The Swampland Distance Conjecture and Walls of Marginal Stability

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Markus Dierigl - Utrecht University

upcoming work with Thomas Grimm

Utrecht University

Delta Institute for Theoretical Physics

The Swampland Program [Ooguri, Vafa '06]

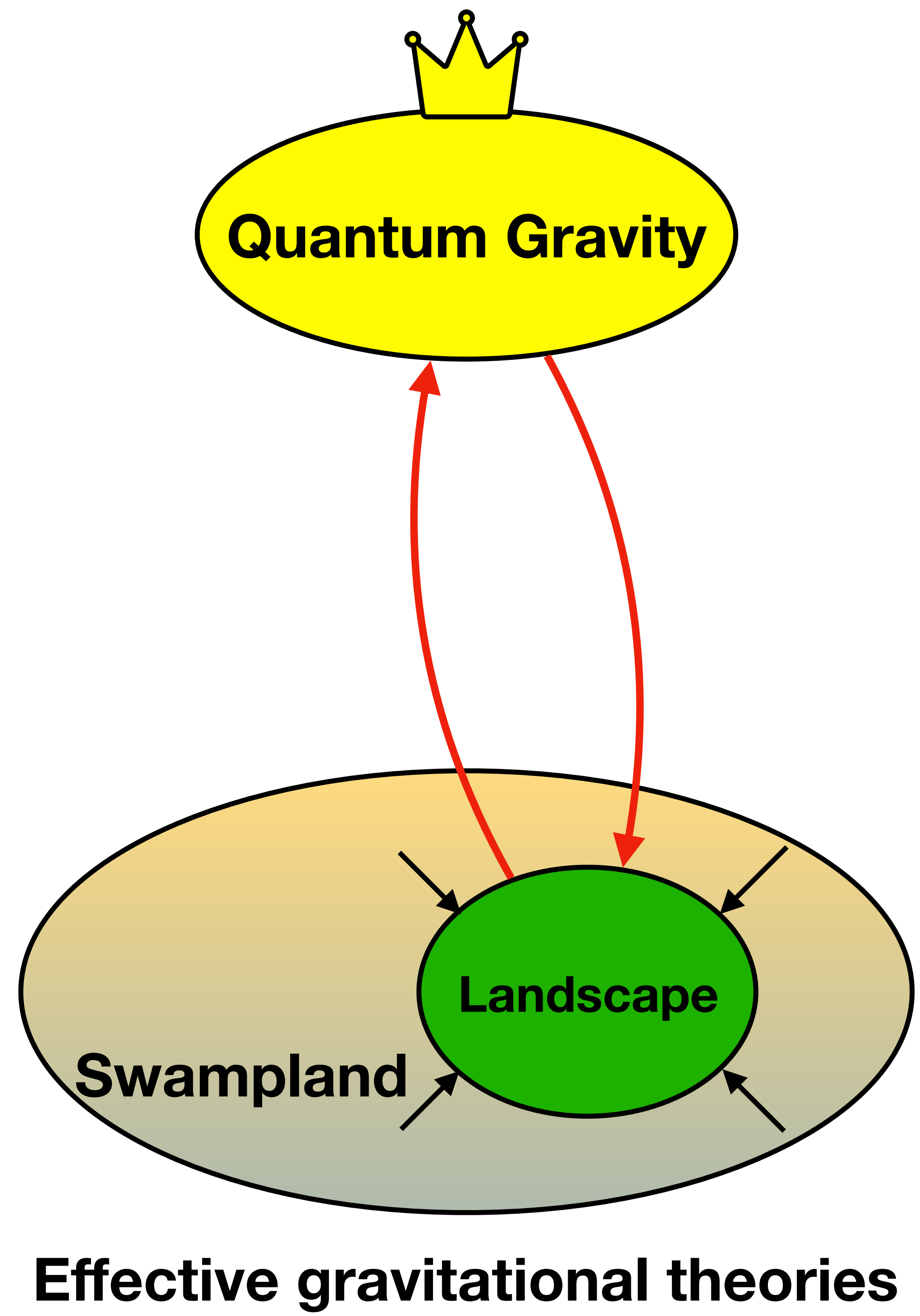
- Criteria for **effective theories** (low energy) to have completion in **quantum gravity** (high energy)

- **Mostly:** Universal behavior of consistent theory of quantum gravity in certain limits (here: string theory compactifications)

↓ **the dream**

- **Prediction** of quantum gravity

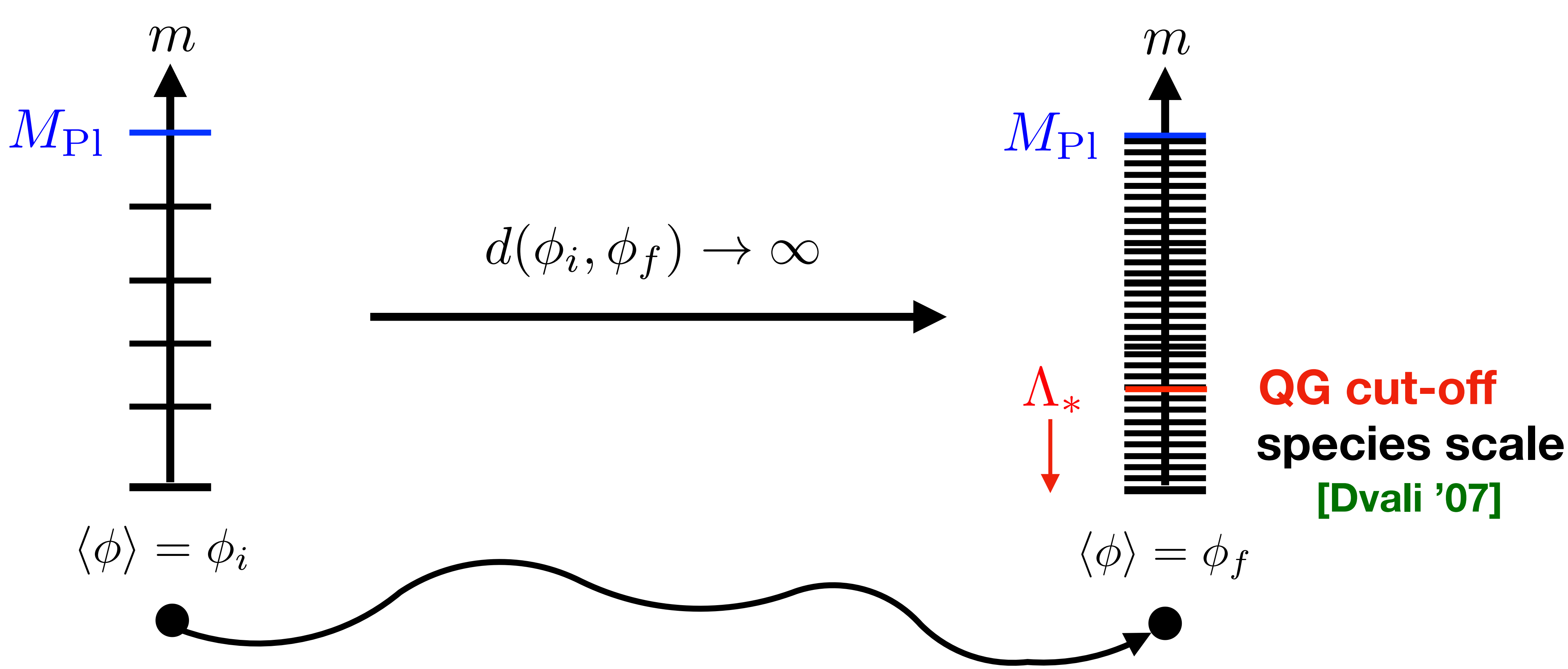
- **Test** of quantum gravity



The Swampland Distance Conjecture [Ooguri, Vafa '06]

Probing infinite (possibly large is enough, [Klaewer, Palti '17]) **distances in moduli space,** one encounters a **tower of states** with **masses** that are **exponentially suppressed in the field distance** (with respect to the Planck scale).

→ **Break-down of EFT** after traveling large distances



Tests of Conjecture

Conjecture has passed several tests in string theory:

- **Weak coupling, decompactification** [Ooguri, Vafa '06],...
- **Complex structure** of **Calabi-Yau 3-folds** [Grimm, Palti, Valenzuela '18], [Grimm, Li, Palti '18],...
- **Kahler moduli** for **F-theory base** [Lee, Lerche, Weigand '18 + '19],...
- **Kahler moduli for Calabi-Yau 3-folds** [Corvilain, Grimm, Valenzuela '18],...
- **Extended objects in string compactifications** [Lee, Lerche, Weigand '19], [Font, Herraez, Ibanez, '19], [Grimm, van de Heisteeg '19], [Marchesano, Wiesner '19],...

Today: Type IIB string theory on $\mathrm{K3} \times T^2$

Outline of strategy

- **Classify infinite distance points** in moduli space
- **Identify** and **construct tower of light states**
- **Ensure stability of states** in limit

We consider complex structure moduli for $\mathrm{K3} \times T^2$
see also [Grimm, Palti, Valenzuela '18], [Grimm, Li, Palti '18]

- **Mathematical classification using limiting mixed Hodge structures**
- $\mathcal{N}=4$ **allows a lot of control in identifying the states**
- **Towers** of **1/2-BPS** and **1/4-BPS** states**;** explicit treatment of **stability** via **walls of marginal stability** ↩

Infinite distance

- **Complex structure moduli** space of Calabi-Yau **3-fold** is a **Kahler manifold** with **Kahler potential**

$$K = -\log\left(i\int \Omega\wedge\bar{\Omega}\right)$$

- For $\mathrm{K3}\times T^2$ the **(3,0)-form** is **composed** of **(2,0)-form from K3** and **(1,0)-form from torus**

$$\Omega = \Omega_{\mathrm{K3}}\wedge(\omega_1 + \lambda\omega_2)$$

complex structure parameter

Technical aside:

- Geometric interpretation demands certain embedding into full moduli space
$$\mathrm{O}(\Lambda^{6,22})\backslash\mathrm{O}(6,22)/\mathrm{O}(6)\times\mathrm{O}(22)\to\mathrm{O}(\Lambda^{3,19})\backslash\mathrm{O}(3,19)/\mathrm{O}(3)\times\mathrm{O}(19)$$
- Identification of complex structure demands restriction to polarized K3s
$$\mathrm{O}(\Lambda^{3,19})\backslash\mathrm{O}(3,19)/\mathrm{O}(3)\times\mathrm{O}(19)\to\mathrm{O}(\Lambda^{2,19})\backslash\mathrm{O}(2,19)/\mathrm{O}(2)\times\mathrm{O}(19)$$

Infinite distance

- **Torus** simple enough ⟶ **completely explicit** (infinite distance at $\lambda \in \mathbb{R} \cup \{i\infty\}$)

- $\mathrm{SL}(2,\mathbb{Z})$ allows to restrict to the degeneration $\lambda_2 \to \infty$

- **Approximate complex structure of K3** close to singularity by **nilpotent orbit theorem** [Schmid '76],[Cattani, Kaplan, Schmid '86],...

$$\Omega_{\mathrm{K3}} = \Pi^a \gamma_a \to \Pi^a_{\mathrm{nil}} \gamma_a$$

basis of $H^2(\mathrm{K3},\mathbb{Z})$

$$\mathbf{\Pi}_{\mathrm{nil}} = e^{-tN} \mathbf{a}_0$$

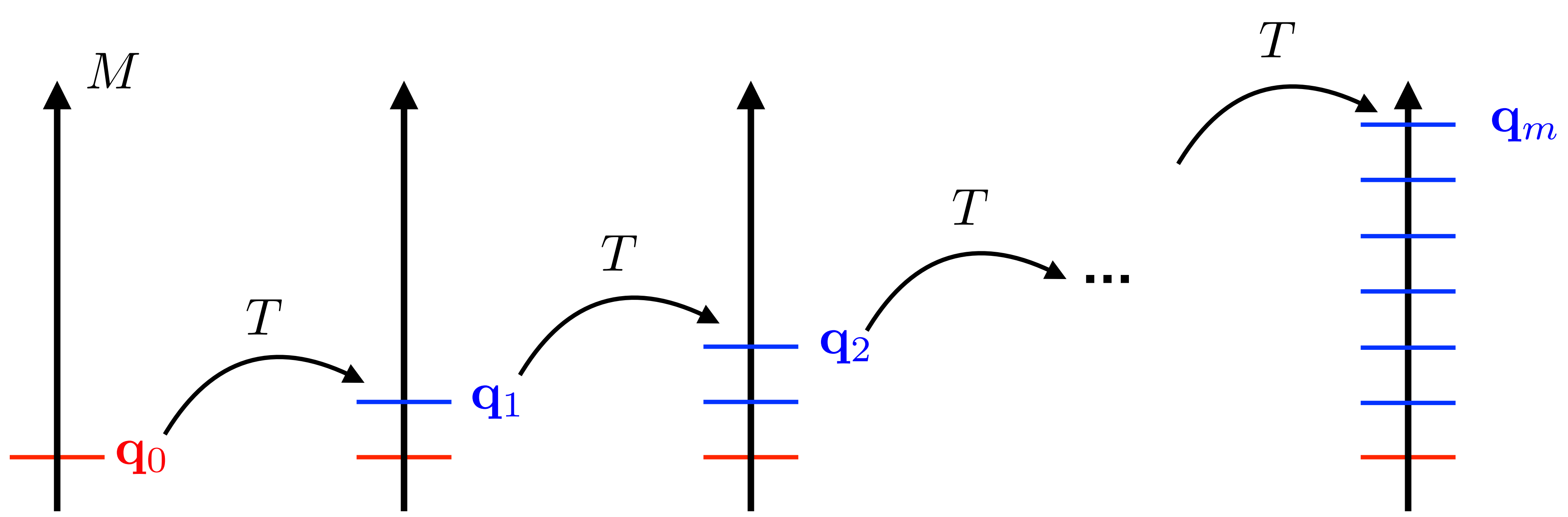
- degeneration for $t \to i\infty$
- log-monodromy N specified by degeneration
- $\mathbf{a}_0$ does not depend on t

Infinite distance for $N\mathbf{a}_0 \neq 0$

Mutual degeneration

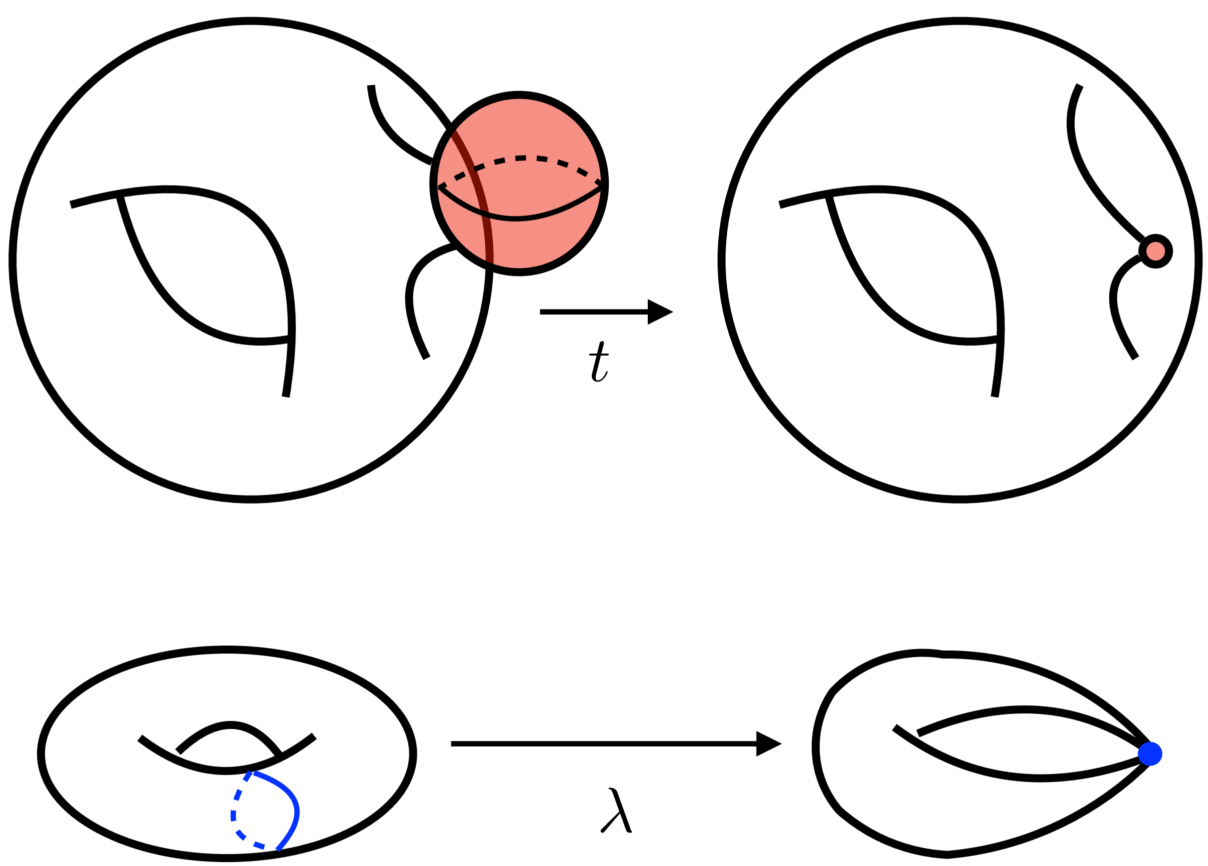
- We restrict to the case of **type III degenerations of K3**
- **Simultaneously** we let the **torus degenerate: type IV enhancement** [Grimm, Palti, Valenzuela '18], [Grimm, Li, Palti '18],…
- **"Maximal degeneration"** and only case for which **tower contains 1/4-BPS states** ⟶ **potential instability**
- **Monodromy generated tower is 1/4-BPS**

$$T = T_{T^2} \otimes e^N$$



Tower of states

- **Complex structure degeneration for K3 and T^2**
- **Natural candidate: D3-branes on 3-cycles**



Type III degeneration singles out two 2-cycles controlled by t

↓

3-cycle defining electric and magnetic charges

↑

Limit on torus singles out 1-cycle controlled by λ

$$\begin{pmatrix} \mathbf{P} \\ \mathbf{Q} \end{pmatrix} = \begin{pmatrix} P\delta + p\gamma \\ q\gamma \end{pmatrix} \qquad P, p, q \in \mathbb{Z}$$

Tower of states

Masses can be **explicitly** evaluated in terms of **charges**:

$$M^2 = \frac{1}{\lambda_2}(\mathbf{P}_L - \lambda \mathbf{Q}_L)(\mathbf{P}_L - \bar{\lambda}\mathbf{Q}_L) + 2|\mathbf{P}_L \wedge \mathbf{Q}_L|$$
$$|\mathbf{P}_L \wedge \mathbf{Q}_L|^2 = \mathbf{P}_L^2 \mathbf{Q}_L^2 - (\mathbf{P}_L \cdot \mathbf{Q}_L)^2$$

For states under consideration:

- **Projection** on Ω_{K3} **only** (no mass contribution from Kahler sector)
- **Goes to zero with expected asymptotic behavior**

$$M^2 \propto \frac{p^2}{t_2^2 \lambda_2}, M^2 \propto \frac{P^2}{\lambda_2}, M^2 \propto \frac{q^2 \lambda_2}{t_2^2}$$

Towers of 1/2-BPS states

$\mathbf{P} \parallel \mathbf{Q}$

$$M^2 \propto \frac{P^2}{\lambda_2} + \frac{q^2 \lambda_2}{t_2^2}$$

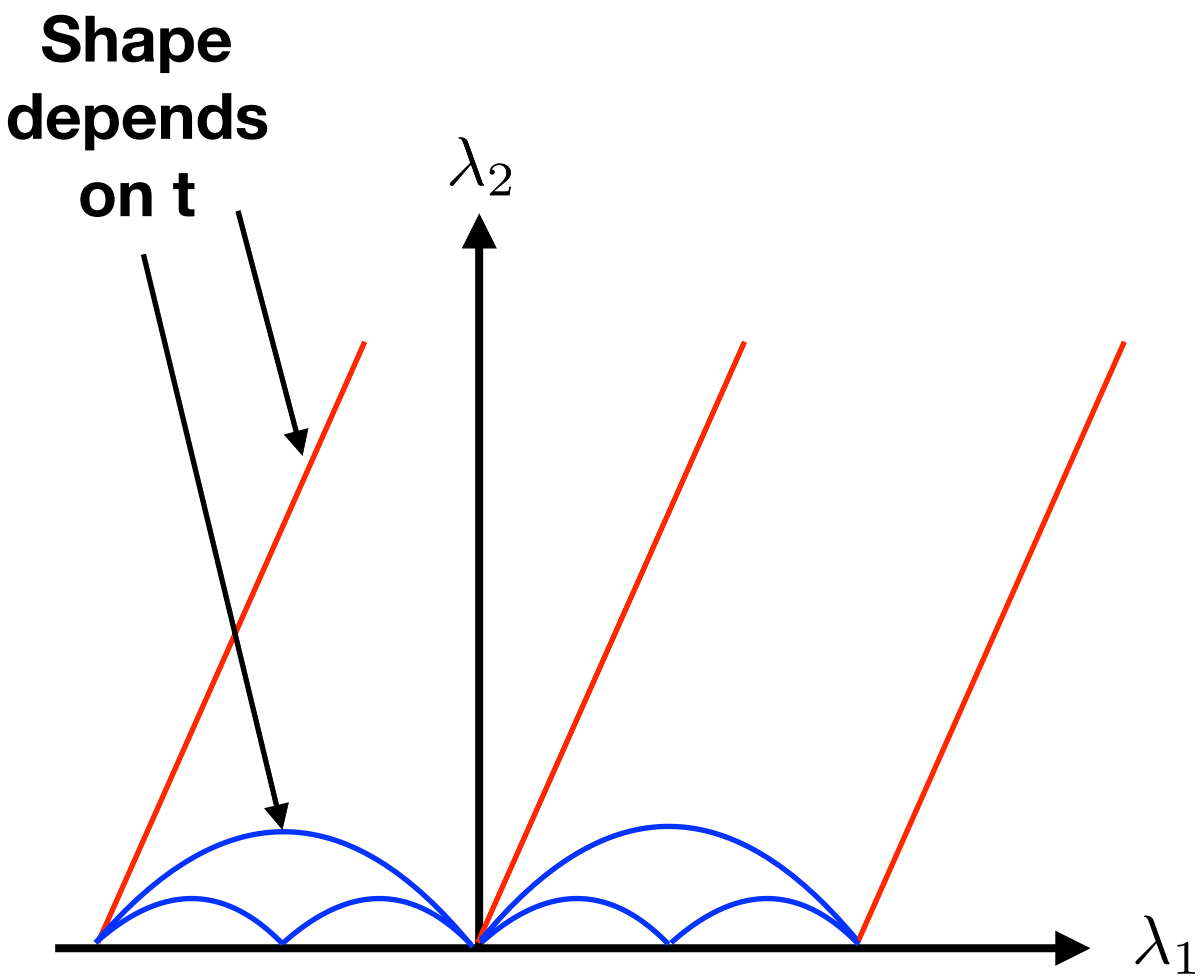
Towers of 1/4-BPS states

$\mathbf{P} \nparallel \mathbf{Q}$

Walls of marginal stability [Sen ’07], [Cheng, Verlinde ’08],...

- **1/4-BPS states generically decay into 1/2-BPS states**

$$\begin{pmatrix} \mathbf{P} \\ \mathbf{Q} \end{pmatrix} \to \begin{pmatrix} \mathbf{P}_1 \\ \mathbf{Q}_1 \end{pmatrix} + \begin{pmatrix} \mathbf{P}_2 \\ \mathbf{Q}_2 \end{pmatrix}$$



1/4-BPS in lattice:

- **red** walls ⟶ **split** into **mutually local charges: no bound state**
- **blue** walls ⟶ **do not extend into bulk in limit: no associated instability**

Exotic walls [Sen '07]

- The **specific degeneration** allows the states in the tower to decay into each other: **exotic decays into 1/4-BPS**

- **Decays happen for:** $M = M_1 + M_2$ ($\mathcal{N} = 2$ decays)

- **Mutual non-locality** demands **presence of heavy charge** in decay products, specifically $Q \neq 0 \to M^2 \propto \lambda_2 Q^2$

$\mathcal{N} = 2$	$\mathcal{N} = 4$
Cancellation with parametrically large charges	**No cancellation (mass dictated by larger central charge)**
↓	↓
Possible decays at large moduli values	**Decays seem to be absent in limit (present status)**
	↓
	Stability **(work in progress)**

Conclusion and Outlook

- **Full explicit control** in **complex structure degenerations** of type IIB **on** $\mathrm{K3} \times T^2$
    - **Classification of infinite distance**
    - **Explicit analysis of lattice of light states**
    - **Control over stability**
- **Decays in** $\mathcal{N} = 2$ (unfortunately hard to compare)
- **Emergence?**
- **Black Holes and Indices?**