Non-abelian discrete gauge symmetries in string theory

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Based on:

M. Berasaluce-González, P. G. Cámara, F. Marchesano, AU, arXiv:1206.2383

(see also M.Berasaluce-González, L. Ibáñez, P. Soler, AU, arXiv:1106.4169)

String Pheno, Cambridge, June 2012

Discrete symmetries in BSM

- Discrete symmetries are a key ingredient in SM and BSM

• For instance, symmetries preventing dim 4 proton decay in the MSSM: R-parity, baryon triality, ...

• Flavour symmetries to explain/reproduce Yukawa textures, ...

- Quantum gravity does not like global symmetries

..., see recent Banks, Seiberg 2011

• Microscopic arguments in string theory Banks, Dixon '88

• General arguments in black hole evaporation

- Exact symmetries should be gauge

Gauge charge is detectable by measurements at infinity

• Also true for discrete gauge symmetries:
lasso black holes with charged strings and measure holonomy

Abelian Z_n discrete gauge symmetries

- Realize Z_n as U(1) Higgssed by field of charge n

Lagrangian for gauge field and phase of scalar field

$$|\partial_\mu \phi - n A_\mu|^2$$

Gauge transformation $A_\mu \to A_\mu + \partial_\mu \lambda \quad ; \quad \phi \to \phi + n\lambda$

- Dual to BF theory $\frac{1}{2} H \wedge *H + nB \wedge F + \frac{1}{2} F \wedge *F$

Zn symmetry read from coefficient of BF coupling

- In string theory
  - p-form on torsion homology classes Cámara, Ibáñez, Marchesano
  - Massive U(1)'s in D-branes Berasaluce-González, Ibáñez, Soler, A.U.
    Ibáñez, Schellekens, A.U.

R-parity, baryon triality etc in MSSM like models

c.f. Schellekens' talk

Understanding building blocks

Building block in Z_n case

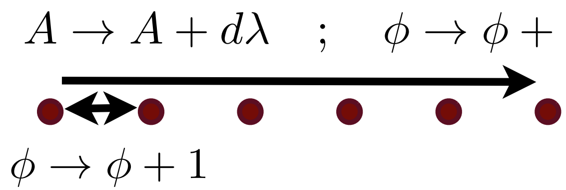
- Axion-like fields (shift symmetry; only derivative couplings)

  Periodic identification $\phi \to \phi + 1$ defines lattice Γ=Z

- Gauging (by a U(1)) $A \to A + d\lambda \quad ; \quad \phi \to \phi + n\lambda$

  Embedding of U(1) S^1 into axion S^1 with winding n

  Defines lattice Γ'=nZ



Discrete gauge symmetry: field identifications not implemented by U(1) gauge transformations

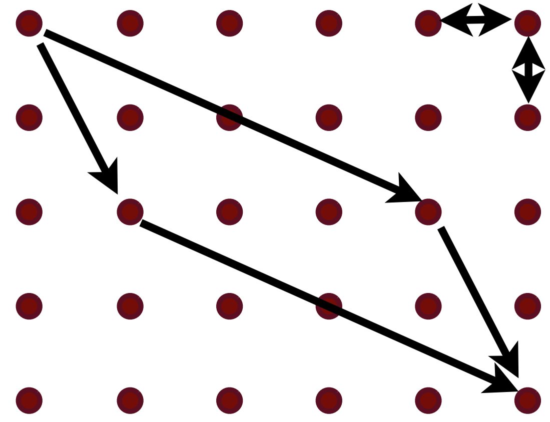
$$\frac{\Gamma}{\Gamma'} = \mathbf{Z}_n$$

Generalization

- Multiple U(1) case

$$\sum_{\alpha} \left(\partial_\mu \phi^a - {k_i}^a A^i_\mu \right) \left(\partial_\nu \phi^b - {k_i}^b A^i_\nu \right) \eta^{\mu\nu} \delta_{ab}$$

$\vec{\phi} \simeq \vec{\phi} + \vec{k}_i \qquad \phi_a \simeq \phi_a + 1$



- Non-abelian case

Non-abelian axions: fields with non-commuting shift symmetries

Lagrangian
$$\sum_{\alpha} \left(\partial_\mu \phi^a - {k_i}^a A^i_\mu \right) \left(\partial_\nu \phi^b - {k_i}^b A^i_\nu \right) \eta^{\mu\nu} G_{ab}(\phi)$$

Gauging
$$\phi^b \to \phi^b + \epsilon^A X^b_A$$

$$k^a_i \, A^i_\mu \;\to\; {k_i}^a \, A^i_\mu \;+\; X^a_C \partial_\mu \epsilon^C \;+\; {f^C}_{AB} \, X^a_C \, (X^{-1})^A_b \, A^j_\mu \, {k_j}^b \, \epsilon^B$$

- Example: axion moduli space is twisted torus

Γ/Γ'= discrete Heisenberg groups H_k

$$A^k = 1 \quad , \quad B^k = 1 \quad , \quad AB = BAC$$

p-forms on torsion homology (with relations)

- E.g. IIB on CY with torsion 1-, 4-cycles $[C] \neq 0 \quad ; \quad k[C] = 0$
  - wrapped D1's, D5's produce Zk charged particles, strings
  - exact 2-form and non-closed 1-form $\quad d\omega_1 = k\beta_2$

Dim. reduction of RR 2-form displays gauging

$$dC_2 \;=\; (d\phi - kA_1) \wedge \beta_2 \;+\; dA_1(x^\mu) \wedge \omega_1 \;+\; \ldots$$

Cámara, Ibáñez, Marchesano

- Non-abelian generalization

Gukov. Rangamani, Witten

  - torsion 1-, 3-cycles (dual 4-cycles intersecting over dual 2-cycle)

  wrapped D1's, F1's and D3's give charged particles

  wrapped D5's, NS5's and D3's give charged strings

  Hanany-Witten effect: crossing D5's and NS5's create D3's

We have shown that dim. reduction of NSNS, RR 2- and 4-form displays non-abelian gauging $\quad \rho_2 \wedge \rho_2 = M\,\tilde{\omega}_4$

Magnetized toroidal models

- Toroidal D-brane or heterotic models with magnetization

$$A_1 = \pi M \,(x dy - y dx) \,, \quad \text{so that} \quad F_2 = 2\pi M \, dx \wedge dy$$

Gauging: Translations in T^2 shift Wilson lines scalars

Non-abelian: translations commute to D-brane U(1)

$$[X_x, X_y] = M X_Q$$

- Action on wavefunctions of M charged matter families

$$\psi^{j,M}(z,U) = e^{i\pi M z \mathrm{Im}\, z / \mathrm{Im}\, U} \cdot \vartheta \left[\begin{array}{c} \frac{j}{M} \\ 0 \end{array} \right] (Mz, MU)$$

clock and shift

$$\psi^j \to \psi^{j+1} \quad ; \quad \psi^j e^{2\pi i \frac{j}{M}} \psi^j$$

independent for each 2-torus

- Valid also for T-dual intersecting branes

Flavour symmetries and Yukawa couplings

Two classes of example: a) Non-coprime and b) coprime mult.

- a) Three D-branes with pairwise intersections M

$$\lambda_{ijk}\,\Phi_i^{ab}\Phi_j^{bc}\Phi_k^{ca}$$

→ Discrete symmetry selection rules

$$\lambda_{ijk} = 0 \quad \text{if} \;\; i+j+k \neq 0 \quad \text{mod} \;\; M$$

$$\lambda_{ijk} = \lambda_{i+1,j+1,k+1}$$

Cremades, Ibáñez, Marchesano; Abe, Choi, Kobayashi, Ohki

- b) MSSM-like: One Higgs, three families

$$Y_{ij} X_L^i X_R^j H$$

Cremades, Ibáñez, Marchesano

→ Independent Heisenberg actions on X_L, X_R enforce

$$Y_{ij} = c_i d_j$$

Rank-one texture dictated/protected by exact symmetry

Conclusions

- Spelling out building blocks of abelian discrete gauge symmetries leads to a natural non-abelian generalization
- Realization in several classes of string models
  - p-forms on torsion classes (with relations)
  - magnetized compactifications
- Remarkable implications for Yukawa couplings
  - e.g. rank-1 texture in certain MSSM-like models
- Further questions
  - R-symmetries c.f. Ratz's talk
  - Non-abelian symmetries in heterotic orbifolds c.f. Nilles, Raby, et al
  - Further systems with gaugings: flux compactifications, etc
  - Discrete isometries (see paper for twisted torus)
  - Beyond Heisenberg, beyond toroidal, ...
- As usual, many open questions in string phenomenology...