More on Dimension-4 Proton Decay Problem in F-theory

SUSY 10, Physikalisches Institut, Bonn

Hirotaka Hayashi

The University of Tokyo

August 23th, 2010

Based on:

H.H., T. Kawano, Y. Tsuchiya & T. Watari : Nucl. Phys. B **840** pp. 304-348 (2010)

arXiv: 1004.3870 [hep-th]

Why F-theory?

A Candidate for beyond Standard Model
→ Minimal Supersymmetric Standard Model (MSSM)
→ Grand Unified Theory (GUT) around 2×10^{16} GeV

↳ Flavor structures, Proton decays, …
might be able to be answered from string theory.

Focus:
Constructing a supersymmetric SU(5) GUT model from string compactifications

☐ Necessary components for a supersymmetric SU(5) GUT model

☆ Matter Contents

Matter

$$10_M \to (3,2)_{\frac{1}{6}} + (\bar{3},1)_{-\frac{2}{3}} + (1,1)_1$$
$$\bar{5}_M \to (\bar{3},1)_{\frac{1}{3}} + (1,2)_{-\frac{1}{2}}$$

Higgs

$$5_H \to (3,1)_{-\frac{1}{3}} + (1,2)_{\frac{1}{2}}$$
$$\bar{5}_H \to (\bar{3},1)_{\frac{1}{3}} + (1,2)_{-\frac{1}{2}}$$

☆ Yukawa Couplings

$$W_{GUT} \supset y_u 10_M 10_M 5_H + y_d \bar{5}_M 10_M \bar{5}_H$$

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← F-theory

Dimension-4 Proton Decay Problem

Phenomenological Target:
Dimension-4 Proton Decay Operator

$$W_{GUT} \supset y_u 10_M 10_M 5_H + y_d \bar{5}_M 10_M \bar{5}_H + \lambda \bar{5}_M 10_M \bar{5}_M$$

Necessary Yukawa interactions

Dimension-4 Proton Decay Operator!

☐ In order to prohibit such a operator, It is important to distinguish…

$$\bar{5}_M \leftrightarrow \bar{5}_H$$

Ex. In MSSM, dimension-4 proton decay operators can be eliminated by imposing Matter Parity or R-Parity.

How is such a kind of symmetry achieved in F-theory compacitifications?

Proposed Solutions so far

☆ Proposed Solutions so far

(i) global compactifications with $\mathbf{Z}_2$ symmetry Tatar, Tsuchiya, Watari 0905
H.H. et al 0910, …

(ii) rank 5- GUT scenario with U(1) Flux Tatar, Watari 0602, …

(iii) factorized spectral surface scenario
(using an unbroken U(1) symmetry obtained by taking a special configuration of adjoint higgs vev)

Beasley, Heckman, Vafa 0806
Tatar, Tsuchiya, Watari 0905
Marsano, Saulina, Schafer-Nameki 0906, 0912
Grimm, Krause, Weigand 0912,
Chen et al 1005, …

(iv) spontaneous R-parity violation

Tatar, Watari 0602, Tatar, Tsuchiya, Watari 0905
Blumenhagen, Grimm, Jurke, Weigand 0908, …

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Chen et al 1005, …

(iv) spontaneous R-parity violation

Tatar, Watari 0602, Tatar, Tsuchiya, Watari 0905
Blumenhagen, Grimm, Jurke, Weigand 0908, …

The (iii) scenario is not without a theoretical concern.
We analyzed carefully whether this U(1) is actually unbroken or not.

Outline

1. Motivation ☑
2. Factorized Spectral Surface Scenario
3. Monodromy and U(1) symmetry
4. Summary

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What is F-theory?

Vafa 96

F-theory $\sim$ including strong coupling effects of Type IIB string theory

Basic components → 7-branes

(not only D7 branes but also mutually non-local ones)

Gauge Fields → Localized on 7-branes (S)
Matters → Localized along intersections (Σ) of 7-branes (S)
Yukawas → Localized at intersection points (p) of matter curves (Σ)

$$E \rightarrow CY_4$$
$$\downarrow$$
$$B_3 \supset S \supset \Sigma\ (= S \cdot S') \supset p\ (= \Sigma \cdot \Sigma')$$
$$\Updownarrow$$
$$G_{GUT} = G_S \subset G_\Sigma \subset G_p$$
$$\uparrow$$

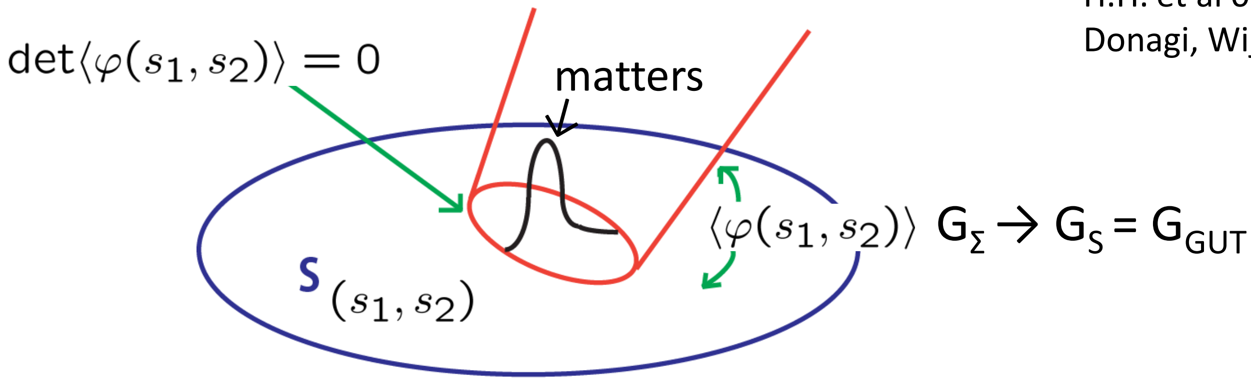
Donagi, Wijnholt 0802
Beasley, Heckman, Vafa 0802
H.H. et al 0805

Enhancement of singularities (vanishing 2-cycles)
$\sim$ gauge symmetry enhancement

8D Gauge Theory on 7-branes

○ 8D gauge theory on 7-branes ("Higgs bundle")

Beasley, Heckman, Vafa 0802,
H.H. et al 0901,
Donagi, Wijnholt 0904



○ E_8 Higgs bundle: incorporating all the necessary Yukawa couplings

$E_8 \supset SU(5)_{GUT} \times \langle SU(5)_{broken} \rangle$

↑ $\qquad\qquad\qquad \langle\varphi(s_1,s_2)\rangle$

a parent gauge group

Marsano, Saulina, Schafer-Nameki 0906, 0912
Blumenhagen, Grimm, Jurke, Weigand 0908
Grimm, Krause, Weigand 0912,
Chen, Chung 1005, Chen et al 1005, Choi 1007,…

Spectral surface

$$\det(\xi I_{5\times 5} - \langle\varphi\rangle) = a_0\xi^5 + a_2\xi^3 + a_3\xi^2 + a_4\xi + a_5 = 0$$

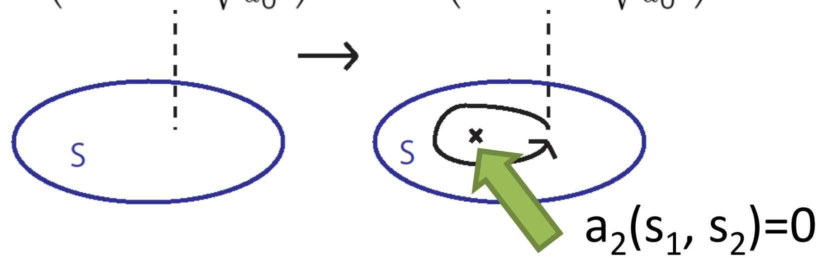
sections over the surface on which GUT 7-branes wrap

Factorized Spectral Surface Scenario

Ex. Rank 2 case :⟨SU(2)⟩ → naively we expect an U(1) symmetry unbroken…

$$a_0(\det(\xi I_{2\times 2} - \langle\varphi\rangle)) = a_0\xi^2 + a_2 = 0 \ \rightarrow \ \xi = \pm\sqrt{\frac{a_2}{a_0}}$$

$$\langle\varphi(s_1, s_2)\rangle = \begin{pmatrix} \sqrt{\frac{a_2}{a_0}} & o \\ 0 & -\sqrt{\frac{a_2}{a_0}} \end{pmatrix} \quad - \begin{pmatrix} \sqrt{\frac{a_2}{a_0}} & o \\ 0 & -\sqrt{\frac{a_2}{a_0}} \end{pmatrix}$$



This monodromy kills the U(1) symmetry.

⇨ Factorization: $a_0\xi^2 + a_2 = (c_0\xi + c_1)(d_0\xi + d_1) \rightarrow \langle\varphi(s_1, s_2)\rangle = \begin{pmatrix} \frac{c_1}{c_0} & 0 \\ 0 & -\frac{c_1}{c_0} \end{pmatrix}$

Then, we have no monodromy
and there seems to be an unbroken U(1) symmetry.

↑

This kind of U(1) symmetry seems to be able to be used for prohibiting dimension-4 proton decay operators when applying to a SU(5) model.

Beasley, Heckman, Vafa 0806
Tatar, Tsuchiya, Watari 0905
Marsano et al 0906, 0912
Grimm et al 0912, Chen et al 1005, …

Factorized Spectral Surface Scenario

Caveats

1. 8D gauge theory description is only an approximation of the global compactification of F-theory. There might be some monodromy missed by this approximation.

2. At $a_0 \sim 0$, higgs vev becomes infinity, then effective gauge theory description fails around this region. There might be another monodromy from the loop in this region.

$$\det(\xi I_{5\times 5} - \langle \varphi \rangle) = a_0 \xi^5 + a_2 \xi^3 + a_3 \xi^2 + a_4 \xi + a_5 = 0$$

→ We have to go beyond 8D gauge theory descriptions in order to find out whether the U(1) symmetry in factorized spectral surface scenario is unbroken or not.

Since we cannot rely on 8D gauge theory descriptions of F-theory, we have to go back to the origin of gauge fields in global compacitifications of F-theory.

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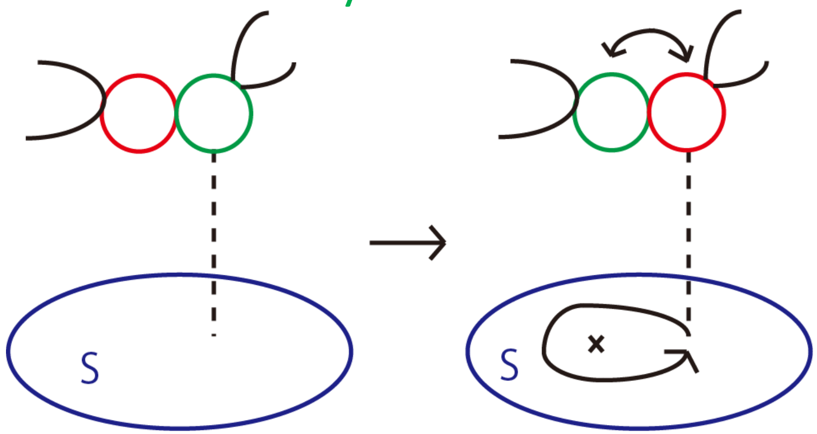
Globally well-defined 2-cycles

The origin of gauge fields in F-theory
→ (p, q) strings ending on 7-branes or
M2-branes wrapping on globally well-defined 2-cycles.

× Not globally well-defined 2-cycle



What we did:
Figure out whether there is a globally well-defined 2-cycle, or a (p, q) string, in the factorized spectral surface scenario by considering a global compacitification manifold.

H.H., T. Kawano, Y. Tsuchiya, T. Watari 1004

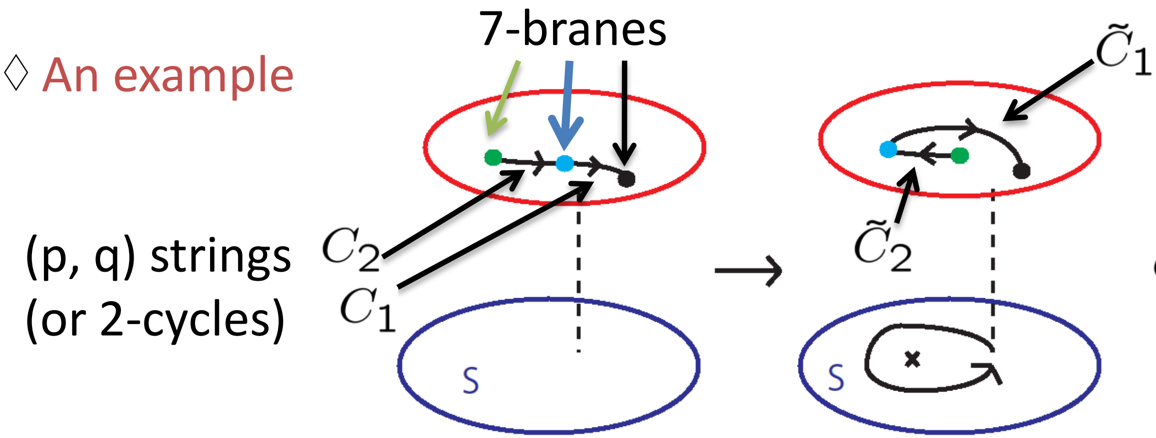
Globally well-defined 2-cycles

Ex. K3 fib. CY_4 with E_6 singularity (SU(3) bdl)
→ take (2+1) factorization of a rank 3 spectral surface

$E \to K3$
$\downarrow$
$\mathbf{P}^1$

22 2-cycles in K3 ⇒ an eliptic fiber and a zero section
20 2-cycles ← Not all of them are globally well-defined

◊ An example



$$\tilde{C}_1 = C_1 + C_2, \quad \tilde{C}_2 = -C_2$$

Monodromy of 2-cycles ↔ The change of the locations of 7-branes

This can be analyzed by calculating the discriminant of the elliptic fibration

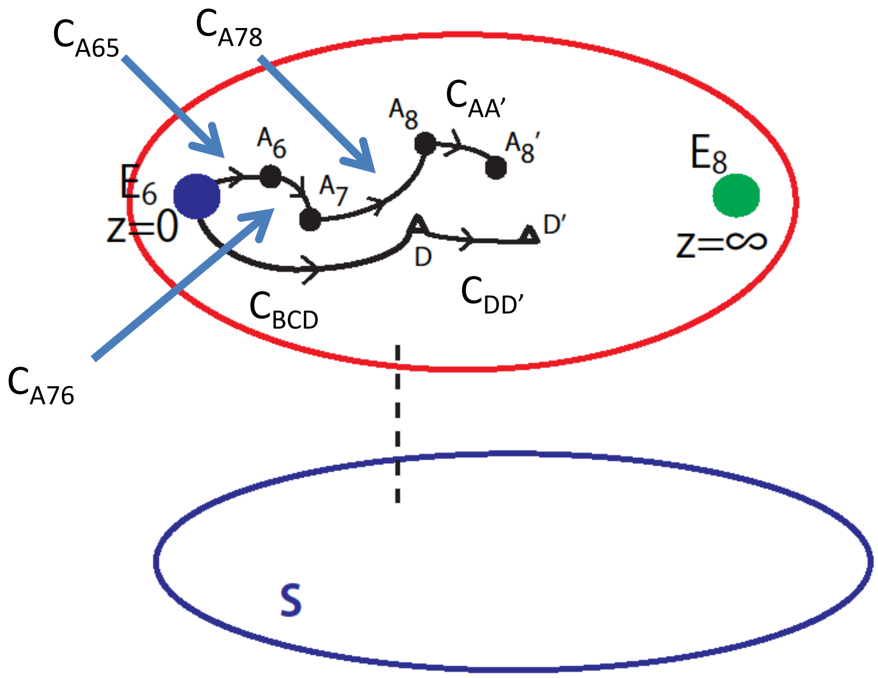
7-brane configurations of a K3 surface

K3 fib. CY_4: $y^2 = x^3 + \underbrace{(a_2 z^3 + f_0 z^4)}_{F}x + \underbrace{(\frac{1}{4}a_3^2 z^4 + a_0 z^5 + g_0 z^6 + a_0'' z^7)}_{G}$

$\Delta = 4F^3 + 27G^2 = z^8 \times$ (degree 6 polynomial)

8 7-branes at z=0 ↑
(E_6 singularity)

↑ 6 other 7-branes
at $z=z_i$ ($i=1,..,6$)



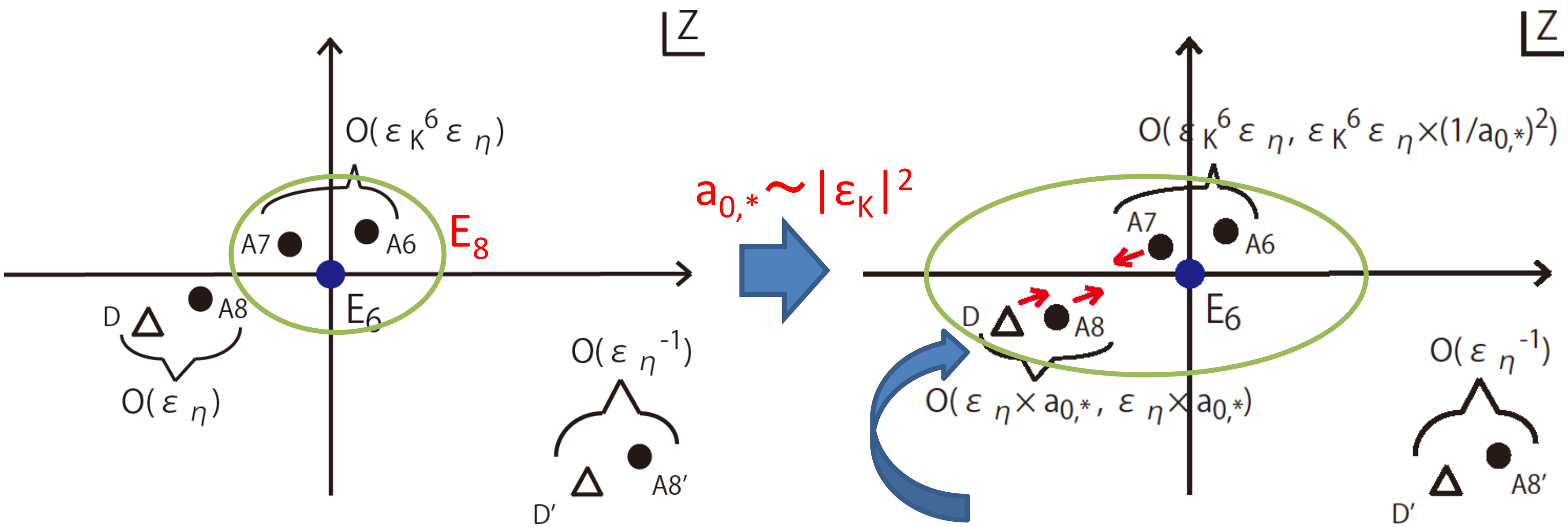
●	[1, 0]-brane (A-brane)
○	[1, -1]-brane (B-brane)
□	[1, 1]-brane (C-brane)
Δ	[3, 1]-brane ("D"-brane)

DeWolfe, Hauer, Iqbal, Zwiebach '98

8D Gauge Theory Region and Beyond

CY$_4$: $y^2 = x^3 + (a_2 z^3 + f_0 z^4)x + (\frac{1}{4}a_3^2 z^4 + a_0 z^5 + g_0 z^6 + a_0'' z^7)$

8D gauge theory region:
$a_0 = a_{0,*}\epsilon_\eta, \quad a_2 = a_{2,*}\epsilon_K^2\epsilon_\eta, \quad a_3 = a_{3,*}\epsilon_K^3\epsilon_\eta$
with $|a_{r,*}| \sim \mathcal{O}(1), \quad 0 \neq |\epsilon_K| << 1, \quad 0 \neq |\epsilon_\eta| < 1$



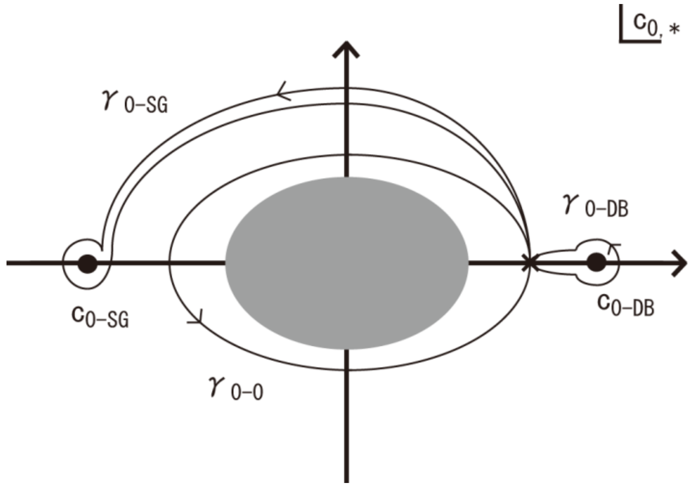
We have to take into account another two 7-branes

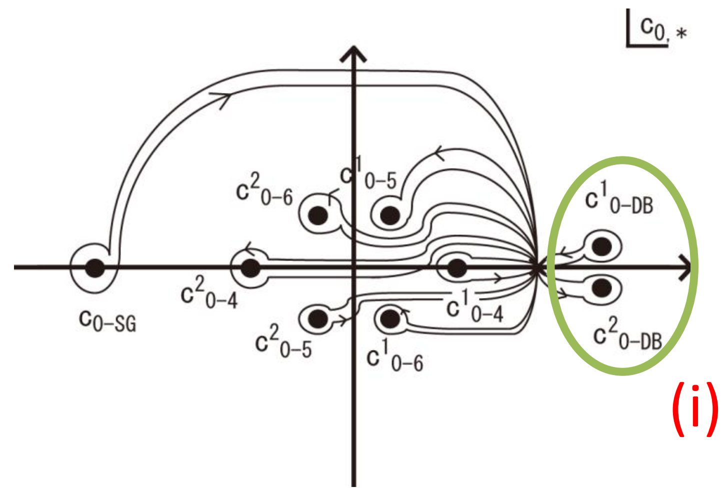
Beyond 8D gauge theory region

Monodromy Locus

(2+1) Factorization: $a_0\xi^3 + a_2\xi + a_3 = (c_0\xi^2 + c_1\xi + c_2)(d_0\xi + d_1)$

(8D gauge theory region) (Beyond 8D gauge theory region)





(i) $c_{0\text{-DB}}$ splits into two $c_{0\text{-DB}}^{1,2}$

$$\begin{aligned} \rho(\gamma_{0-SG}) &= W_{C_{A76}+C_{-\theta}} \\ \rho(\gamma_{0-DB}) &= id \\ \rho(\gamma_{0-0}) &\sim id \end{aligned}$$

$$\rho(\gamma_{0-SG}) = W_{C_{A76}+C_{-\theta}}$$

$$\rho(\gamma_{0-DB}^{1,2}) = \rho(\gamma_{0-out}) = W_{C_{A76}}$$

$Z_2 \subset SU(3)$ $S_3\,! \subset SU(3)$

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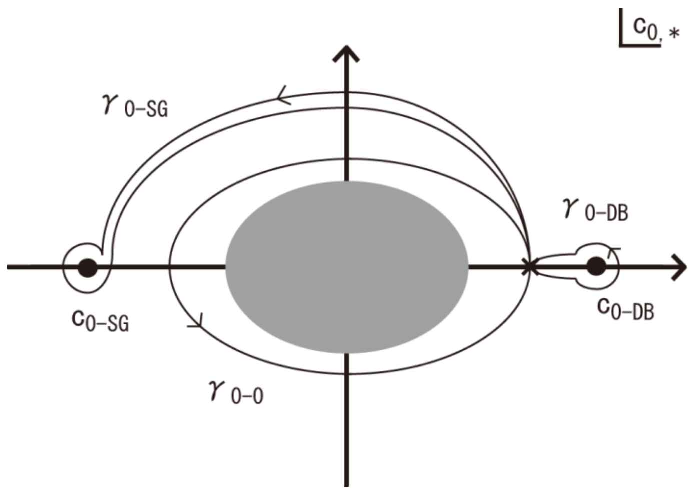
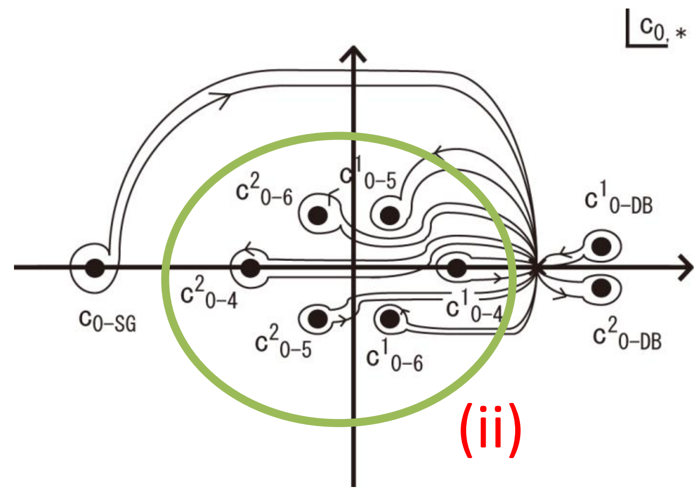


(Beyond 8D gauge theory region)



(ii) New 6 $c_{0\text{-}4,5,6}^{1,2}$ points

$\rho(\gamma^{1,2}_{0-4,5,6})$

→mix the 2-cycles within E_8 with the ones without E_8! (i.e. beyond S_3!)

Even after the factorization, monodromy is NOT reduced.
i.e. NO UNBROKEN U(1) SYMMETRY!

Loopholes

1. To avoid the mixing of 2-cycles within E_8 and those without E_8, the easiest way is to take a_0 as a section of a trivial line bundle. Then, a_0 do not have zeros and every region can be characterized by gauge theory descriptions. However, in this case also, we can not avoid the higher order terms which cause the splitting in the previous example.

2. Other solution is that to impose the factorization condition more globally. In a simple factorization limit, we only impose the factorization condition on the leading terms of the defining equation of CY_4. But we can also extend the condition to other higher order terms.

$$\begin{aligned} y^2 &= x^3 \\ &+ (a_0 z^5 + g_0 z^6 + a_0'' z^7 + \mathcal{O}(z^8)) + (a_2 z^3 + f_0 z^4 + \mathcal{O}(z^5))x + (a_3 z^2 + \mathcal{O}(z^3))y + \cdots \end{aligned}$$

Imposing conditions further on higher order terms

Grimm, Weigand 1006
Marsano, Saulina, Schafer-Nameki 1006

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Summary

We revisited the dimension-4 proton decay problem in F-theory and we explicitly computed globally well-defined 2-cycles in CY_4 in order to find out how many U(1) symmetries are left unbroken. Then we found that a supposed unbroken U(1) symmetry in a simple factorization limit is indeed broken.

To avoid the problem, we need to tune more parameters of the internal space of compacitifications.

Discussion

Although we showed that dimension-4 proton decay operators are likely to be generated in a factorized spectral surface scenario, it would be interesting to compute the coefficients of those operators. There may be a chance to suppresse the dangerous operators