# Happy Birthday, Misha

# Comments on FI-terms

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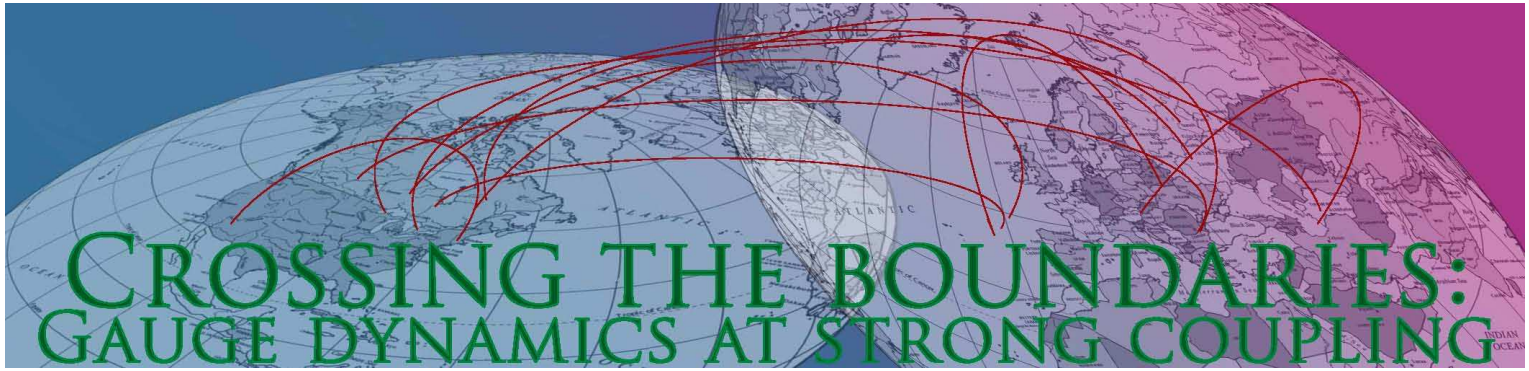
IAS




Based on: Komargodski and N.S. arXiv:0904.1159

# Supersymmetry breaking

- We need to spontaneously break supersymmetry (SUSY):
  - Tree breaking
  - Dynamical breaking (DSB)

- Tree breaking
  - O'Raifeartaigh (O'R) model – F-term breaking
  - Fayet-Iliopoulos (FI) model – D-term breaking

# More advanced questions

- All calculable dynamical models of SUSY breaking look like O'R models at low energies. Are there models which are effectively FI models?
- Is there an invariant distinction between F-term and D-term breaking? Can a strongly coupled theory continuously interpolate between these two phenomena?
- What about the coupling of FI-terms to supergravity (SUGRA)? Is it consistent? Note that there is no example of an FI-term in string theory…

# The Ferrara-Zumino (FZ) multiplet

The SUSY current and the energy momentum tensor $S_{\mu\alpha},\ T_{\mu\nu}$ reside in a real superfield $\mathcal{J}_\mu \sim \mathcal{J}_{\alpha\dot{\alpha}}$ which satisfies the conservation equation

$$\bar{D}^{\dot{\alpha}} \mathcal{J}_{\alpha\dot{\alpha}} = D_\alpha X$$

with $X$ a chiral superfield.

$X = 0$ means that the theory is superconformal.

# The FZ-multiplet in FI-models

Consider a free theory of a single vector superfield $V$ with an FI term

$$\mathcal{L} = \frac{1}{4g^2}\int d^2\theta W_\alpha^2 + h.c. + \int d^4\theta \xi V$$

Here the FZ-multiplet is

$$\begin{aligned} \mathcal{J}_{\alpha\dot{\alpha}} &= -\frac{4}{g^2} W_\alpha W_{\dot{\alpha}}^\dagger - \frac{2}{3}\xi[D_\alpha, \bar{D}_{\dot{\alpha}}]V \\ X &= -\frac{\xi}{3}\bar{D}^2 V \end{aligned}$$

# Gauge invariance

The FZ-multiplet

$$\mathcal{J}_{\alpha\dot{\alpha}} = -\frac{4}{g^2} W_\alpha W^\dagger_{\dot{\alpha}} - \frac{2}{3}\xi[D_\alpha, \bar{D}_{\dot{\alpha}}]V$$

is not invariant under gauge transformations

$$V \to V + \Lambda + \Lambda^\dagger$$

$S_{\mu\alpha},\ T_{\mu\nu}$ change by improvement terms.

Their charges are gauge invariant.

This does not affect the consistency of the theory.

This is true in any model with FI-terms.

# Consequences

- The FI-term is not renormalized perturbatively or non-perturbatively. In particular, starting without an FI-term, it cannot be generated. (Exception: anomalous theories where the sum of the charges does not vanish.)
- This is a new perspective on old results [Witten; Fischler et al; Shifman and Vainshtein; Dine; Weinberg].
- The same applies to emergent gauge fields. (This can also be shown using the old methods.)
- This explains why all calculable models of DSB have F-term breaking. The FI-model never arises from the dynamics.

# “Field dependent FI-terms”

“Field dependent FI-terms” are common in field theory and string theory.

Some charged field $\Phi$ Higgses the gauge symmetry with $\langle\Phi\rangle = 0$ at infinite distance.
Expanding $K(V + \log|\Phi|^2)$ around some $\langle\Phi\rangle$ leads to an approximate FI-term whose coefficient is $\langle\Phi\rangle$ dependent.

These are not genuine FI-terms – the gauge symmetry is everywhere Higgsed at or above the mass of $\Phi$ .

# Coupling to supergravity: history

- [Freedman (77)] coupled the FI-model to SUGRA.
- [Barbieri, Ferrara, Nanopoulos, Stelle (82); Ferrara Girardello, Kugo, Van Proeyen (83)] showed that this construction is possible only when the rigid theory has a global $U(1)_R$ symmetry.
- The gauge charges are shifted by an amount proportional to $r\xi/M_P^2$ where $r$ is that R-charge.
- Hence the gravitino is charged and the theory is gauged supergravity.
- …

# Coupling to supergravity: history

- [Witten (89)] pointed out that in the presence of magnetic monopoles this shift of electric charges is inconsistent with Dirac quantization.
- [Chamseddine, Dreiner (96); Castano, Freedman, Manuel (96); Binetruy, Dvali, Kallosh, Van Proeyen (04); Elvang, Freedman, Kors (06)] considered the restrictive conditions on the charges due to anomaly cancelation.
- No example in string theory.

- [Many people]: perhaps it simply does not exist…

# Coupling to SUGRA (new)

- We focus on $\xi \ll M_P^2$. If $\xi \sim M_P^2$ , a field theory description is not valid.
- The complexity of coupling these theories to SUGRA stems from the lack of gauge invariance of the SUSY current multiplet.
- The need for a global $U(1)_R$ symmetry follows from the same fact.
- It can be shown that this global symmetry has to be exact in the full theory including all higher derivative terms.

# Consequences of the global symmetry

- However, considerations based on black hole physics make continuous global symmetries incompatible with quantum gravity.

- We learn that a SUGRA with FI-terms (which is also equivalent to gauged SUGRA) is quantum mechanically inconsistent.
- Clearly, this conclusion does not apply to “field dependent FI-terms.”

# Conclusions

- The energy momentum tensor and the SUSY current are members of the FZ-multiplet.
- In the presence of an FI-term this multiplet is not gauge invariant.
- This gives a new perspective on the lack of renormalization of the FI-term.
- It explains why all calculable models of dynamical SUSY breaking have F-term breaking.
- This is the root of the difficulties of having an FI-term in SUGRA.

# Conclusions

- The only theories with an FI-term which can be coupled to SUGRA have a global continuous R-symmetry  The resulting theory is gauged supergravity.
- This theory has an exact continuous global symmetry.  Hence it must be inconsistent.
- This explains why string theory never leads to models with genuine FI-terms.
- There is no problem with “field dependent FI-terms.”
- There are many consequences in models of particle physics and cosmology and in string constructions.

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