hep-th], arXiv:1310.6897 [hep-th] ABDPR

Motivation

Symmetry breaking by strongly coupled dynamics
is often crucial in physical theories

Some examples:

- Chiral symmetry in QCD
- Dynamical SUSY breaking $\leftrightarrow$ hierarchy problem
- High T_c superconductors
- Higher spin symmetry $\leftrightarrow$ string theory

Here we will focus on SUSY breaking at strong coupling.

Our approach to strong coupling is through holography.

Models of SUSY breaking in holography:

- KPV: anti-D3 branes in Klebanov-Strassler
- $d \neq 4$ examples: Maldacena-Nastase, Massai et al.,...
- ... anyone?
- bottom-up: $\mathcal{N} = 2$ SUGRA in 5d

The complexity of the bottom-up model (and its reach towards top-down models) depends on the hyper- and vector-multiplet content.

We will consider as training ground models of $\mathcal{N} = 2$ SUGRA coupled to a universal hypermultiplet.

Given that we define the SUSY breaking strongly coupled theory through its holographic dual, how are we going to probe/characterize its SUSY breaking features?

Our aim will be to compute two-point correlators through holographic renormalization

This will give us information on several physical properties:

- Presence/absence of massless modes such as:
  - dilaton
  - R-axion
  - Goldstino
  - ’t Hooft fermions
- Violation of SUSY Ward identities
- Spectrum of resonances
- Stability: no tachyonic resonances

New RG-flow SUGRA solutions

We restrict to solutions with at most two backreacting scalars.
We start form the action (choice of gauging!)

$$\mathcal{S} = \int d^5x\sqrt{G}\left[-\frac{1}{2}R + \partial_M\eta\partial^M\eta + \frac{1}{4}\cosh^2\eta\partial_M\phi\partial^M\phi + \frac{3}{4}\left(\cosh^2 2\eta - 4\cosh 2\eta - 5\right)\right]$$

together with the ansatz

$$ds^2 = \frac{1}{z^2}\left(dz^2 + F(z)\eta_{\mu\nu}dx^\mu dx^\nu\right) \qquad \eta = \eta(z) \qquad \phi = \phi(z)$$

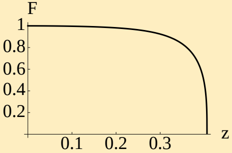
3-parameter worth of solutions, including dilaton DW and GPPZ:

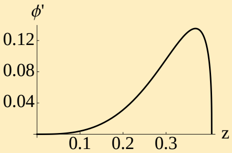
$$\phi = \tilde{\phi}_4 z^4 + \dots \qquad \eta = \eta_0 z + \tilde{\eta}_2 z^3 + \dots$$

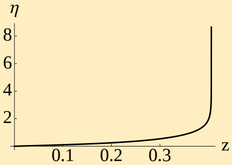
All solutions are singular in the IR.

Some examples:

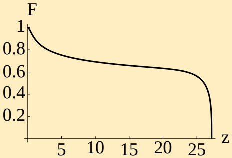
$F(z)$, $\phi'(z)$ and $\eta(z)$ field profiles in the generic explicit R-symmetry breaking background:

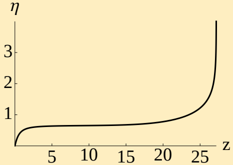






$F(z)$ and $\eta(z)$ field profiles in a walking solution (here $\phi(z) = 0$):





Massless modes

As a warm up, we consider a toy model for the holographic realization of Goldstone bosons: 5d model with a vector and an axion-like scalar

[See also Bianchi, Freedman, Skenderis 01]

$$\mathcal{S} = \int d^5x\sqrt{G}\left[\frac{1}{4}F^{MN}F_{MN} + \frac{1}{2}m(z)^2(\partial_M\alpha - A_M)(\partial^M\alpha - A^M)\right]$$

The bulk vector's $U(1)$ symmetry is broken by the profile

$$m(z) = m_0 z + \tilde{m}_2 z^3$$

From the boundary FT point of view:

- m_0 explicit breaking of global $U(1)$
- $\tilde{m}_2$ spontaneous breaking of global $U(1)$

The correlator we will be probing is

$$\langle J_\mu(k) J_\nu(-k)\rangle = -(k^2\delta_{\mu\nu} - k_\mu k_\nu)C(k^2) - m_0^2 \frac{k_\mu k_\nu}{k^2} F(k^2)$$

In holographic renormalization, the transverse and longitudinal parts of A_μ are related to the transverse and longitudinal parts of J_μ, respectively.

The longitudinal part of A_μ however mixes with α, which is related to $\mathrm{Im}O_m$, i.e. the imaginary part of the operator that breaks the symmetry.

Expectations:

- spontaneous breaking: $F(k^2) = 0$, massless pole in $C(k^2)$, Schwinger term in $\langle J_\mu \, \mathrm{Im}O_m\rangle$
- explicit breaking: no massless poles, $F(k^2) \neq 0$, Ward identity $\partial_\mu J^\mu = m_0 \, \mathrm{Im}O_m$

Holographic renormalization:

Spontaneous: $\mathcal{S}_{\rm ren} = -\int d^4k \left\{ a^t_{0\mu}\tilde{a}^t_{2\mu} + \tilde{m}_2^2 \alpha_0(\tilde{\alpha}_2 + a^l_0) + \text{local} \right\}$

- $a^t_{0\mu}\tilde{a}^t_{2\mu}$ term leads to $C(k^2)$. Massless pole appears because of bulk boundary conditions.
- $\tilde{m}_2^2\alpha_0 a^l_0$ term leads to the Schwinger term $\langle \partial_\mu J^\mu \, \text{Im}O_m \rangle = \tilde{m}_2$.

Explicit: $\mathcal{S}_{\rm ren} = -\int d^4k \left\{ a^t_{0\mu}\tilde{a}^t_{2\mu} + m_0^2(\alpha_0 - a^l_0)\tilde{\alpha}_2 + \text{local} \right\}$

- massless pole in $C(k^2)$ can be cancelled by local terms $\propto m_0^2$ (cancels anyhow from full $\langle J_\mu J_\nu \rangle$)
- Ward identity consequence of $\mathcal{S}_{\rm ren}$ depending only on $\alpha_0 - a^l_0$ (bulk gauge symmetry)

In full $\mathcal{N} = 2$ SUGRA models, these considerations apply to the R-axion and the dilaton.

The correlators are

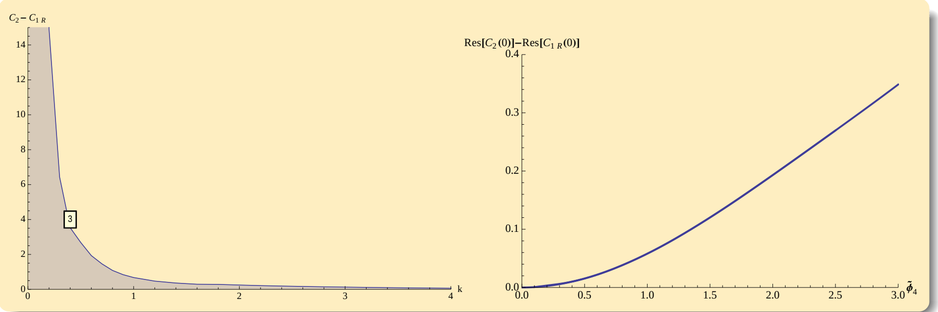
$$\langle T_{\mu\nu}(k)\, T_{\rho\sigma}(-k)\rangle = -\frac{1}{8} X_{\mu\nu\rho\sigma}\, C_2(k^2) - \frac{1}{12}\frac{m^2}{k^2}\, P_{\mu\nu} P_{\rho\sigma}\, F_2(k^2)$$

$$\langle j^R_\mu(k)\, j^R_\nu(-k)\rangle = -P_{\mu\nu}\, C_{1R}(k^2) - \frac{1}{3}\, m^2 \frac{k_\mu k_\nu}{k^2}\, F_1(k^2)$$

- $F_2 = 0 = F_1$ if conformal and R-symmetry are not explicitly broken.
- SUSY Ward identities require $C_2 = C_{1R}$ and $F_2 = F_1$ for a SUSY preserving RG-flow.

Both C_2 and C_{1R} have a massless pole when $\eta_0 = 0$.

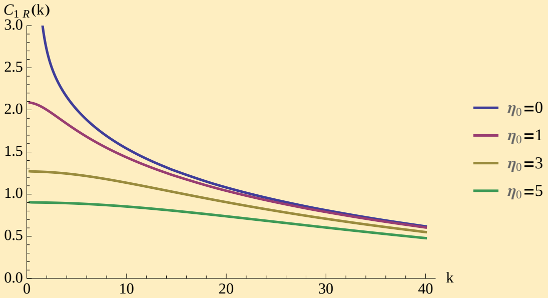
SUSY is recovered when also $\tilde{\phi}_4 = 0$.
In this case we expect $C_2 = C_{1R}$.



The pole in C_2 corresponds to the dilaton of broken conformal symmetry, and the pole in C_{1R} to the R-axion of broken R-symmetry.

In the SUSY limit, the R-axion and dilaton become superpartners.

The massless poles disappear when η_0 is turned on:



The R-axion acquires a mass proportional to η_0.

Goldstino

When SUSY is spontaneously broken, a massless fermion, the Goldstino is expected.

Problem: spontaneous SUSY breaking is allowed only when conformal symmetry is explicitly broken.

This is because spontaneous SUSY breaking is heralded by

$$\langle T_{\mu\nu} \rangle = -F^2 \eta_{\mu\nu}$$

This relation is impossible in a conformal theory in which we have the operator constraint $T^{\mu}_{\mu} = 0$.

$\Rightarrow$ We need a solution where conformal symmetry is broken by a SUSY source. [This requires a different gauged SUGRA–no details here]

Q: Where should the Goldstino massless pole appear?
A: in the correlator of the supercurrent!

More precisely, in a Schwinger term in this correlator.

$$\langle (\partial^\mu S_{\mu\alpha})(k)\bar{S}_{\nu\dot{\beta}}(-k)\rangle = -\langle \delta_\alpha \bar{S}_{\nu\dot{\beta}}\rangle = 2i\sigma^\nu{}_{\alpha\dot{\beta}}\,\langle T_{\mu\nu}\rangle \neq 0$$

implies

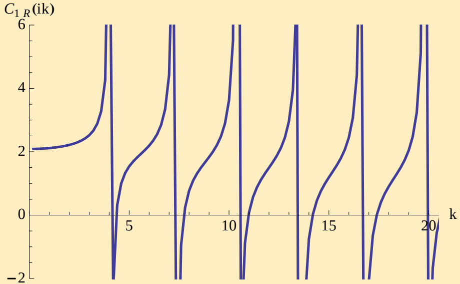
$$\langle S_{\mu\alpha}(k)\,\bar{S}_{\nu\dot{\beta}}(-k)\rangle = \cdots + F^2(\sigma_\mu\bar{\sigma}^\rho\sigma_\nu)_{\alpha\dot{\beta}}\frac{2k_\rho}{k^2}$$

$\Rightarrow$ boundary analysis in holographic renormalization is enough to find the Goldstino. [In progress!]

Spectrum of resonances

The poles appearing in the correlators give the spectrum in the corresponding channel.

If all the poles lie on the $k^2 < 0$ axis, then no tachyonic resonance is present and the solution represents an RG-flow to a stable vacuum.



In the generic case the first pole corresponds to a mass of the order of the mass gap.

Outlook

- Holographic realization of massless particles related to dynamical symmetry breaking.
- These particles arise as part of the spectrum of resonances, and also from Schwinger terms.
- New classes of SUGRA solutions representing SUSY-breaking RG-flows.

- More general and more realistic classes of solutions $\rightarrow$ more hypermultiplets in the $\mathcal{N} = 2$ SUGRA.
- Embedding in string theory/consistent truncations $\rightarrow$ top down models.
- Finding the Goldstino can be a useful discriminant to determine whether we have the gravity dual of a SUSY breaking field theory.