Anomaly Mediation from String Theory

Based on arXiv:1008.4361 with Joseph Conlon and Eran Palti

Mark Goodsell

DESY, Hamburg

23rd September, 2010

Overview

- Recall: what is anomaly mediation and why does it matter?
- What do we expect in local string models?
- How can we calculate from CFT in string theory?
- What do we get?

Gaugino masses

- Supersymmetric lagrangian contains term

$$\int d^2\theta \frac{1}{4} f_{ab} W_a W_b$$

- f_{ab} is holomorphic, can use "analytic continuation in superspace" to obtain physical gaugino masses for $f_{ab} = \delta_{ab} f_a$:

$$M_a^{\rm tree} = \frac{1}{2{\rm Re} f_a} F^i \partial_i f_a$$

- At tree level, ${\rm Re}(f_a) = g_a^{-2}$
- What about corrections at one loop? Very important if $F^i = 0$! (e.g. sequestered models, 5d models...)
- Can we take $M_a = \frac{1}{2} F^i \partial_i \log g_a^{-2}$ in general?

Gravity mediation

- Kaplunovsky-Louis formula relates the physical gauge couplings to the holomorphic f_a in SUGRA theories:

$$\begin{aligned} g_a^{-2}(\Phi,\bar{\Phi},\mu) \quad &= \quad \mathrm{Re}(f_a(\Phi)) + \frac{\left(\sum_r n_r T_a(r) - 3T_a(G)\right)}{8\pi^2} \ln\left(\frac{M_P}{\mu}\right) \\ &\quad + \frac{\left(\sum_r n_r T_a(r) - T(G)\right)}{16\pi^2} \hat{K}(\Phi,\bar{\Phi}) - \sum_r \frac{T_a(r)}{8\pi^2} \ln\det Z^r(\Phi,\bar{\Phi},\mu) \\ &\quad + \frac{T(G)}{8\pi^2} \ln g_a^{-2}(\Phi,\bar{\Phi},\mu) \end{aligned}$$

- Would obtain for gaugino masses

$$M_a = \frac{g^2}{16\pi^2}\left[(T_G - T_R)\, K_i F^i + \frac{2T_R}{d_R} F^i \partial_i \left(\ln \det Z\right) - 2T_G F^I \partial_I \ln\left(\frac{1}{g_0^2}\right)\right]$$

- Could call this “gravity mediation at one loop”

Anomaly mediation

- [Randall and Sundrum], [Giudice, Luty, Murayama and Ratazzi] claimed there is also a contribution from the F-term of the conformal compensator/supergravity mutliplet

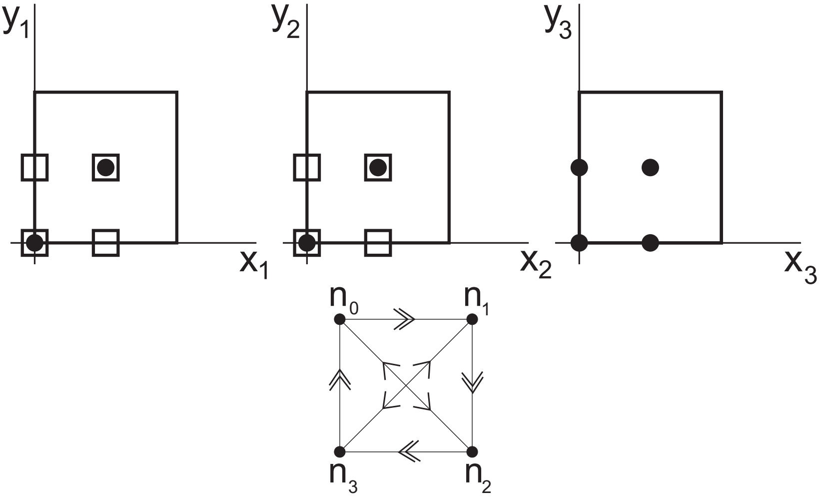
$$M_a = g_a^2 \frac{b_a}{16\pi^2} m_{3/2} = -\frac{g_a^2}{16\pi^2}(3T(G) - T(R))m_{3/2}$$

- They claimed comes from the conformal anomaly, hence "anomaly mediation"; [Dine and Seiberg] say due to counterterms and IR divergences instead
- [de Alwis, 2008] however claimed it should not be there
- Can check via a string computation!

Toroidal orbifolds in IIB

- String CFT computations only possible in few types of theory
- Want to use the simplest setup where the expression can be checked; need to be able to compare with the SUGRA predictions
- Would like to perform an explicit calculation - must be at one loop (cf [Antoniadis and Taylor])
- Toroidal orbifolds are well understood: know the superpotentials and Kähler potentials to required order
- $D3$ branes at $\mathbb{Z}_N$ singularities are ideal; and are also local models that can be generalised (c.f. [Conlon and Palti])
- Need a theory with non-vanishing beta-function - $N = 2$ sectors in the orbifold twist, i.e. $\mathbb{Z}_2 \subset \mathbb{Z}_N$

$T^6/\mathbb{Z}_4$



$T^6/\mathbb{Z}_4$ cont'd

- Twist $\theta : (z_1, z_2, z_3) \to (iz_1, iz_2, -z_3)$
- 3 untwisted Kähler moduli $T_I = dz_I \wedge d\bar{z}_I$ and one untwisted complex structure modulus $U = dz_1 \wedge dz_2 \wedge d\bar{z}_3$ are non-zero, others irrelevant
- Kähler potential
  $K = -\log(S + \bar{S}) - \log(U + \overline{U}) - \sum_{I=1}^{3} \log(T_I + \overline{T}_I)$
- Matter Kähler metric

$$K_{1\bar{1}} = \frac{1}{T_1 + \overline{T}_1}, K_{2\bar{2}} = \frac{1}{T_2 + \overline{T}_2}, \quad K_{3\bar{3}} = \frac{1}{(T_3 + \overline{T}_3)(U + \overline{U})}$$

SUSY breaking

- Give a vev to bulk three-form flux $G = F - iSH \rightarrow F - \frac{i}{g_s}H$,
- If we give a vev to a $G^{(0,3)} \pm G^{(3,0)}$, get dilaton and Kähler modulus F-terms:

$$W = \int G \wedge \Omega$$

$$K_U F^U = -(U + \overline{U}) \int \bar{G} \wedge \overline{\chi}^{(1,2)} \rightarrow 0$$

$$K_T F^T = 3\left| \int G \wedge \Omega \right| \rightarrow 3m_{3/2}$$

$$K_S F^S = \int G \wedge \overline{\Omega} \rightarrow \pm m_{3/2}$$

Anomaly mediation expectations

- Expected value for gaugino mass, $G = |G|(dz^1 \wedge dz_2 \wedge dz_3 \pm d\bar{z}^1 \wedge d\bar{z}_2 \wedge d\bar{z}_3)$

$$m_{1/2} = -\frac{g^2}{16\pi^2}\left[\delta_{AM}\left(3T_G - T_R\right)m_{3/2} - \left(T_G - T_R\right)K_i F^i - \frac{2T_R}{d_R}F^i\partial_i\left(\ln\det Z\right) + 2T_G F^I\partial_I \ln\left(\frac{1}{g_0^2}\right)\right]$$
$$= -\frac{\mathcal{V}U|G|g^2}{16\pi^2}\left(3T_G - T_R\right)m_{3/2}(\delta_{AM} - 1 \mp 1)$$

- If take lower sign, get only δ_{AN} term, corresponds to using NS-NS flux $(G - \overline{G} = -i(S + \overline{S})H)$
- Note that there is a tree-level mass

$$M_{\rm tree} = \frac{F^S}{2{\rm Re}(S)} = \mp m_{3/2} = \mp \mathcal{V}U|G|$$

- This should give us a running mass

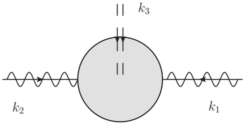
$$M_{\rm running} = \mp\frac{\mathcal{V}U|G|g^2}{16\pi^2}\left(3T_G - T_R\right)m_{3/2}\log\frac{M_W^2}{\mu^2}$$

- Relative magnitude gives size of δ_{AN}

NS-NS flux amplitude

- Want to calculate gaugino mass in NS-NS flux background
- For generic flux values this is impossible in R-NS formalism, but we only need leading order term

$$\mathcal{A} = \langle \lambda\lambda H \rangle \rightarrow \mathcal{L} \supset -\mathcal{A}\langle H \rangle \lambda\lambda$$



One loop amplitudes in CFT

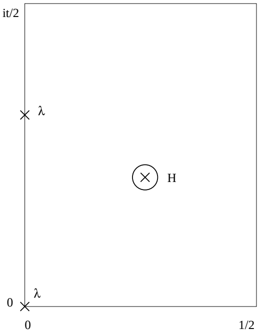
- Gaugino vertex operator

$$V_\lambda^{-1/2} = e^{-\frac{\phi}{2}} e^{ik\cdot X} \lambda_\alpha S^\alpha \prod_{k=3}^{5} e^{\frac{i}{2} H_k}$$

- Flux vertex operator for an NS-NS two-form is

$$\mathcal{V}_B^{(-1,-1)} = e^{-\phi-\tilde{\phi}} B_{jk} \psi^j \tilde{\psi}^k e^{ik\cdot X(z,\bar{z})}$$

- For the three-form, have
$B = H_{345}(X^5 dX^3 \wedge dX^4 + \overline{X}^5 d\overline{X}^3 \wedge d\overline{X}^4)$ so

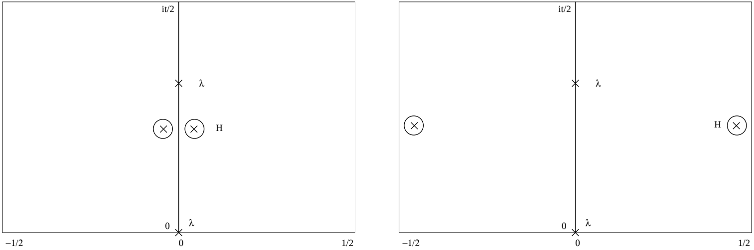


$$\mathcal{V}_H^{(-1,-1)} = H_{345} e^{-\phi(w)-\tilde{\phi}(\bar{w})} \overline{X}^5(w,\bar{w}) \left(\overline{\psi^3}(w) \overline{\tilde{\psi}^4}(\bar{w}) - \overline{\psi^4}(w) \overline{\tilde{\psi}^3}(\bar{w}) \right) e^{ik\cdot X(w,\bar{w})}$$

- Choose to picture-change both sides of flux, and one gaugino

Poles

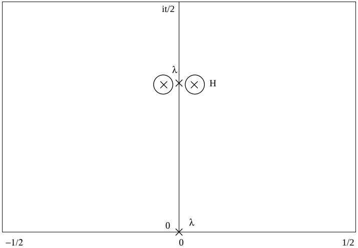
- Use doubling trick to write antiholomorphic operators in terms of holomorphic ones, $\tilde{\psi}(\bar{w}) \sim \psi(-\bar{w})$
- In picture-changed flux operator, have term $(k \cdot \psi)^2$ (from PCO on non-compact directions $e^{\phi}\dot{X}_{\mu}\psi^{\mu}(z)e^{-\phi}e^{ik\cdot X}(w)$)
- Leads to poles from factorising onto boundary $k_{\mu}k_{\nu}\psi^{\mu}(w)\tilde{\psi}^{\nu}(\bar{w}) \sim k^2(w+\bar{w})^{-1}$



- When we integrate over positions and include $\langle \prod e^{ik\cdot X} \rangle$ this yields a pole $1/k^2$ that cancels the k^2 prefactor
- We are left with a classical contribution from winding modes from $\langle \partial_n X^5(z_2) X^5(w, \bar{w}) \rangle$ (involves also PCO acting on gaugino)

Poles II

We have other poles from the flux approaching the gauginos:



- These can be simply understood in terms of factorising onto the tree-level mass term since $H(w, \bar{w})\lambda(z) \sim \bar{\lambda}$
- These yield only running mass terms

Classical parts

- The only non-zero contribution to the amplitude comes from $N = 2$ twisted sectors that leave third torus invariant - this is the same as threshold corrections (as it must be!)
- In the third torus there is a classical piece from winding modes

$$\Delta X = (2\pi n R_1 + x_1) + i(2\pi m R_2 + x_2)$$

- This gives

$$Z(t) = \exp[-S] = \sum_{n,m} e^{-\frac{t}{4\pi\alpha'}|\Delta X(m,n)|^2}$$

- For the correlator $\langle \partial_n X^5(z_2) X^5(w,\bar{w})\rangle$ we find a classical contribution given by

$$(w+\bar{w})\sum_{n,m}|\Delta X|^2 e^{-\frac{t}{4\pi\alpha'}|\Delta X(m,n)|^2} = -(w+\bar{w})4\pi\alpha'\partial_t Z$$

- Note that on the boundary $\mathrm{Re}(w) = 1/2$ the prefactor is one, but from the quantum pieces we have a pole in $1/(w+\bar{w}-1)$

Results

- Once we collect the parts together, we find the total amplitude

$$\mathcal{A} = A_0 \int \frac{dt}{t} \left(-Z(t) + t \frac{d}{dt} Z(t) \right)$$

- As $t \to \infty$, $Z \to 1$ while as $t \to 0, Z \to 0$ exponentially provided we have tadpole cancellation
- We can then integrate the result with a momentum cutoff for the first term to give

$$\mathcal{A} = A_0 \Big[-\log \frac{M_W^2}{\mu^2} + 1 \Big]$$

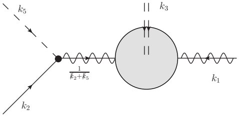
- This is exactly the form we expected for an “anomaly” mass term

Conclusions

- We have confirmed the predictions of anomaly mediation via string theory, a UV complete theory
- This approach does not depend on choice of compensators etc
- The non-vanishing of the result relies on presence of compact space

Other details and future work

- Have not discussed IR divergent terms which contribute to 1PI action but not Wilsonian → would be nice to match to the counterterms from [Dine and Seiberg]
- Choice of pictures is somewhat subtle, showing equivalence is tricky and involves integration by parts over vertex operator positions
- Have confirmed the result for different choice of fluxes, and higher-point diagrams; subtleties to do with $k^2 \neq 0$



- Have not discussed R-R flux; can demonstrate the mass term there but confirming the running mass with correct sign is long and complicated!
- Many more quantities in flux backgrounds could now be studied at one loop...