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Orbifolds as Free Fermionic Models

String Pheno 2015, Madrid
11th June

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arXiv:1506.xxxxx

String Model Building

The Heterotic String

- Closed string theory
- Synthesis of bosonic string and superstring
- Particle phenomenology widely explored - most promising string theory?

  Ohio, Pennsylvania, Oxford, Liverpool, Munich, Bonn,...
- Many descriptions
  - Effective constructions
  - Worldsheet constructions

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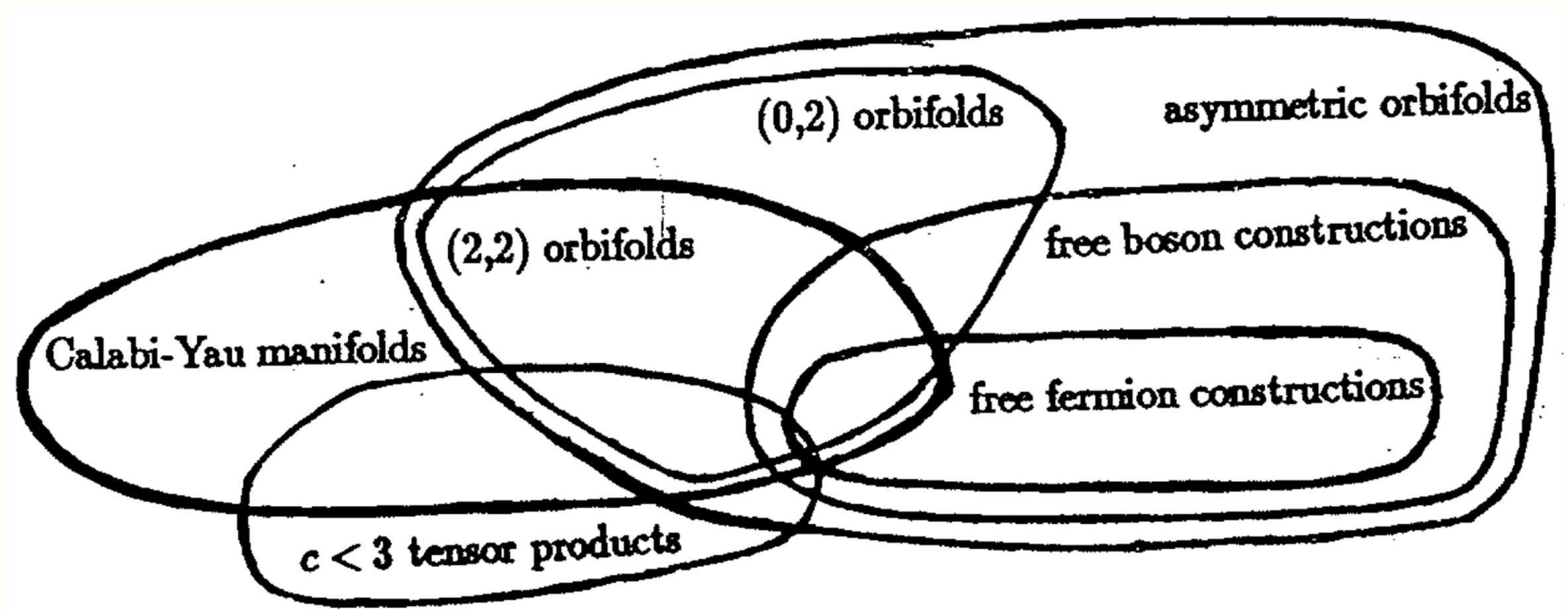
  - Effective constructions
  - Worldsheet constructions → Orbifolds, Free fermions

Orbifolds and Free Fermions

History

- Since Antoniadis-Bachas-Kounnas/Kawai-Lewellen-Tye `87 (FFF) and Dixon-Harvey-Vafa-Witten `85 (Orbifolds), worldsheet constructions have been widely explored
- Previous works have discussed a correspondence
  - Including Kounnas-Kiritsis `97, Gregori-Kounnas-Rizos `99, Donagi-Faraggi `04, Donagi-Wendland `08,...
- However, model builder's dictionary still missing...
    - Computational comparison currently inaccessible!

A Hitchhiker's Guide to Heterotic Vacua



Dixon 1987

Orbifolds

The who, what, why

- $X^{\mu,i}_{L/R}$ and Y^I_L describe 10D spacetime and internal T^{16}
- $\psi^{\mu,i}_R$ are worldsheet superpartners of bosonic coordinates
- Models described by twists, shifts and discrete torsion
- Symmetric orbifolds classified

  The Orbifolder - Nilles, Ramos-Sanchez, Vaudrevange, Wingerter
- Generic points in the moduli space

Free Fermionic Construction

The who...

superpartners of X^μ

"compactified" directions

hidden gauge group generators

$$\psi^\mu, \chi^i, \overbrace{y^i, w^i, \overline{y}^i, \overline{w}^i}, \overline{\psi}^{1,\ldots,5}, \overline{\eta}^{1,2,3}, \overline{\phi}^{1,\ldots,8}$$

superpartners of compactification bosons

visible gauge group generators

Free Fermionic Construction

... what, why

- Fermion boundary condition basis vectors $\mathbf{b}_i$

$$\alpha \in \Xi = \mathrm{span}\left\{\mathbf{b}_1, \ldots, \mathbf{b}_k\right\}$$

- GSO projections $\left\{ e^{i\pi(\mathbf{b}_i \cdot F_\alpha)} - \delta_\alpha c^* \begin{pmatrix} \alpha \\ \mathbf{b}_i \end{pmatrix} \right\} |s\rangle_\alpha = 0$

- Large classifications conducted

  Bernard, Christodoulides, Faraggi, Glasser, Kounnas, Nooij, Rizos, Sonmez

- Fermions may be real or complex

- Special point in moduli space

Worldsheet Correspondence

Fermionisation/Bosonisation

- In 2D, known relationships between real bosons/fermions

$$\zeta^i = \frac{y^i + iw^i}{\sqrt{2}} = :e^{iX_R^i}: \qquad :\zeta^i\left(\zeta^i\right)^*: = i\partial X_R^i$$

- Relate boundary conditions of compactified dimensions:

Fermion	Boson	
$\{y,w\}^i \to -\{y,w\}^i$	$X_R^i \to X_R^i + \pi$	"shift"
$\{y,w\}^i \to \{y,-w\}^i$	$X_R^i \to -X_R^i$	"twist"
$\{y,w\}^i \to \{-y,w\}^i$	$X_R^i \to -X_R^i + \pi$	"roto-translation"

up to lattice vector...

Comparison

The DF/DW Classification

- $\mathbb{Z}_2 \times \mathbb{Z}_2'$ symmetric orbifolds classified in terms of twists / twists and shifts / twists, shifts and roto-translations

- Corresponding classification in terms of free fermions - seemingly absent

- Backgrounds classified for Type II strings in Gregori-Kounnas-Rizos `99 but heterotic classification missing

- What are the identifying features and how do these arise in FFF?

Comparison

NAHE Set $\equiv$ DW(0-1) orbifold?

Fermions that appear are periodic *i.e.* do *not* transform

$$\mathbf{b}_1 \supset \{\psi^\mu, \chi^{1,2}, y^{3,\ldots,6}, \overline{y}^{3,\ldots,6}\} \longleftrightarrow \theta_1 : (0+, 0-, 0-)$$

$$\mathbf{b}_2 \supset \{\psi^\mu, \chi^{3,4}, y^{1,2}, w^{5,6}, \overline{y}^{1,2}, \overline{w}^{5,6}\} \leftrightarrow \theta_2 : (0-, 0+, 0-)$$

$$\mathbf{b}_3 \supset \{\psi^\mu, \chi^{5,6}, w^{1,\ldots,4}, \overline{w}^{1,\ldots,4}\} \longleftrightarrow \theta_1 \cdot \theta_2 : (0-, 0+, 0-)$$

Chiral matter originates in twisted sectors, $\mathbf{b}_i$

$$\left(h^{1,1}, h^{2,1}\right) \stackrel{?}{=} (51, 3)$$

Comparison

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Chiral matter originates in twisted sectors, $\mathbf{b}_i$

$$\left(h^{1,1}, h^{2,1}\right) = (51, 3) \checkmark$$

Comparison

NAHE+$\mathbf{e}_{\text{even}}$ $\equiv$ DW(1-1) orbifold

$$\mathcal{B} \supset \{\mathbf{b}_1, \mathbf{b}_2, \mathbf{b}_3, \mathbf{e}_2, \mathbf{e}_4, \mathbf{e}_6\}$$

$$\sum_{\text{even } i} \mathbf{e}_i \longleftrightarrow (\tau, \tau, \tau)$$

$$\mathbf{e}_i = \{y^i, w^i, \overline{y}^i, \overline{w}^i\}$$

Chiral matter originates in twisted sectors, $\mathbf{b}_i$

$$\left(h^{1,1}, h^{2,1}\right) = (27, 3) \checkmark$$

Comparison

NAHE+$\mathbf{e}_{\text{even}}$ + T $\equiv$ DW(2-1) orbifold

$$\mathbf{T} \equiv \sum_i \mathbf{e}_i = \{y^{1,\ldots,6}, w^{1,\ldots,6}, \overline{y}^{1,\ldots,6}, \overline{w}^{1,\ldots,6}\}$$

$$\sum_{\text{even } i} \mathbf{e}_i \longleftrightarrow (\tau, \tau, \tau)$$

$$\sum_{\text{odd } i} \mathbf{e}_i \longleftrightarrow (1, 1, 1)$$

$$\left(h^{1,1}, h^{2,1}\right) = (15, 3) \checkmark$$

Conclusions and Outlook

- Correspondence between classes of $\mathbb{Z}_2 \times \mathbb{Z}_2'$ orbifolds and FFF
- Shifts, twists and roto-translations $\longleftrightarrow$ FFF basis vectors verified
- Identify "fixed points"
- Deform away from FFF point for full verification
- FFF pheno models $\longrightarrow$ asymmetric shift orbifolds?
- Classification of asymmetric shift/twist orbifolds?

Muchas gracias por su atención!