Cosmological constant at finite string coupling in F-theory flux compactifications

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Based on : Y. Honma (Meijigakuin U.), HO, Physics Lett. B. **774** (2017) 225

Y. Honma (Meijigakuin U.), HO, Work in Progress

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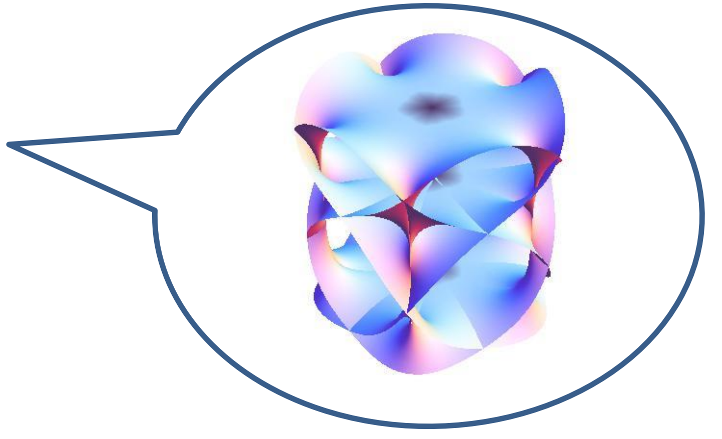
Moduli stabilization in string theory

(Perturbative) superstring theory predicts the extra 6D space

10＝4＋6



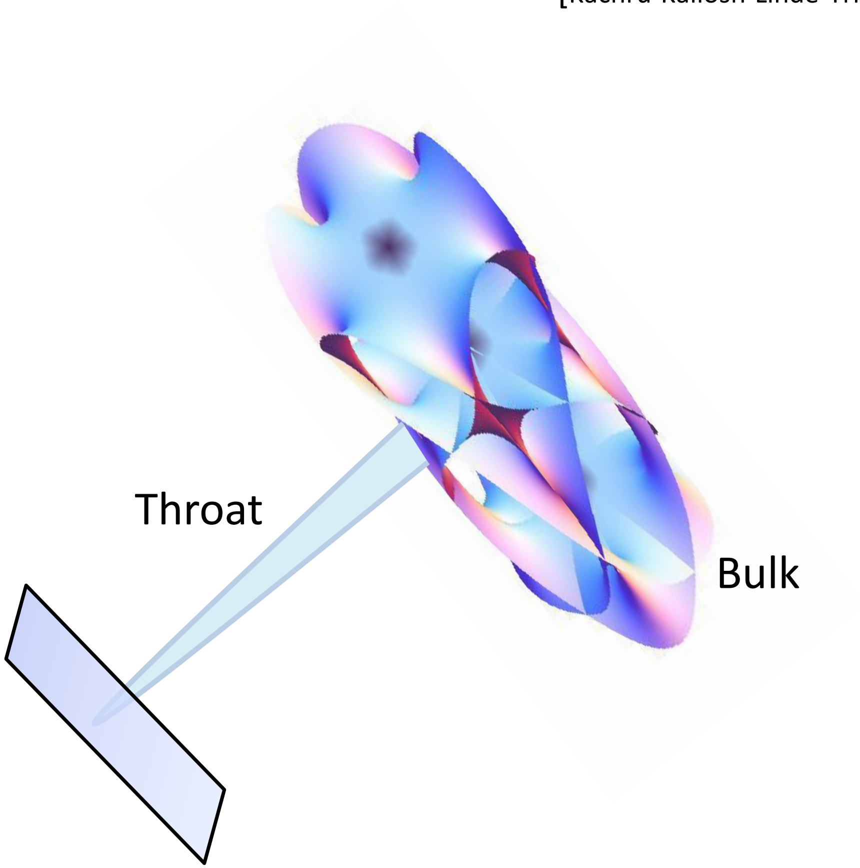
・The geometric parameters of extra 6D dimensions
→4D scalar fields (called moduli)

・ Stabilization of the extra dimensional space
→ <u>Moduli stabilization (creating a moduli potential)</u>

・ Realization of de Sitter spacetime
(dark energy and inflation)

KKLT scenario : Prototypical example of dS vacua

[Kachru-Kallosh-Linde-Trivedi ’03]



$\overline{\mathrm{D3}}$ sits at the bottom of a warped throat of CY

→Tiny positive energy

$$V_{\overline{D3}} \sim \frac{e^{4A_{\min}}}{V_{\mathrm{CY}}^2}$$

V_{CY} : CY volume

Recently,
Maldacena-Nunez type no-go theorem for the KKLT uplift was strongly debated.

- Gaugino condensation on D7-branes in the analysis of the 10D Einstein equation, starting from [Moritz-Retolaza-Westphal ’17,…]

- Reliability of the KKLT minimum :
  A finite number of KK modes are lighter than UV cut-off. [Blumenhagen-Klawer-Schlechter, ’19]

- Existence of the runaway behavior for the conifold modulus, parametrizing the length of the throat [Bena-Dudas-Grana-Lust, ’18]

<u>Can we construct the dS models in a general moduli space of CY ?</u>

▪ Non-supersymmetric fluxes (in contrast to the GKP construction)

$$iG_3 \neq *_6 G_3$$

Non-supersymmetric fluxes also lead to the positive energy demonstrated in toroidal orientifold

▪ No a priori need for warped throats

[A. Saltman and E. Silverstein'04]

This talk :
We discuss non-SUSY minima in F-theory compactifications

with Y. Honma

Outline

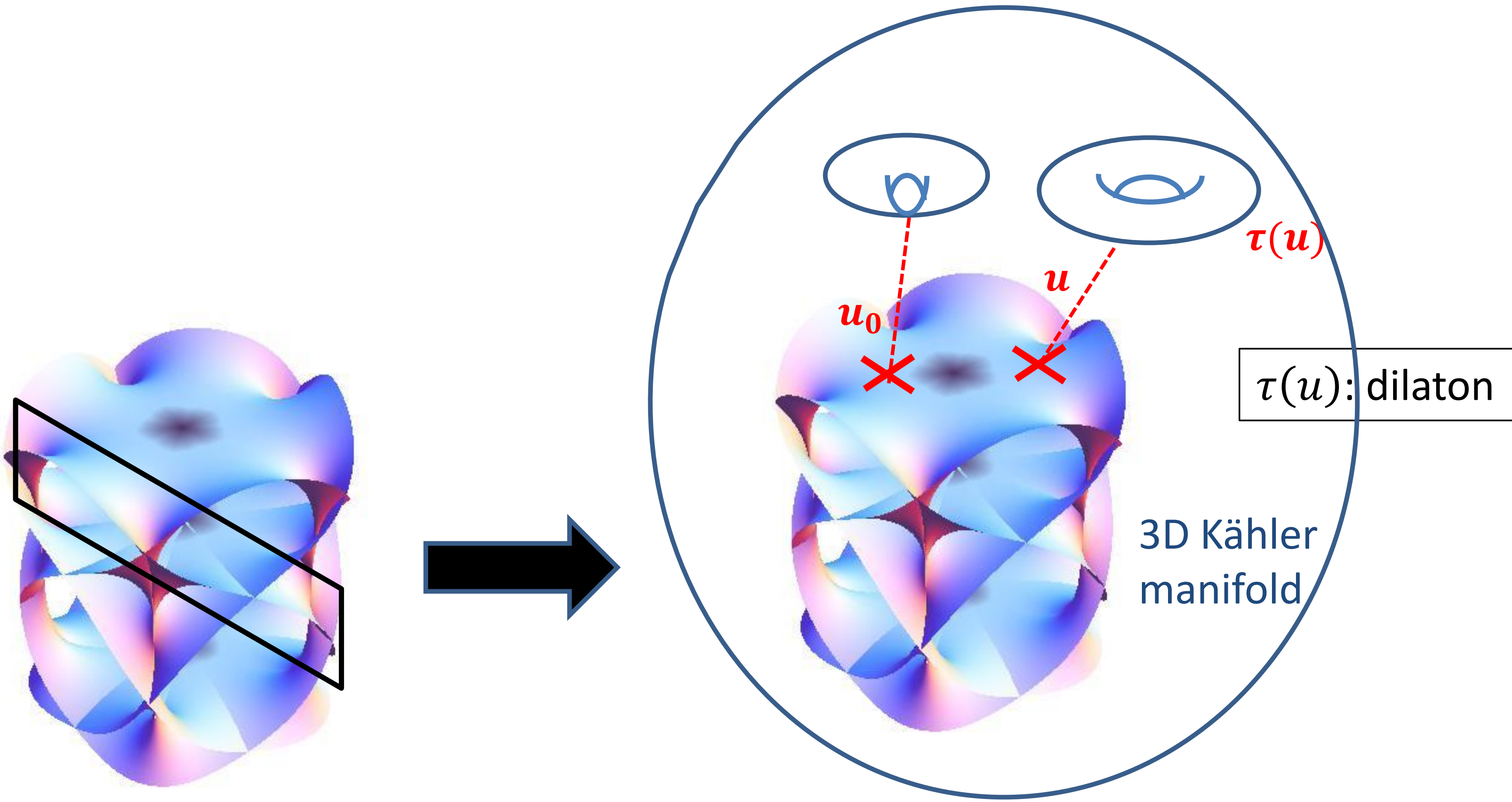
✔ **Introduction**

○ **Flux compactification in F-theory**

- SUSY minimum
- SUSY-breaking (de Sitter) minimum

○ **Conclusion**

F-theory compactification on CY4



CY3+branes

Elliptically fibered CY4

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

Complex structure moduli of CY4

Flux compactification in F-theory on CY4

- The orientifold limit of F-theory

[Dasgupta-Rajesh-Sethi ‘99, Denef-Douglas-Florea-Grassi-Kachru ‘05]

- K3 × K3 background [Berglund-Mayr ‘13]

- Elliptically fibered CY4 in the large complex structure limit

[Honma-Otsuka ‘17,19]

We focus on

Elliptically fibered CY4 = mirror-dual to Quintic CY3 over CP^1

[Berglund-Mayr ‘98, Jockers-Mayr-Walcher ’09]

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 effective SUGRA (in $M_{\rm pl} = 1$ unit)

Kähler potential:

$$K = -\ln \int_{\rm CY4} \Omega \wedge \bar{\Omega} - 2 \ln V_{\rm vol}$$

Ω : hol. 4-form of CY4

$V_{\rm vol}$: Volume of 3D Kähler base

Superpotential:

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

[Gukov-Vafa-Witten, '99]

Scalar potential:

$$V = e^K \left(\sum_{I,J} K^{I\bar{J}} D_I W D_{\bar{J}} W \right)$$

I, J : CS moduli of CY4

$$D_I W = \partial_I W + W \partial_I K$$

F-theory compactification on elliptically fibered CY4

(mirror-dual to Quintic CY3 over CP^1)

[Berglund-Mayr '98, Jockers-Mayr-Walcher '09, Honma-Otsuka'17]

z: Closed string modulus

S: Dilaton

z_1: Brane modulus

$n_i = \int_{\gamma^i} G_4$: Quantized fluxes $_{\gamma^i \in H_4^H(CY4,\mathbf{Z})}$ $(i = 1,2,\ldots,11)$

Kähler potential:

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

NLO in g_s correction

Superpotential:

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

Result : SUSY fluxes

As a consequence of the self-dual condition to G_4 fluxes, all the moduli fields are stabilized at

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

z: Closed string modulus
S: Dilaton
z_1: Brane modulus
n_i: Quantized fluxes

VEVs:

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

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

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

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

Result : SUSY fluxes

- Taking into account the tadpole condition,

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

χ=1860: Euler number of CY4

n_{D3}: # of D3

we find the consistent F-theory SUSY 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

$$\begin{aligned} &{\rm Re}z = {\rm Re}z_1 = {\rm Re}S = 0, \\ &{\rm Im}z \simeq 2.28, \quad {\rm Im}z_1 \simeq 1.14, \quad {\rm Im}S \simeq 1.71 \end{aligned}$$

- The masses of all the moduli fields are positive definite.

SUSY-breaking fluxes

- We consider full G_4-fluxes, leading to the stabilization of moduli

$$V > 0 \qquad \partial_I V = 0 \qquad \partial_I \partial_J V > 0$$

$I = z, S, z_1$

- Fluxes are constrained by the tadpole cancellation condition :

$$\frac{\chi}{24} = 0 + \frac{1}{2}\int_{CY4} G_4 \wedge G_4$$

χ=1860: Euler number of CY4

$n_{D3} = 0$

- We numerically search for fluxes to realize dS minimum with

$$V = \frac{C}{V_{\rm vol}^2} M_{\rm pl}^4 > 0 \qquad C < 1$$

C: constant determined by fluxes

Result: SUSY-breaking fluxes

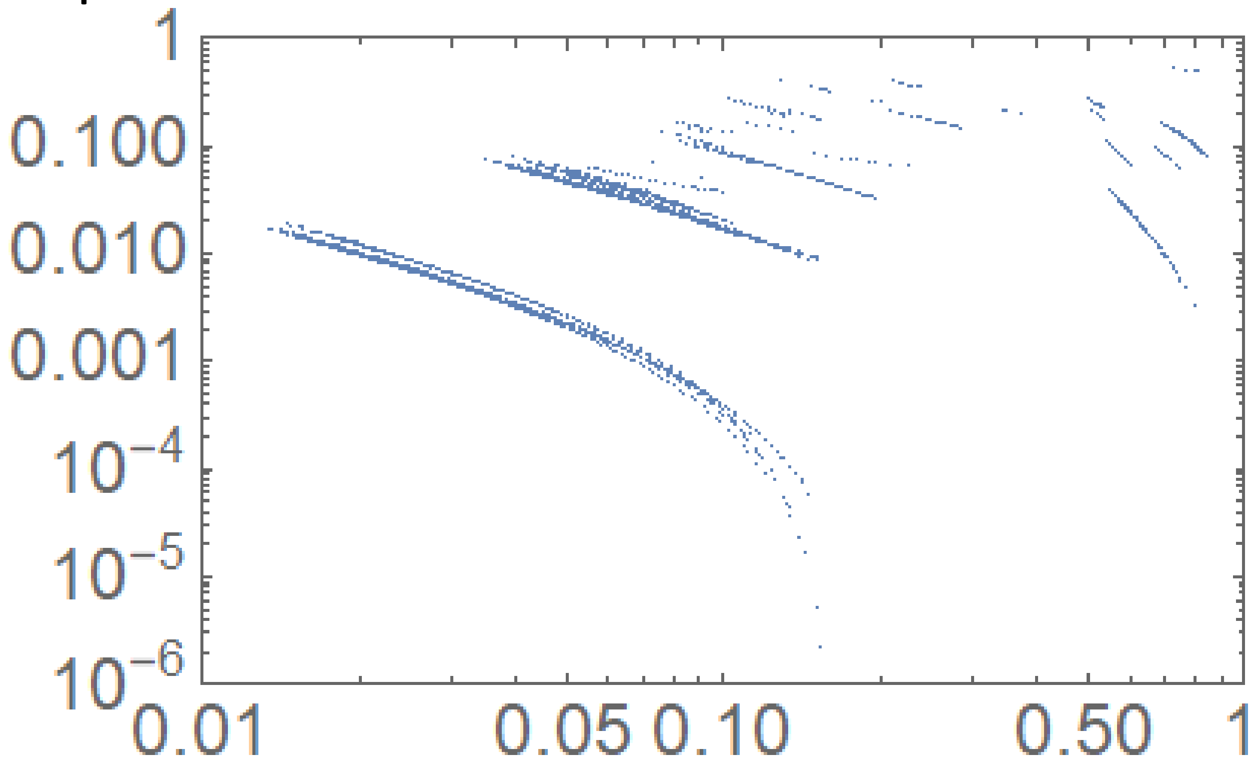
At present, dS minima exist within the following set of fluxes:

$$n_1 = n_2 = 0 \qquad -6 \le n_7 \le 6 \qquad -10 \le n_5, n_6 \le 10$$

$$-8 \le n_3, n_4, n_8, n_9, n_{10}, n_{11} \le 8$$

Each dot corresponds to the dS minima.

$$C = \frac{V_{\rm vol}^2 \times V}{M_{\rm pl}^4}$$



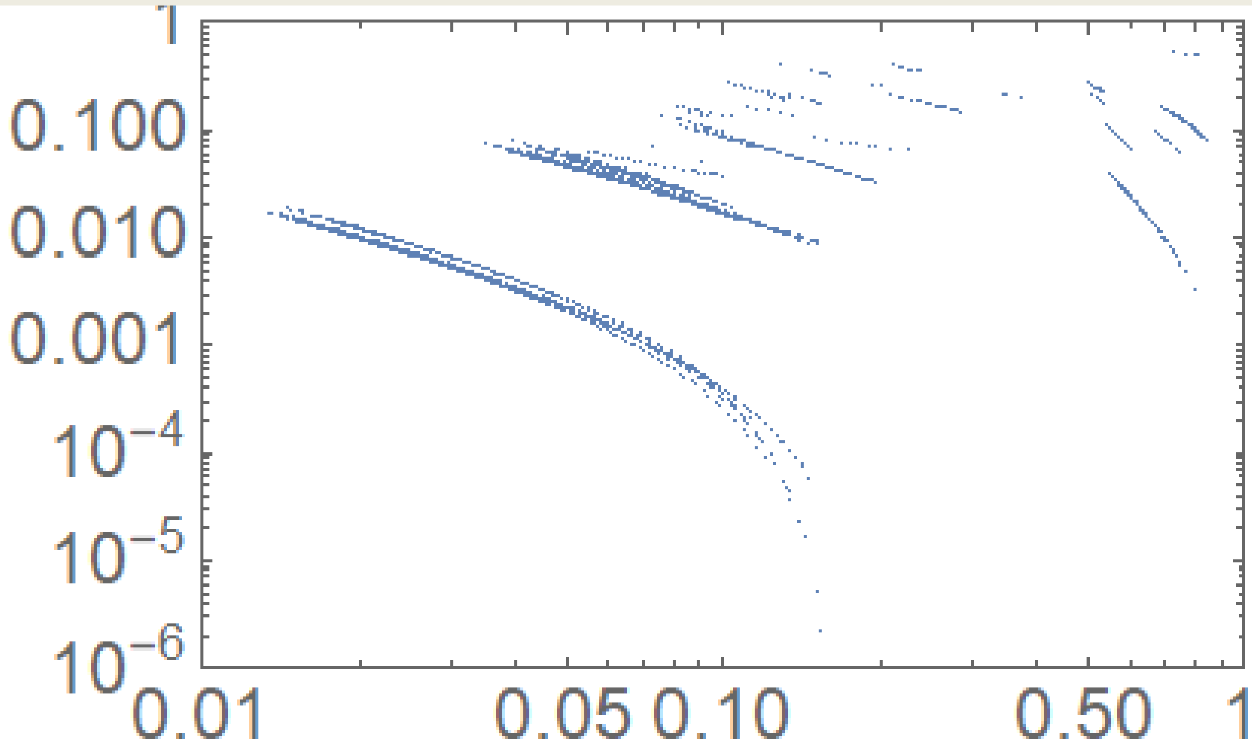
$$g_s = ({\rm Im}S)^{-1}$$

Result: SUSY-breaking fluxes

- Finite g_s leads to smaller vacuum energy !
- At present, smallest dS potential is given by

$$V \simeq \frac{10^{-8}}{V_{\mathrm{vol}}^2} \times M_{\mathrm{pl}}^4$$

$$C = \frac{V_{\mathrm{vol}}^2 \times V}{M_{\mathrm{pl}}^4}$$



$$g_s = (\mathrm{Im}S)^{-1}$$

Comment on the dS solution

- No a priori need for $\overline{\mathrm{D3}}$-brane
- Tiny dS potential could be a candidate of uplifting potential

$$V \simeq \frac{10^{-8}}{V_{\mathrm{vol}}^2} \times M_{\mathrm{pl}}^4$$

- The richness of the set of possible fluxes
  → A more tiny dS energy, similar to toroidal orientifold model (type IB)
  [A. Saltman and E. Silverstein'04]
- Full G_4-fluxes and stringy corrections are necessary to obtain the dS solution (in the M-theory context) [Dasgupta-Gwyn-McDonough-Mia-Tatar'14]
- Our model includes the leading stringy (g_s)-corrections
  (It is straightforward to include instanton corrections)
- It is interesting to check such dS solutions from the perspective of the E.O.M., using M/F-duality

Conclusion

- We explicitly demonstrate the moduli stabilization around the LCS point of the elliptically-fibered F-theory fourfold

- G_4-fluxes lead to the stabilization of all the complex structure moduli at the Minkowski minimum or dS minimum

- In the dS case, small but finite string coupling prefers tiny dS potential (No a priori need for $\overline{\mathrm{D3}}$ -brane)

- "Swampland conjecture" in the F-theory context