# On the vacuum structure of F-theory compactifications

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# Moduli stabilization in string theory

(Perturbative) superstring theory predicts the extra 6D space.

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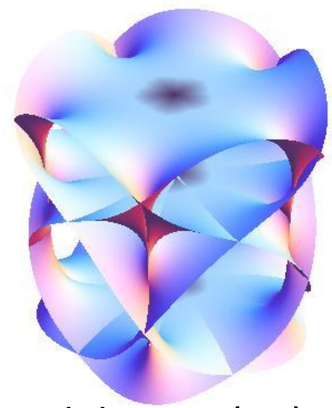


6D Calabi-Yau (CY)Manifold

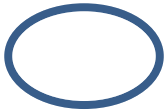
$R_{ij} = 0$

Extra 6D space should be compactified to be consistent with the observational and experimental data.

→ Stabilization of the extra dimensional space
<u>Moduli stabilization</u>

# Two types of moduli fields

①Closed string moduli

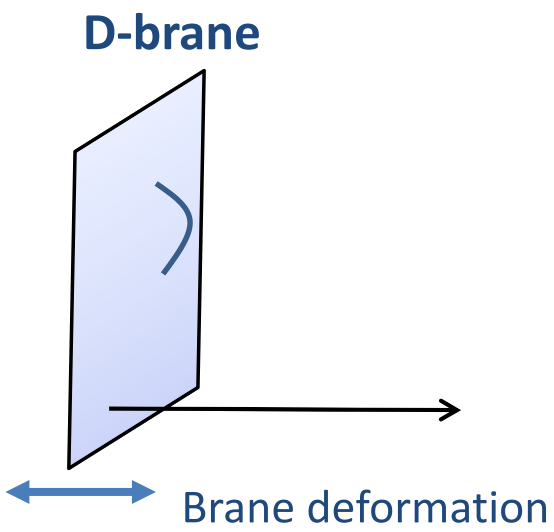


Complex structure moduli

Kähler moduli

Dilaton

②Open string moduli



# Flux compactification in type IIB on CY

## ①Closed string moduli

$$W_{\mathrm{flux}} \propto \int_{\Gamma, \partial\Gamma = 0} \Omega$$

[Gukov-Vafa-Witten '99]

GVW superpotential is calculated by the closed mirror symmetry.
→Stabilization of complex structure moduli and dilaton

[Giddings-Kachru-Polchinski '01,..

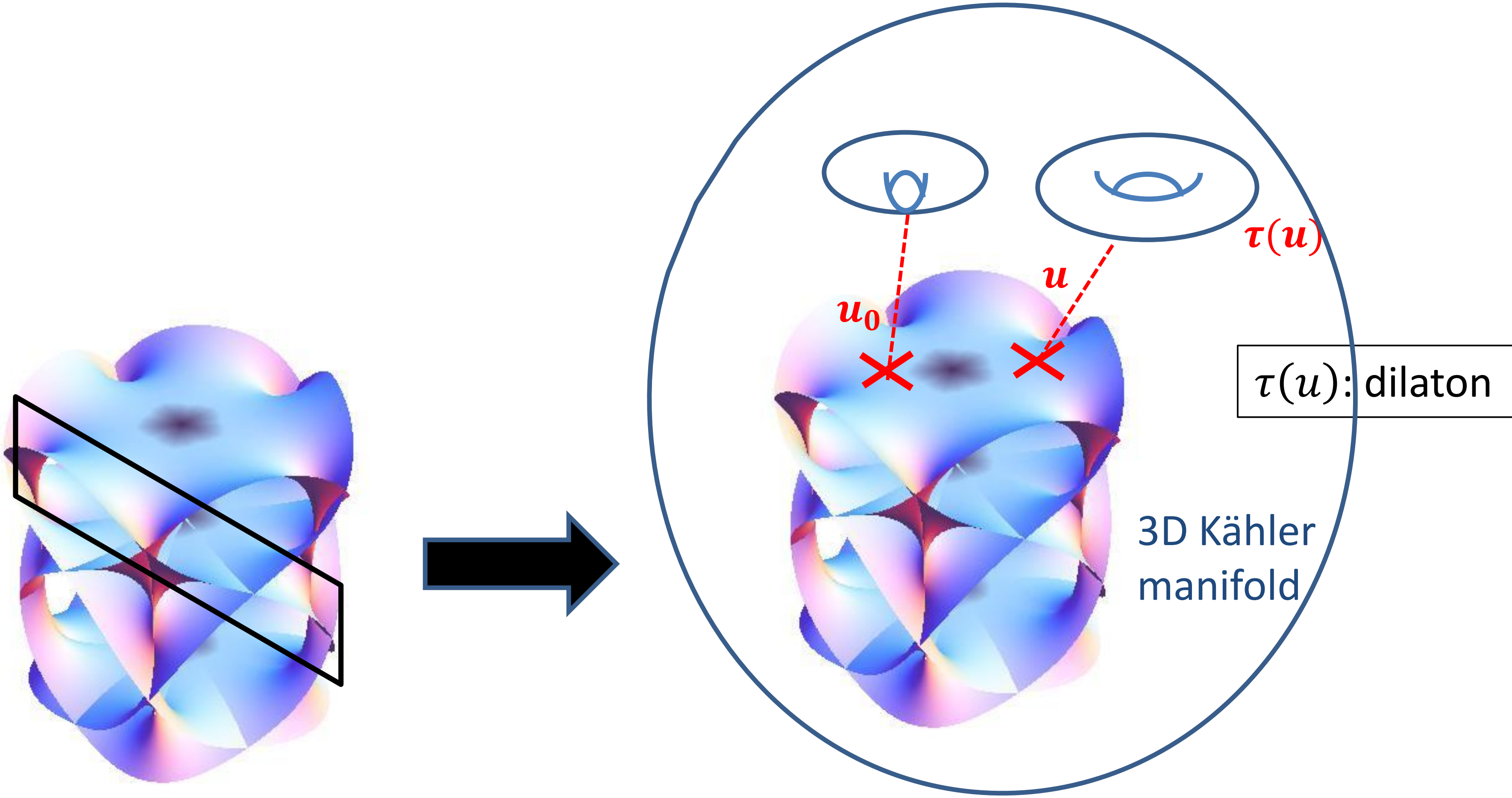
## ②Open string moduli

$$W_{\mathrm{brane}} \propto \int_{\Gamma, \partial\Gamma \neq 0} \Omega$$

[Witten '97]

Brane superpotential is calculated by the open mirror symmetry.
→Stabilization of open string moduli

# F-theory compactification on CY4




CY3+branes

Elliptically fibered CY4

Complex structure moduli of CY3
Dilaton
Open string (position) moduli

Complex structure moduli of CY4

# Flux compactification in F-theory on CY4

○GVW superpotential + brane superpotential in type IIB
=$G_4$-flux superpotential in F-theory [Grimm-Ha-Klemm-Klevers '09,…]

$$W = \int_{\mathrm{CY4}} G_4 \wedge \Omega$$

Imaginary self-dual three-form fluxes in type IIB
=Self-dual $G_4$-fluxes

$$G_4 = * G_4$$

<u>In this talk, we study moduli stabilization based on F-theory</u>

# Outline

- Introduction
- Flux compactification in F-theory
- Conclusion

# Elliptically fibered CY4

○In the toric language,

A-model : Quintic CY3 over $CP^1$

[Berglund-Mayr '98,
Grimm-Ha-Klemm-Klevers '09,
Jockers-Mayr-Walcher '09]

$$l_1 = (-4,0,1,1,1,1,-1,-1,0)$$
$$l_2 = (-1,1,0,0,0,0,1,-1,0)$$
$$l_3 = (0,-2,0,0,0,0,0,1,1)$$

$l_1 + l_2$: Quintic CY3
$l_2$: brane deformation
$l_3$: base $CP^1$

B-model : Elliptically fibered CY4

# F-theory on elliptically fibered CY4 → 4D N=1 supergravity

**In 4D N=1 SUGRA**

Kähler potential:

$$K = -\ln \int_{\mathrm{CY4}} \Omega \wedge \bar{\Omega} - 2\ln V$$
$$= -\ln(\Pi^i \eta_{ij} \bar{\Pi}^j) - 2\ln V$$

Superpotential:

$$W = \int_{\mathrm{CY4}} G_4 \wedge \Omega = n^i \eta_{ij} \Pi^j$$

$\Pi_i = \int_{\gamma^i} \Omega$ : Fourfold periods

$\gamma^i$ : Homology basis of $H_4^H(CY4, \boldsymbol{Z})$

$\eta_{ij}$ : Topological intersection matrix

$n^i$ : Quantized four-form fluxes

$V$ : Volume of 3D Kähler base

# F-theory compactification on elliptically fibered CY4

$z$: Complex structure modulus

$S$: Dilaton

$z_1$: Open string modulus

$n_i$: Quantized fluxes

Kähler potential:

$$K = -\ln\left[-i(S-\overline{S})\right] - \ln\left[\frac{5i}{6}(z-\overline{z})^3 + \boxed{\frac{i}{S-\overline{S}}\left(-\frac{1}{6}(z_1-\overline{z_1})^4 + \frac{5}{12}(z-\overline{z})^4\right)}\right] - 2\ln\mathcal{V}$$

Deviation from the weak coupling limit

Superpotential:

$$W = n_{11} + n_{10}S + n_8 z + n_6 S z + \frac{5}{2}\left(\frac{n_5}{5} + \frac{2n_6}{5}\right)z^2 - \frac{5n_4}{6}z^3 - n_2\left(\frac{5}{2}Sz^2 + \frac{5}{3}z^3\right) - n_9 z_1 - \frac{n_7}{2}z_1^2 - \frac{2n_3}{3}z_1^3 + n_1\left(\frac{5}{6}Sz^3 + \frac{5}{12}z^4 - \frac{1}{6}z_1^4\right)$$

# F-theory compactification on elliptically fibered CY4

$z$: Complex structure modulus

$S$: Dilaton

$z_1$: Open string modulus

$n_i$: Quantized fluxes

Kähler potential:

$$K = -\ln\left[-i(S-\overline{S})\right] - \ln\left[\frac{5i}{6}(z-\overline{z})^3 + \boxed{\frac{i}{S-\overline{S}}\left(-\frac{1}{6}(z_1-\overline{z_1})^4 + \frac{5}{12}(z-\overline{z})^4\right)}\right] - 2\ln\mathcal{V}$$

Deviation from the weak coupling limit

Superpotential:

$$W = n_{11} + n_6 S z + \frac{5}{2}\left(\frac{n_5}{5} + \frac{2n_6}{5}\right)z^2 - \frac{n_7}{2}z_1^2 + n_1\left(\frac{5}{6}Sz^3 + \frac{5}{12}z^4 - \frac{1}{6}z_1^4\right)$$

The self-dual $G_4$ fluxes

# Vacuum structure of F-theory

After imposing the self-dual condition to $G_4$ fluxes,
we find that minimum of all the moduli fields:

$$D_S W = D_z W = D_{z_1} W = 0$$

$z$: CS modulus
$S$: Dilaton
$z_1$: Open string modulus
$n_i$: Quantized fluxes

VEVs

$$\mathrm{Re}z = \mathrm{Re}z_1 = \mathrm{Re}S = 0$$

$$\mathrm{Im}z = \left(\frac{6n_{11}}{5n_1}\right)^{1/4} \frac{2\sqrt{n_6}}{(8n_6(n_5+n_6)-5n_7^2)^{1/4}},$$

$$\mathrm{Im}z_1 = \left(\frac{30n_{11}}{n_1}\right)^{1/4} \frac{\sqrt{n_7}}{(8n_6(n_5+n_6)-5n_7^2)^{1/4}},$$

$$\mathrm{Im}S = \left(\frac{6n_{11}}{5n_1}\right)^{1/4} \frac{n_5}{\sqrt{n_6}(8n_6(n_5+n_6)-5n_7^2)^{1/4}}$$

# Vacuum structure of F-theory

Although the fluxes are constrained by the tadpole condition,

$$\frac{\chi}{24} = n_{D3} + \frac{1}{2}\int_{CY4} G_4 \wedge G_4$$

$\chi$=1860: Euler number of CY4
$n_{D3}$: # of D3

we find the consistent F-theory vacuum, e.g.,

$$n_1 = 1, n_5 = 15, n_6 = 10, n_7 = 2, n_{11} = 28$$

$$n_{\rm D3} = 0$$

All the moduli fields can be stabilized at the LCS point of CY fourfold

$$\mathrm{Re}z = \mathrm{Re}z_1 = \mathrm{Re}S = 0,$$
$$\mathrm{Im}z \simeq 2.28, \quad \mathrm{Im}z_1 \simeq 1.14, \quad \mathrm{Im}S \simeq 1.71$$

## Conclusion

○Mirror symmetry techniques can be applied to the F-theory compactifications.

○We explicitly demonstrate the moduli stabilization around the large complex structure point of the F-theory fourfold.

○All the complex structure moduli can be stabilized at the Minkowski minimum.

## Discussion

○Quantum corrections to the moduli potential
○Other CY4
○Stabilization of Kähler moduli
→LARGE volume scenario or KKLT