Anomaly Mediation from Unbroken SUGRA

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Anomaly Mediation and its Surprises

- Anomaly Mediation (AMSB)
  - Ubiquitous source of soft terms in supergravity (SUGRA) models
- Unbroken SUGRA is SUSY in AdS! (not flat space)
  - Tree-level “soft masses" (with no goldstino couplings)
- Anomaly Mediation is not SUSY-breaking
  - Present in unbroken AdS SUSY!
- Don’t have to worry about any anomaly in Anomaly Mediation!
  - Can regulate consistent with scale (super-Weyl) anomaly
  - Follows from 1PI action given AdS algebra

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Anomaly Mediation

- In flat space:

	Soft Term	Goldstino Coupling
Gaugino Mass	$(\beta_g/g)m_{3/2}$	0
B-term	$\frac{1}{2}\mu_{ij}(-2+\gamma_i+\gamma_j)m_{3/2}$	0
A-term	$\frac{1}{2}\lambda_{ijk}(\gamma_i+\gamma_j+\gamma_k)m_{3/2}$	0
Scalar Mass	$-\frac{1}{4}\dot{\gamma}m_{3/2}^2$	$(2-\gamma)m_{3/2}^2$

- New to this work: goldstino couplings, AdS 'soft terms'
- In global SUSY, would expect columns to be identical!

SUGRA and Vacuum Energy

- Global Flat-Space SUSY
  - Order parameter $\langle V \rangle \geq 0$.
  - SUSY is broken in nature.
- Supergravity (local, gauged SUSY)
  - $\langle V \rangle = 0$ in nature.
  - Unbroken SUGRA lives in AdS
  - SUSY-breaking lifts us to flat space.

$$r_{AdS}^{-1} = m_{3/2}$$

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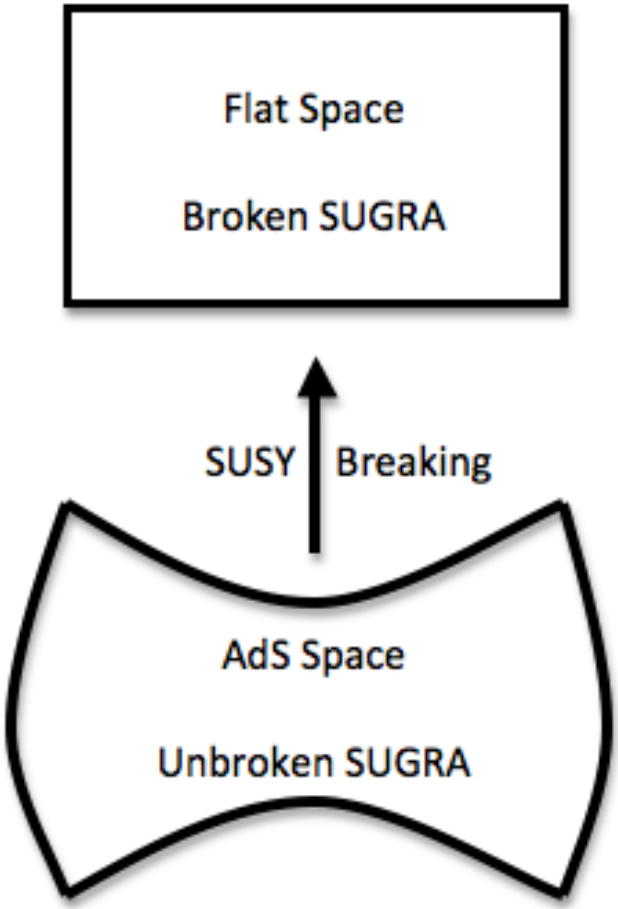

$$r_{AdS}^{-1} = m_{3/2}$$

Two order parameters of SUGRA

- F/M_{Pl}
  - Breaks SUSY.
- $m_{3/2} = r_{AdS}^{-1}$
  - Gravitino mass parameter (in Lagrangian)
  - Order parameter for R-symmetry breaking
  - Does *not* break SUSY!
- If fine-tune to remove cosmological constant:
  - $F/M_{Pl} = \sqrt{3} m_{3/2}$
  - In flat space: easy to confuse SUSY-breaking and SUSY-preserving effects.

Surprise 1: SUSY in AdS

Mass Splittings in Unbroken SUSY

Rigid SUSY in AdS

$$\{Q, Q^\dagger\} = -2i\sigma^m P_m$$
$$[Q, P_m] = -\frac{i}{2} m_{3/2} \sigma_m Q^\dagger \neq 0!$$

- *Unbroken* AdS SUSY features boson-fermion mass differences!

$$\begin{array}{ll} \chi: & m_\chi \\ \phi: & m_\chi^2 - 2m_{3/2}^2 \pm m_\chi m_{3/2} \end{array}$$

- 'B-term': $-m_{3/2} m_\chi$
- Tachyonic scalar mass: $-2m_{3/2}^2$?
  - Stable in AdS
    - Breitenlohner-Freedman bound: $m_\phi^2 \geq -9/4 m_{3/2}^2$

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SUSY Breaking: SUGRA

- Need SUSY-breaking. At the very least:
  - Flat Space
  - No $-2m_{3/2}^2$ scalar masses
- Goldstino $\widetilde{G}_L$
  - Goldstone fermion of SUSY
  - Couplings proportional to SUSY-breaking effects
- Super-Higgs Mechanism
  - Gravitino ψ_μ 'eats' goldstino degrees of freedom.
- Goldstino Equivalence Theorem
  - longitudinally polarized gravitino couplings = goldstino couplings for $E \gg m_{3/2}$
- Goldstino couplings probe rigid AdS structure:

Tree-Level: *B*-terms, Universal goldstino couplings

$$\mathcal{L} \supset \widetilde{m}_\phi^2 \phi^* \phi + \tfrac{1}{F}(\widetilde{m}_\phi^2 + 2m_{3/2}^2)\widetilde{G}_L \chi \phi^* + \tfrac{1}{2} B \phi^2 + \tfrac{1}{F}(B + m_{3/2} m_\chi)\widetilde{G}_L \chi \phi + \text{h.c.}$$

- $\widetilde{G}_L$ couplings still proportional to “SUSY-breaking parameters"
  - *relative* to their values for unbroken (AdS) SUSY:
  - Mandated by *AdS* supercurrent conservation!
- ‘*B*-terms’ without goldstino couplings!
  - $B = -m_{3/2} m_\chi$
- Stability: must remove $-2m_{3/2}^2$ scalar masses.
  - This *is* SUSY-breaking!
  - Goldstino coupling despite vanishing soft scalar mass!

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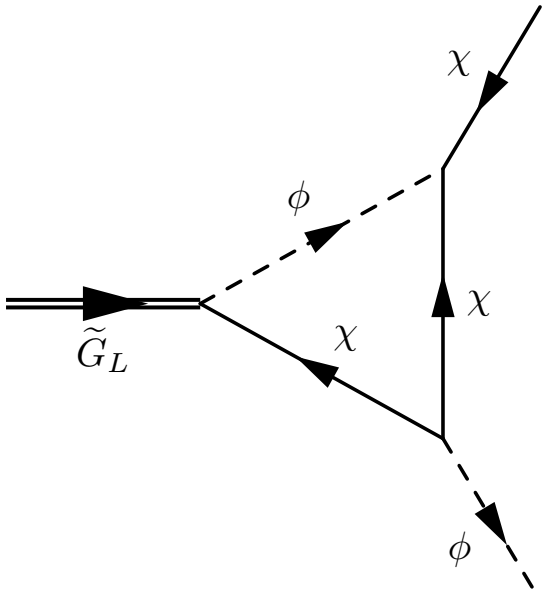
Universal Goldstino coupling to scalars

$$\mathcal{L} \supset \frac{2m_{3/2}^2}{F} \widetilde{G}_L \chi \phi^*$$

- Universal: same for all fields
- RG stable: no loop corrections
  - Diagrams cancel on $\widetilde{G}_L$, ψ_μ equations of motion



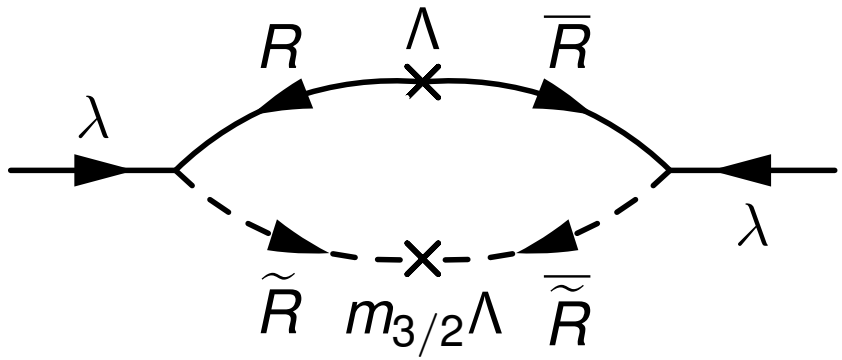
Surprise 2:

Anomaly-Mediated SUSY-Breaking...

...does not break SUSY!

Loop Level: Regulator B-terms and Anomaly Mediation

- Regulate the theory using e.g. Pauli-Villars
- Regulators have B-terms (as in AdS)!
  - $B = -m_{3/2}\Lambda$
  - No goldstino coupling!
- Finite “SUSY-breaking" effects at loop level
  - Gaugino masses
  - A-terms
  - Scalar masses
- Happens in both AdS and flat space!
  - No goldstino couplings!



$$m_\lambda \sim \frac{g^2}{16\pi^2} m_{3/2}$$

Results

- Flat Space:

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B-term	$\frac{1}{2}\mu_{ij}(-2+\gamma_i+\gamma_j)m_{3/2}$	0
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Scalar Mass	$-\frac{1}{4}\dot{\gamma}m_{3/2}^2$	$(2-\gamma)m_{3/2}^2$

- Scaling Dimension of $\boldsymbol{Q}^\dagger \boldsymbol{Q}$

Surprise 3:

Anomaly Mediation can be derived without having to worry about anomalies or regulators!

Superspace 1PI Effective Action

$$\mathcal{L} \sim \int d^2\theta\, 2\mathcal{E}\, \boldsymbol{W}^\alpha \boldsymbol{S}(\widetilde{\Box})\, \boldsymbol{W}_\alpha + \int d^4\theta\, \boldsymbol{E}\, \boldsymbol{Q}^\dagger \boldsymbol{Z}(\widetilde{\Box})\, \boldsymbol{Q}$$

- 1PI Effective Action
- SUGRA (and super-Weyl) invariant.
- No need to worry about regulators!
- No super-Weyl anomaly to worry about!
- $\widetilde{\Box}$: picks out renormalization scale μ^2

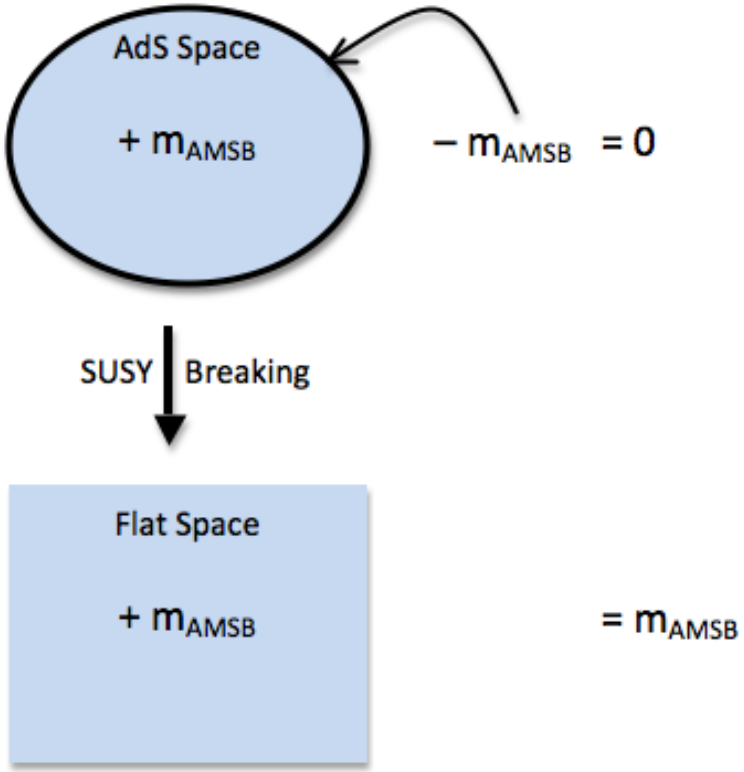
Supercovariant $\Box$

$$\mathcal{L} \sim \int d^2\theta\, 2\mathcal{E}\, \boldsymbol{W}^\alpha \boldsymbol{S}(\widetilde{\Box})\boldsymbol{W}_\alpha + \int d^4\theta\, \boldsymbol{E}\, \boldsymbol{Q}^\dagger \boldsymbol{Z}(\widetilde{\Box})\boldsymbol{Q}$$

- $\widetilde{\Box}$: SUGRA, super-Weyl covariant version of μ^2.
  - Reduces to $\Box$ in global flat-space SUSY
  - Many possible ansätze, all yield same result
- $\boldsymbol{Z}(\widetilde{\Box})$, $\boldsymbol{S}(\widetilde{\Box})$ contain anomaly mediation:
  - $[Q, P_m] \neq 0$
  - $(\Box \boldsymbol{V})|_{\theta^2} \neq \Box(\boldsymbol{V}|_{\theta^2})$
- Compare unbroken AdS to flat space
  - Yields goldstino couplings (measures SUSY breaking)
  - Generalizes usual AMSB results to arbitrary curvature.

Prospects

- Non-local terms in 1PI action
  - $\mathcal{T}(F^* \Box^{-1} F + i\chi^\dagger \bar{\sigma}^\mu \mathcal{D}_\mu \Box^{-1} \chi)$
- AdS Boundary effects
  - cf. Gripaios et al. 2008
- 1PI Gaugino Masses beyond 1 loop.



Summary

- Two ‘order parameters’ in SUGRA: F/M_{Pl} and $m_{3/2} = r_{AdS}^{-1}$
  - Only F/M_{Pl} breaks SUSY!
- Unbroken SUGRA is SUSY in AdS
  - $[Q, P_\mu] \neq 0$
  - “soft masses" in unbroken SUSY with no goldstino couplings
- Anomaly Mediation arises from the infrared structure of AdS
  - Not a SUSY-breaking effect
  - Follows from AdS superspace 1PI action
  - Don’t have to consider anomaly.