Chiral fermions and anomaly cancellation on orbifolds with Wilson lines and flux

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in collaboration with W. Buchmuller, F. Ruehle, J. Schweizer

DESY Theory Workshop

Markus Dierigl

DESY, Hamburg

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Motivation
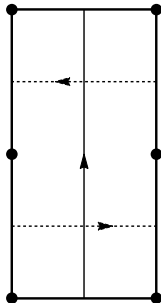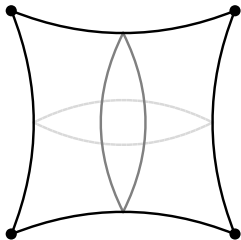
Realistic models from theories with extra dimensions:

- ▶ Chiral fermions

- ▶ Supersymmetry breaking

- ▶ (Grand unification)

All realized with:

<div style="border:1px solid black; display:inline-block; padding:8px;">

Flux compactification of 6d SUGRA on orbifolds

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$T^2/\mathbb{Z}_2$ orbifold
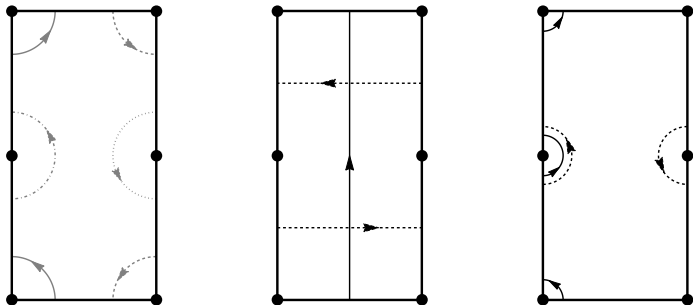
Start with 2-torus T^2 and mod out $\mathbb{Z}_2$ symmetry: $y \to -y$

Usual procedure for Wilson lines: Project torus 1-cycles

Orbifold 1-cycles

Choice of more convenient basis of the orbifold Wilson lines (1-cycles)

$\Rightarrow$ Three linearly independent, **"canonical" 1-cycles winding around the fixed points**

Orbifold 1-cycles

Canonical basis	**Projection from T^2**
▶ Gauge field configuration of Wilson lines: **Superposition of vortices**	Projection of gauge field does not fulfill orbifold parity
▶ Direct interpretation as **fractional, localized flux**, e.g. [von Gersdorff '07]	Interpretation as flux not obvious
▶ **Influence on wave functions** (see Julian's talk), [Cremades et al. '04], [Abe et al. '13]	Influence on wave functions obscured
▶ All these properties **directly generalize to flux background**	Not directly from Wilson lines on torus, [Bachas '95]

Flux background

Introduce flux in extra dimensions:

- ▶ Flux quantization

- ▶ Chiral zero modes due to index theorem

- ▶ SUSY breaking due to non-vanishing energy density

> ⇒ **How is the 4d low energy theory affected?**

- ▶ Effective action
- ▶ Anomaly cancellation
- ▶ Particle spectrum

Effective action

<u>Start with 6d SUGRA:</u> [Nishino, Sezgin '84, '86]

$$S = \int \left(\tfrac{1}{2}R - \tfrac{1}{2}d\phi \wedge *d\phi - \tfrac{1}{2}e^{2\phi}H \wedge *H - \tfrac{1}{2}e^{\phi}F \wedge *F \right)$$

with: $F = dA, \quad H = dB - A \wedge F$

$\Rightarrow$ under gauge transformations: $B \to B - \Lambda F$

<u>Note:</u>

▶ Gravitational anomalies demand large number of fields (can be fulfilled)

▶ We **concentrate on chiral anomaly** in 6d and 4d

6d Anomaly

Contribution to 6d chiral anomaly from:

- Chiral boundary conditions from orbifold (bulk), e.g. [Erler '93]
- Localized contributions (fixed points), e.g. [Scrucca, Serone '04]

$$\mathcal{A} = \Lambda F \wedge \left(\tfrac{\beta}{2} F \wedge F + \alpha\, \delta_{\mathcal{O}} F \wedge v_2 \right)$$

(Λ: gauge transformation parameter, α, β: loop factors, v_2: volume form)

Cancellation via 6d Green-Schwarz mechanism: [Green, Schwarz '84]

$$S_{GS} = -\int \left(\tfrac{\beta}{2} A \wedge F + \alpha\, \delta_{\mathcal{O}} A \wedge v_2 \right) \wedge dB$$

$\Rightarrow$ **What about additional zero modes in flux background in 4d?**

4d Anomaly

Dimensional reduction in flux background: [Braun et al. '07]

$$F = f\,v_2 + \hat{F} \quad \Rightarrow \quad \mathcal{A}_4 = \left(\alpha + \tfrac{3\beta}{2}f\right)\Lambda\hat{F}\wedge\hat{F}$$

Canceled by two contributions from 2-form B:

$$b \propto \int_{T^2/\mathbb{Z}_2} B\,, \quad dc \propto *_4 d\hat{B}$$

with **flux dependent**, axionic shift symmetry:

$$\boxed{b \to b - 2f\Lambda\,, \quad c \to c - \left(\alpha + \tfrac{\beta}{2}f\right)\Lambda}$$

Effective action

Bosonic effective action for axion and gauge sector:

(with moduli fields: $s = r^2 e^{\phi}$, $t = r^2 e^{-\phi}$)

$$
\begin{aligned}
S_{\text{eff}} = \int \Big[& -\tfrac{1}{2} s\, \hat{F} \wedge *\hat{F} - \frac{f^2}{2st^2} \\
& -\tfrac{1}{2t^2}(db + 2f\hat{A})^2 - \tfrac{1}{2s^2}\left(dc + \left(\alpha + \tfrac{\beta}{2}f\right)\hat{A}\right)^2 \\
& -\hat{A} \wedge \hat{F} \wedge \left(\tfrac{\beta}{2}db + dc\right) \Big]
\end{aligned}
$$

- All contributions to 4d anomaly canceled by two axions
- Axions mix dependent on number of flux quanta and moduli
- Vector boson mass:
    - classical mass (via flux)
    - anomaly contribution (Green-Schwarz term)
- SUSY breaking in flux background

Conclusion and outlook

Conclusion:

- ▶ Convenient description of Wilson lines in flux background

- ▶ Interesting version of anomaly cancellation and vector boson mass generation in effective 4d theory

- ▶ Model with chiral fermions and SUSY breaking

Outlook:

- ▶ Framework for GUTs; see Julian's talk
  - ▶ Effect on wave functions (interesting for phenomenology)
  - ▶ Families via number of flux quanta
  - ▶ Mass spectra similar to "split SUSY"

- ▶ Description of full 4d effective action (in terms of spontaneously broken SUSY)