Moduli in Orbifolds, Supergravity and Linear Sigma Models

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Based on work with: S. Groot Nibbelink, F. Rühle; P. Oehlmann

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Motivation

- Heterotic Orbifold models sucessful in constructing vacua with many realistic properties

  MB, W. Buchmüller, S. Groot Nibbelink, K. Hamaguchi, J. E. Kim, B. Kyae, O. Lebedev, H. P. Nilles, S. Raby, S. Ramos-Sánchez, M. Ratz, F. Rühle, M. Trapletti, P.K.S. Vaudrevange, A. Wingerter, ...

- target space dynamics and phenomenology requires VEVs of twisted fields
  $\rightarrow$ SUGRA approximation on Resolution CY

  MB, N. Cabo-Bizet, S. Groot Nibbelink, T.-W. Ha, J. Held, D. Klevers, H. P. Nilles, F. Plöger, F. Rühle, M. Trapletti, P.K.S. Vaudrevange, M.G.A. Walter, ...

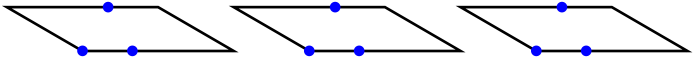
- GLSM description interpolates between different phases

  MB, S. Groot Nibbelink, F. Rühle

- How do these three fit together? What is the proper theory?

Heterotic Orbifolds

Dixon, Harvey, Vafa, Witten; Ibanez, Nilles, Quevedo



- Orbifold $\mathcal{O} = T^6/\mathbb{Z}_3$
  $\rightarrow$ fully solvable free CFT
- Abelian embedding into gauge sector
  $\Rightarrow$ shift Vector V and discrete Wilson lines W
- twisted sectors with chiral matter localized at fixed points
- generally: study effective 4d theory, exact in α'
- action from selection rules

SUGRA on Resolution

- In realistic models Twisted States need to get VEVs:
  - Cancellation of *FI* term of $U(1)_{\text{Anomalous}}$
  - Decoupling of exotic states
- Fixed Points (singularities) get resolved
  Rightarrow study compactified SUGRA approximation on smooth CY with vector bundles, perturbative in α'
- Spectrum from cohomologies(hard) or Index theorems(easier)

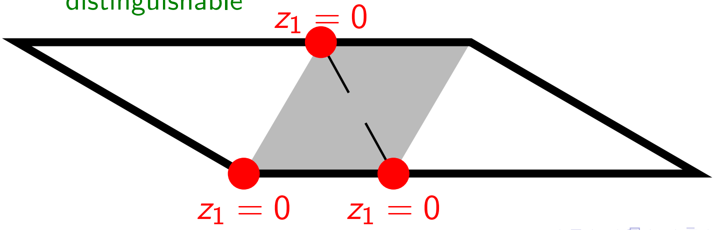
Gauged Linear Sigma Models

- $\mathcal{N} = (2,0)$ SUSY models in $d = 2$ with gauge group $U(1)^N$
- Target space = Complete Intersection CY with Vector Bundle

  Witten
- gauge couplings and superpotential parameters dimensionful
  $\longrightarrow$ take conformal limit to NLSM
- Can be used to study many phases:
  Singular, Smooth, non-Geometric, hybrid,...
  see talk by Fabian Rühle (in 15 Minutes)
- But: $(2,0)$ models hard due to $\propto (h^{1,1})^2$ Anomaly constraints
  e.g. line bundles only engeneered non-canonically

$Res(T^6/\mathbb{Z}_3)$ as Complete Intersection

- Start with $T^6 = \left(\mathbb{P}^2[3]\right)^3$
- Include Gauge Symmetries and Coordinates s.th.
  $\langle x \rangle \;\Rightarrow U(1) \rightarrow \mathbb{Z}_3$
- FI parameters of $U(1)$ control resolution process
- One Gauge Symmetry $\Rightarrow$ All Exceptional Divisors have same size, carry same bundle
- Multiple Gauge Symmetires $\Rightarrow$ Exceptional Divisors are distinguishable



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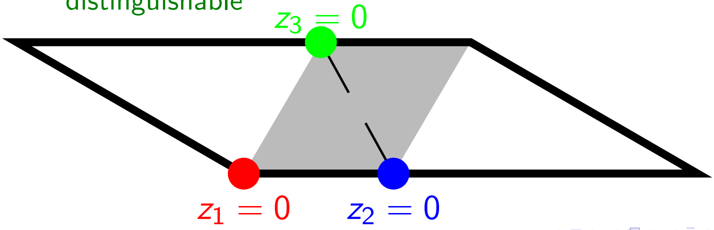

Conceptual Comparison

Orbifold	SUGRA	GLSM
Shift Embedding	General Bundle	Monad Vector Bundle
Mod. Inv.	Bianchi Identities	Anomalies
Massless Spectrum	$h^{1,1}$, $h^{2,1}$, $h^1(V)$	parameters (FI + Superpot.)
Flat Directions	higher Constraints	kinetic terms
...	...	...

Example: Std. Embedding $\leftrightarrow$ (2,2)

Hamidi, Vafa; Aspinwall, Plesser

On orbifold CFT:

- $SU(3) \times E6 \times E_8$
- At each fixed point: $1 \times (1, 27) \; + \; 3 \times (3, 1)$
- D- $+$ F- flatness $\Rightarrow$ Each fx.pt. has one independent flat direction

In GLSM:

- Maximal Model best suited
- Exceptional Divisor has its own resolution FI-parameter

Here: Next-To-Std.Emb. $\leftrightarrow$ (2,0)

On orbifold:

- $V = (1/3, 1/3, -2/3, 0^5)(1/3, 1/3, -2/3, 0^5)$
- Gauge Group $= SU(3) \times E_6 \times SU(3) \times E_6$
- At each fixed point: $1 \times (3, 1, 3, 1) \rightarrow \Psi^{qr}_{\alpha\beta\gamma}$
- $W = \Psi^{qr}_{\alpha\beta\gamma} \Psi^{q'r'}_{\alpha'\beta'\gamma'} \Psi^{q''r''}_{\alpha''\beta''\gamma''} \epsilon_{\vec{q}} \epsilon_{\vec{r}} (N\delta_{\vec{\alpha}} + Md_{\vec{\alpha}}) \times \ldots$
- D- and F- flatness required dependence of vevs at different fixed points on each other
- $\Psi^{qr}_{\alpha\beta\gamma} = \delta^q_\alpha \delta^r_\beta v_\gamma +$ fluctuations
- 32 of the fluctuations are massless, $\#$ flat directions ≤ 18

Here: Next-To-Std.Emb. $\leftrightarrow$ (2,0)

In SUGRA:

- One VEV at each fixed point $\rightarrow$ Line Bundles

$$V_{\alpha\beta\gamma} = \left\{ \begin{array}{ll} (-2/3, 1/3, 1/3, 0^5) & \alpha = 1 \\ (1/3, -2/3, 1/3, 0^5) & \alpha = 2 \\ (1/3, 1/3, -2/3, 0^5) & \alpha = 3 \end{array} \right\} \{\text{same with } \beta\}$$

- Index Theorem counts: no net chiral states at fixed points
- Local Index Theorem $N = \sum_{\alpha\beta\gamma} N_{\alpha\beta\gamma}$ finds 2 states at each fixed point
- But: Non-Perturbative corrections give non-local masses:

$$\sim e^{-\frac{\mathrm{Area}(T^2)}{\alpha'}} \langle \Psi \rangle \Psi \Psi$$

Here: Next-To-Std.Emb. $\leftrightarrow$ (2,0)

In GLSM:

- VEVS differ only in third torus
  $\longrightarrow$ suggests model with three exceptional gauge symmetries
  $(E_{111}, E_{112}, E_{113})$
- Bundle differs only in first and second torus
  $\longrightarrow$ suggests model with nine exc. gauge symmetries
  $(E_{111}, E_{121}, E_{131}, E_{211}, E_{221}, E_{231}, E_{311}, E_{321}, E_{331},)$
- Does not seem to fit!?!

Conclusion

- In SUGRA: difficulties with obtaining # massless states / flat directions
- Hard to explicitely construct $(2,0)$ GLSM models that match with orbifold
  - Anomalies vs. Line Bundles
  - structure of flat directions

Outlook:

- Try the other Way.
  Scan for GLSM, find Orbifold limit.

Thanks!