Local Phenomenological Models in M-Theory and F-Theory

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[arXiv:0905.0142], [arXiv:0901.3785], [arXiv:0706.3364], [arXiv:0804.1132], [arXiv:0704.0445], and [arXiv:0704.0444]

String Phenomenology 2009, Warsaw

16th June 2009

String Phenomenology 2009, Warsaw Local Phenomenological Models in M-Theory and F-Theory

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Outline

Building Blocks and Global Architecture

- An Engineer's Guide to Model Building in F/M-Theory
- Local Structural Engineering: A Group-Theoretic Classification of Locally-Engineered Effective Theories
- Global Architecture: The Ubiquity and Uniqueness of E_8
- 2 Unfolding The Standard Model Out of E_8
 - Geometric Analogues to Grand Unification
 - Physics from Geometry:
 - Novel Approaches to Model Building
 - Examples with Monodromies: The Diamond Ring of F-Theory
- 3 Conclusions and Future Directions

An Engineer's Guide to Model Building in F/M-Theory Local Structural Engineering: Effective Theories of Local Models Global Architecture: The Ubiquity and Uniqueness of E_8

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An Engineer's Toolbox: the Basic Building Blocks

Gauge symmetries arise via co-dim 4 'ADE'-type orbifold singularities

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- F-theory: these are 'curves' (Riemann surfaces) in the co-dim 4 singular surface (think D7-branes)
- only curves with non-vanishing flux generate chiral matter, making 'exotic' matter curves relatively easy to ignore.
 - allows a single curve to support multiple 'generations'
 - allows for a nice solution to doublet-triplet splitting



an E_7 'matter-curve' can support a massless **27** of E_6

Local Phenomenological Models in M-Theory and F-Theory

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 - makes M-theory models relatively more constrained (and hence predictive)
 - softens flavour problems



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a conical E_7 -singularity can support a massless **27** of E_6

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 - notice that both structures appear topologically nongeneric, but they are in fact additional in ALE-florations



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origin of a 27 27 27 coupling in F-theory.

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Notice some very generic features of any such superpotential:

- sparse
 - ubiquitous U₁'s: think of the extra 'flavour-branes' which must intersect along each matter-curve;
- hierarchical
 - coefficients are typically exponentially suppressed



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Correspondence of Local Geometries for F-Theory and M-Theory

• For any local model, the most important topological data to have is:

- a list of all (potentially-massless-)matter-supporting singularities, and
- the selection rules which determine how matter living along these singularities can interact in the theory
- This data can be encoded in F-theory by a cartoon-collection of mutuallyintersecting matter-curves



- These models are constructed explicitly as ALE-fibrations over an appropriate base W, e.g. $\widehat{E_8}(a(W), b(W), 0, 0, 0, 0, 0, 0)$
- Any local geometry constructed in this way for F-theory can be immediately translated into a corresponding geometry for M-theory, with the same matter-singularities and interactions
- It is not hard to classify all possible 'cartoons' that can arise from a local ALE-fibration leading to an extremely small landscape of possibilities

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- Recall that the new light degrees of freedom arising from an ALE-fibration are due to 2-branes wrapping vanishing cycles within the ALE-fibres.
- The correspondence between two-cycles in the ALE-space \widehat{G} and the root lattice of the ADE-group G then leads to the following:
 - A generic * G
 -fibred Calabi-Yau four-fold or G
 -fibred G₂ manifold for which the typical fibre has a singularity of type H ⊂ G will have one matter-singularity for each vector-like representation in the branching:

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$$\operatorname{adj}(G) = \operatorname{adj}\left(H \times \prod_{i=1}^{k} U_{1}\right) \bigoplus \left(\mathbf{R}_{\vec{q}} \oplus \overline{\mathbf{R}}_{-\vec{q}}\right).$$

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for example, $E_8 \supset E_6 \times U_1^a \times U_1^b$:

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Spectrum of Matter-Curves



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Spectrum of Matter-Curves





Local Phenomenological Models in M-Theory and F-Theory

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T_1	M_1	H_1^u	H_1^d	ν_1^c	S_1	N_1
T_2	M_2					



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T_1	M_1	H_1^u	H_1^d	ν_1^c	S_1	N_1
T_2	M_2		H_2^d			



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T_1	M_1	H_1^u	H_1^d	ν_1^c	S_1	N_1	
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T_3	M_3						
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T_1	M_1	H_1^u	H_1^d	ν_1^c	S_1	N_1	
T_2	M_2	H_2^u	H_2^d	ν_2^c	S_2	N_2	
T_3	M_3	H_3^u	H_3^d	ν_3^c	S_3	N_3	
T_X	M_X	Ŭ	ν_X^c	, in the second s			
T_X^c							
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Local Phenomenological Models in M-Theory and F-Theory

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8

The matter content of a general E_8 -fibred geometry can be derived by thinking in terms of sequential 'unfoldings':



	$E_6 \times$	$U_1^a \times$	U_1^b
T_1	27	1	1
T_2	27	1	-1
T_3	27	-2	0
S_1	1	3	$^{-1}$
S_3	1	3	1
S_2	1	0	2

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	$E_6 \times$	$U_1^a \times$	U_1^b
T_1	27	1	1
T_2	27	1	-1
T_3	27	-2	0
S_1	1	3	$^{-1}$
S_3	1	3	1
S_2	1	0	2

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8

The matter content of a general E_8 -fibred geometry can be derived by thinking in terms of sequential 'unfoldings':



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'Unfolding' Three Generations out of E_8

The matter content of a general E_8 -fibred geometry can be derived by thinking in terms of sequential 'unfoldings':



$SO_{10} \times U_1^a \times U_1^b \times U_1^c$				
T_1	16	1	1	-1
T_2	16	1	-1	-1
T_3	16	-2	0	$^{-1}$
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	-1	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	-1	0
S_1	1	3	1	0
S_2	1	0	2	0

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T_2	16	1	-1	$^{-1}$
T_3	16	-2	0	$^{-1}$
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	$^{-1}$	1	-2
Y_b	10	2	0	-2
X_1	1	$^{-1}$	-1	4
X_2	1	$^{-1}$	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	-1	0
S_1	1	3	1	0
S_2	1	0	2	0

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Local Phenomenological Models in M-Theory and F-Theory

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8

The matter content of a general E_8 -fibred geometry can be derived by thinking in terms of sequential 'unfoldings':



$SO_{10} \times U_1^a \times U_1^b \times U_1^c$					
T_1	16	1	1	-1	
T_2	16	1	-1	$^{-1}$	
T_3	16	-2	0	$^{-1}$	
T_X^c	$\overline{16}$	0	0	-3	
H	10	1	1	2	
Y_a	10	-1	1	-2	
Y_b	10	2	0	-2	
X_1	1	-1	-1	4	
X_2	1	-1	1	4	
N_2^c	1	-2	0	-4	
N_3^c	1	3	-1	0	
S_1	1	3	1	0	
S_2	1	0	2	0	

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T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	-1	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	-1	0
S_1	1	3	1	0
S_2	1	0	2	0

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The matter content of a general E_8 -fibred geometry can be derived by thinking in terms of sequential 'unfoldings':



	SO_{10}	$_0 \times U_1^a$	$\times U_1^b$	$\times U_1^c$
T_1	16	1	1	-1
T_2	16	1	-1	$^{-1}$
T_3	16	-2	0	-1
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	-1	$^{-1}$	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	$^{-1}$	0
S_1	1	3	1	0
S_2	1	0	2	0
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'Unfolding' Three Generations out of E_8

The matter content of a general E_8 -fibred geometry can be derived by thinking in terms of sequential 'unfoldings':



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	SO_{10}	$_0 \times U_1^u$	$\times U_1^0$	$\times U_1^c$
T_1	16	1	1	-1
T_2	16	1	-1	-1
T_3	16	-2	0	-1
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	-1	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	-1	0
S_1	1	3	1	0
S_2	1	0	2	0

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	SO_1	$_0 \times U_1^a$	$\times U_1^b$	$\times U_1^c$
T_1	16	1	1	-1
T_2	16	1	-1	$^{-1}$
T_3	16	-2	0	$^{-1}$
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	$^{-1}$	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
$N_3^{\overline{c}}$	1	3	$^{-1}$	0
S_1	1	3	1	0
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X_2	1	-1	1	4
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S_1	1	3	1	0
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T_3	16	-2	0	$^{-1}$
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H	10	1	1	2
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Y_b	10	2	0	-2
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T_2	16	1	-1	$^{-1}$
T_3	16	-2	0	$^{-1}$
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	$^{-1}$	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
$N_3^{\overline{c}}$	1	3	$^{-1}$	0
S_1	1	3	1	0
S_2	1	0	2	0

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T_1	16	1	1	-1		
T_2	16	1	-1	-1		
T_3	16	-2	0	-1		
T_X^c	$\overline{16}$	0	0	-3		
H	10	1	1	2		
Y_a	10	-1	1	-2		
Y_b	10	2	0	-2		
X_1	1	-1	-1	4		
X_2	1	-1	1	4		
N_2^c	1	-2	0	-4		
N_3^c	1	3	-1	0		
S_1	1	3	1	0		
S_2	1	0	2	0		

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T_X^c	$\overline{16}$	0	0	-3		
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Y_a	10	-1	1	-2		
Y_b	10	2	0	-2		
X_1	1	-1	-1	4		
X_2	1	-1	1	4		
N_2^c	1	-2	0	-4		
N_3^c	1	3	-1	0		
S_1	1	3	1	0		
S_2	1	0	2	0		

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Y_b	10	2	0	-2		
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X_2	1	-1	1	4		
N_2^c	1	-2	0	-4		
N_3^c	1	3	-1	0		
S_1	1	3	1	0		
S_2	1	0	2	0		

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Y_b	10	2	0	-2		
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X_2	1	-1	1	4		
N_2^c	1	-2	0	-4		
N_3^c	1	3	-1	0		
S_1	1	3	1	0		
S_2	1	0	2	0		

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T_X^c	$\overline{16}$	0	0	-3		
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Y_a	10	-1	1	-2		
Y_b	10	2	0	-2		
X_1	1	-1	-1	4		
X_2	1	-1	1	4		
N_2^c	1	-2	0	-4		
N_3^c	1	3	-1	0		
S_1	1	3	1	0		
S_2	1	0	2	0		

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	SO_{10}	$_0 \times U_1^a$	$\times U_1^b$	$\times U_1^c$
T_1	16	1	1	-1
T_2	16	1	-1	-1
T_3	16	-2	0	-1
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	-1	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	-1	0
S_1	1	3	1	0
S_2	1	0	2	0

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Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	-1	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	-1	0
S_1	1	3	1	0
S_2	1	0	2	0

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	SO_{10}	$_0 \times U_1^a$	$\times U_1^b$	$\times U_1^c$
T_1	16	1	1	-1
T_2	16	1	-1	-1
T_3	16	-2	0	-1
T_X^c	$\overline{16}$	0	0	-3
H	10	1	1	2
Y_a	10	-1	1	-2
Y_b	10	2	0	-2
X_1	1	-1	-1	4
X_2	1	-1	1	4
N_2^c	1	-2	0	-4
N_3^c	1	3	-1	0
S_1	1	3	1	0
S_2	1	0	2	0

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'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	ŏ	-2^{-2}	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2^{1}	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_2^{c}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_{2}^{c}	1	3	$^{-1}$	0	0
$T_{\mathbf{v}}^{c}$	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



			1		
	SU_5	$\times U_1^a \times$	$U_1^o \times$	$U_1^c \times$	U_1^a
T_1	10	1	1	-1	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	$^{-1}$	$^{-1}$	3
M_3	5	-2	0	$^{-1}$	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
Y_1^c	5	2	0	-2	-2
Y_2^{\perp}	5	2	0	-2	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_2^{c}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	-3	5
N_2^t	1	$^{-2}$	0	-4	0
N_3^c	1	3	-1	0	0
$T_{\mathbf{x}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SUE	$\times U_{*}^{a} \times$	$U_{4}^{b} \times$	$U^{c}_{4} \times$	U^d_{\star}
T_1	10	1	1	-1	-1
T_{0}^{1}	10	1	-1	_1	_1
T_{0}^{12}	10	_2	¹	_1	_1
13 M.	ŧ	ĩ	1	_1	3
Ma	F	1	_1	_1	3
M	문	1	-1	-1	
1113	2	-2	1	-1	3
H	<u> </u>	1	1	2	2
H^{u}	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	$^{-2}$	-2
Y_2	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	$^{-2}$	-2
X_1^2	1	-1	$^{-1}$	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_{2}^{c}	1	-2	0	-1	-5
N_1^{e}	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_{2}^{c}	1	3	-1	0	0
T_{v}^{c}	10	0	0	$^{-3}$	1
T_{Y}^{Λ}	10	0	0	0	4
M_{Y}^{c}	5	Ő	Ó	-3	-3
S_1	1	3	ĩ	ŏ	ŏ
S_2^1	1	Ő	2	Ó	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_{2}	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	$-\hat{1}$	î	$-\bar{2}$	2
Y_{c}^{1}	5	2	0	-2^{-2}	-2
Y_2	5	2	ŏ	$-\bar{2}$	2
V_{c}^{2}	5	-1	ĩ	-2	-2
X_{1}^{2}	1	-1	-1	4	õ
X_2	ĩ	-1	î	4	ŏ
12 Z	ĩ	î	1	-1	$-\tilde{5}$
ve	1	1	-1	-1	$-\tilde{5}$
ν_{0}^{c}	ī	-2	õ	-1	$-\tilde{5}$
N_1^{e}	1	0	0	-3	5
N_2^{t}	1	-2	0	$^{-4}$	0
N_2^{ϵ}	1	3	-1	0	0
T_{v}^{c}	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
$M_{\mathbf{Y}}^{\hat{c}}$	5	0	0	-3	-3
S_1^{Λ}	1	3	1	0	0
S_2^{\uparrow}	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_{2}^{1}	5	1	$^{-1}$	-1	3
M_2	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	_2
Y_1	5	-1	1	$-\tilde{2}$	2
Y_{i}^{c}	5	2	Ō	-2^{-2}	-2
Y_2	5	2	ŏ	$-\bar{2}$	2
V_c^2	5	-1	ĩ	-2	_2
X_{1}^{2}	1	-1	-1	4	õ
Xa	ĩ	-1	1	4	ŏ
11 2 V.C	ĩ	î	1	-1	-5
"t	ĩ	î	-1	-1	-5
ν_{0}^{c}	ī	-2	õ	-1	$-\tilde{5}$
N_1^{e}	1	0	0	-3	5
N_2^{t}	1	-2	0	$^{-4}$	0
N_2^{ϵ}	1	3	-1	0	0
$T_{\mathbf{v}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
$M_{\mathbf{y}}^{\hat{c}}$	5	0	0	-3	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	õ	-2^{-2}	2
Y_{c}^{c}	5	-1	ĩ	-2	-2
X_1^2	1	-1	$-\hat{1}$	4	õ
X_2	1	-1	1	4	õ
$\nu_1^{\hat{c}}$	1	1	1	-1	$-\tilde{5}$
ve	1	1	-1	-1	$-\tilde{5}$
ν_{0}^{c}	ī	-2	õ	-1	$-\tilde{5}$
N_1^{e}	1	0	0	-3	5
N_2^t	1	-2	0	-4	0
N_2^{ϵ}	1	3	-1	0	0
T_{v}^{c}	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
$M_{\mathbf{Y}}^{\hat{c}}$	5	0	0	-3	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

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'Unfolding' Three Generations out of E_8

The matter content of a general E_8 -fibred geometry can be derived by thinking in terms of sequential 'unfoldings':

Unfolding $SO_{10} \rightarrow SU_5$

	SU_5	$\times U_1^a \times$	$U_1^b \times$	U_1^c	$\langle U_1^d$
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	-1	3
M_{2}	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	î	$-\overline{2}$	$\overline{2}$
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	õ	-2^{-2}	2
Y_{0}^{c}	5	-1	1	-2^{-2}	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_2^{c}	1	-2	0	$^{-1}$	-5
N_1^c	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
T_X^c	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	$^{-1}$	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_{2}	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^{d}	5	1	1	2	_2
V_1	5	_1	1	$-\tilde{2}$	2
V^{c}	Ĕ	2	0	_2	_2
V_{2}^{1}	5	2	0	-2	2
V^{c}	F	1	1	-2	2
V_{1}^{1}	1	-1	1	-2	-2
X 1	1	-1	1	4	0
22	1	1	1	1	5
μt	1	1	1	-1	-5
22	1	_2	-1	_1	-5
N2	1	-2	0	-1	-5
Nt	1	2	0	-3	0
N2	1	-2	_1	-4	0
	10	0	-1	2	1
$T_T^{I}X$	10	0	0	-3	1
1 X	10	0	0	0	4
^{IVI} X	ə 1	2	1	-3	-3
51	1	3	1	0	0
s_2	T	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a$	$\langle U_1^b \times$	U_1^c	$\langle U_1^d$
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
$\nu_2^{\hat{c}}$	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	-1	0	0
$T_{\mathbf{Y}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a$	$\langle U_1^b \times$	U_1^c	$\langle U_1^d$
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	$^{-2}$	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
$\nu_2^{\hat{c}}$	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	-1	0	0
$T_{\mathbf{Y}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a$	$\langle U_1^b \times$	U_1^c	$\langle U_1^d$
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	$^{-2}$	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
$\nu_2^{\hat{c}}$	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	-1	0	0
$T_{\mathbf{Y}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a$	$\langle U_1^b \times$	U_1^c	$\langle U_1^d$
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	$^{-2}$	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
$\nu_2^{\hat{c}}$	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	-1	0	0
$T_{\mathbf{Y}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

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'Unfolding' Three Generations out of E_8



	SU_5	$\times U_1^a$	$\langle U_1^b \times$	U_1^c	$\langle U_1^d$
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	$^{-2}$	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
$\nu_2^{\hat{c}}$	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	-1	0	0
$T_{\mathbf{Y}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	$-\hat{1}$	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	ŏ	-2^{-2}	2
Y_{0}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	$^{-1}$	-5
ν_{2}^{t}	1	1	-1	$^{-1}$	-5
ν_2^{c}	1	-2	0	-1	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
$N_3^{\tilde{c}}$	1	3	$^{-1}$	0	0
T_{Y}^{c}	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	$-\hat{1}$	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2^{-2}	2
Y_{0}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	$^{-1}$	-5
ν_{2}^{t}	1	1	-1	$^{-1}$	-5
ν_2^{c}	1	-2	0	-1	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
$N_3^{\tilde{c}}$	1	3	$^{-1}$	0	0
T_{Y}^{c}	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	$-\hat{1}$	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	ŏ	-2^{-2}	2
Y_{0}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	$^{-1}$	-5
ν_{2}^{t}	1	1	-1	$^{-1}$	-5
ν_2^{c}	1	-2	0	-1	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
$N_3^{\tilde{c}}$	1	3	$^{-1}$	0	0
T_{Y}^{c}	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	$-\hat{1}$	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2^{-2}	2
Y_{0}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	$^{-1}$	-5
ν_{2}^{t}	1	1	-1	$^{-1}$	-5
ν_2^{c}	1	-2	0	-1	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
$N_3^{\tilde{c}}$	1	3	$^{-1}$	0	0
T_{Y}^{c}	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	$-\hat{1}$	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2^{-2}	2
Y_{0}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	$^{-1}$	-5
ν_{2}^{t}	1	1	-1	$^{-1}$	-5
ν_2^{c}	1	-2	0	-1	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
$N_3^{\tilde{c}}$	1	3	$^{-1}$	0	0
T_{Y}^{c}	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology

- The freedom to 'conjugate' fields is quite unusual in traditional unified model building, but leads to powerful new phenomenological mechanisms.
- For any non-trivial choice of fluxes, there are always anomalous *U*₁-symmetries, which become Higgsed by the Green-Schwarz mechanism, which also generates mass-terms for some fields: 'vacuum realignment.'
- By choosing fluxes appropriately, one can find models that are surprisingly realistic in both M-Theory and F-Theory.

	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_{2}	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	$-\hat{1}$	î	$-\bar{2}$	2
Y.C	5	2	0	-2^{-2}	-2
Y_2	5	2	ŏ	$-\bar{2}$	2
V_{c}^{2}	5	-1	ĭ	-2	_2
X_{1}^{2}	1	-1	-1	4	õ
Xa	ĩ	-1	1	4	ŏ
$\nu_1^{\hat{c}}$	1	1	1	-1	-5
ve	1	1	-1	-1	-5
ν_{0}^{c}	ī	-2	õ	-1	$-\tilde{5}$
N_1^{e}	1	0	0	-3	5
N_{2}^{t}	1	-2	0	$^{-4}$	0
N_{2}^{c}	1	3	-1	0	0
T_{V}^{c}	10	0	0	-3	1
T_{Y}^{Λ}	10	0	0	0	4
M_{Y}^{c}	5	Ő	Ó	-3	-3
S_1	1	3	í	Ő	0
S_2^1	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology

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	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	$-\hat{1}$	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	$^{-1}$	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	õ	-2^{-2}	2
Y_{0}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	-1	-1	4	0
X_2^{1}	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_{2}^{t}	1	1	$^{-1}$	-1	-5
ν_2^{c}	1	-2	0	-1	-5
N_1^2	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_{2}^{τ}	1	3	-1	0	0
$T_{\mathbf{v}}^{c}$	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	-3	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Realistic Examples of Phenomenology

- The freedom to 'conjugate' fields is quite unusual in traditional unified model building, but leads to powerful new phenomenological mechanisms.
- For any non-trivial choice of fluxes, there are always anomalous *U*₁-symmetries, which become Higgsed by the Green-Schwarz mechanism, which also generates mass-terms for some fields: 'vacuum realignment.'
- By choosing fluxes appropriately, one can find models that are surprisingly realistic in both M-Theory and F-Theory.

	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	$^{-1}$	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
Y_1^c	5	2	0	$^{-2}$	-2
Y_2^1	5	2	0	-2	2
Y_2^c	5	-1	1	$^{-2}$	-2
X_1^2	1	-1	-1	$\overline{4}$	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_3^{t}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
T_X^c	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0
Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Re-Folding the Geometry to Enforce Couplings

• The choice of fluxes listed in the table on the right would generate a superpotential of the form:

	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	-1	-1^{-1}
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
$Y_1^{\hat{c}}$	5	2	0	-2	-2
Y_2^1	5	2	0	$^{-2}$	2
$Y_2^{\tilde{c}}$	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_{3}^{t}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
(T_X^c)	$\overline{10}$	0	0	$^{-3}$	1)
(T_X)	10	0	0	0	4)
(M_X^c)	5	0	0	$^{-3}$	-3)
$(S_1$	1	3	1	0	0)
$(S_2$	1	0	2	0	0)

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Re-Folding the Geometry to Enforce Couplings

• The choice of fluxes listed in the table on the right would generate a superpotential of the form:

$$W = T_2 T_3 H^u + T_2 M_3 H^d + T_3 M_2 H^d + H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c + X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c + X_2 N_2^c N_3^c.$$

	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	$^{-2}$	-2
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	$^{-2}$	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^c	1	1	-1	-1	-5
$\nu_3^{\overline{c}}$	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	-3	5
N_2^c	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
(T_X^c)	10	0	0	$^{-3}$	1)
(T_X)	10	0	0	0	4)
(M_X^c)	5	0	0	$^{-3}$	-3)
$(S_1$	1	3	1	0	0)
$(S_2$	1	0	2	0	0)

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Re-Folding the Geometry to Enforce Couplings

 The choice of fluxes listed in the table on the right would generate a superpotential of the form:

$$W = T_2 T_3 H^u + T_2 M_3 H^d + T_3 M_2 H^d$$

+ $H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c$
+ $X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c$
+ $X_2 N_2^c N_3^c$.



Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Re-Folding the Geometry to Enforce Couplings

• The choice of fluxes listed in the table on the right would generate a superpotential of the form:

$$W = T_2 T_3 H^u + T_2 M_3 H^d + T_3 M_2 H^d$$

+ $H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c$
+ $X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c$
+ $X_2 N_2^c N_3^c$.



Notice that T_1 and M_1 do not appear in the superpotential at all!

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Re-Folding the Geometry to Enforce Couplings

• The choice of fluxes listed in the table on the right would generate a superpotential of the form:

$$W = T_2 T_3 H^u + T_2 M_3 H^d + T_3 M_2 H^d + H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c + X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c + X_2 N_2^c N_3^c.$$

Notice that T_1 and M_1 do not appear in the superpotential at all!

	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c >$	$\langle U_1^d$
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	$^{-1}$	-1	3
M_3	5	-2	0	-1	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	$^{-2}$	-2
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	$^{-2}$	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_{2}^{t}	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^c	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	$^{-1}$	0	0
$ (T_X^c)$	10	0	0	$^{-3}$	1)
(T_X^A)	10	0	0	0	4)
(M_X^c)	5	0	0	$^{-3}$	-3)
$(S_1$	1	3	1	0	0)
$(S_2$	1	0	2	0	0)

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Re-Folding the Geometry to Enforce Couplings

 The choice of fluxes listed in the table on the right would generate a superpotential of the form:

$$W = T_2 T_3 H^u + T_2 M_3 H^d + T_3 M_2 H^d + H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c + X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c + X_2 N_2^c N_3^c.$$

Consider the operator $T_1 T_1 H^u$, it has charges (3, 3, 0, 0) under $U_1^a \times U_1^b \times U_1^c \times U_1^d$.

	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
$Y_1^{\hat{c}}$	5	2	0	$^{-2}$	-2
Y_2^1	5	2	0	$^{-2}$	2
$Y_2^{\tilde{c}}$	5	-1	1	$^{-2}$	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	$^{-1}$	-5
$\nu_3^{\overline{c}}$	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	-3	5
N_2^c	1	-2	0	$^{-4}$	0
N_3^c	1	3	$^{-1}$	0	0
(T_X^c)	10	0	0	-3	1)
(T_X)	10	0	0	0	(4)
(M_X^c)	5	0	0	$^{-3}$	-3)
$(S_1$	1	3	1	0	0)
$(S_2$	1	0	2	0	0)

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

Re-Folding the Geometry to Enforce Couplings

 The choice of fluxes listed in the table on the right would generate a superpotential of the form:

$$W = T_2 T_3 H^u + T_2 M_3 H^d + T_3 M_2 H^d + H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c + X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c + X_2 N_2^c N_3^c.$$

Consider the operator $T_1 T_1 H^u$, it has charges (3,3,0,0) under $U_1^a \times U_1^b \times U_1^c \times U_1^d$.

	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	$^{-2}$	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	$^{-1}$	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
$Y_1^{\hat{c}}$	5	2	0	$^{-2}$	-2
Y_2^1	5	2	0	$^{-2}$	2
$Y_2^{\tilde{c}}$	5	-1	1	$^{-2}$	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	$^{-1}$	-5
ν_2^t	1	1	$^{-1}$	-1	-5
$\nu_3^{\overline{c}}$	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^c	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
(T_X^c)	$\overline{10}$	0	0	$^{-3}$	1)
(T_X)	10	0	0	0	4)
(M_X^c)	5	0	0	$^{-3}$	-3)
$(S_1$	1	3	1	0	0)
$(S_2$	1	0	2	0	0)

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$

Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\overline{2}$	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2^{-2}	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_{2}^{t}	1	1	-1	-1	-5
$\nu_2^{\hat{c}}$	1	-2	0	-1	-5
N_1^c	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	-1	0	0
$T_{\mathbf{v}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

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 Local Phenomenological Models in M-Theory and F-Theory

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	-2	$^{-2}$
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	-2	$^{-2}$
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	$^{-1}$	-5
ν_2^t	1	1	-1	$^{-1}$	-5
ν_3^{t}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^c	1	-2	0	$^{-4}$	0
N_3^c	1	3	$^{-1}$	0	0
T_X^c	$\overline{10}$	0	0	-3	1
T_X	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	$^{-1}$	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	$^{-1}$	-5
ν_2^t	1	1	-1	$^{-1}$	-5
ν_3^{t}	1	-2	0	-1	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^c	1	-2	0	-4	0
N_3^c	1	3	$^{-1}$	0	0
T_X^c	$\overline{10}$	0	0	-3	1
T_X	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	$^{-1}$	-5
ν_2^t	1	1	-1	$^{-1}$	-5
ν_3^{t}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^c	1	-2	0	$^{-4}$	0
N_3^c	1	3	$^{-1}$	0	0
T_X^c	$\overline{10}$	0	0	-3	1
T_X	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	$^{-1}$	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	-2	$^{-2}$
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	-2	$^{-2}$
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	$^{-1}$	-5
ν_2^t	1	1	-1	$^{-1}$	-5
ν_3^{t}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^c	1	-2	0	-4	0
N_3^c	1	3	$^{-1}$	0	0
T_X^c	$\overline{10}$	0	0	-3	1
T_X	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	$^{-1}$	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	î	$-\bar{2}$	2
Y^{c}	5	2	0	-2^{-2}	-2
Y_2	5	2	ŏ	-2^{-2}	2
V_{c}^{2}	<u> </u>	-1	ĩ	-2	-2
X_{1}^{2}	1	-1	-1	4	õ
Xa	ĩ	-1	î	4	ŏ
<i>V</i> ^C	ĩ	1	î	-1	$-\tilde{5}$
ve	ĩ	1	-1	-1	-5
ν_{c}^{c}	ĩ	-2^{-1}	ō	$-\hat{1}$	$-\tilde{5}$
N_1^c	1	0	ŏ	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_{2}^{ϵ}	1	3	-1	0	0
T_{V}^{c}	10	0	0	-3	1
$T_{\mathbf{Y}}^{X}$	10	Ő	Ó	Ó	4
$M_{\mathbf{v}}^{c}$	5	Ő	Ó	-3	-3
S_1	1	3	í	Ó	0
S_2	1	0	2	Ó	0
$\stackrel{S_1}{S_2}$	î	0	2	0	0

Local Phenomenological Models in M-Theory and F-Theory

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SUr	$\times U^a_* \times$	$U_{*}^{b} \times$	$U_{4}^{c} \times$	U^d_{\star}
T_1	10	1	1	-1	-1
T_{2}	10	1	-1	-1	-1
T_2^2	10	-2^{-1}	ō	-1	-1
M_1	Ē	1	ĩ	-1	3
Mo	ğ	1	-1	_1	3
Mo	5	_2	0	_1	3
H^{u}	5	ĩ	1	2	2
IId	÷	1	1	2	2
N.	- Э Б	1	1	2	-2
I1 VC	글	-1	1	-2	4
Y1	5	2	0	-2	-2
Y2	<u>-</u>	2	0	-2	2
Y_2	5	-1	1	-2	-2
A1 V	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_{\tilde{1}}$	1	1	1	-1	-5
$\nu_{\tilde{2}}$	1	1	-1	-1	-5
$\nu_{\tilde{3}}$	1	-2	0	-1	-5
NL	1	0	0	-3	5
N ₂	1	-2	0	-4	0
N 3	1	3	-1	0	0
T_X	10	0	0	-3	1
T_X	10	0	0	0	4
$M_{\alpha X}^{\circ}$	Б	0	0	-3	-3
S_1	T	3	1	0	U
S_2	T	0	2	0	U

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	$-\hat{1}$	î	$-\bar{2}$	2
Y_1^c	5	2	0	-2^{-2}	-2
Y_2	5	2	õ	-2^{-2}	2
Y_{0}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	$-\hat{1}$	$-\hat{1}$	4	õ
X_2^{1}	1	-1	1	4	0
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_{2}^{t}	1	1	$^{-1}$	-1	-5
ν_{2}^{c}	1	-2	0	-1	-5
N_1^c	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_{2}^{τ}	1	3	-1	0	0
$T_{\mathbf{Y}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Local Phenomenological Models in M-Theory and F-Theory

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	an		T T b	T.T.C	r.d.
	SU_5	$\times U_1 \times$	$U_1 \times$	$U_1 \times$	U_1^{-}
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	$^{-1}$	$^{-1}$	3
M_3	5	-2	0	$^{-1}$	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_2^{c}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{τ}	1	3	$^{-1}$	0	0
T_{Y}^{c}	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	-3	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Local Phenomenological Models in M-Theory and F-Theory

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	î	$-\hat{1}$	-1
T_2	10	1	$^{-1}$	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	$^{-1}$	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	0	-2	2
Y_2^c	5	-1	1	$^{-2}$	-2
X_1^2	1	-1	-1	$\overline{4}$	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_3^{t}	1	$^{-2}$	0	$^{-1}$	-5
N_1^e	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
T_{X}^{c}	$\overline{10}$	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	-3	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0
S_1 S_2	5 1 1	0 3 0		$-3 \\ 0 \\ 0$	$-3 \\ 0 \\ 0$

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	CIL	, ITA V	TTP Y	TTC V	$T^{T}d$
	505	× 0 ₁ ×	U ₁ ×	U ₁ ×	v_1
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	$^{-1}$	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
Y_1^c	5	2	0	-2	-2
Y_2^1	5	2	ŏ	-2^{-2}	2
Y_{c}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	-1	$-\hat{1}$	4	õ
X_2	1	-1	1	4	õ
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_{0}^{t}	1	1	-1	-1	-5
ν_{0}^{t}	1	-2	0	-1	-5
N_1^2	1	0	0	-3	5
N_2^{t}	1	-2	0	-4	0
N_{2}^{c}	1	3	-1	0	0
T_{v}^{c}	10	0	0	$^{-3}$	1
T_{Y}^{Λ}	10	0	0	0	4
M_{V}^{c}	5	Ó	Ó	-3	-3
S1	1	3	ĭ	õ	ŏ
S_2^1	1	õ	2	ő	ŏ

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	CII	v tra v	TTP V	ITC V	IId
	505	<u>× 0₁ ×</u>	U1X	$U_1 \times$	v_1
T_1	10	1	1	$^{-1}$	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\tilde{2}$	2
V_{c}^{1}	Ē	2	ō	-2	-2
V_0^{11}	5	2	ŏ	-2	2
V^{c}	Ĕ	_1	1	_2	_2
X^{1}	1	_1	_1	-2	-2
X 1	1	_1	-1	4	0
20	1	1	1	_1	-5
ž	1	1	1	-1	5
22	1	_2	-1	_1	-5
N2	1	-2	0	- 3	-5
w.t	1	2	0	-3	0
N2	1	-2	_1	-4	0
	10	0	-1	2	1
$T^{I}X$	10	0	0	-3	1
1 X	10	0	0	2	4
$M_{C}X$	- D - 1	9	1	-3	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2^{-2}	2
Y_1^c	5	2	0	-2	-2
Y_2^{\perp}	5	2	0	-2	2
Y_{0}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	-1	-5
ν_2^{c}	1	-2	0	$^{-1}$	-5
N_1^{e}	1	0	0	$^{-3}$	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
T_X^c	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	SUr	$\times U^a_* \times$	$U_{4}^{b} \times$	$U^{c}_{\star} \times$	U^d_{*}
T_1	10	1	1	-1	-1
T_0	10	1	_1	-1	_1
T_{0}^{12}	10	_2	¹	_1	_1
13 M.	Ē	1	1	1	2
Ma	Ĕ	1	_1	_1	3
M	문	1	-1	-1	3
1113	5	-2	1	-1	3
п d	<u>-</u>	1	1	4	4
H^{u}	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	$^{-2}$	-2
Y_2	5	2	0	-2	2
Y_2^c	5	-1	1	$^{-2}$	-2
X_1	1	-1	-1	4	0
X_2	1	-1	1	4	0
ν_1^c	1	1	1	-1	-5
ν_2^c	1	1	$^{-1}$	$^{-1}$	-5
ν_3^c	1	-2	0	-1	-5
N_1^c	1	0	0	-3	5
N_2^c	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
T_X^c	$\overline{10}$	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	-3	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

Local Phenomenological Models in M-Theory and F-Theory

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SUL	V U ^a V	$U^b \times$	UC V	U^d
T	10	<u>^ 01 ^</u>	1	1	1
I_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	-1	3
M_3	5	-2	0	-1	3
H^{u}	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	-2	2
Y_1^c	5	2	0	-2	-2
Y_2^{\dagger}	5	2	0	-2	2
Y_2^c	5	-1	1	-2	-2
X_1	1	-1	-1	4	0
X_2	1	-1	1	4	0
ν_1^c	1	1	1	$^{-1}$	-5
ν_2^t	1	1	-1	-1	-5
ν_{q}^{τ}	1	-2	0	$^{-1}$	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{c}	1	3	$^{-1}$	0	0
T_{X}^{c}	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2^{\uparrow}	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	$^{-1}$	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	$-\hat{1}$	î	$-\bar{2}$	2
Y^c	5	2	0	-2^{-2}	-2
Y_2	5	2	ŏ	$-\bar{2}$	2
V_{c}^{2}	5	-1	ĩ	-2	-2
X_{1}^{2}	1	-1	-1	4	õ
X_2	1	-1	1	4	õ
$\nu_1^{\hat{c}}$	1	1	1	-1	$-\tilde{5}$
,t	1	1	-1	-1	$-\tilde{5}$
ν_{c}^{c}	î	-2^{-1}	ō	$-\hat{1}$	$-\tilde{5}$
N_1^{e}	1	0	õ	-3	5
Nt	1	-2	õ	-4	õ
N_{0}^{c}	ī	3	-1	Ō	ŏ
T_{V}^{c}	10	0	0	-3	1
T_{Y}^{X}	10	Ő	Ó	Ó	4
M_{Y}^{c}	5	Ő	Ó	-3	-3
S_1	1	3	ĭ	ŏ	ŏ
S_2^1	1	0	2	Ó	0
- 4			-	,	-

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_{2}	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	ĩ	$-\bar{2}$	2
Y^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2^{-2}	2
Y_{c}^{c}	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	ō
X_2	1	-1	1	4	ŏ
$\nu_1^{\tilde{c}}$	1	1	1	-1	-5
ν_{2}^{t}	1	1	-1	-1	-5
ν_{2}^{c}	1	-2	0	-1	-5
N_1^2	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^{c}	1	3	$^{-1}$	0	0
$T_{\mathbf{v}}^{c}$	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
$M_{\mathbf{Y}}^{c}$	5	0	0	-3	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	$-\hat{1}$	î	$-\overline{2}$	2
Y_1^c	5	2	0	-2	-2
Y_2	5	2	ŏ	-2^{-2}	2
Y_{c}^{c}	5	-1	ĩ	-2^{-2}	-2
X_1^2	1	$-\hat{1}$	$-\hat{1}$	4	ō
X_2	1	-1	1	4	õ
$\nu_1^{\hat{c}}$	1	1	1	-1	$-\tilde{5}$
ν_{2}^{t}	1	1	-1	-1	-5
ν_{2}^{c}	1	-2	0	-1	-5
N_1^2	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_2^{c}	1	3	-1	0	0
$T_{\mathbf{v}}^{c}$	10	0	0	-3	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	-3	-3
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	$^{-1}$	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_{2}	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$-\tilde{2}$	2
V_{c}^{c}	5	2	ō	-2	-2
V_0^{11}	5	2	ő	-2	2
V^{c}	Ĕ	_1	1	_2	_2
X^{1}	1	-1	_1	-2	-2
X ₁	1	-1	1	4	0
12	1	1	1	_1	-5
ž	1	1	1	1	5
22	1	_2	-1	_1	-5
N2	1	-2	0	- 3	-5
NE	1	_2	0	-4	0
N^2	1	- 2	-1	-4	ő
TC	10	0	0	_3	1
T^{1}_{T}	10	0	0	-3	1
MC	10	0	0	2	2
^{WI} _S X	1	3	1	-3	-3
S1 S2	1	0	2	0	ő
\mathcal{S}_2	т	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	-1	3
M_2	5	1	$^{-1}$	-1	3
M_3	5	-2	0	-1	3
$H^{\breve{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	$-\hat{1}$	î	$-\bar{2}$	2
V_{c}^{c}	5	2	ō	-2	-2
V_0^{11}	5	2	ő	-2	2
V^{c}	Ĕ	_1	1	_2	_2
X_1^2	1	-1	-1	-2	-2
Xo	1	-1	1	4	ő
12	1	1	1	-1	-5
~t	1	1	-1	_1	-5
, e	1	_2	ň	-1	-5
N^{c}	î	ō	ŏ	-3	5
Nt	1	-2	ő	-4	ő
NC	î	3	-1	Ō	ŏ
T^{c}	$\frac{-}{10}$	ő	Ō	-3	ĩ
T_{U}^{T}	10	ő	ő	ő	4
M^{1}	5	0	0	-3	_3
S_1	1	3	1	0	ŏ
Sa	ĩ	õ	2	ő	ŏ
52	-	0		0	0

Local Phenomenological Models in M-Theory and F-Theory

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



			h		and
	SU_5	$\times U_1^u \times$	$U_1^0 \times$	$U_1^{c} \times$	U_1^u
T_1	10	1	1	-1	-1
T_2	10	1	-1	-1	-1
T_3	10	-2	0	-1	-1
M_1	5	1	1	-1	3
M_2	5	1	-1	-1	3
M_2	5	-2	0	-1	3
$H^{\widetilde{u}}$	5	1	ĩ	2	2
H^{d}	Ē	1	1	2	_2
V.	E E	_1	1	-2	-2
V^{c}	E	-1	0	-2	2
V^{I_1}	2 2	2	0	-2	-2
12 VC		2	1	-2	4
$\frac{Y_2}{V^2}$	Ð	-1	1	-2	-2
X_1	1	-1	-1	4	0
X_{2}	1	-1	1	4	0
ν_1^{\vee}	1	1	1	-1	-5
ν_2^{c}	1	1	-1	-1	-5
ν_3^c	1	-2	0	$^{-1}$	-5
N_1^c	1	0	0	-3	5
N_2^c	1	-2	0	-4	0
N_3^c	1	3	-1	0	0
T_X^c	10	0	0	$^{-3}$	1
T_X^{α}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	$^{-3}$
S_1^{Λ}	1	3	1	0	0
S_2	1	0	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$ Constraining the Moduli Space



	SU_5	$\times U_1^a \times$	$U_1^b \times$	$U_1^c \times$	U_1^d
T_1	10	1	1	-1	-1
T_2	10	1	$^{-1}$	$^{-1}$	-1
T_3	10	-2	0	$^{-1}$	-1
M_1	5	1	1	$^{-1}$	3
M_2	5	1	-1	$^{-1}$	3
M_3	5	-2	0	-1	3
$H^{\vec{u}}$	5	1	1	2	2
H^d	5	1	1	2	-2
Y_1	5	-1	1	$^{-2}$	2
Y_1^{c}	5	2	0	-2	-2
Y_2^1	5	2	0	$^{-2}$	2
Y_2^c	5	-1	1	-2	-2
X_1^2	1	-1	-1	4	0
X_2	1	-1	1	4	0
$\nu_1^{\overline{c}}$	1	1	1	-1	-5
ν_2^t	1	1	-1	$^{-1}$	-5
ν_{3}^{t}	1	$^{-2}$	0	$^{-1}$	-5
N_1^e	1	0	0	-3	5
N_2^t	1	-2	0	$^{-4}$	0
N_3^c	1	3	-1	0	0
T_X^c	10	0	0	$^{-3}$	1
T_X^{Λ}	10	0	0	0	4
M_X^c	5	0	0	$^{-3}$	-3
S_1	1	3	1	0	0
S_2	1	0	2	0	0

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



$SU_5 \times U_1^a \times U_1^c \times U_1^d$							
T_1	10	0	-1	-1			
T_2	10	2	-1	-1			
T_3	10	-2	-1	-1			
M_1	5	0	-1	3			
M_2	5	2	-1	3			
M_3	5	-2	-1	3			
$H^{\vec{u}}$	5	0	2	2			
H^d	5	0	2	-2			
Y_1	5	-2	-2	2			
Y_1^c	5	2	-2	-2			
Y_2^{\perp}	5	2	-2	2			
$Y_2^{\tilde{c}}$	5	-2	$^{-2}$	-2			
X_1^2	1	0	4	0			
X_2	1	-2	4	0			
$\nu_1^{\overline{c}}$	1	0	-1	-5			
ν_2^t	1	2	-1	-5			
ν_3^{t}	1	$^{-2}$	-1	-5			
N_1^e	1	0	-3	5			
N_2^t	1	$^{-2}$	-4	0			
N_3^c	1	4	0	0			
T_X^c	10	0	-3	1			
T_X^{Λ}	10	0	0	4			
M_X^c	5	0	-3	-3			
S_1	1	2	0	0			

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



$SU_5 \times U_1^a \times U_1^c \times U_1^d$							
T_1	10	0	-1	-1			
T_2	10	2	-1	-1			
T_3	10	-2	-1	-1			
M_1	5	0	-1	3			
M_2	5	2	-1	3			
M_3	5	-2	-1	3			
$H^{\vec{u}}$	5	0	2	2			
H^d	5	0	2	-2			
Y_1	5	-2	-2	2			
Y_1^c	5	2	-2	-2			
Y_2^{\perp}	5	2	-2	2			
$Y_2^{\tilde{c}}$	5	-2	$^{-2}$	-2			
X_1^2	1	0	4	0			
X_2	1	-2	4	0			
$\nu_1^{\overline{c}}$	1	0	-1	-5			
ν_2^t	1	2	-1	-5			
ν_3^{t}	1	$^{-2}$	-1	-5			
N_1^e	1	0	-3	5			
N_2^t	1	$^{-2}$	-4	0			
N_3^c	1	4	0	0			
T_X^c	10	0	-3	1			
T_X^{Λ}	10	0	0	4			
M_X^c	5	0	-3	-3			
S_1	1	2	0	0			

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



$SU_5 \times U_1^a \times U_1^c \times U_1^d$							
T_1	10	0	-1	-1			
T_2	10	2	-1	-1			
T_3	10	-2	-1	-1			
M_1	5	0	-1	3			
M_2	5	2	-1	3			
M_3	5	-2	-1	3			
$H^{\vec{u}}$	5	0	2	2			
H^d	5	0	2	-2			
Y_1	5	-2	-2	2			
Y_1^c	5	2	-2	-2			
Y_2^{\perp}	5	2	-2	2			
$Y_2^{\tilde{c}}$	5	-2	$^{-2}$	-2			
X_1^2	1	0	4	0			
X_2	1	-2	4	0			
$\nu_1^{\overline{c}}$	1	0	-1	-5			
ν_2^t	1	2	-1	-5			
ν_3^{t}	1	$^{-2}$	-1	-5			
N_1^e	1	0	-3	5			
N_2^t	1	$^{-2}$	-4	0			
N_3^c	1	4	0	0			
T_X^c	10	0	-3	1			
T_X^{Λ}	10	0	0	4			
M_X^c	5	0	-3	-3			
S_1	1	2	0	0			

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



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T_1	10	0	-1	-1			
T_2	10	2	-1	-1			
T_3	10	-2	-1	-1			
M_1	5	0	-1	3			
M_2	5	2	-1	3			
M_3	5	-2	-1	3			
$H^{\vec{u}}$	5	0	2	2			
H^d	5	0	2	-2			
Y_1	5	-2	-2	2			
Y_1^c	5	2	-2	-2			
Y_2^{\perp}	5	2	-2	2			
$Y_2^{\tilde{c}}$	5	-2	$^{-2}$	-2			
X_1^2	1	0	4	0			
X_2	1	-2	4	0			
$\nu_1^{\overline{c}}$	1	0	-1	-5			
ν_2^t	1	2	-1	-5			
ν_3^{t}	1	$^{-2}$	-1	-5			
N_1^e	1	0	-3	5			
N_2^t	1	$^{-2}$	-4	0			
N_3^c	1	4	0	0			
T_X^c	10	0	-3	1			
T_X^{Λ}	10	0	0	4			
M_X^c	5	0	-3	-3			
S_1	1	2	0	0			

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



$SU_5 \times U_1^a \times U_1^c \times U_1^d$							
T_1	10	0	-1	-1			
T_2	10	2	-1	-1			
T_3	10	$^{-2}$	-1	-1			
M_1	5	0	-1	3			
M_2	5	2	-1	3			
M_3	5	$^{-2}$	-1	3			
$H^{\breve{u}}$	5	0	2	2			
H^d	5	0	2	-2			
Y_1	5	-2	-2^{-2}	2			
Y_1^c	5	2	$^{-2}$	-2			
Y_2^{\perp}	5	2	$^{-2}$	2			
$Y_2^{\tilde{c}}$	5	$^{-2}$	-2	-2			
X_1^2	1	0	4	0			
X_2	1	$^{-2}$	4	0			
$\nu_1^{\overline{c}}$	1	0	-1	-5			
ν_2^t	1	2	-1	-5			
ν_3^{t}	1	$^{-2}$	-1	-5			
N_1^e	1	0	-3	5			
N_2^t	1	$^{-2}$	-4	0			
N_3^c	1	4	0	0			
T_{X}^{c}	$\overline{10}$	0	-3	1			
T_X^{Λ}	10	0	0	4			
M_X^c	5	0	-3	-3			
S_1	1	2	0	0			

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory



$SU_5 \times U_1^a \times U_1^c \times U_1^d$							
T_1	10	0	-1	-1			
T_2	10	2	-1	-1			
T_3	10	$^{-2}$	-1	-1			
M_1	5	0	-1	3			
M_2	5	2	-1	3			
M_3	5	$^{-2}$	-1	3			
$H^{\breve{u}}$	5	0	2	2			
H^d	5	0	2	-2			
Y_1	5	-2	-2^{-2}	2			
Y_1^c	5	2	-2	-2			
Y_2^{\perp}	5	2	-2	2			
$Y_2^{\tilde{c}}$	5	$^{-2}$	-2	-2			
X_1^2	1	0	4	0			
X_2	1	$^{-2}$	4	0			
$\nu_1^{\overline{c}}$	1	0	-1	-5			
ν_2^t	1	2	-1	-5			
ν_3^{t}	1	$^{-2}$	-1	-5			
N_1^e	1	0	-3	5			
N_2^t	1	$^{-2}$	-4	0			
N_3^c	1	4	0	0			
T_{X}^{c}	$\overline{10}$	0	-3	1			
T_X^{Λ}	10	0	0	4			
M_X^c	5	0	-3	-3			
S_1	1	2	0	0			

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$

Once this condition is imposed, we obtain the following superpotential,

 $W = T_1 T_1 H^u + T_2 T_3 H^u + T_1 M_1 H^d$ $+ T_2 M_3 H^d + T_3 M_2 H^d + H^u M_1 \nu_1^c$ $+ H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c$ $+ X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c$ $+ X_2 N_2^c N_3^c.$

	SU_5	$\times U_1^a$	$\times U_1^c$	$\times U_1^d$
T_1	10	0	-1	-1
T_2	10	2	-1	-1
T_3	10	$^{-2}$	-1	-1
M_1	5	0	-1	3
M_2	5	2	-1	3
M_3	5	$^{-2}$	-1	3
$H^{\breve{u}}$	5	0	2	2
H^d	5	0	2	-2
Y_1	5	-2	-2	2
Y_1^c	5	2	$^{-2}$	-2
Y_2^{\perp}	5	2	$^{-2}$	2
Y_2^c	5	$^{-2}$	$^{-2}$	-2
X_1^2	1	0	4	0
X_2	1	-2	4	0
$\nu_1^{\overline{c}}$	1	0	-1	-5
ν_2^t	1	2	-1	-5
ν_3^c	1	$^{-2}$	-1	-5
N_1^{c}	1	0	-3	5
N_2^c	1	$^{-2}$	-4	0
N_3^c	1	4	0	0
T_X^c	10	0	-3	1
T_X^{α}	10	0	0	4
M_X^c	5	0	$^{-3}$	-3
S_1	1	2	0	0

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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$

Once this condition is imposed, we obtain the following superpotential,

$$W = T_1 T_1 H^u + T_2 T_3 H^u + T_1 M_1 H^d + T_2 M_3 H^d + T_3 M_2 H^d + H^u M_1 \nu_1^c + H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c + X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c + X_2 N_2^c N_3^c.$$

	SU_5	$\times U_1^a$	$\times U_1^c$	$\times U_1^d$
T_1	10	0	-1	-1
T_2	10	2	-1	-1
T_3	10	-2	-1	-1
M_1	5	0	-1	3
M_2	5	2	-1	3
M_3	5	-2	-1	3
$H^{\breve{u}}$	5	0	2	2
H^d	5	0	2	-2
Y_1	5	-2	$^{-2}$	2
Y_1^c	5	2	$^{-2}$	-2
Y_2^{\perp}	5	2	$^{-2}$	2
Y_2^c	5	-2	$^{-2}$	-2
X_1^2	1	0	4	0
X_2	1	-2	4	0
$\nu_1^{\overline{c}}$	1	0	-1	-5
ν_2^t	1	2	-1	-5
ν_{2}^{t}	1	$^{-2}$	-1	-5
N_1^e	1	0	-3	5
N_2^t	1	-2	$^{-4}$	0
N_3^{τ}	1	4	0	0
T_X^c	10	0	-3	1
T_X^{Λ}	10	0	0	4
M_X^c	5	0	-3	-3
S_1	1	2	0	0

Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$

Once this condition is imposed, we obtain the following superpotential,

 $W = T_1 T_1 H^u + T_2 T_3 H^u + T_1 M_1 H^d$ + $T_2 M_3 H^d + T_3 M_2 H^d + H^u M_1 \nu_1^c$ + $H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c$ + $X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c$ + $X_2 N_2^c N_3^c$.



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Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

To enforce the gauge-invariance of $T_1 T_1 H^u$, we should impose the **geometric** condition b = -a: $E_8(c+d, 2a+c+d, -3c+d, -4d, 0, 0, 0, 0)$

Once this condition is imposed, we obtain the following superpotential,

$$W = T_1 T_1 H^u + T_2 T_3 H^u + T_1 M_1 H^d + T_2 M_3 H^d + T_3 M_2 H^d + H^u M_1 \nu_1^c + H^u M_2 \nu_3^c + H^u M_3 \nu_2^c + X_1 Y_1 Y_1^c + X_1 Y_2 Y_2^c + X_1 N_1^c \nu_1^c + X_2 N_1^c \nu_2^c + X_2 N_2^c N_3^c.$$



Geometric Analogues to Grand Unification Physics from Geometry: Novel Approaches to Model Building Examples with Monodromies: The Diamond Ring of F-Theory

A Local Diamond Ring in F-Theory

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Notice that the operator $X_1^{\dagger} H^u H^d$ is gauge invariant.

	SU_5	$\times U_1^a$	$\times U_1^c$	$\times U_1^d$
T_1	10	0	-1	-1
T_2	10	2	-1	-1
T_3	10	-2	-1	-1
M_1	5	0	-1	3
M_2	5	2	-1	3
M_{2}	5	$^{-2}$	-1	3
$H^{\breve{u}}$	5	0	2	2
H^d	5	0	2	-2
Y_1	5	$-\tilde{2}$	-2	2
Y_1^c	5	2	-2	-2
Y_2^1	5	2	-2	2
Y_2^c	5	$^{-2}$	-2	-2
X_1^2	1	0	4	0
X_2^{\uparrow}	1	-2	4	0
$\nu_1^{\overline{c}}$	1	0	-1	-5
ν_2^t	1	2	-1	-5
ν_3^{t}	1	-2	-1	-5
N_1^e	1	0	-3	5
N_2^t	1	-2	$^{-4}$	0
N_3^c	1	4	0	0
$T_{\mathbf{x}}^{c}$	10	0	-3	1
T_X^{Λ}	10	0	0	4
M_X^c	5	0	-3	-3
S_1	1	2	0	0

Conclusions and Future Directions

- We have seen that explicit, purely local phenomenological models with three generations exist in both F-theory and M-theory, but only just-so.
- These models are 'in principle' explicit enough to be exhaustively studied, and even make falsifiable predictions for low-energy physics.
 - To what extent is this claim true in both F-theory and M-theory?
 - How many assumptions are required in each case?
- What about moduli stabilization? Are there compact manifolds with these local patches? How is the locally continuous landscape of fibrations quantized by compactification?
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