# Asymptotic curvature and non-gravitational theories

Based on work in progress with
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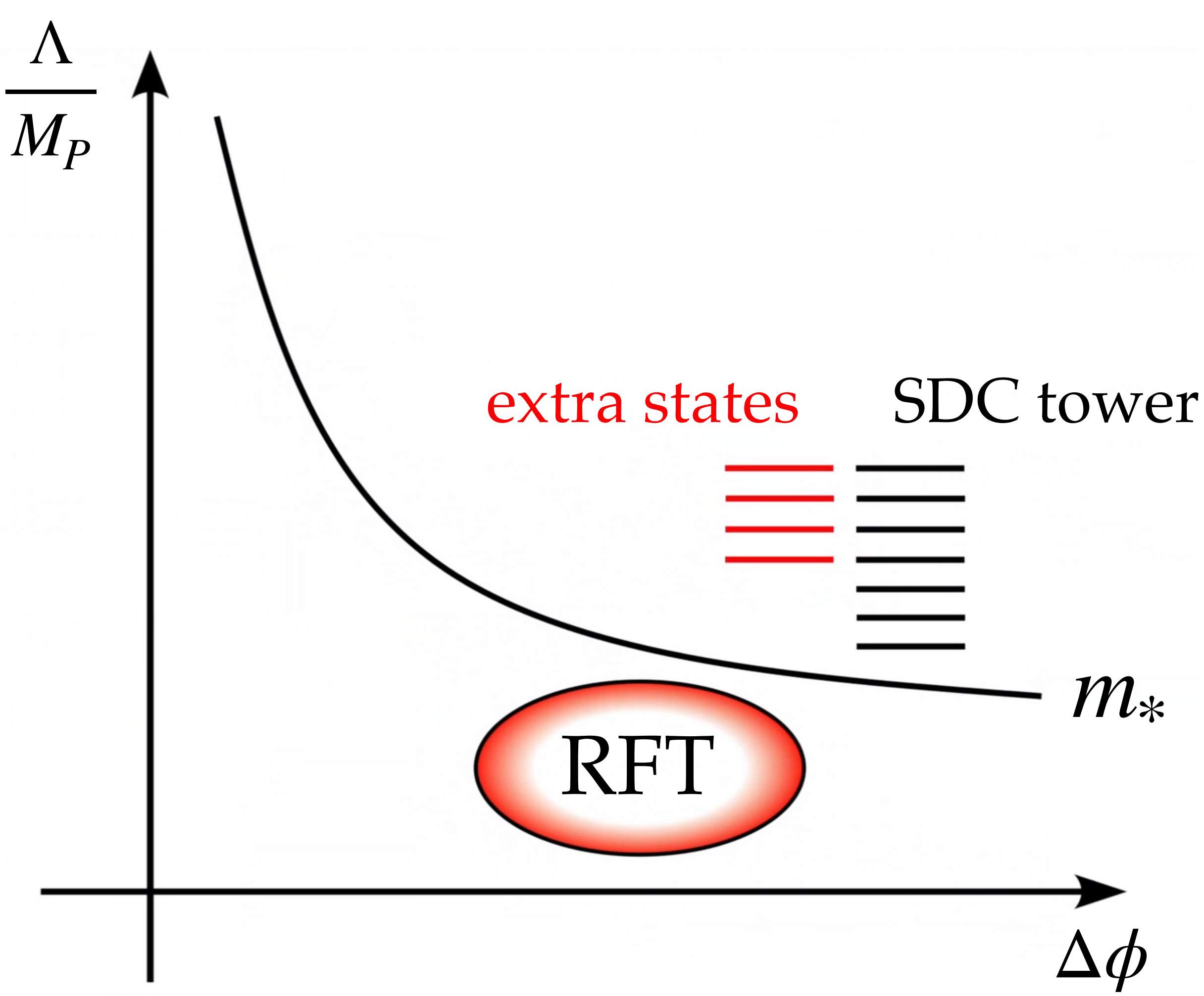
# Motivation

- **Swampland Distance Conjecture** Ooguri, Vafa '06
  Along infinite distance limits there is an infinite tower of states that becomes light as
  $$m_* \sim M_P \, e^{-\alpha \Delta\phi}$$
- **Emergent String Conjecture** Lee, Lerche, Weigand '19
  Two universal **weakly coupled** descriptions: - KK modes
  - string oscillations
- More refined classifications of infinite distance limits,
  e.g. type $\mathrm{II}_b$, $\mathrm{III}_c$, $\mathrm{IV}_d$ singularities Grimm, Li, Palti '18

  What **extra physics** can they capture?

# Motivation

- Moduli space curvature contains information about rigid field theory (RFT) sectors
- A **divergence in moduli space curvature** signals a **RFT that decouples from gravity**




$$R_{\text{IIA}} \simeq \frac{M_P}{m_*} R_{\text{rig}}$$

$$R_{\text{rig}} \simeq g_{\text{rig}}^6 (\partial_t^3 F_{\text{rig}})^2$$

$$m_* = \text{cutoff of RFT}$$

Marchesano, LM, Paoloni '23

see Lorenzo Paoloni's parallel talk

# Setup

- Setup: **type IIA** compactifications on CY3, **vector multiplet** moduli space

- Complex scalars $T^a = b^a + it^a$ $\longrightarrow$ kinetic term $g_{ab} dT^a \wedge * d\overline{T}^b$

  $g_{ab}$ = **moduli space metric**

- Large volume and strong 10d coupling

  $t^a \sim e^a \phi$ with $\phi \to \infty$

  $g_s \sim \sqrt{V_{CY}} \sim \phi^w$

Corvilain, Grimm, Valenzuela '18 Lee, Lerche, Weigand '19

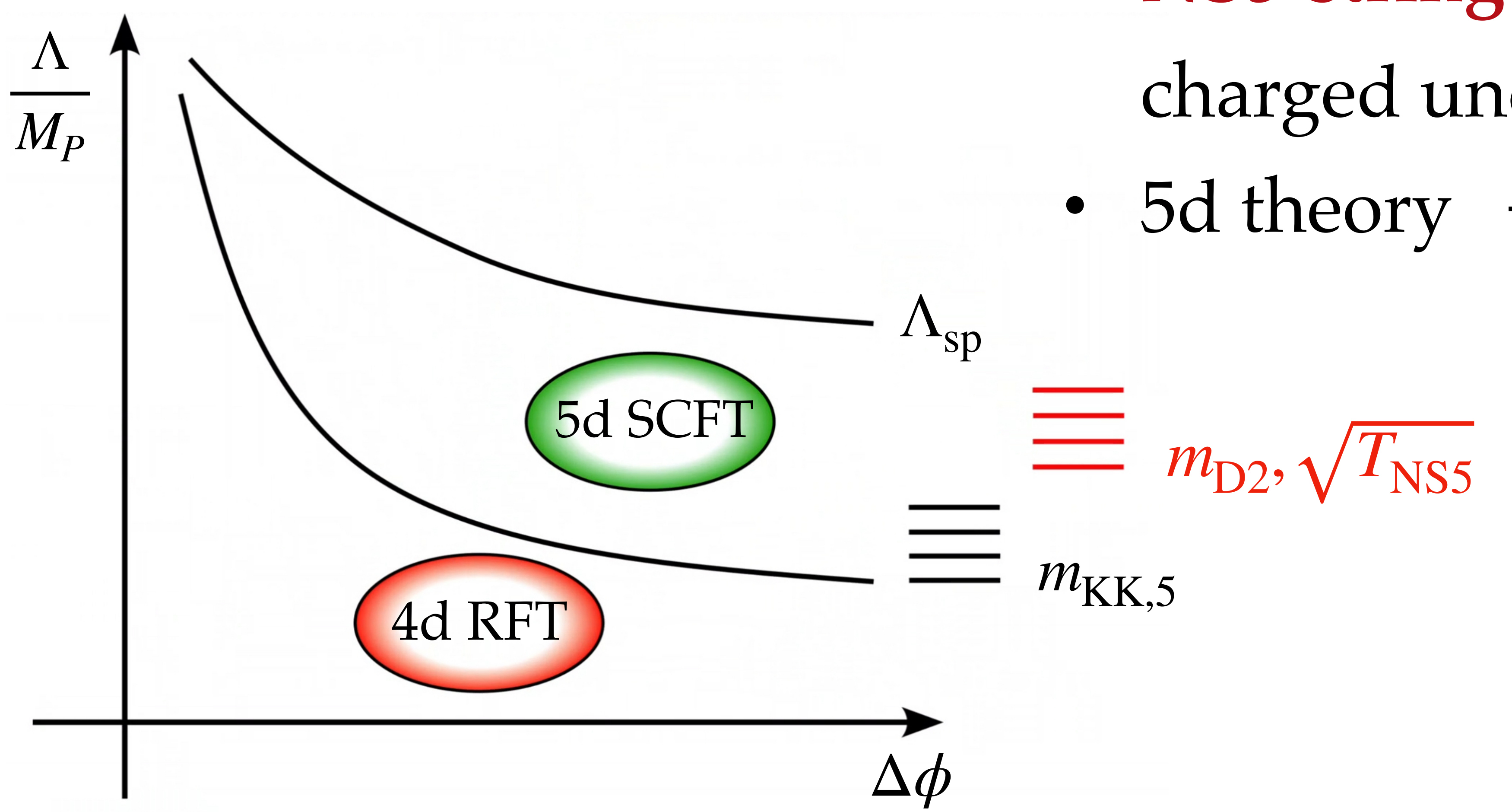
- RFTs supported on **divisors that shrink** wrt $V_{CY}$

| w | Mixed Hodge Structure | Emergent String Conjecture |
|---|---|---|
| 3 | $IV_d$ | 5d M-theory |
| 2 | $III_c$ | 6d F-theory |
| 1 | $II_b$ | Emergent heterotic string |

# M-theory limits

- Decompactification to 5d: M-theory on $CY_3$
- $R_{\rm IIA} \to \infty \longleftrightarrow$ effective divisor collapsing to a point at finite distance in M-theory $\longrightarrow$ 5d SCFT

Witten '96

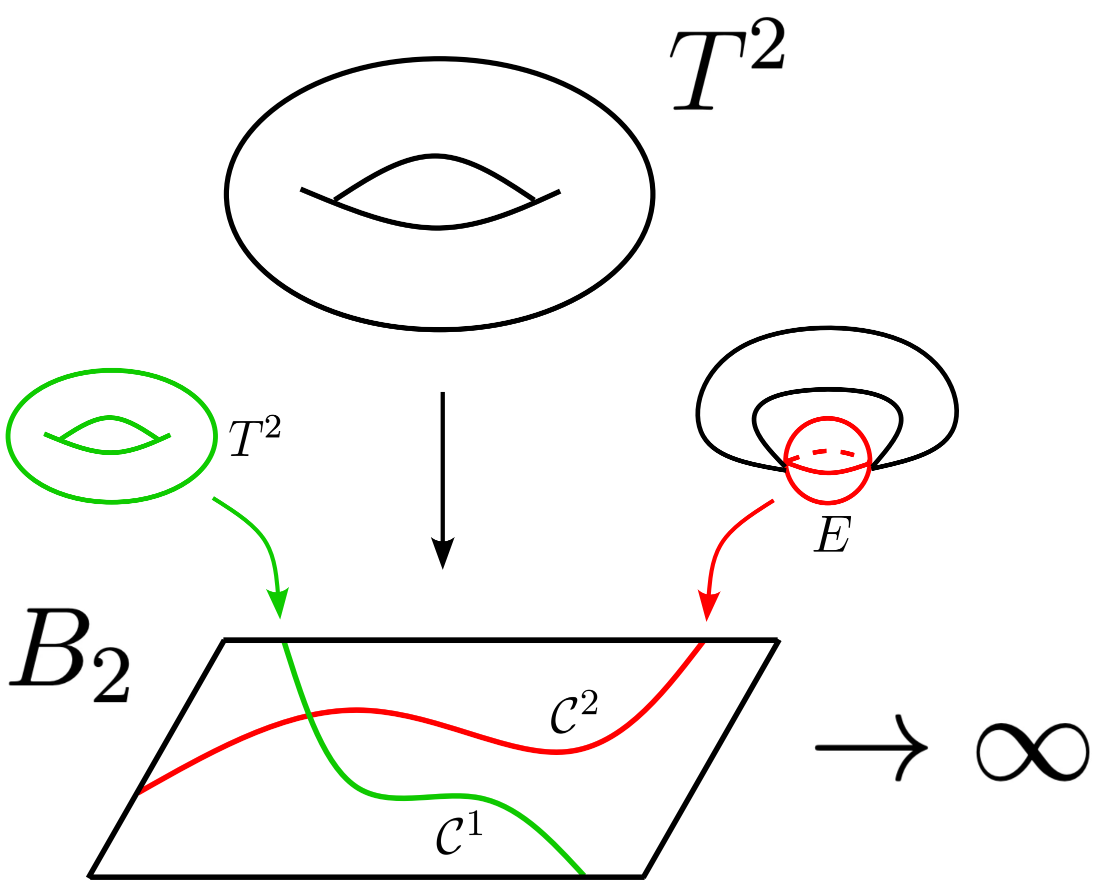



- **NS5-string and D2-particles** charged under the RFT
- 5d theory $\xrightarrow[S^1]{}$ 4d RFT

# What about **F-theory** and emergent string limits

# F-theory limits

- Decompactification to 6d: F-theory on elliptically fibered $CY_3$
- Geometric engineering of 6d SCFTs in F-theory Review: Heckman, Rudelius '19




Two possible 6d origin for 4d RFT sector:

- Vector mult. $\longleftrightarrow$ $E \to C$
- Tensor mult. $\longleftrightarrow$ $T^2 \to C$

$C$ = contractible curve in the base

- 6d gauge th $\longrightarrow$ $m_{\text{KK},5} < m_W < m_{\text{KK},6}$ $\longrightarrow$ **5d moduli-dependent gauge coupling**

$\implies R_{\text{rig}} \neq 0 \implies R_{\text{IIA}} \to \infty$

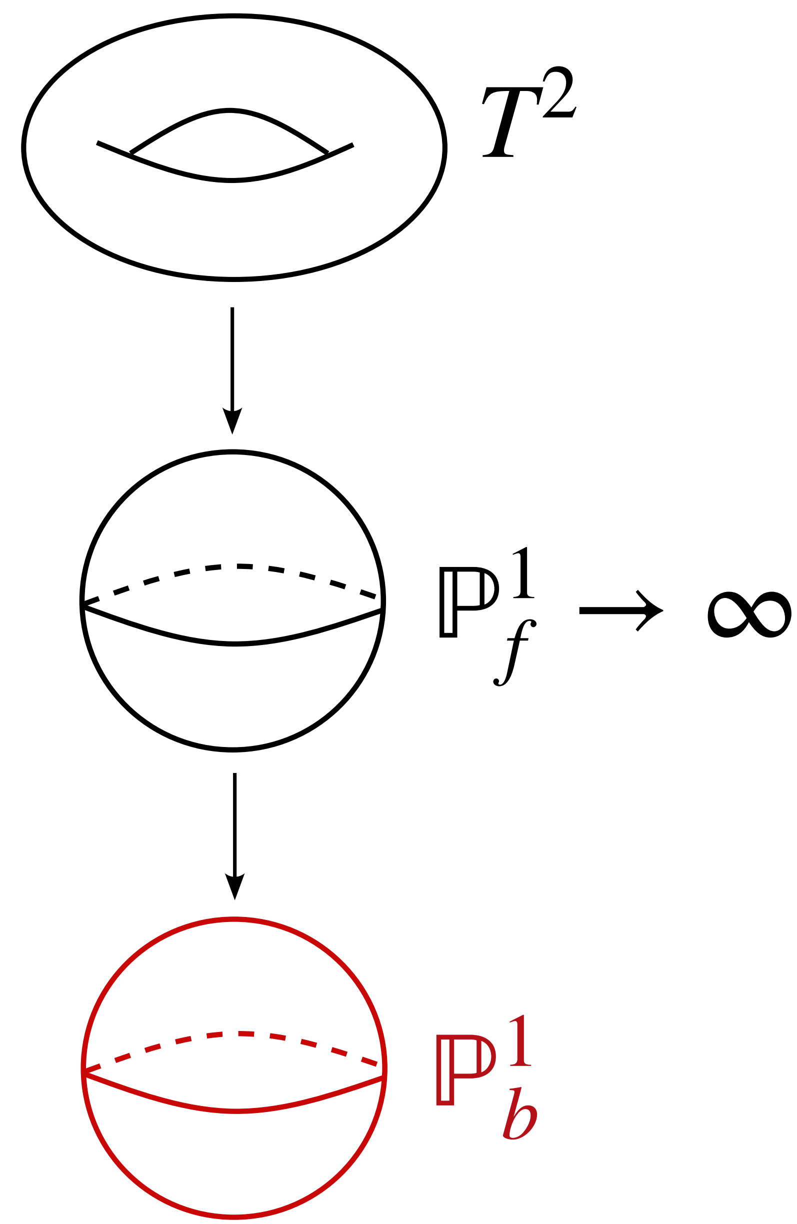
# F-theory limits: tensor branch

- Let's look at a simple example: KMV conifold Klemm, Mayr, Vafa '96

$$\frac{m_{\text{KK},5}}{M_P} \sim \frac{1}{\sqrt{V_{CY}}}$$

$$\frac{m_{\text{KK},6}}{m_{\text{KK},5}} \sim V_{T^2}$$

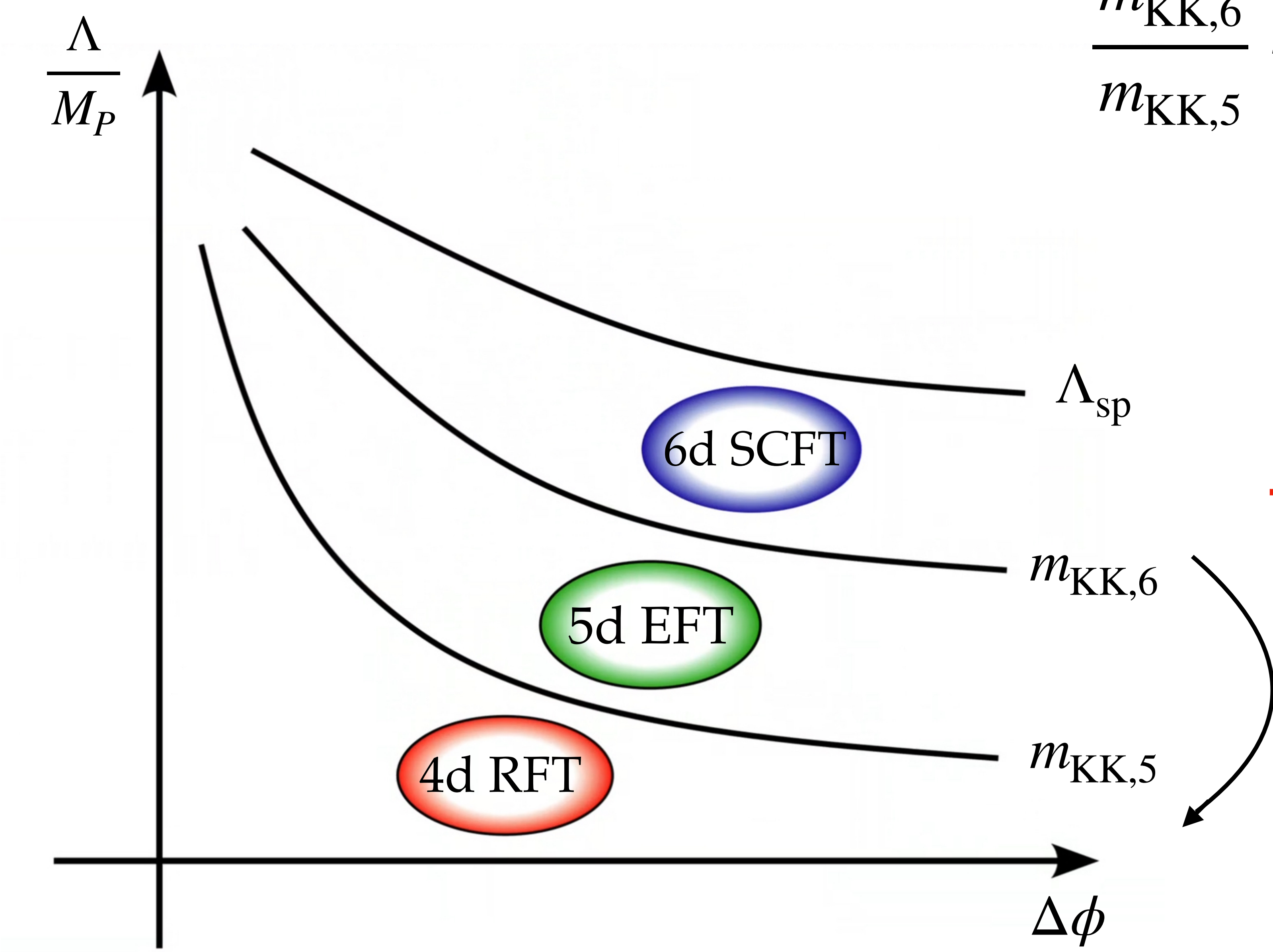
$$\frac{m_{\text{D2}}}{m_{\text{KK},5}} \sim V_{\mathbb{P}^1_b}$$



# F-theory limits: tensor branch

- "Standard" F-theory limits: $V_{T^2} < V_{\mathbb{P}^1_b}$

$$\frac{m_{\mathrm{KK},6}}{m_{\mathrm{KK},5}} \sim V_{T^2} \qquad \frac{m_{\mathrm{D2}}}{m_{\mathrm{KK},5}} \sim V_{\mathbb{P}^1_b}$$




$$V_{T^2} < V_{\mathbb{P}^1_b}$$

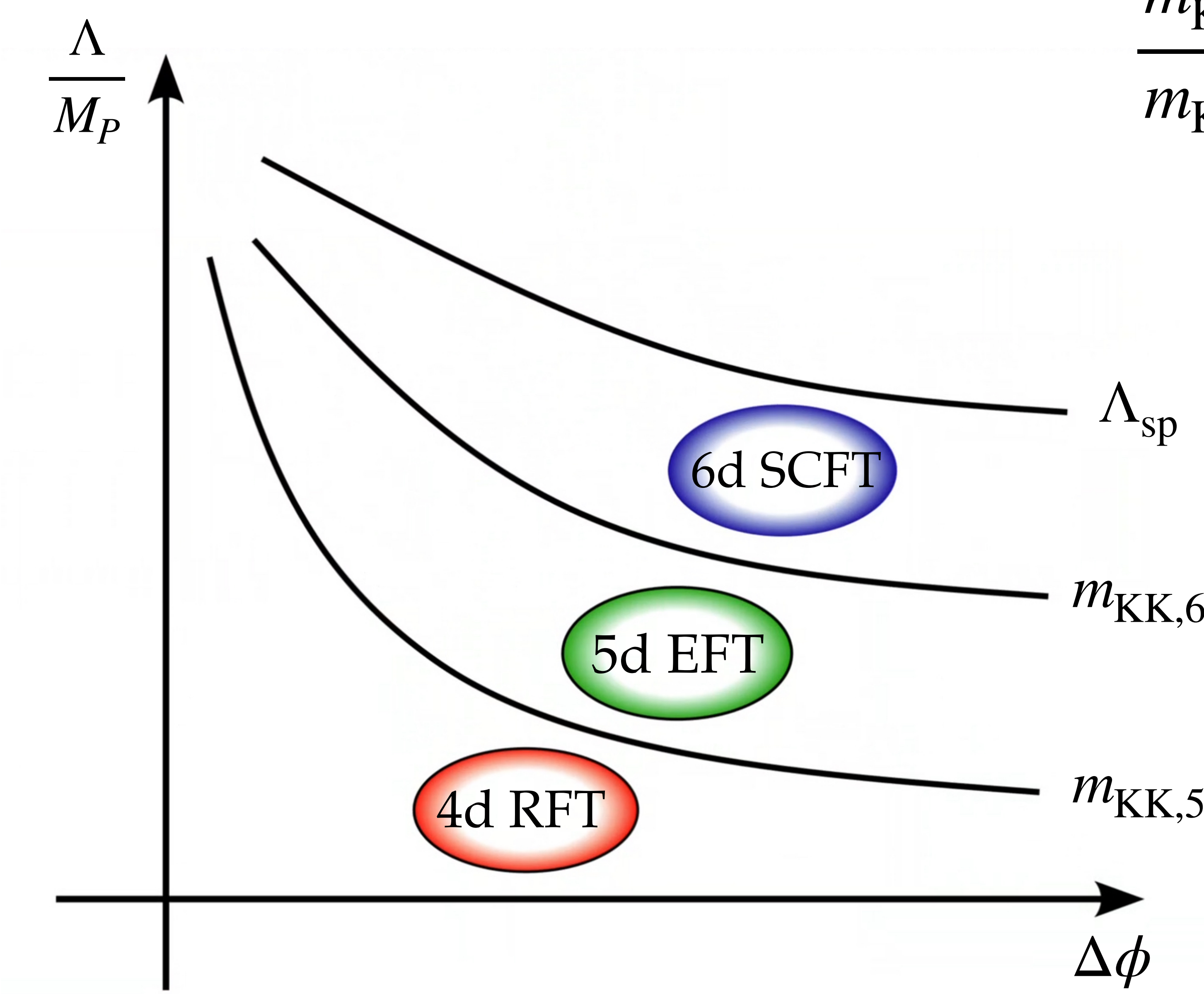
$m_{\mathrm{D2}}, \sqrt{T_{\mathrm{NS5}}}$

Simple dimensional reduction of 6d theory

$$R_{\mathrm{rig}} = 0$$

# F-theory limits: tensor branch

- More "exotic" limits: $V_{T^2} > V_{\mathbb{P}^1_b}$




$$\frac{m_{\rm KK,6}}{m_{\rm KK,5}} \sim V_{T^2} \qquad \frac{m_{\rm D2}}{m_{\rm KK,5}} \sim V_{\mathbb{P}^1_b}$$

$$V_{T^2} > V_{\mathbb{P}^1_b}$$

— $\sqrt{T_{\rm NS5}}$

— $m_{\rm D2}$

— $m_{\rm D2}$

Phase transition in 5d by integrating in M2

Instanton corrections in 4d

$R_{\rm rig} \sim e^{-t_{\rm rig}}$

# Summary

Three main possibilities:

- All massive states integrated out in 6d
  $\Longrightarrow$ simple dimensional reduction on $T^2$ of the RFT

- Some massive states between $m_{\text{KK},5}$ and $m_{\text{KK},6}$
  $\Longrightarrow$ phase transition in 5d $\longrightarrow$ $\partial_t^3 F_{\text{rig}} \sim c$

- Massive states at $m_{\text{KK},5}$
  $\Longrightarrow$ instanton corrections in 4d can source $R_{\text{rig}}$
  $\longrightarrow$ $\partial_t^3 F_{\text{rig}} \sim e^{-t_{\text{rig}}}$

# Conclusions

- The **moduli space curvature** captures information about **rigid field theory sectors** (RFTs) that decouple from gravity

- These RFTs can be seen as **dimensional reduction** of higher dimensional RFTs + **integrating out massive states**

  ↓ classical vs instanton-generated divergence

- In F-theory limits from 6d SCFTs

- In emergent string limits from 6d LSTs (elliptic fibration ⟷ K3 fibration)

*Thank you!*

# Back-up slides

# Emergent string limits

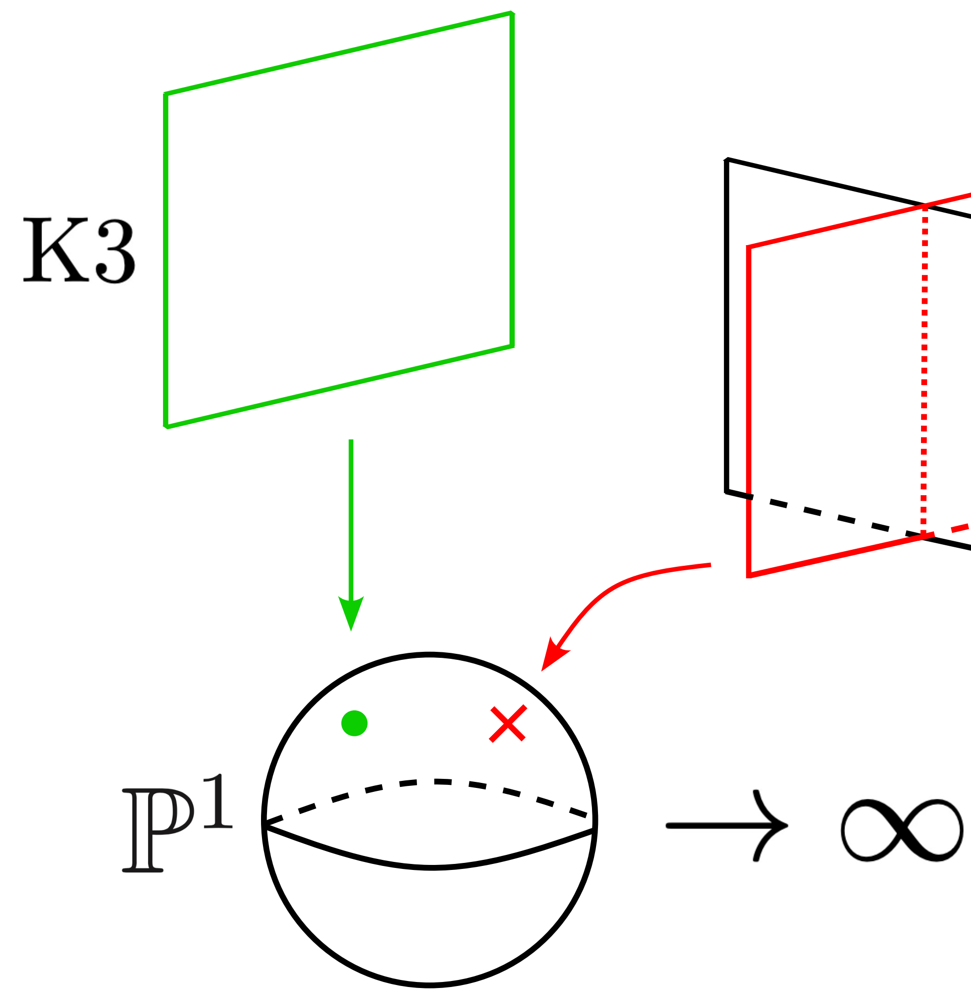
- $CY_3$ is K3 fibered
- The presence of a RFT signals a degeneration of K3

↕

LST in F-theory on $CY_3$

6d origin of 4d RFT sector:

- Vector mult. ⟷ split K3
- Tensor mult. ⟷ generic K3



# F-theory limits

| $R_{IIA}$ divergence | 6d origin of 4d RFT |
|---|---|
| Classical | SCFT with gauge theory |
| By world-sheet instantons | SCFT without gauge theory |
| No divergence | SCFT w/o gauge theory and enhanced SUSY |

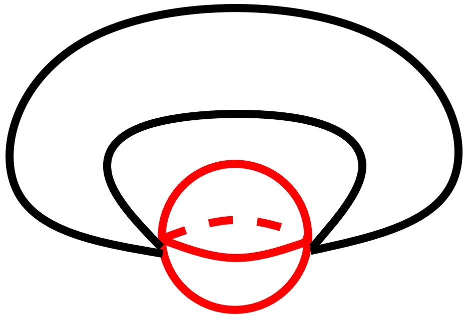
- 6d gauge theory $\xrightarrow{S^1}$ moduli dependent 5d gauge coupling $\longrightarrow$ classical curvature for rigid theory
- 6d tensor branch $\xrightarrow{S^1}$ constant 5d gauge coupling $\longrightarrow$ no curvature for rigid theory

# F-theory limits: vectors

6d gauge theory

$\Big\downarrow S^1$

5d gauge theory




$$\frac{m_W}{m_{\text{KK},5}} \sim V_E < V_{T^2}$$

$$m_{\text{KK},5} < m_W < m_{\text{KK},6}$$

$\Big\downarrow$ integrate out W bosons

5d gauge coupling

$$g_{\text{rig}} \simeq g_0 + t_{\text{rig}} \quad \Longrightarrow \quad R_{\text{rig}} \simeq g_{\text{rig}}^6 (\partial_t^3 F_{\text{rig}})^2 \neq 0$$

$$\Longrightarrow \quad R_{\text{IIA}} \to \infty$$

6d tensor branch has more casuistic: let's look at a simple example