A perfect match of MSSM-like orbifold and resolution models via anomalies

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Based on work with: N. Cabo Bizet, H. P. Nilles, F. Rühle; 1108.0667

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Motivation

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

  M.B., 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

  M.B., 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

- confirm relation between these models, transfer orbifold calculability to resolution

Earlier Attempts

- local matching of spectra and anomalies

  S. Groot Nibbelink, H. P. Nilles, M. Trapletti

- difficulties in matching due to:
  - discrete torsion on Orbifold side

    F. Plöger, S. Ramos-Sánchez, M. Ratz, P.K.S. Vaudrevange

  - jumps in spectrum due to flop transitions on resolution

    M.B., S. Groot Nibbelink, F. Rühle, M. Trapletti, P.K.S. Vaudrevange

  - non-local properties

$\Rightarrow$ simple setup to avoid these problems: $\mathbb{Z}_7$ Orbifold

Outline

- Orbifolds and Resolution models
- Spectrum Matching
- Anomaly Matching

Orbifold model

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

- Orbifold $\mathcal{O} = T^6/\mathbb{Z}_7, \quad T^6 = \mathbb{C}^3/\Lambda_{SU(7)}$
- 7 $\mathbb{Z}_7$ fixed points, 3 chiral sectors each
- Abelian embedding into gauge sector:
  shift vector V and discrete Wilson line W, $V, W \in 1/7\Lambda_{E_8 \times E_8}$

$$V = \frac{1}{7}(0,0,-1,-1,-1,5,-2,6)\,(-1,-1,0,0,0,0,0,0)$$
$$W = \frac{1}{7}(-1,-1,-1,-1,-1,-10,2,-9)\,(4,3,-3,0,0,0,0,0)$$

Casas, de la Maccora, Mondragon, Munoz

Gauge Group: $SU(3) \times SU(2) \times SO(10) \times U(1)^8$

$(\mathbf{3},\mathbf{2},\mathbf{1})$	$(\mathbf{3},\mathbf{1},\mathbf{1})$	$(\overline{\mathbf{3}},\mathbf{1},\mathbf{1})$	$(\mathbf{1},\mathbf{2},\mathbf{1})$	$(\mathbf{1},\mathbf{1},\mathbf{10})$	$(\mathbf{1},\mathbf{1},\mathbf{1})$
3	12	18	21	1	133

Anomalous $U(1)$

One $U(1)$ gauge factor appears anomalous

- universal anomaly coefficients

$$I_6^{\mathrm{Orb}} = F_{\mathrm{Anom}} X_4^{\mathrm{Orb}}$$

- universal axion a^{Orb} cancels anomaly

$$a^{\mathrm{Orb}} X_4^{\mathrm{Orb}}\,, \qquad a^{\mathrm{Orb}} \to a^{\mathrm{Orb}} + \theta_{\mathrm{Anom}}$$

- FI-term gets induced, requires VEVs to restore SUSY
- geometric backreaction: singularities get blown up

Resolution SUGRA model

- resolve $T^6/\mathbb{Z}_7$ by gluing local $\mathbb{C}^3/\mathbb{Z}_3$ resolutions

  Lüst, Reffert, Scheidegger, Stieberger

- topological data: $H^{1,1} = \langle E_{r=1,\dots,21}; R_a \rangle$, Chern classes, ...
  $\Rightarrow$ SUGRA approx, valid in large volume limit
- Abelian gauge flux: $\mathcal{F} = E_r V_r^I H^I$ (H^I = Cartan generators)
- $\mathrm{Ad}_{E_8 \times E_8} \to \mathrm{Ad}_{SU(3)} + \mathrm{Ad}_{SU(2)} + \mathrm{Ad}_{SO(10)} + \sum_\alpha R_\alpha$
- multiplicity operator: net number of chiral states $N = N_R - N_{\bar{R}}$
- 22 axions: $a^{uni} \sim B_2\big|_{4D}$, $\beta_r \sim B_2\big|_{E_r}$

$(\mathbf{3},\mathbf{2},\mathbf{1})$	$(\mathbf{3},\mathbf{1},\mathbf{1})$	$(\overline{\mathbf{3}},\mathbf{1},\mathbf{1})$	$(\mathbf{1},\mathbf{2},\mathbf{1})$	$(\mathbf{1},\mathbf{1},\mathbf{10})$	$(\mathbf{1},\mathbf{1},\mathbf{1})$
3	10	16	17	1	86

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Spectrum Matching

- Blowup mode on Orbifold $\cong$ Kähler modulus + local axions

$$\Phi_r^{\mathrm{BU-Mode}} = e^{b_r + i\beta_r}$$

- chiral twisted states need to be redefined

$$\Phi_\gamma^{\mathrm{BU}} = e^{-\sum_k r_{k,\sigma}^\gamma (b_{k,\sigma} + i\beta_{k,\sigma})} \Phi_\gamma^{\mathrm{Orb}} ,$$

- states can become massive from trilinear couplings

$$\mathcal{W} \supset \Phi^{\mathrm{BU-Mode}} \Phi_1^{\mathrm{Orb}} \Phi_2^{\mathrm{Orb}}$$

  - local coupling: Φ_1, Φ_2 disappear from spectrum
  - non-local coupling: instantonic, SUGRA sees Φ_1^{BU}, Φ_2^{BU} as massless states

Local Multiplicity

multiplicity operator = sum over local pieces $N = \sum_{\sigma=1}^{7} N_\sigma$

- we see locus of states
  - Q_1 is smeared over the global geometry $\cong$ untwisted state
  - Q_2 is localized at fixed point 1
- we see spatially separated non-chiral pairs
  - t_9 appears as triplet at f.pt. 3 and antitriplet at f.pt. 6

	N	N_1	N_2	N_3	N_4	N_5	N_6	N_7
Q_1	1	$1/7$	$1/7$	$1/7$	$1/7$	$1/7$	$1/7$	$1/7$
Q_2	1	1	$-1/7$	$-1/7$	$1/7$	$-1/7$	$1/7$	$1/7$
t_9	0	$-1/7$	$-1/7$	1	$1/7$	$1/7$	$-8/7$	$1/7$

(local) R-parity

- local $\mathbb{C}^3/\mathbb{Z}_7$ Orbifold has $U(1)_R^3$ R-symmetry

$$z_i \to e^{i\varphi} z_i$$

- gets broken globally by torus lattice $\Lambda_{SU(7)}$
- without R-symmetry:

$$\mathcal{W} \supset (s_{111}\ s_{112}\ s_{113}) \begin{pmatrix} a_{11}\Phi_1 & a_{12}\Phi_1 & a_{13}\Phi_2 \\ a_{21}\Phi_1 & a_{22}\Phi_1 & a_{23}\Phi_2 \\ a_{31}\Phi_1 & a_{32}\Phi_1 & a_{33}\Phi_2 \end{pmatrix} \begin{pmatrix} s_{25} \\ s_{26} \\ s_{70} \end{pmatrix}$$

s_i: singlets, Φ_i: blowup modes

$\rightarrow$ all s_i should disappear

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- with R-symmetry:

$$\mathcal{W} \supset (s_{111}\ s_{112}\ s_{113}) \begin{pmatrix} 0 & 0 & 0 \\ a_{21}\Phi_1 & 0 & a_{23}\Phi_2 \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} s_{25} \\ s_{26} \\ s_{70} \end{pmatrix}$$

s_i: singlets, Φ_i: blowup modes

$\to$ four s_i remain massless

- we indeed see those four states
- R-parity violating couplings surpressed by volume

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Anomalies

Orbifold Anomaly:

$$I_6^{\mathrm{Orb}} \propto F_{\mathrm{Anom}} \underbrace{\left(\operatorname{tr} R^2 + \operatorname{tr} F_{SU(3)}^2 + \operatorname{tr} F_{SU(2)}^2 + \operatorname{tr} F_{SO(10)}^2 + \sum_i F_i^2 \right)}_{X_4^{\mathrm{orb}}}$$

Resolution Anomaly:

$$I_6^{\mathrm{BU}} \propto a_1 F_1 \operatorname{tr} R^2 + a_2 F_2 \left(\operatorname{tr} F_{SU(3)}^2 + \operatorname{tr} F_{SU(2)}^2 \right) + a_3 F_3 \operatorname{tr} F_{SO(10)}^2 + c_{ijk} F_i F_j F_k$$

Resolution Anomaly

- orbifold perspective: anomaly changes due to redefinitions

$$I_6^{\mathrm{BU}} = I_6^{\mathrm{Orb}} + I_6^{\mathrm{red}}$$

I_6^{red} canceled by BU-modes: $\sum_r \tau_r X_4^{\mathrm{red,r}}$

- resolution perspective: from 10D

$$I_{12} = X_4 X_8 = X_{4,0} X_{2,6} + X_{2,2} X_{4,4}$$

$$I_6^{\mathrm{BU}} = \int I_{12} = X_2^{\mathrm{uni}} X_4^{\mathrm{uni}} + \sum_r X_2^r X_4^r$$

cancelled by universal and local axion couplings:

$$a^{\mathrm{uni}} X_4^{\mathrm{uni}} + \sum_r \beta^r X_4^r$$

Anomaly Matching

- relating both sides gives

$$a^{\mathrm{Orb}} X_4^{\mathrm{Orb}} + \sum_r \tau_r X_4^{\mathrm{red,r}} = a^{\mathrm{uni}} X_4^{\mathrm{uni}} + \sum_r \beta^r X_4^r$$

- solution: relation between axions
  - local axions = BU modes

$$\beta^r \propto \tau_r$$

  - universal axion gets redefined

$$a^{\mathrm{uni}} \propto a^{\mathrm{Orb}} + c_r \tau_r$$

Conclusions

- compate Orbifold and resolution models
- spectrum match by local properties
- non-local influence on Yukawa couplings
- redefinition of states / axions
- confirmation via match of anomalies