Green–Schwarz Mechanism in Heterotic (2,0) GLSMs

Torsion and NS5 Branes

Fabian Rühle

Bethe Center for Theoretical Physics
Bonn University

String Phenomenology 2011 – 08/24/2011

Based on: [Blaszczyk,Groot Nibbelink,FR: 1107.0320]

(see also: [Quigley,Sethi])

Motivation

String theory promising candidate for unified description of **fundamental forces**.

Much effort spent on construction of MSSM–like models in last decade.

Motivation

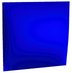
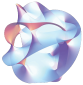
String theory promising candidate for unified description of **fundamental forces**.

Much effort spent on construction of **MSSM**–like models in last decade.

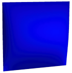
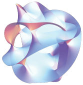
Approaches in $E_8 \times E_8$ heterotic string theory:

- **Orbifold** model building [Blaszczyk, Buchmüller, Groot Nibbelink, Hamaguchi, Kim, Kyae, Lebedev, Nilles, Raby, Ramos–Sanchez, Ratz, FR, Trapletti, Vaudrevange, Wingerter, . . .]
- **Calabi–Yau** model building [Anderson, Bouchard, Braun, Donagi, Gray, He, Lukas, Ovrut, Palti, Pantev, Waldram, . . .]
- **Free fermionic** constructions [Faraggi, Nanopoulos, Yuan, . . .]
- **Gepner Models** [Dijkstra, Gato–Rivera, Huiszoon, Schellekens, . . .]

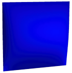
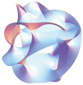
Motivation – Compactification Geometries

 Orbifold	 Calabi–Yau
singular, non–generic	smooth, generic

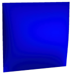
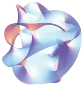
Motivation – Compactification Geometries

 Orbifold	 Calabi–Yau
singular, non–generic	smooth, generic
simple	complicated

Motivation – Compactification Geometries

 Orbifold	 Calabi–Yau
singular, non–generic	smooth, generic
simple	complicated
exact CFT calculations possible	only SUGRA approximation

Motivation – Compactification Geometries

 Orbifold	 Calabi–Yau
singular, non–generic	smooth, generic
simple	complicated
exact CFT calculations possible	only **SUGRA approximation**
Anomaly drives model **away** from **Orbifold** point	**Phenomenology** (torsion) **drives** model **away** from **CY** space

Motivation – Problems

Problem 1

Evidence for **purely stringy constraints** that are **only seen** in **exact CFT** caluclation on the **orbifold** and **NOT** on **CY**

[Blaszczyk,Groot Nibbelink,FR,Trapletti,Vaudrevange]

Motivation – Problems

Problem 1

Evidence for **purely stringy constraints** that are **only seen** in **exact CFT** caluclation on the **orbifold** and **NOT** on **CY**

[Blaszczyk,Groot Nibbelink,FR,Trapletti,Vaudrevange]

Problem 2

Need a framework capable of **describing** both **departure** from the **orbifold** and **torsion**

Motivation – Problems

Problem 1

Evidence for **purely stringy constraints** that are **only seen** in **exact CFT** caluclation on the **orbifold** and **NOT** on **CY**

[Blaszczyk,Groot Nibbelink,FR,Trapletti,Vaudrevange]

Problem 2

Need a framework capable of **describing** both **departure** from the **orbifold** and **torsion**

Suggestion

Use **Gauged Linear Sigma Models**

Outline

Definition of GLSM

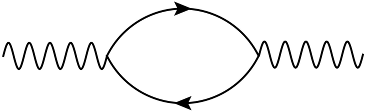
Consider **2D SUSY** with **Abelian** gauge groups and field content:

superfield type	superfield notation	charge	bosonic DOF	fermionic DOF
chiral	Ψ^a	$(q_I)^a$	z^a	ψ^a
chiral–Fermi	Λ^α	$(Q_I)^\alpha$	h^α	λ^α
gauge	$(V, A)^I$	0	$a^I_\sigma, a^I_{\bar\sigma}$	Φ^I
Fermi–gauge	σ^i	0	s^i	φ^i
chiral	Φ^m	$(q_I)^m$	x^m	ψ^m
chiral–Fermi	Γ^μ	$(Q_I)^\mu$	–	γ^μ

Geometry given by **D–terms** and **F–terms**

Gauge group given by **monad bundle**

Anomalies



$$\mathcal{A}_{IJ} := q_I \cdot q_J - Q_I \cdot Q_J \,,$$

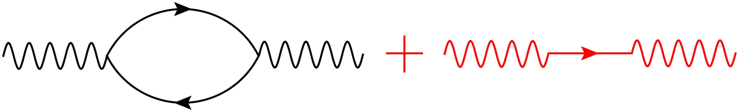
$$q_I \cdot q_J := \sum_a (q_I)^a (q_J)^a + \sum_m (q_I)^m (q_J)^m \,,$$

$$Q_I \cdot Q_J := \sum_\alpha (Q_I)^\alpha (Q_J)^\alpha + \sum_\mu (Q_I)^\mu (Q_J)^\mu \,.$$

Problem

In general **many** $U(1)$ gauge groups
$\Rightarrow$ **Huge amount** of stringent **anomaly conditions**.

Anomalies



$$\mathcal{A}_{IJ} := q_I \cdot q_J - Q_I \cdot Q_J + \mathcal{T}_{IJ} \,,$$

$$q_I \cdot q_J := \sum_a (q_I)^a (q_J)^a + \sum_m (q_I)^m (q_J)^m \,,$$
$$Q_I \cdot Q_J := \sum_\alpha (Q_I)^\alpha (Q_J)^\alpha + \sum_\mu (Q_I)^\mu (Q_J)^\mu \,.$$

Idea

Introduce **new fields** to obtain **Green–Schwarz mechanism** on the world–sheet to **cancel gauge anomalies**. [Adams,Ernebjerg,Lapan]

Green–Schwarz mechanism

Green–Schwarz mechanism needs fields that transform with shifts.

Our approach

$\Rightarrow$ Use **logarithm** of **coordinate fields** Ψ

$$W_{\text{FI}} = \left[\rho_I^0 + T_{XI} \ln \left| R^X(\Psi) \right| \right] F^I \quad \Rightarrow \quad \mathcal{T}_{IJ} = r_I^X T_{XI}$$

$$\mathcal{A}_{IJ} = q_I \cdot q_J - Q_I \cdot Q_J + \mathcal{T}_{IJ}$$

with

- ρ_I^0: constant FI parameter
- $R^X(\Psi)$: homogeneous polynomials w/ charges r_I^X
- T_{XI}: (quantized) coefficients: $T_{XI} \int f^I \in \mathbb{Z}$

Consequences

$$H = dB + \omega_{\mathrm{L}} - \omega_{\mathrm{YM}}$$

Consequences

$$H = dB + \omega_{\mathrm{L}} - \omega_{\mathrm{YM}}$$

Int. BI's: $0 = \int dH = \int \mathrm{tr}\mathcal{R}^2 - \mathrm{tr}\mathcal{F}^2 + \mathrm{NS5}$

Consequences

$$H = dB + \omega_{\mathrm{L}} - \omega_{\mathrm{YM}}$$

$$\text{Int. BI's:} \quad 0 = \int dH = \int \mathrm{tr}\mathcal{R}^2 - \mathrm{tr}\mathcal{F}^2 + \mathrm{NS5}$$

$$\text{Anomalies:} \quad 0 = \mathcal{A}_{IJ} = \underbrace{[q_I^a q_J^a - Q_I^\mu Q_J^\mu]}_{\subset\, \mathrm{tr}\mathcal{R}^2} - \underbrace{[Q_I^\alpha Q_J^\alpha - q_I^m q_J^m]}_{\subset\, \mathrm{tr}\mathcal{F}^2} + \underbrace{\mathcal{T}_{IJ}}_{\subset\, \mathrm{NS5}}$$

Consequences

$$H = dB + \omega_{\text{L}} - \omega_{\text{YM}}$$

Int. BI's: $0 = \int dH = \int \text{tr}\mathcal{R}^2 - \text{tr}\mathcal{F}^2 + \text{NS5}$

Anomalies: $0 = \mathcal{A}_{IJ} = \underbrace{[q_I^a q_J^a - Q_I^\mu Q_J^\mu]}_{\subset \text{tr}\mathcal{R}^2} - \underbrace{[Q_I^\alpha Q_J^\alpha - q_I^m q_J^m]}_{\subset \text{tr}\mathcal{F}^2} + \underbrace{\mathcal{T}_{IJ}}_{\subset \text{NS5}}$

Relationship orbifold ↔ CY

BIs on CY ↔ Modular invariance on orbifold.

Consequences

$$H = dB + \omega_{\mathrm{L}} - \omega_{\mathrm{YM}}$$

Int. BI's: $0 = \int dH = \int \mathrm{tr}\mathcal{R}^2 - \mathrm{tr}\mathcal{F}^2 + \mathrm{NS5}$

Anomalies: $0 = \mathcal{A}_{IJ} = \underbrace{[q_I^a q_J^a - Q_I^\mu Q_J^\mu]}_{\subset \mathrm{tr}\mathcal{R}^2} - \underbrace{[Q_I^\alpha Q_J^\alpha - q_I^m q_J^m]}_{\subset \mathrm{tr}\mathcal{F}^2} + \underbrace{\mathcal{T}_{IJ}}_{\subset \mathrm{NS5}}$

Relationship orbifold $\leftrightarrow$ CY

BIs on **CY** $\leftrightarrow$ **Modular invariance** on **orbifold**.

NS5 and anti–NS5 branes, torsion

- $\mathrm{tr}\mathcal{R}^2 < \mathrm{tr}\mathcal{F}^2 \Rightarrow$ **NS5** and **torsion**
- $\mathrm{tr}\mathcal{R}^2 > \mathrm{tr}\mathcal{F}^2 \Rightarrow$ **anti–NS5** and **torsion**
- $[\mathrm{tr}\mathcal{R}^2] = [\mathrm{tr}\mathcal{F}^2] \Rightarrow$ **torison**

Example

1.) No anomalies

superfield	$\Psi^{a=1,\ldots,8}$	$\Gamma^{\mu=1,\ldots,4}$	$\Lambda^{\alpha=1,\ldots,8}$	$\Phi^{m=1,\ldots,4}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-2

$\mathbb{P}^7[2,2,2,2]$ with $SU(3)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 + \mathcal{T}_{11}\right]$$

1.) No anomalies

superfield	$\Psi^{a=1,\ldots,8}$	$\Gamma^{\mu=1,\ldots,4}$	$\Lambda^{\alpha=1,\ldots,8}$	$\Phi^{m=1,\ldots,4}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-2

$\mathbb{P}^7[2,2,2,2]$ with $SU(3)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 + \mathcal{T}_{11}\right]$$

$$W_{\mathrm{FI}} = \rho^0 + T \ln|\Psi^1| \quad \Rightarrow \quad r_1^1 = 1\,, \quad \mathcal{T}_{11} = T\,, \quad T \in 2\mathbb{Z}$$

Green–Schwarz mechanism

Green Schwarz mechanism needs fields that transform with shifts.

Our approach

$\Rightarrow$ Use **logarithm** of **coordinate fields** Ψ

$$W_{\text{FI}} = \Big[\rho^0_I + T_{XI}\ln[R^X(\Psi)]\Big]\, F^I \quad \Rightarrow \quad \mathcal{T}_{IJ} = r^X_I\, T_{XI}$$

$$\mathcal{A}_{IJ} = q_I \cdot q_J - Q_I \cdot Q_J + \mathcal{T}_{IJ}$$

with

- ρ^0_I: constant FI parameter
- $R^X(\Psi)$: homogeneous polynomials w/ charges r^X_I
- T_{XI}: (quantized) coefficients: $T_{XI} \int f^I \in \mathbb{Z}$

1.) No anomalies

superfield	$\Psi^{a=1,\dots,8}$	$\Gamma^{\mu=1,\dots,4}$	$\Lambda^{\alpha=1,\dots,8}$	$\Phi^{m=1,\dots,4}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-2

$\mathbb{P}^7[2,2,2,2]$ with $SU(3)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 + \mathcal{T}_{11}\right]$$

$$W_{\mathrm{FI}} = \rho^0 + T\ln|\Psi^1| \quad \Rightarrow \quad r_1^1 = 1\,, \quad \mathcal{T}_{11} = T\,, \quad T \in 2\mathbb{Z}$$

$$V_D = \frac{1}{2}\Big[\sum_a |z^a|^2 - 2\sum_m |x^m|^2 - \xi - T\ln|z^1|\Big]^2 \stackrel{!}{=} 0$$

1.) No anomalies

superfield	$\Psi^{a=1,\dots,8}$	$\Gamma^{\mu=1,\dots,4}$	$\Lambda^{\alpha=1,\dots,8}$	$\Phi^{m=1,\dots,4}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-2

$\mathbb{P}^7[2,2,2,2]$ with $SU(3)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 + \mathcal{T}_{11}\right]$$

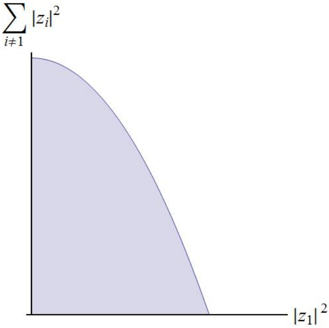
$$W_{\text{FI}} = \rho^0 + T \ln|\Psi^1| \quad \Rightarrow \quad r_1^1 = 1\,, \quad \mathcal{T}_{11} = T\,, \quad T \in 2\mathbb{Z}$$

$$V_D = \frac{1}{2}\Big[\sum_a |z^a|^2 - 2\sum_m |x^m|^2 - \xi - T\ln|z^1|\Big]^2 \overset{!}{=} 0$$

$$\mathcal{A}_{11} = \frac{1}{2}\left[8\cdot(1)^2 + 4\cdot(-2)^2 - 8\cdot(1)^2 - 4\cdot(-2)^2 + \mathcal{T}_{11}\right] \overset{!}{=} 0$$

$\mathcal{T}_{11} = T = 0$

1.) No anomalies



$\xi = 1$

$$\xi > 0 \;\Rightarrow\; |x^a| = 0\,, \quad V_D \stackrel{!}{=} 0 \;\Rightarrow\; \sum_{a=1}^{8} |z^a|^2 = \xi$$

Geometry **compact**, no anomalies.

2.) $T > 0$, compact geometry, effective curve

superfield	$\Psi^{a=1,\dots,8}$	$\Gamma^{\mu=1,\dots,4}$	$\Lambda^{\alpha=1,\dots,4}$	$\Phi^{m=1,2}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-2

$\mathbb{P}^7[2,2,2,2]$ with $SU(2)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 - \mathcal{T}_{11}\right]$$

$$W_{\mathrm{FI}} = \rho^0 + T\ln[\Psi^1] \quad \Rightarrow \quad r_1^1 = 1\,, \quad \mathcal{T}_{11} = T\,, \quad T \in 2\mathbb{Z}$$

$$V_D = \frac{1}{2}\left[\sum_a |z^a|^2 - 2\sum_m |x^m|^2 - \xi - T\ln|z^1|\right]^2 \overset{!}{=} 0$$

2.) $T > 0$, compact geometry, effective curve

superfield	$\Psi^{a=1,\dots,8}$	$\Gamma^{\mu=1,\dots,4}$	$\Lambda^{\alpha=1,\dots,4}$	$\Phi^{m=1,2}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-2

$\mathbb{P}^7[2,2,2,2]$ with $SU(2)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 - \mathcal{T}_{11}\right]$$

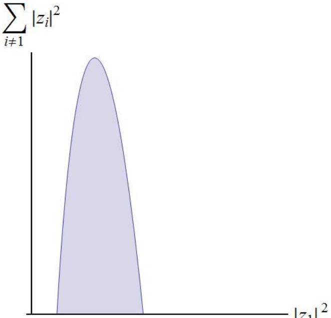
$$W_{\text{FI}} = \rho^0 + T\ln[\Psi^1] \quad \Rightarrow \quad r_1^1 = 1\,, \quad \mathcal{T}_{11} = T\,, \quad T \in 2\mathbb{Z}$$

$$V_D = \frac{1}{2}\Big[\sum_a |z^a|^2 - 2\sum_m |x^m|^2 - \xi - T\ln|z^1|\Big]^2 \overset{!}{=} 0$$

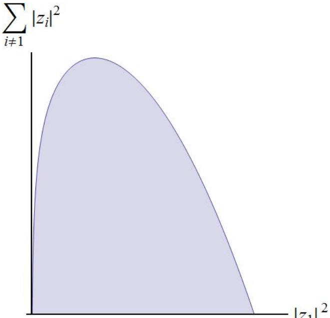
$$\mathcal{A}_{11} = \frac{1}{2}\left[8\cdot(1)^2 + 2\cdot(-2)^2 - 4\cdot(1)^2 - 4\cdot(-2)^2 + \mathcal{T}_{11}\right] \overset{!}{=} 0$$

$$\mathcal{T}_{11} = T = 2$$

2.) $T > 0$, compact geometry, effective curve



$\xi = 1$



$\xi = 10$

$$\xi > 0 \;\Rightarrow\; |x^a| = 0\,, \quad V_D \overset{!}{=} 0 \;\Rightarrow\; \sum_{a=2}^{8} |z^a|^2 = \xi + 2\ln|z_1| - |z_1|^2$$

Geometry still **compact**, anomalies canceled by **NS5 branes**.

3.) $T < 0$, decompactified geometry, non–effective curve

superfield	$\Psi^{a=1,\ldots,8}$	$\Gamma^{\mu=1,\ldots,4}$	$\Lambda^{\alpha=1,\ldots,8}$	$\Phi^{m=1,2}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-4

$\mathbb{P}^7[2,2,2,2]$ with $SU(6)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 - \mathcal{T}_{11}\right]$$

$$W_{\text{FI}} = \rho^0 + T \ln[\Psi^1] \quad \Rightarrow \quad r_1^1 = 1\,, \quad \mathcal{T}_{11} = T\,, \quad T \in 4\mathbb{Z}$$

$$V_D = \frac{1}{2}\Big[\sum_a |z^a|^2 - 4\sum_m |x^m|^2 - \xi - T\ln|z^1|\Big]^2 \stackrel{!}{=} 0$$

3.) $T < 0$, decompactified geometry, non–effective curve

superfield	$\Psi^{a=1,\dots,8}$	$\Gamma^{\mu=1,\dots,4}$	$\Lambda^{\alpha=1,\dots,8}$	$\Phi^{m=1,2}$
lowest component	z^a	γ^μ	λ^α	x^m
gauge charge	1	-2	1	-4

$\mathbb{P}^7[2,2,2,2]$ with $SU(6)$ bundle

$$\mathcal{A}_{11} = \frac{1}{2}\left[q_1^2 - Q_1^2 - \mathcal{T}_{11}\right]$$

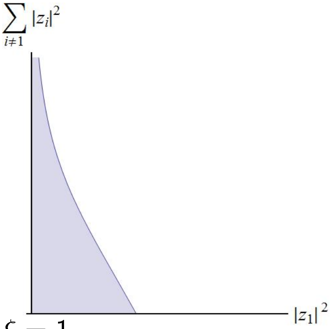
$$W_{\text{FI}} = \rho^0 + T\ln[\Psi^1] \quad \Rightarrow \quad r_1^1 = 1\,, \quad \mathcal{T}_{11} = T\,, \quad T \in 4\mathbb{Z}$$

$$V_D = \frac{1}{2}\Big[\sum_a |z^a|^2 - 4\sum_m |x^m|^2 - \xi - T\ln|z^1|\Big]^2 \overset{!}{=} 0$$

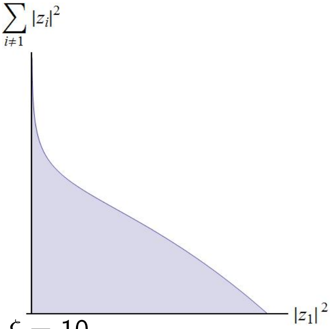
$$\mathcal{A}_{11} = \frac{1}{2}\left[8\cdot(1)^2 + 2\cdot(-4)^2 - 8\cdot(1)^2 - 4\cdot(-2)^2 + \mathcal{T}_{11}\right] \overset{!}{=} 0$$

$$\mathcal{T}_{11} = T = -8$$

3.) $T < 0$, decompactified geometry, non–effective curve



$\xi = 1$



$\xi = 10$

$$\xi > 0 \;\Rightarrow\; |x^a| = 0\,, \quad V_D \stackrel{!}{=} 0 \;\Rightarrow\; \sum_{a=2}^{8} |z^a|^2 = \xi - 8\ln|z_1| - |z_1|^2$$

Geometry **decompactified**, anomalies canceled with **anti–NS5 branes**.

Conclusion

GLSMs powerful tool for string model building.

Conclusion

GLSMs powerful tool for string model building.

Anomaly conditions extremely severe, GS mechanism can ameliorate them (but cannot cancel arbitrary anomalies due to quantization).

Conclusion

GLSMs powerful tool for string model building.

Anomaly conditions extremely severe, GS mechanism can ameliorate them (but cannot cancel arbitrary anomalies due to quantization).

Logarithmic counter terms introduce torsion or NS5 branes, which strongly backreact on geometry.

Conclusion

GLSMs powerful tool for string model building.

Anomaly conditions extremely severe, GS mechanism can ameliorate them (but cannot cancel arbitrary anomalies due to quantization).

Logarithmic counter terms introduce torsion or NS5 branes, which strongly backreact on geometry.

Thank you for your attention!