Swampland Conjectures at the Limits of Field Space

Thomas W. Grimm

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Based on: 1811.02571 with Chongchuo Li, Eran Palti
1812.07548 with Irene Valenzuela, Pierre Corvilain
1905.00901 with Damian van de Heisteeg

Work in Progress with Irene & Chongchuo - asymptotic flux comactification

Introduction and general comments

Quantum consistent effective theories?

- Important Question:

  Which low energy effective theories are consistent with Quantum Gravity? What are the imprints of the underlying theory?

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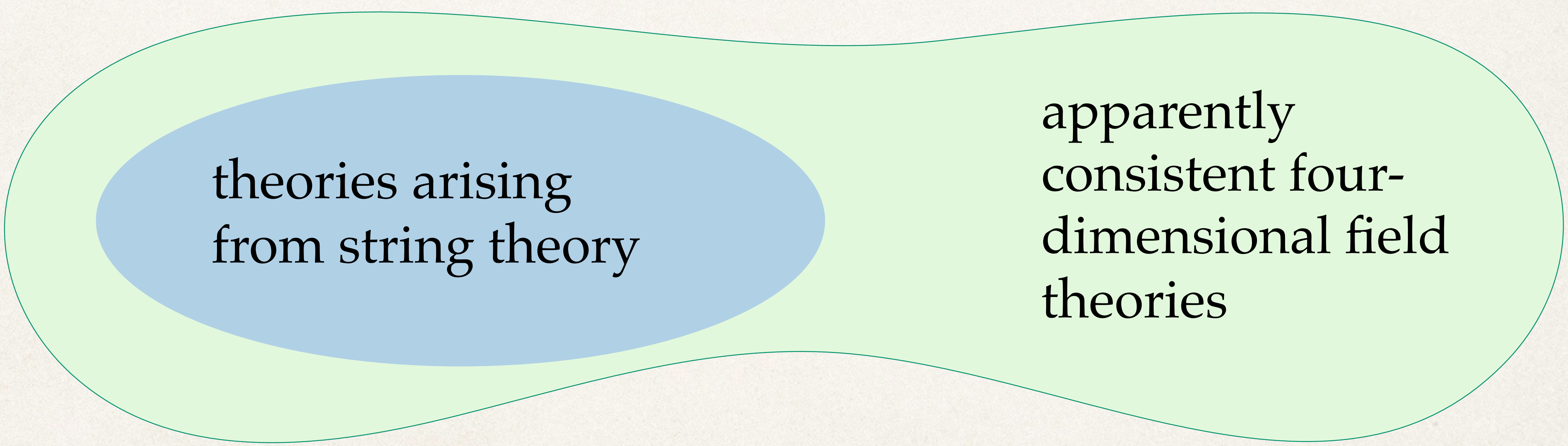

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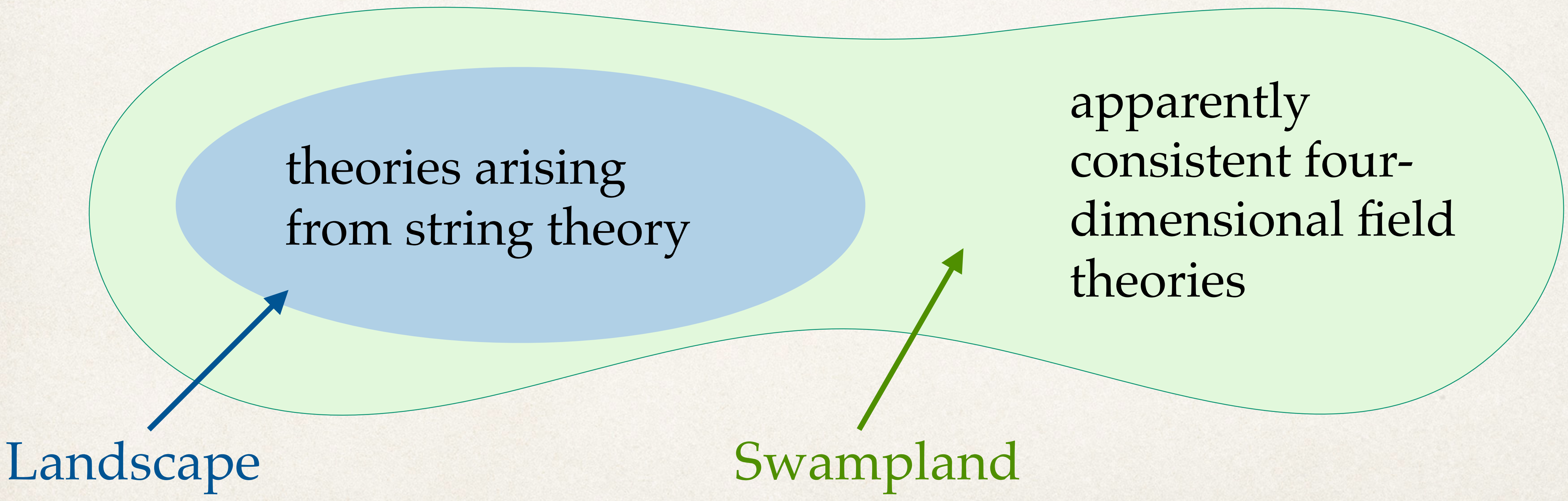

Many important works on the Swampland

Plenary talks at this conference about the landscape/swampland:

Shiu, Montero, Marchesano, Savelli, Gray, Parameswaran, McAllister, Lukas, Anderson, Vafa, Valenzuela, Heidenreich, Grana, Blumenhagen, Wrase, Palti, Uranga, Taylor, Westphal, Van Riet, Hebecker, Ibanez, Tomasiello, Sethi, Halverson, Nelson, Krippendorf, Schafer-Nameki, Martucci, Garcia-Etxebarria, Quevedo, Cvetic, Faraggi, Choi, Heckman, Nilles, Dudas, Lüst

Many interesting parallel session talks!

And important works of our organizers:

Andriot, [Lee, Lerche, Weigand], Ruehle

Not possible to do justice!

Related motivation: Search for structure

- Well-known setting: Large volume compactification
  - Couplings in the effective action are determined by intersection numbers, Chern classes of compact CY space

$$K = -\mathrm{Log}\left(\frac{1}{6}\mathcal{K}_{IJK} v^I v^J v^K + \frac{\zeta(3)\chi}{32\pi^2} \right)$$

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- What is the structure dictating 'allowed' couplings?

  Example from the Kreuzer-Skarke list:

$$\{\mathcal{K}_{IJK}\} = \{\{\{2, 2, 2\}, \{2, 0, 2\}, \{2, 2, 2\}\}, \{\{2, 0, 2\}, \{0, 0, 0\}, \{2, 0, 0\}\}, \{\{2, 2, 2\}, \{2, 0, 0\}, \{2, 0, 0\}\}\}$$

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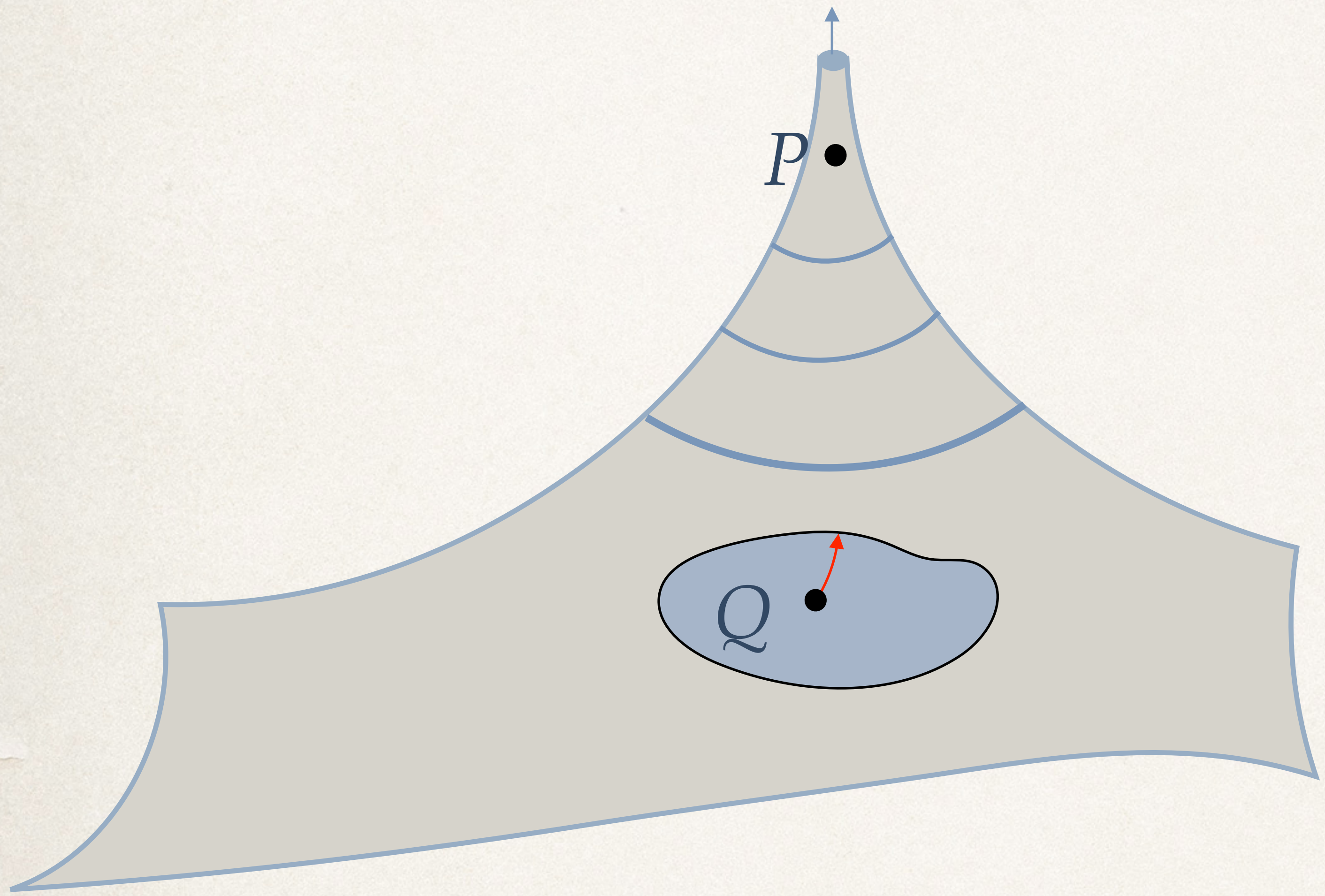
Can one set the red numbers to zero?

Swampland Distance Conjecture as a Guide

consider a moduli space and two points [Ooguri,Vafa]



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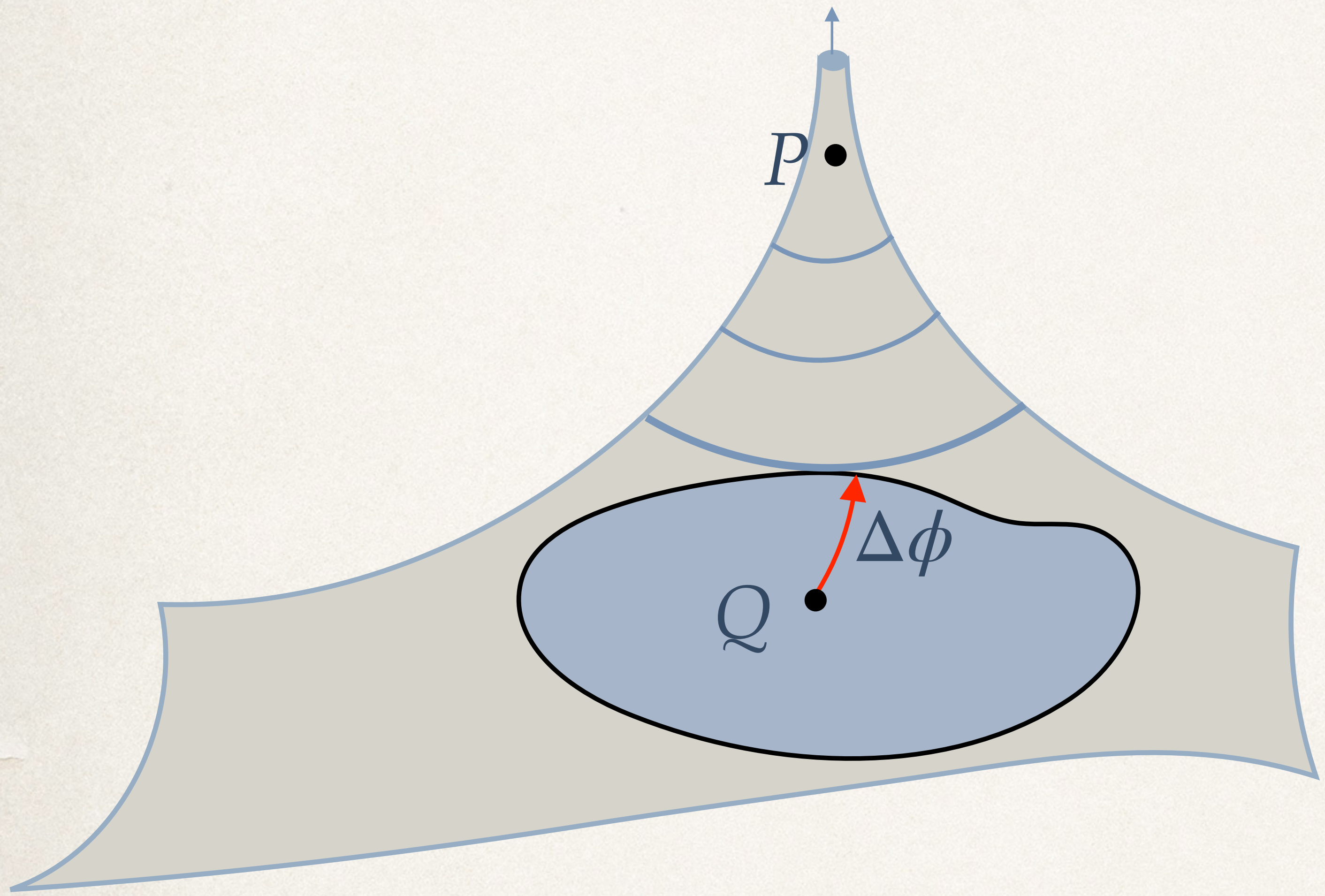

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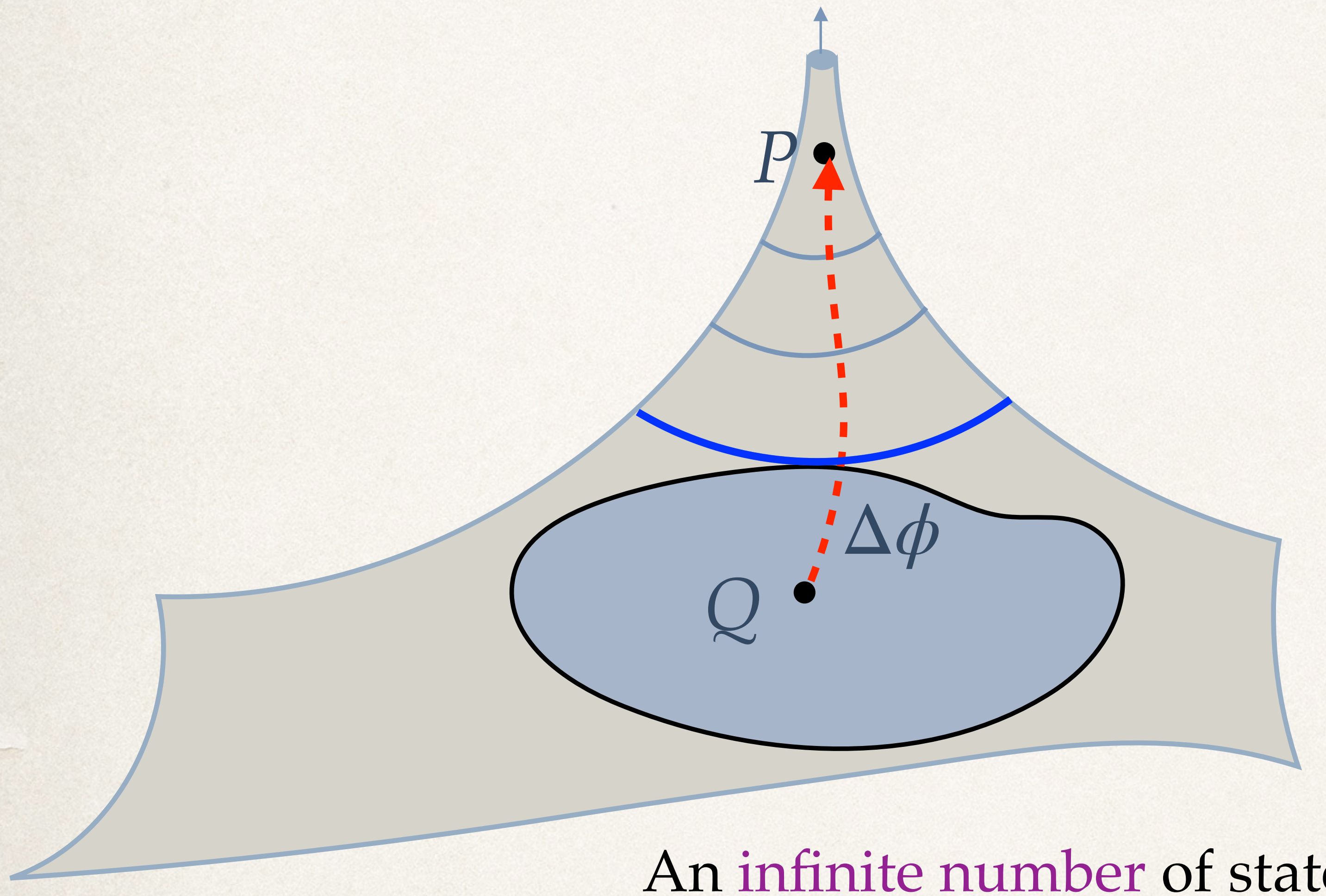


shortest geodesic between P, Q (length $d(P,Q)$)

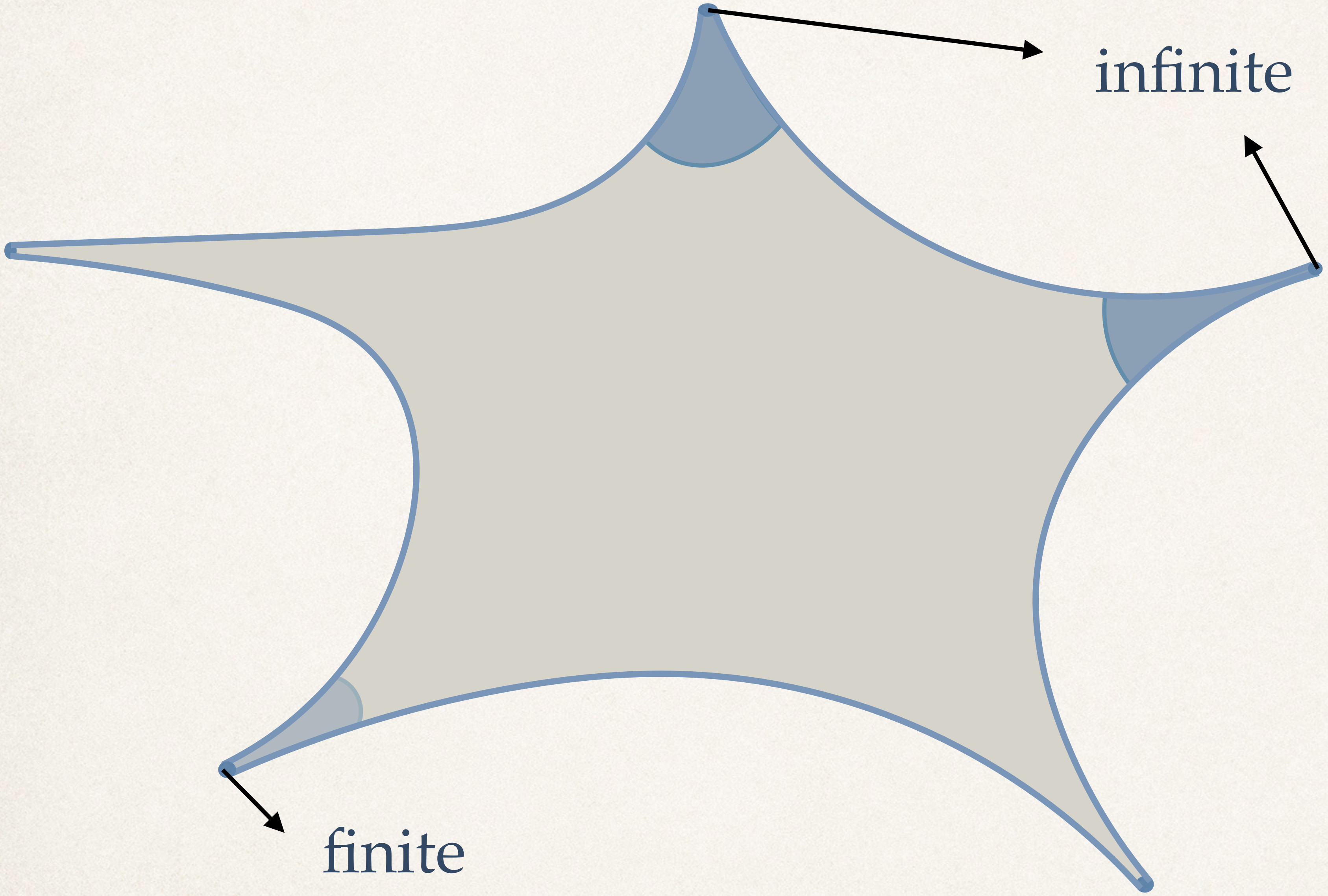
An infinite number of states become light on paths approaching an infinite distance point:

$$m(P) \propto M_P \, e^{-\gamma \, d(P,G)} \text{ as } d(P,Q) \gg 1$$

signaling the breakdown of an effective description

$\Rightarrow$ universal structure near infinite distance points

Limits in Moduli Space



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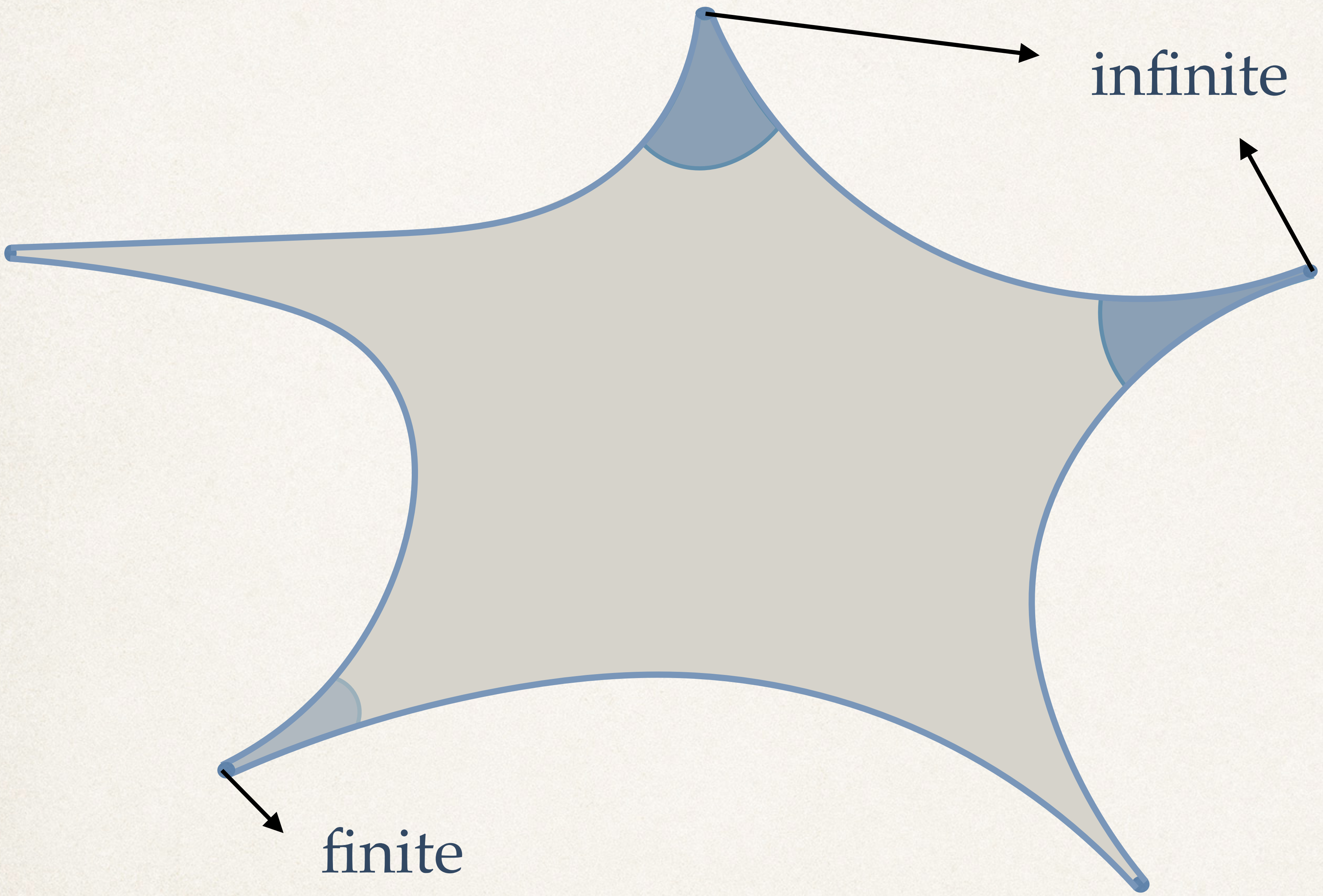

- In the following: restrict to geometric moduli spaces arising in Calabi-Yau compactifications: T^2, K3, CY_3 , CY_4

$\Rightarrow$ Universal structure?!

Universal Structure at the Limits in Moduli Space

Moduli space of Calabi-Yau compactifications

- Consider complex structure moduli space $\mathcal{M}_{\mathrm{cs}}$ (Kähler as a mirror)

Kähler metric: $g_{I\bar{J}} = \partial_{z^I}\partial_{\bar{z}^J} K$ $$K = -\log\Big[i \int_{\mathrm{CY}_n} \Omega\wedge\bar{\Omega}\Big]$$

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- Periods of the (n,0)-from Ω

$$\Omega = \mathbf{\Pi}^T \boldsymbol{\gamma} \qquad \Pi^{\mathcal{I}} = \int_{\Gamma_{\mathcal{I}}} \Omega$$

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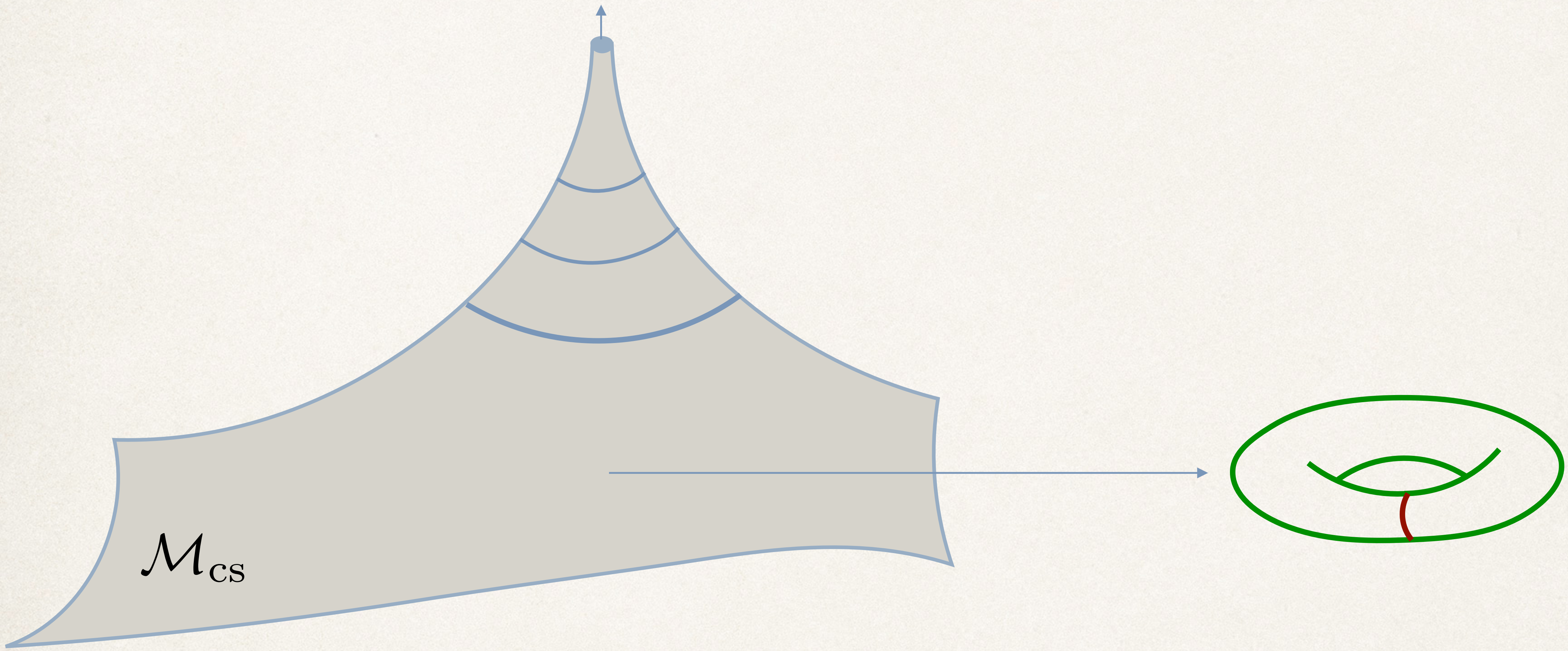
Question: Is there a universal behavior of $\mathbf{\Pi}$ at the limits of the moduli space?

Limits in complex structure moduli space

- Limits are the points where Calabi-Yau manifold degenerates!



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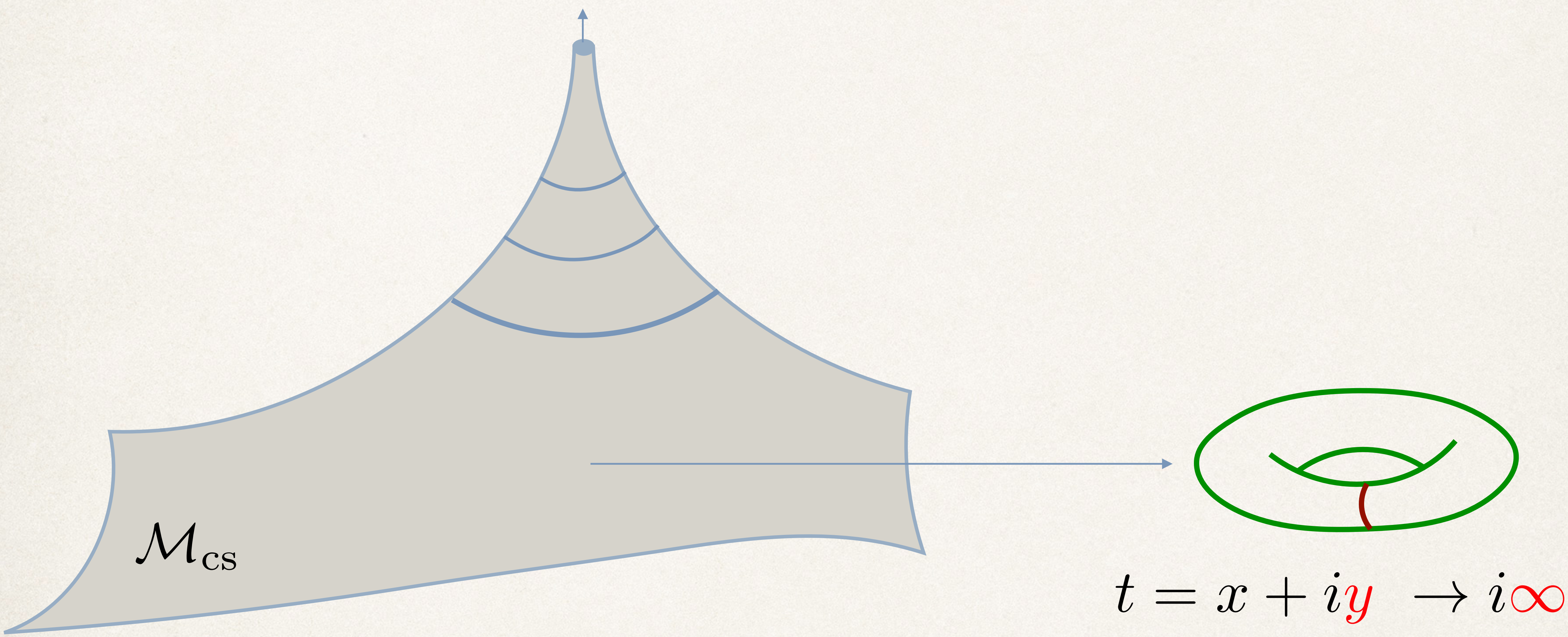

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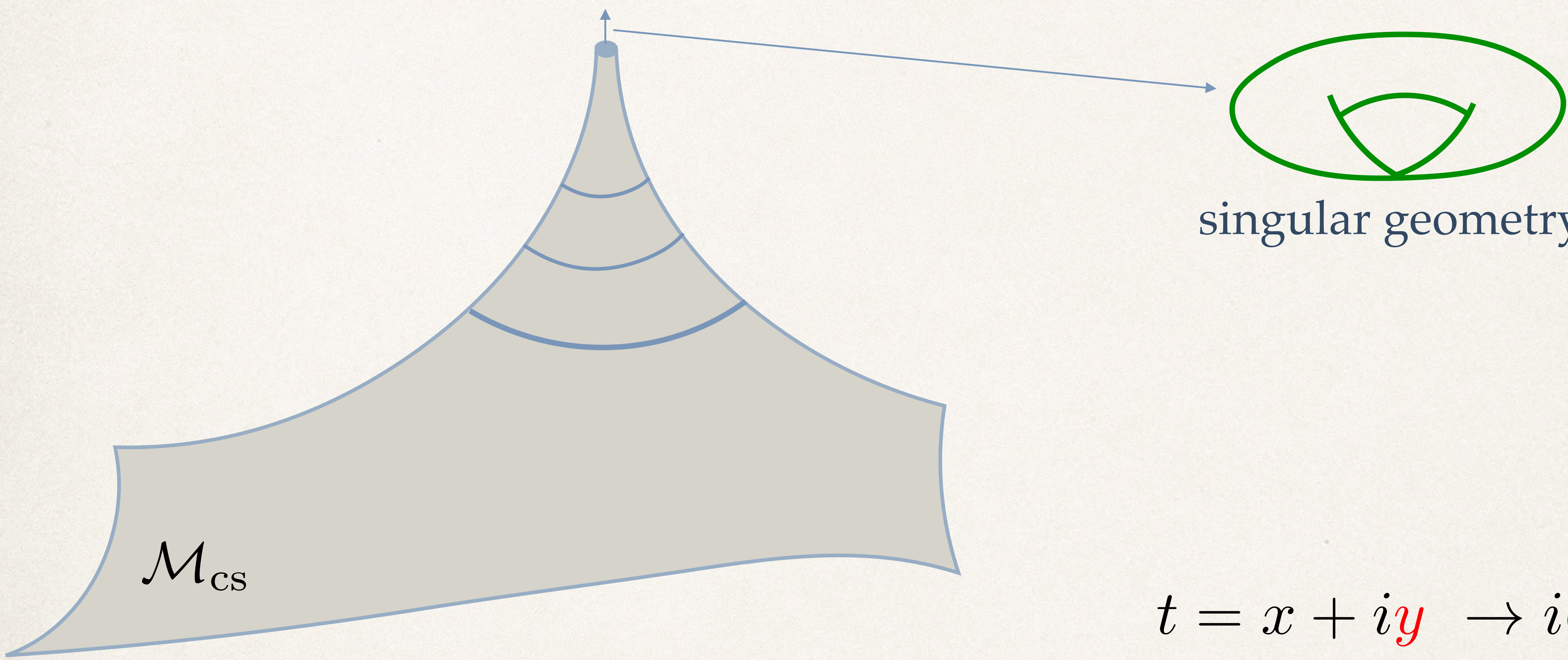

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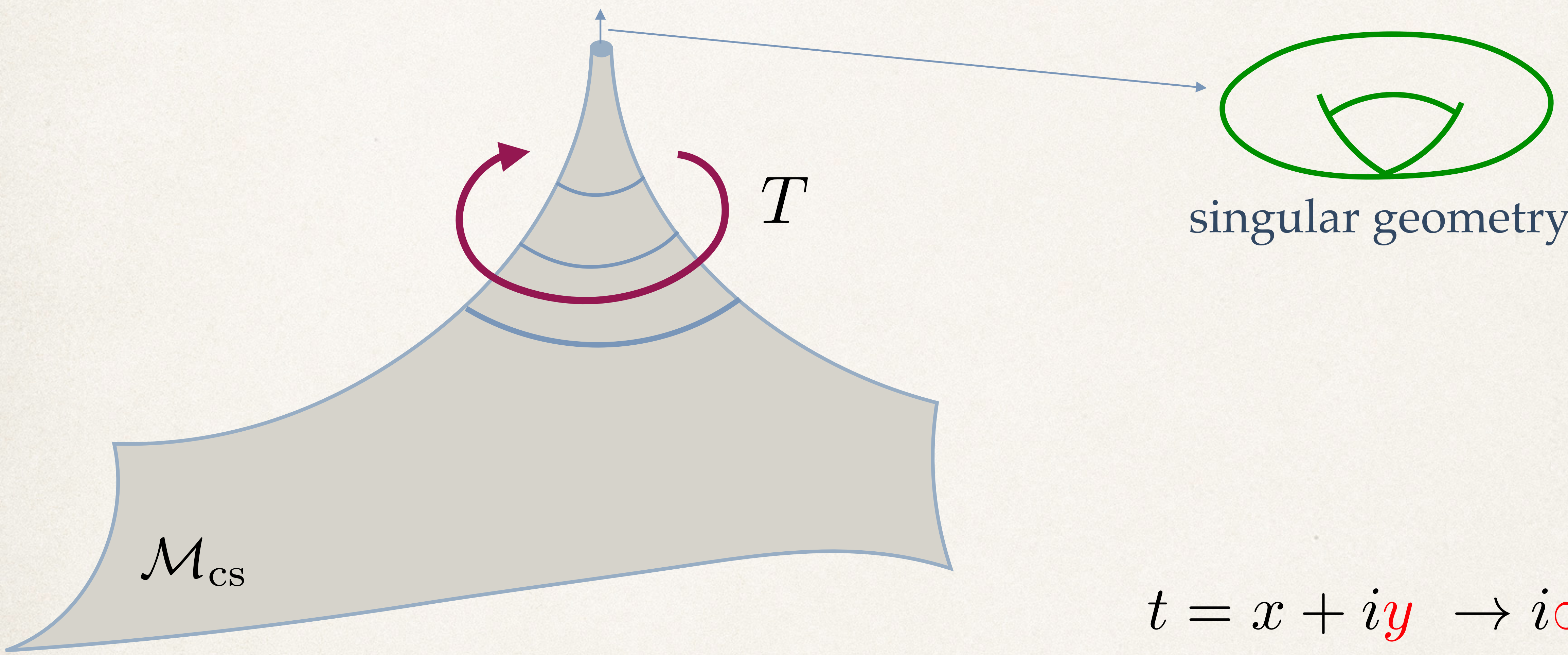

$$t = x + iy \;\; \to i\infty$$

$\Rightarrow$ monodromy around singular loci: $\mathbf{\Pi}(t+1, \ldots) = T \cdot \mathbf{\Pi}(t, \ldots)$

Universal behavior of periods

- Limiting behavior of $\mathbf{\Pi}$ near degeneration points

$$t^1, \ldots, t^n \rightarrow i\infty \qquad \zeta^\kappa \text{ finite}$$

[Schmid]

$$\mathbf{\Pi} = e^{t^i N_i} \mathbf{a}_0 + \mathcal{O}(e^{2\pi i t})$$

(up to rescaling)

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  - log-monodromy: $N_i = \log T_i^u$ - nilpotent matrix ($N^k = 0$, some k)
  - 'limiting' vector $\mathbf{a}_0(\zeta)$ - can depend on the coords not send to limit

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Polynomial in t^i
nilpotent orbit
("perturbative part")

Strongly suppressed in the limit
$\Longrightarrow$ neglect
("non-perturbative part")

Emergence of an $\mathfrak{sl}(2)^n$ - algebra

- Remarkably: can associate an $\mathfrak{sl}(2)^n$ - algebra to N_i, $\mathbf{a}_0$ [Cattani, Kaplan, Schmid]

n commuting $\mathfrak{sl}(2)$-triples: $N_i^-, \ N_i^+, \ Y_i$

$\Rightarrow$ raising, lowering, level-operator

aside: need to fix sector in moduli space, or enhancement chain…later

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- Can split form into fine splitting associated to the asymptotic region

$$H^n(Y_n, \mathbb{Q}) = \sum_{l_1,\ldots,l_n} V_{l_1,\ldots,l_n}$$

eigenspaces of $Y_{(i)} = Y_1 + \ldots + Y_i$

Asymptotic of the Hodge norm

- Hodge norm is omnipresent in string compactifications:

$$\|\alpha\|^2 = \int_{\mathrm{CY}_n} \alpha \wedge \star\, \alpha \qquad\qquad \alpha \in H^n(Y_n, \mathbb{Q})$$

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For example:

Type IIB / Y_3 : - $\|\alpha\|^2$ determines gauge coupling of R-R gauge field $C_4 = A \wedge \alpha$

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WGC

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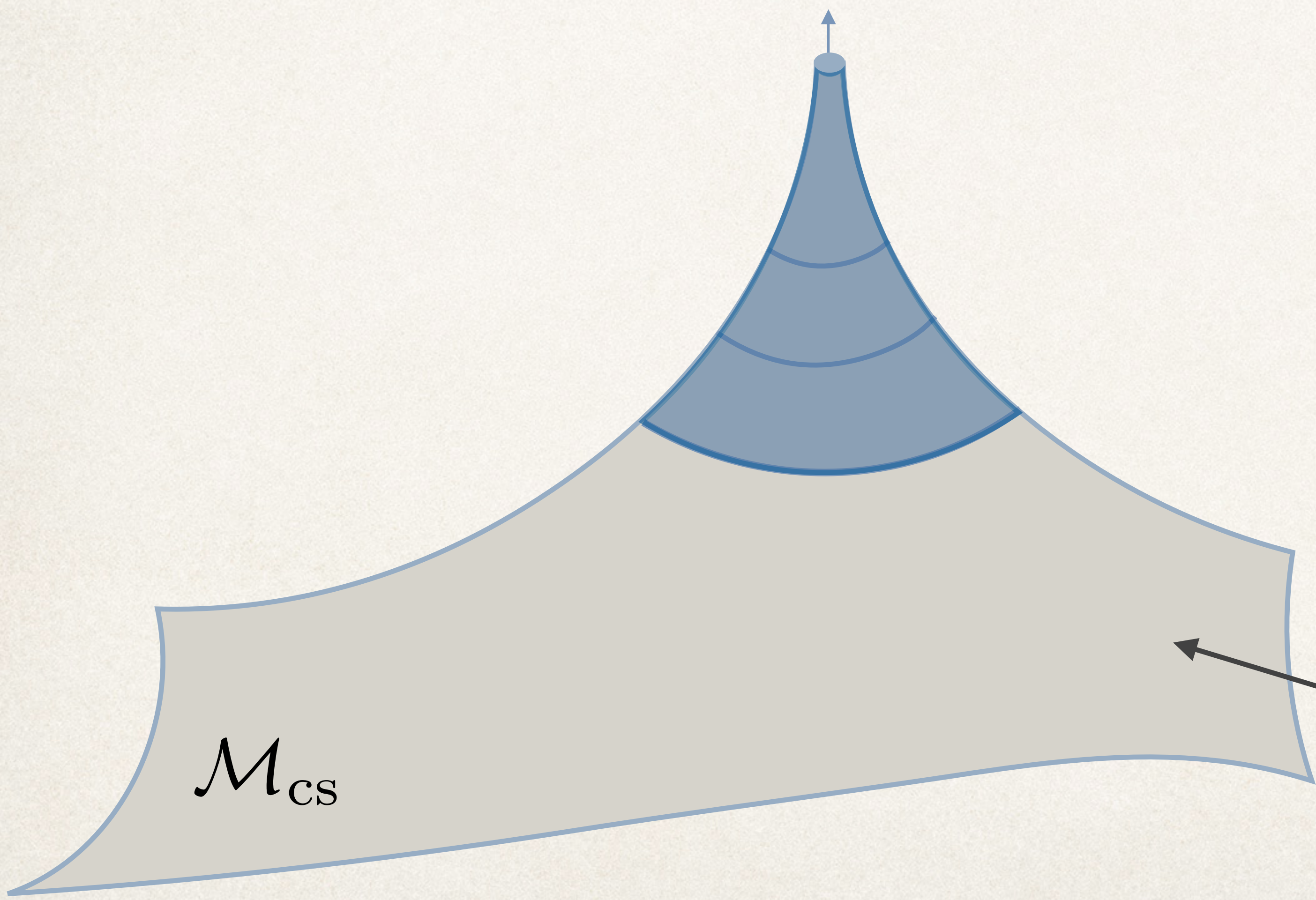
dSC

Asymptotic of the Hodge norm

- Hodge norm in asymptotic region: $t^i = x^i + iy^i \to i\infty$

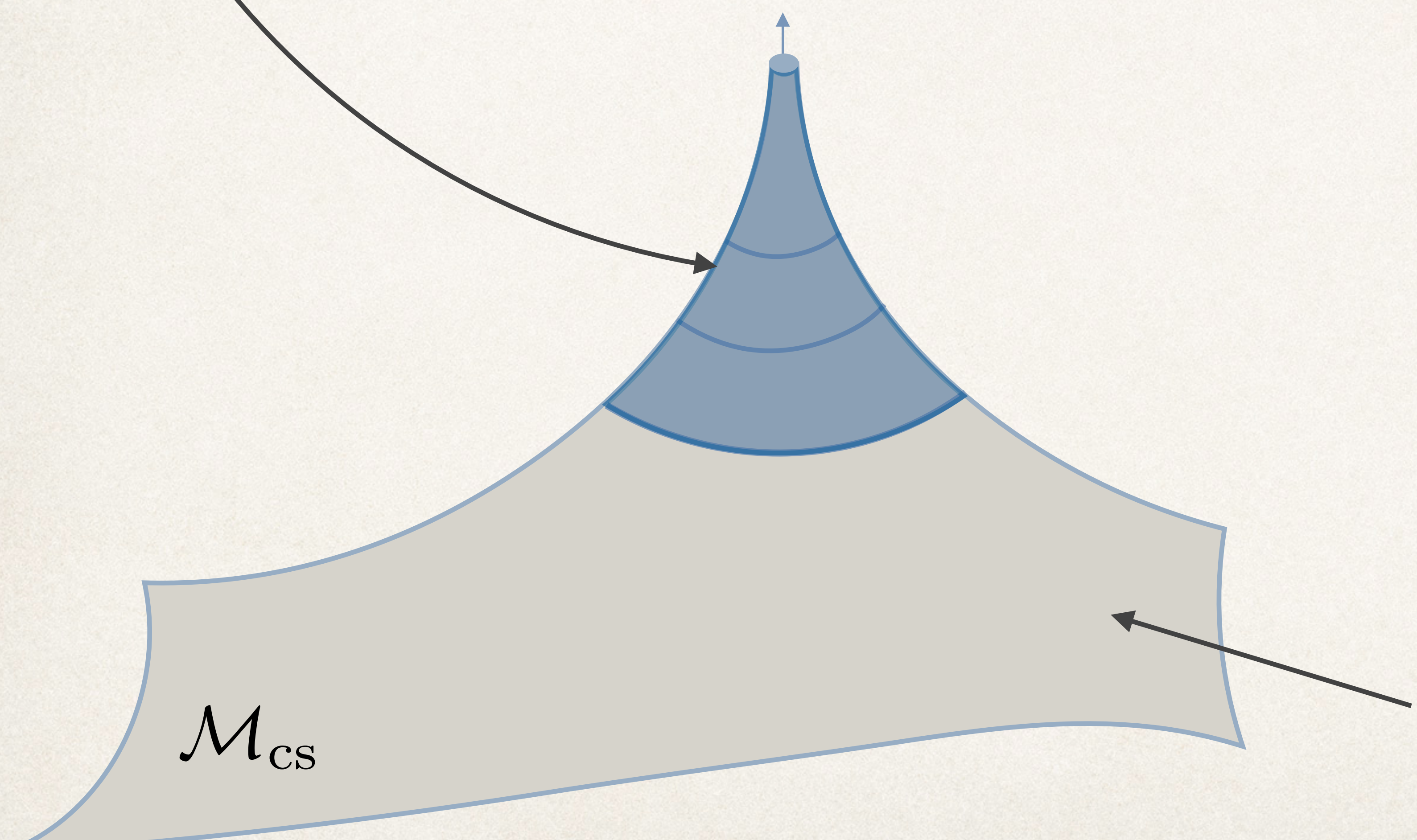


$$||\alpha||^2 = \int_{\mathrm{CY}_n} \alpha \wedge \star\, \alpha$$

Asymptotic of the Hodge norm

- Hodge norm in asymptotic region: $t^i = x^i + i y^i \to i\infty$

$$\|\alpha\|^2 \sim \sum_{l_1,\ldots,l_n} (y^1)^{l_1-n} (y^2)^{l_2-l_1} \ldots (y^n)^{l_{n-1}-l_n} \|\rho_{l_1\ldots l_n}\|_\infty$$



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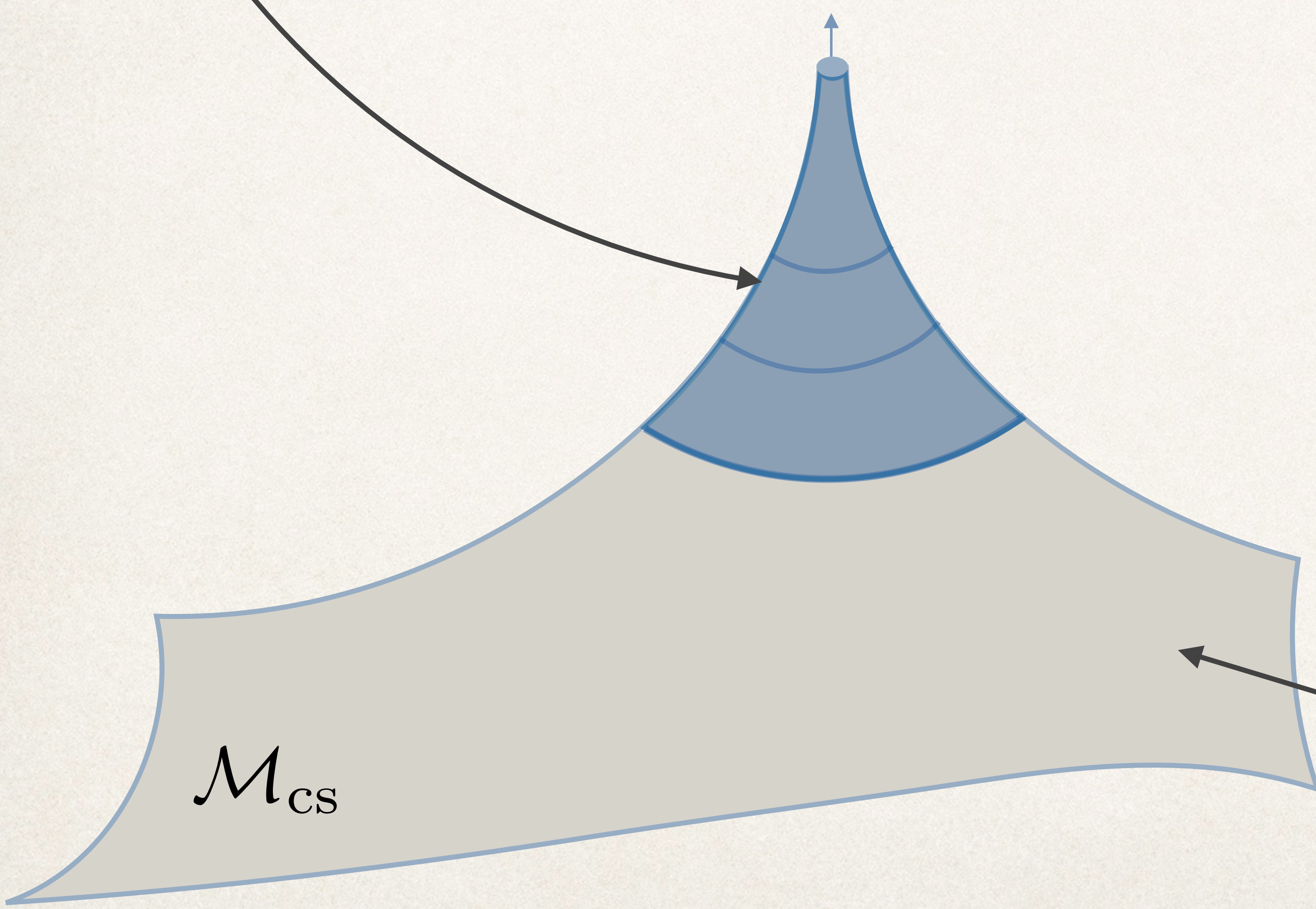
restriction of $e^{-x^i N_i}\alpha$ to subspaces $V_{l_1\dots l_n}$



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Can split

$$H^n(Y_n,\mathbb{Q}) = V_{\text{light}} \oplus V_{\text{heavy}} \oplus V_{\text{rest}}$$

V_{light}: $\|\alpha\|^2 \to 0$

V_{heavy}: $\|\alpha\|^2 \to \infty$

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related expression: [Herraez,Ibanez, Marchesano,Zoccarato]

Upshot:

In the asymptotic regime the dependents on y^i (saxions) and x^i (axions) is explicit $\Rightarrow$ classification requires to classify all asymptotic limits

Classification of asymptotic limits

- K3 surface: [Kulikov]

  $$\text{Types: I, II, III}$$

- Calabi-Yau threefolds: $4\, h^{2,1}$ types of limits [Kerr,Pearlstein,Robles 2017] [Green,Griffiths,Robles]…

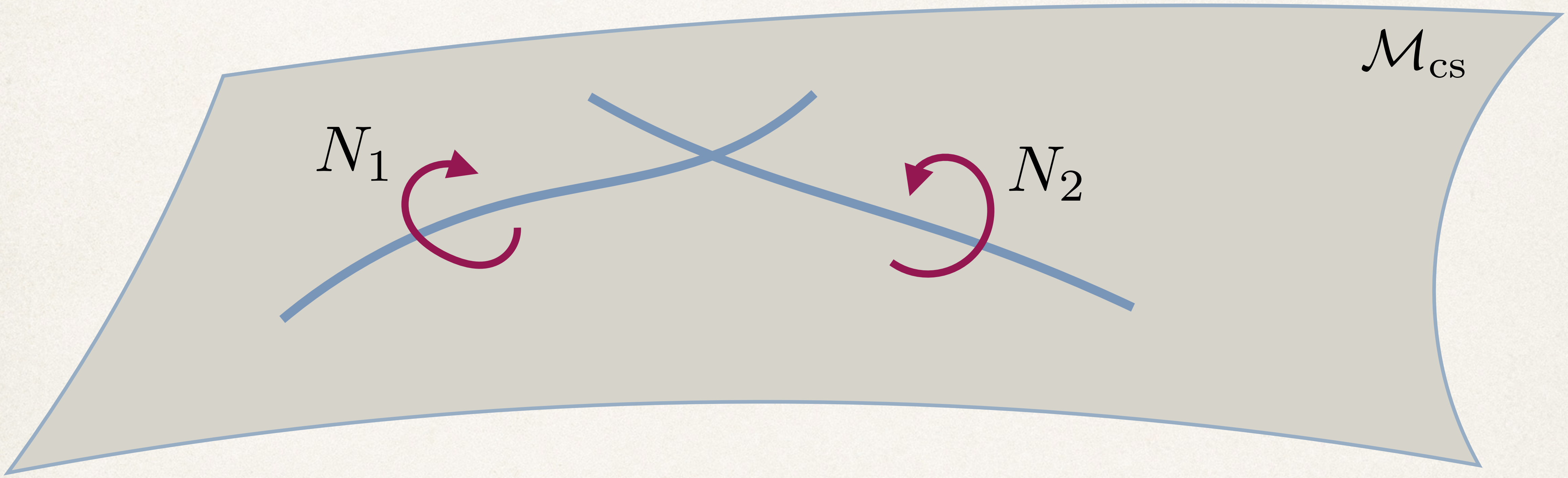
  $$\text{Types: } \mathrm{I}_a,\ \mathrm{II}_b,\ \mathrm{III}_c, \mathrm{IV}_d$$

- Calabi-Yau fourfolds: $8\, h^{3,1}$ types of limits [TG,Li,Zimmermann] [TG,Li,Valenzuela]

  $$\text{Types: } \mathrm{I}_{a,a'},\ \mathrm{II}_{b,b'},\ \mathrm{III}_{c,c'},\ \mathrm{IV}_{d,d'},\ \mathrm{V}_{e,e'}$$

Classification of singularity enhancements

- multi-dimensional moduli spaces:



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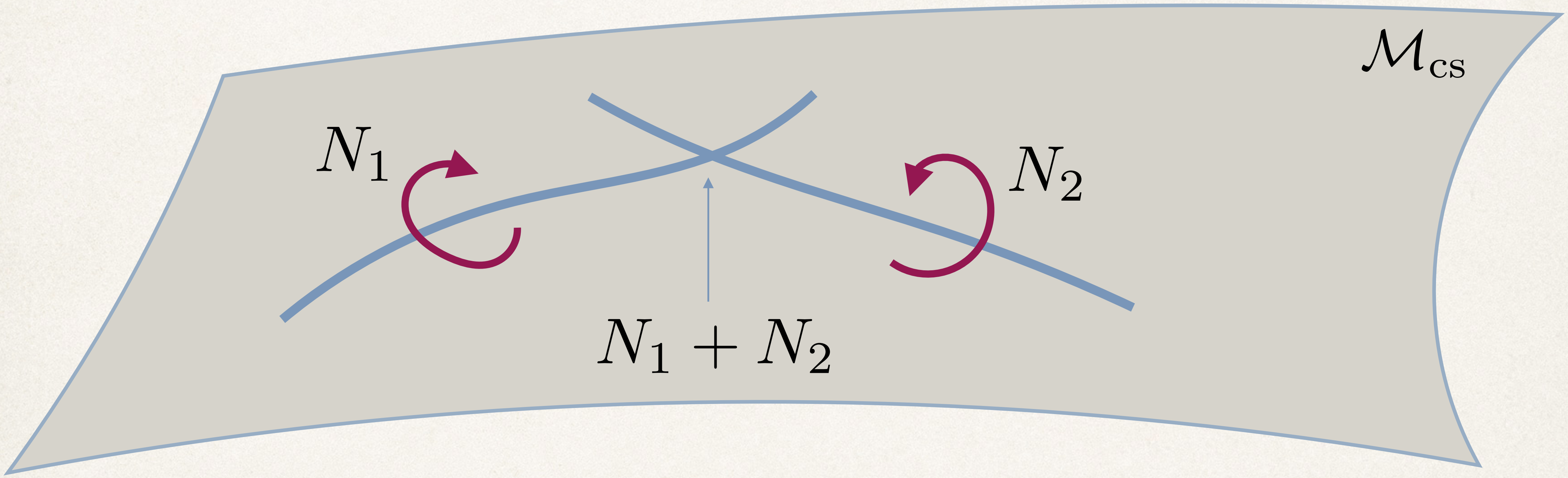

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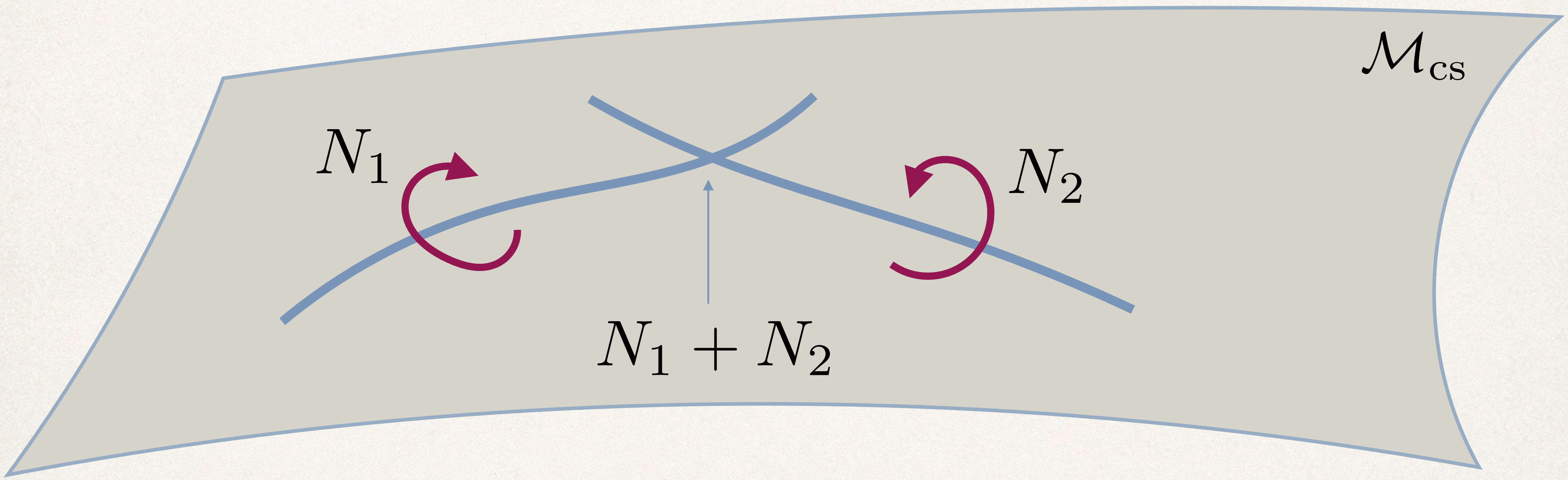
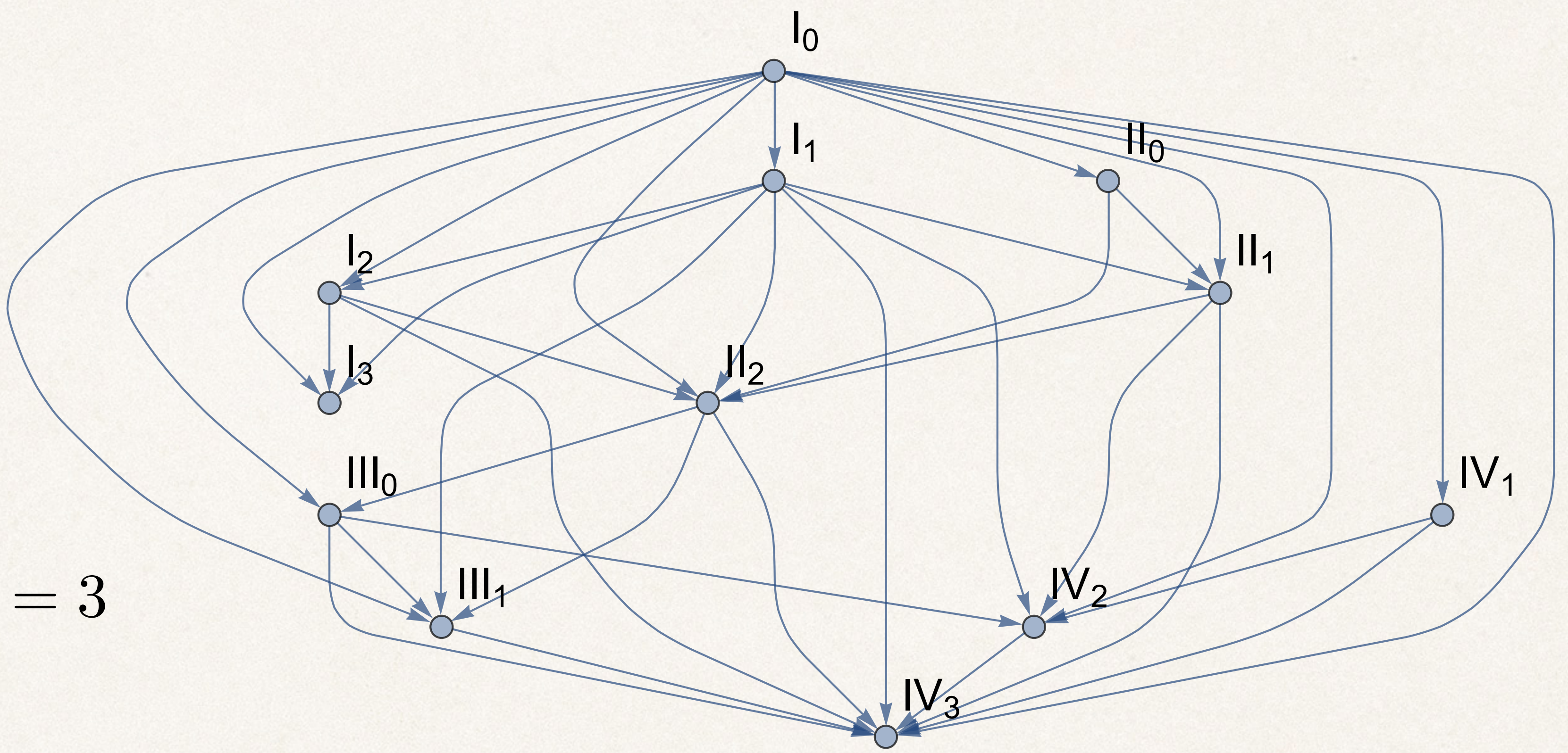


What enhancements are allowed?

- Enhancement rules can be systematically determined:
  - K3, CY_3 [Kerr,Pearlstein,Robles]
  - CY_4 [TG,Li,Valenzuela], [TG,Li,Zimmermann]

An example: general CY3, with 3 moduli



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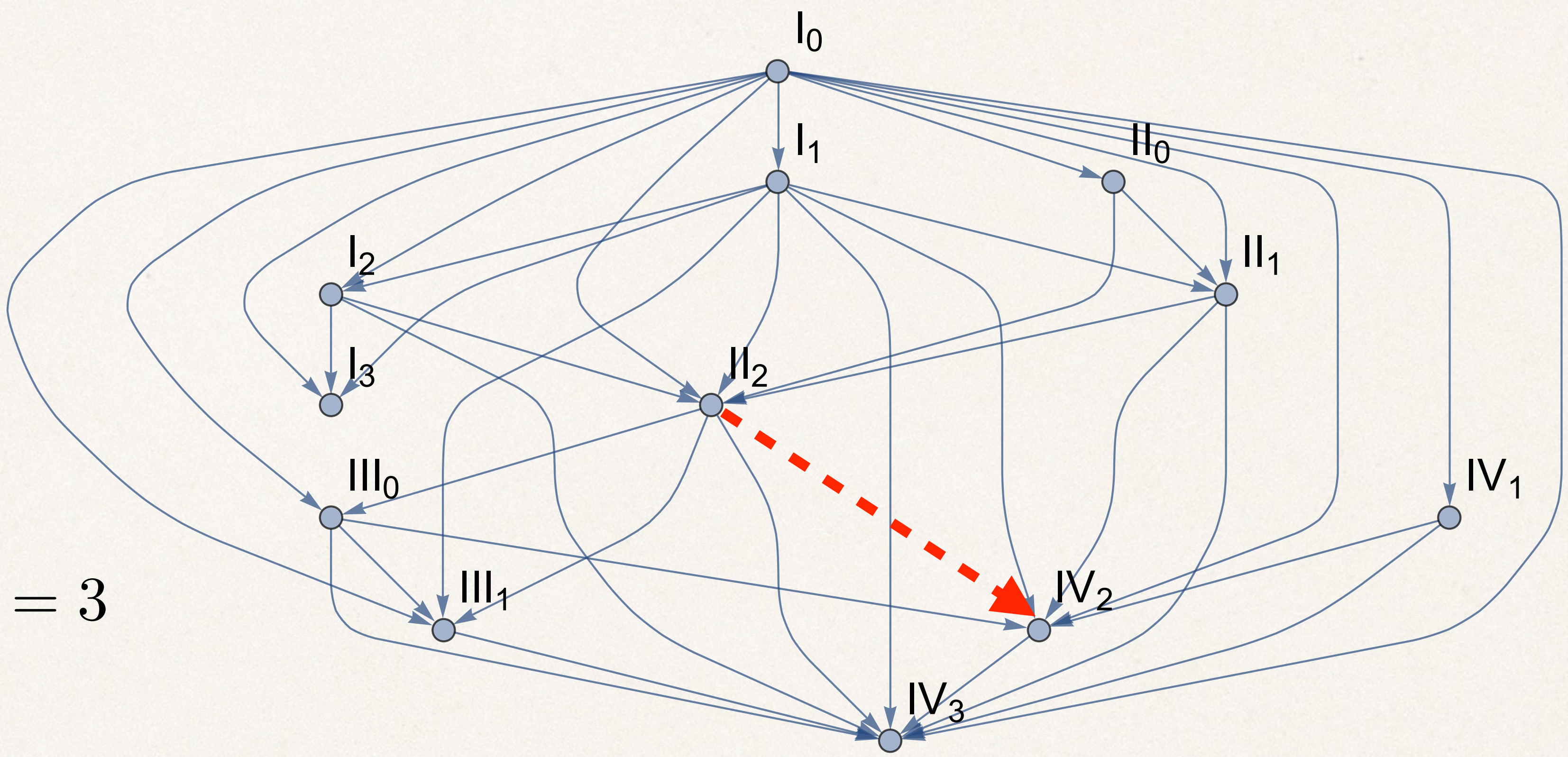

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$II_2 \rightarrow IV_2$ not possible

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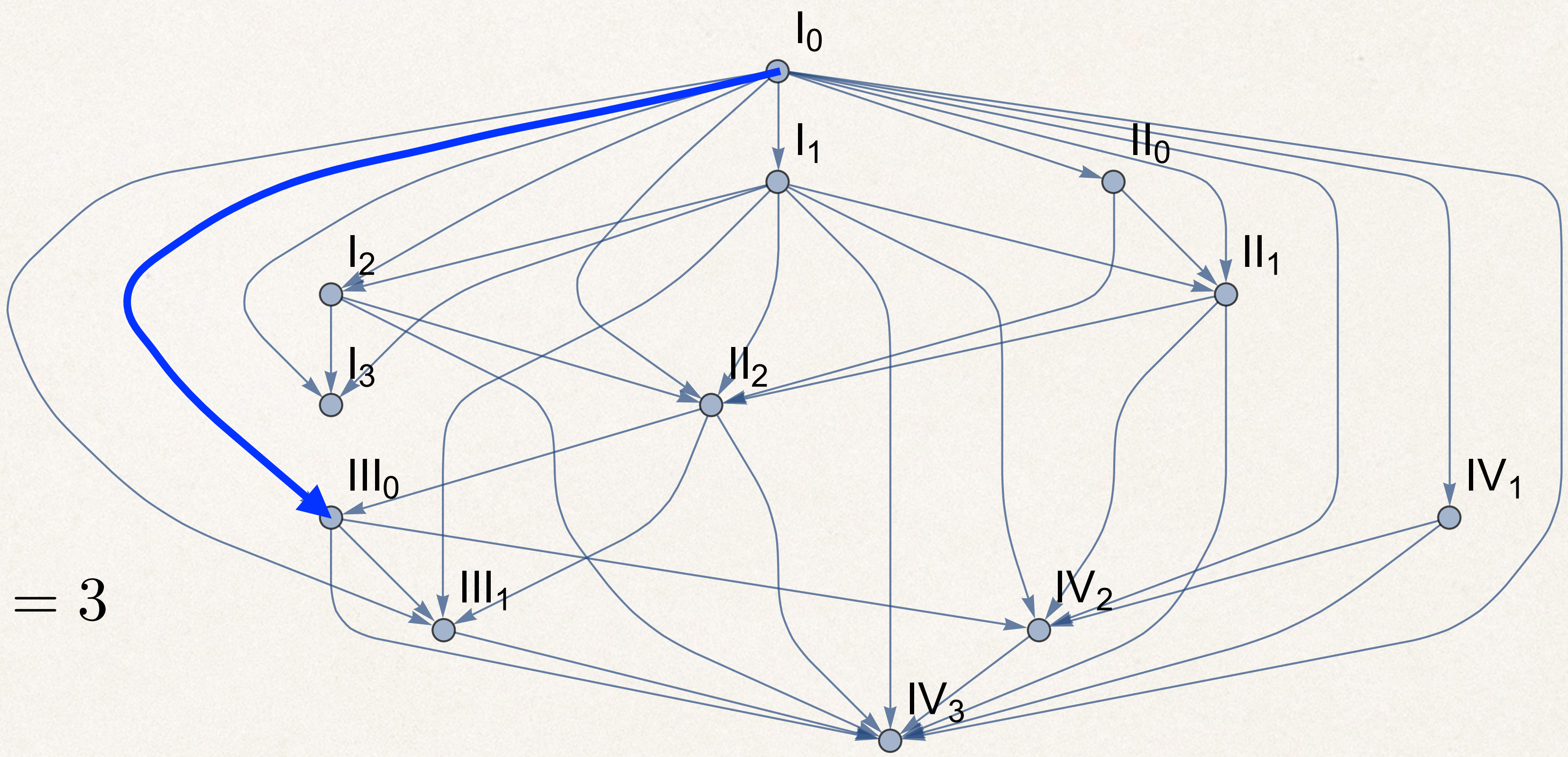

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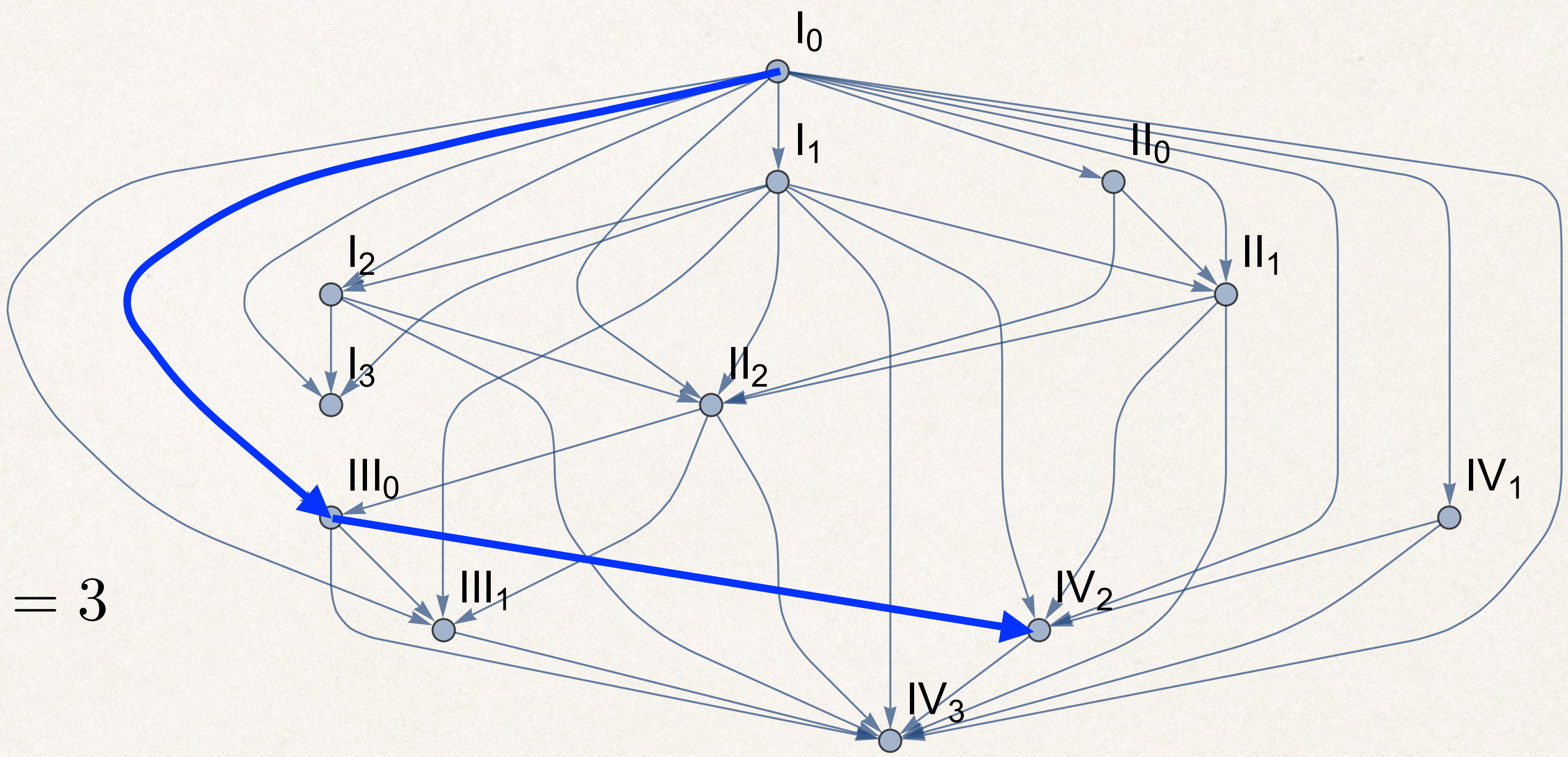

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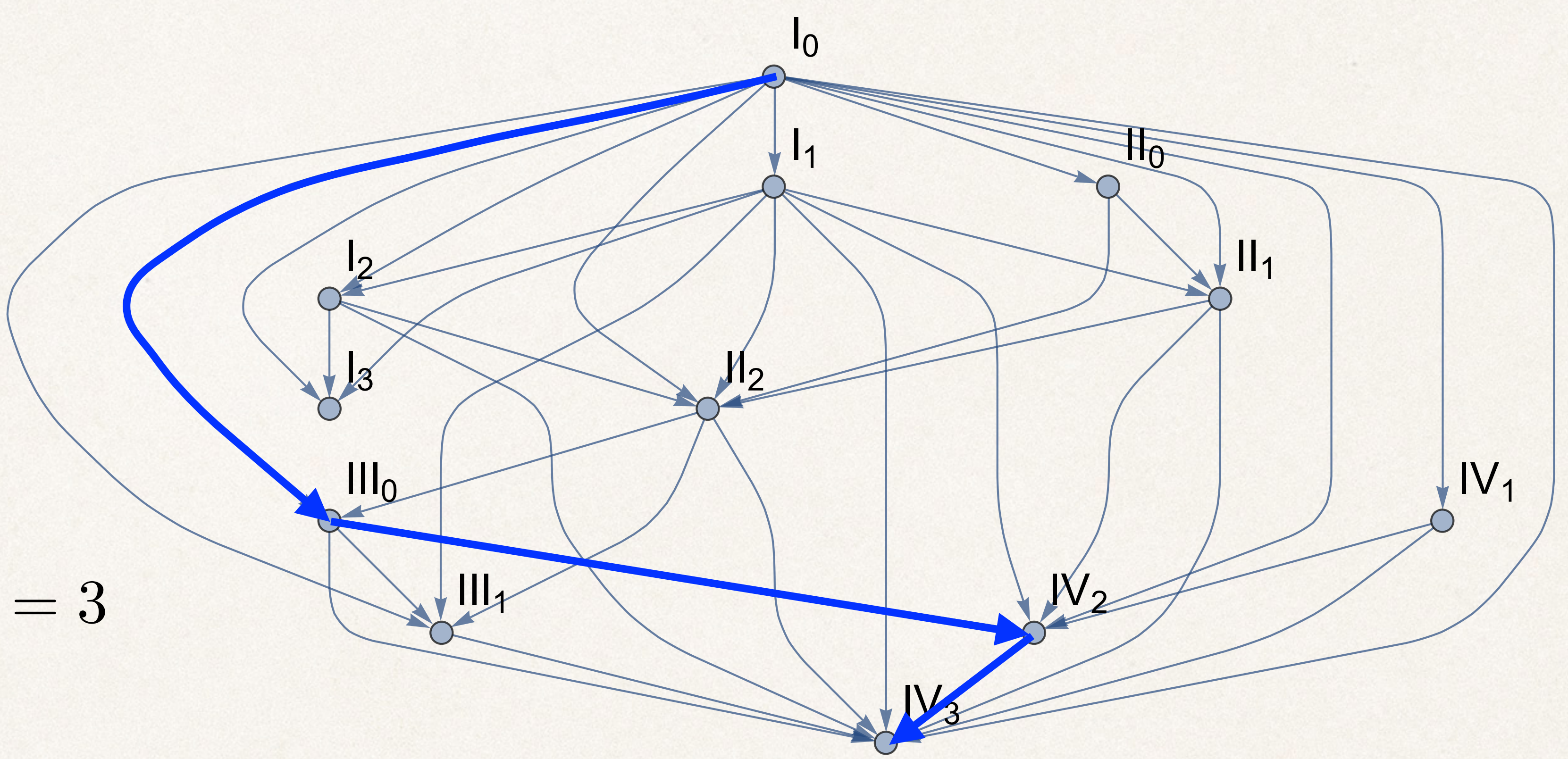

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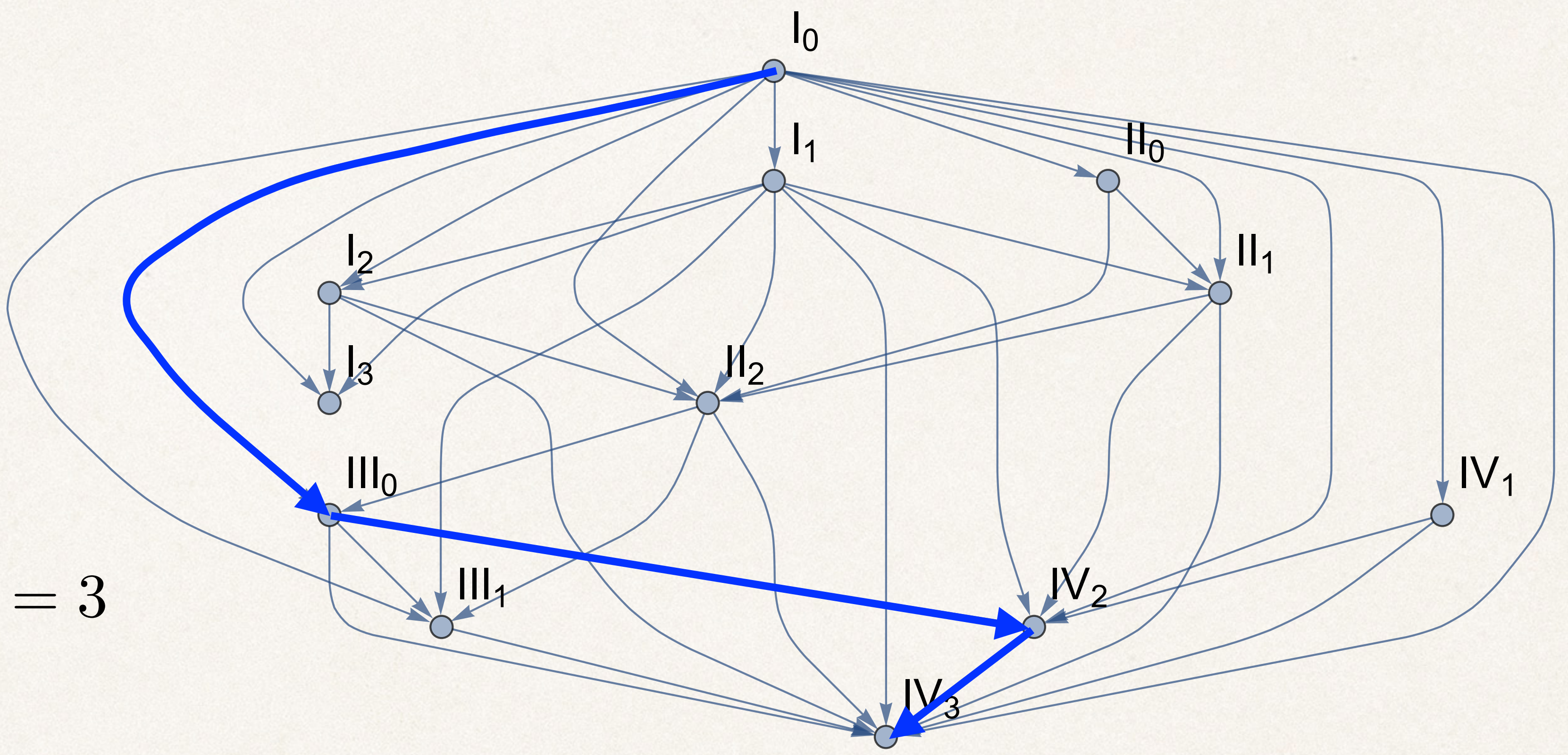
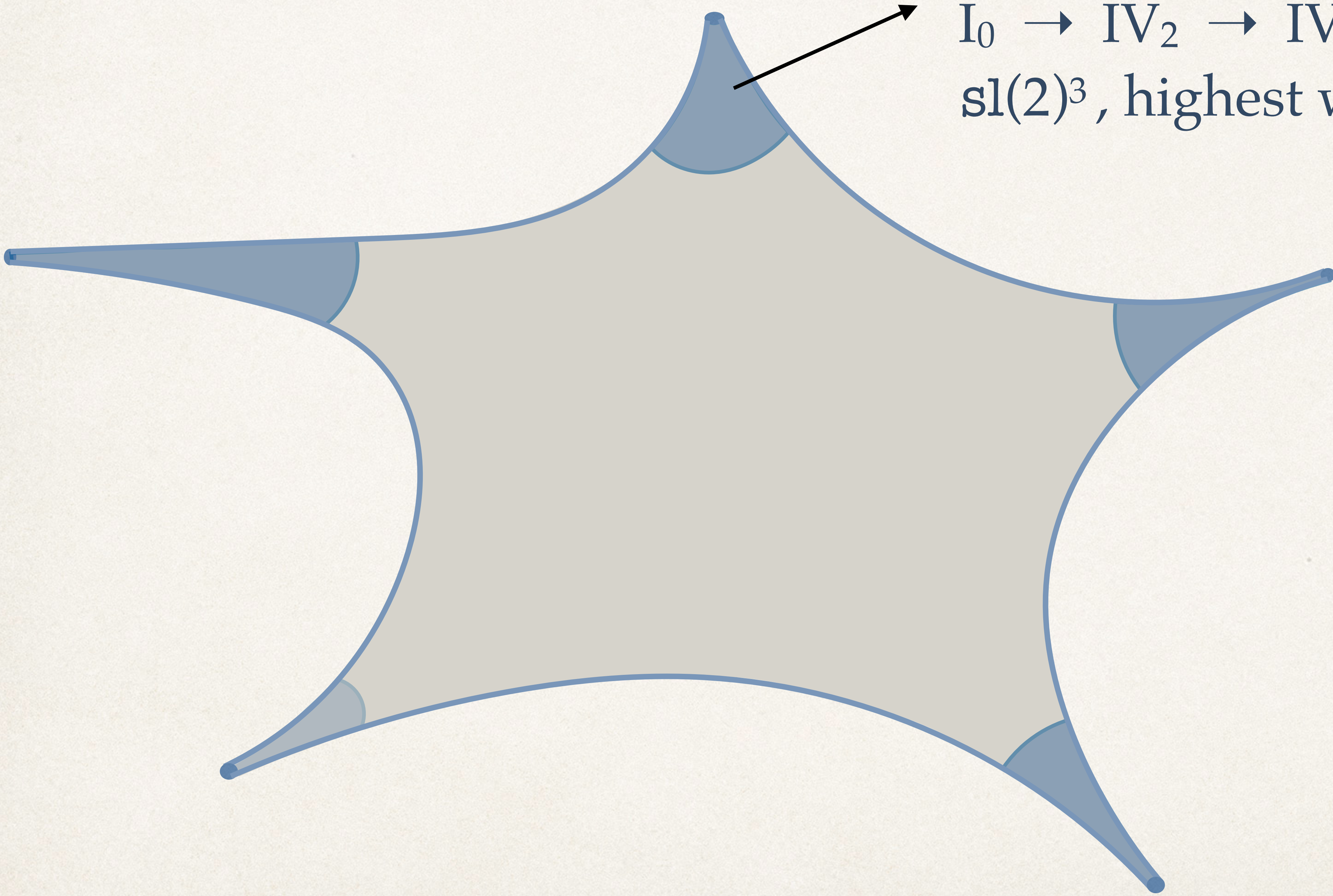


$h^{2,1} = 3$

$I_0 \rightarrow III_0 \rightarrow IV_2 \rightarrow IV_3 \implies sl(2)^3$ - algebra

- each enhancement chain has its associated sl(2)-algebra and highest weight states relevant in the limit $\rightarrow$ can be computed from $\mathbf{a_0}, \mathbf{N_i}$

Limits in Moduli Space



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$\mathfrak{sl}(2)^3$, highest weight states

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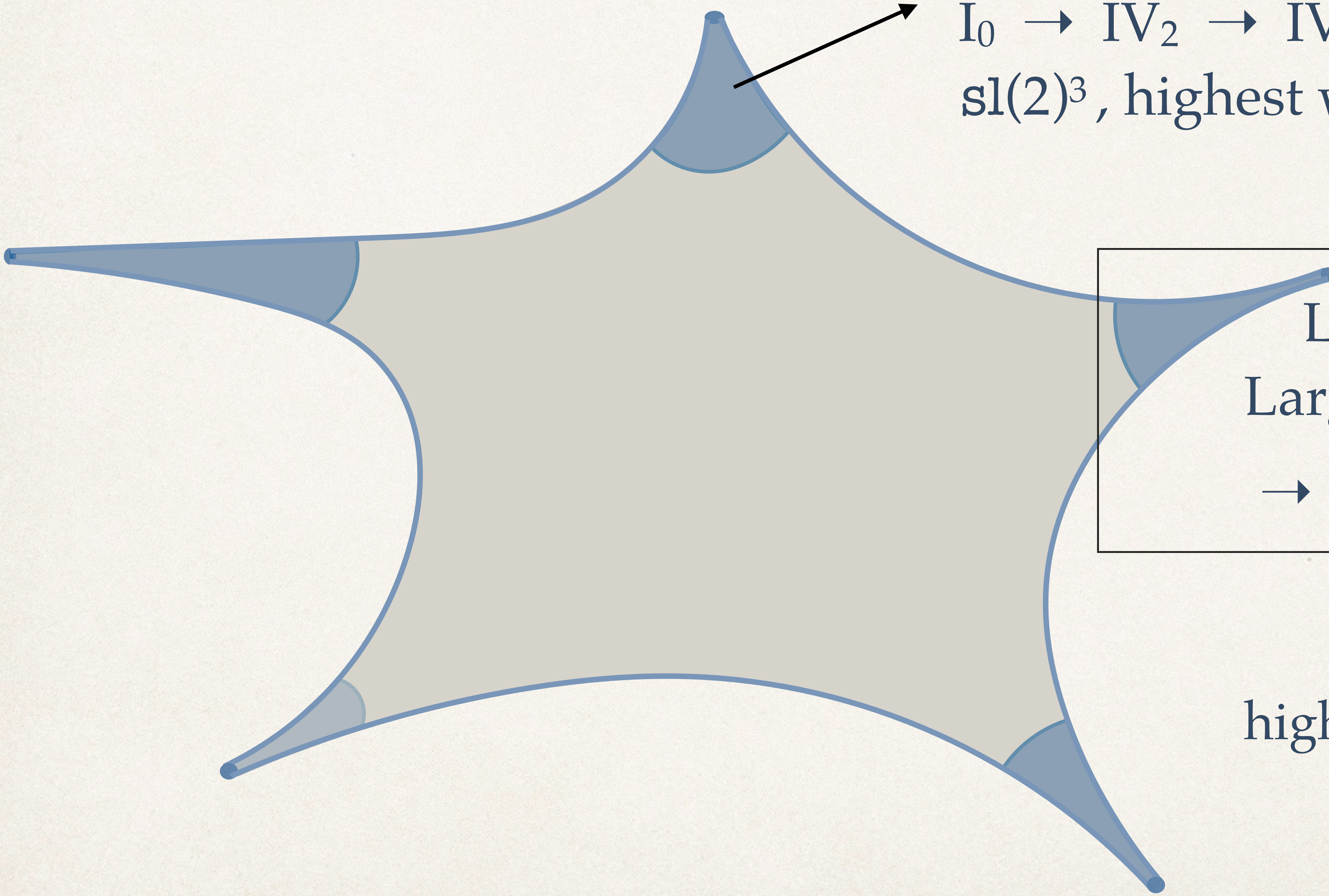

Large CS

Large volume

$\rightarrow \ldots \rightarrow IV_n$

highest singularity type

New perspective on Kähler sector

[TG,Li,Palti]
[Corvilain,TG,Valenzuela]

- Monodromies in Kähler moduli spaces (CY_3):

$$N_A = \begin{pmatrix} 0 & 0 & 0 & 0 \\ -\delta_{AI} & 0 & 0 & 0 \\ -\frac{1}{2}\mathcal{K}_{AAI} & -\mathcal{K}_{AIJ} & 0 & 0 \\ \frac{1}{6}\mathcal{K}_{AAA} & \frac{1}{2}\mathcal{K}_{AJJ} & -\delta_{AJ} & 0 \end{pmatrix} \qquad \mathbf{a}_0 = \begin{pmatrix} 1 \\ 0 \\ -c_{2\,I} \\ \frac{i\zeta(3)\chi}{8\pi^3} \end{pmatrix}$$

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- Arising singularities: II_b, III_c, IV_d and enhancements among them
  $\Rightarrow$ distinguished by: rank(N), rank(N^2), rank(N^3)

see also [Bloch, Kerr,Vanhove]

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$$N_A = \begin{pmatrix} 0 & 0 & 0 & 0 \\ -\delta_{AI} & 0 & 0 & 0 \\ -\frac{1}{2}\mathcal{K}_{AAI} & -\mathcal{K}_{AIJ} & 0 & 0 \\ \frac{1}{6}\mathcal{K}_{AAA} & \frac{1}{2}\mathcal{K}_{AJJ} & -\delta_{AJ} & 0 \end{pmatrix} \qquad \mathbf{a}_0 = \begin{pmatrix} 1 \\ 0 \\ -c_{2\,I} \\ \frac{i\zeta(3)\chi}{8\pi^3} \end{pmatrix}$$

- Arising singularities: II_b, III_c, IV_d and enhancements among them
  $\Rightarrow$ distinguished by: rank(N), rank(N^2), rank(N^3)

  see also [Bloch, Kerr,Vanhove]

- Enhancement rules allow to rule out non-consistent intersection numbers (→ example from the intro is forbidden, would be $II_2 \rightarrow IV_2$) MSc thesis S.Bruning

New perspective on Kähler sector

[TG,Li,Palti]
[Corvilain,TG,Valenzuela]

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- Can do much more! ‘massless states’, other limits in moduli space
  $\Rightarrow$ Talk of Pierre Corvilain

Application to Swampland Conjectures

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- Condition for limit to be at infinite distance: [Wang]

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- Idea: start with a single BPS state $q_0 \in V_{\text{light}}$ (constructed using sl(2)) [GLP]

$$Q_3(m_1, \ldots, m_n) = e^{m^i N_i} q_0$$ infinite orbit of charges

[TG,van de Heisteeg] stable BPS states? → talk of Markus Dierigl

Reasons for being anti de Sitter

→ Irene's talk

- Consider F-theory with G_4 -flux:

$$V_{\rm M} = \frac{1}{\mathcal{V}_4^3}\Big(\int_{Y_4} G_4 \wedge *G_4 - \int_{Y_4} G_4 \wedge G_4\Big)$$

Can be considered in all asymptotic regions of moduli space

⇒ asymptotic flux compactifications

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$\Rightarrow$ exactly as in Type IIA flux compactifications

$\Rightarrow$ de Sitter no-go! [Hertzberg etal] What about the other 45 cases?

Axion Weak Gravity Conjecture

- Connect (axion) Weak Gravity Conjecture with Distance conjecture

  [TG,Palti,Valenzuela] [Lee,Lerche,Weigand] [Font,Herraez,Ibanez] [Marchesano,Wiesner]

- Type IIA R-R axions from $C_3 = \phi\alpha$
  - decay constants $f \propto \|\alpha\|$ grow parametrically for $\alpha \in V_{\text{heavy}}$

    [TG,van de Heisteeg]

- Can we find a D2-instanton with decreasing action S_{inst} s.t. $S_{\text{inst}} f \leq q M_p$?
  - use distance conjecture to argue for instantons on $\alpha \in V_{\text{light}}$

- V_{heavy} and V_{light} are dual spaces

$\rightarrow$ talk of Damian van de Heisteeg

Conclusions

- Motivated by the Swampland Conjectures we uncovered a universal structure emerging in the asymptotic regimes of geometric moduli spaces

  ⇒ limits characterized by $sl(2)^n$ and its representations
  ⇒ asymptotic of Hodge norm
  ⇒ attainable for a classification

  limiting mixed Hodge structures

- New general evidence for the Conjectures at the limits of moduli space

- New way to study the Kähler moduli sector: structure behind intersection numbers, Chern classes determining type of Calabi-Yau

- Numerous further questions
  - control over numerical behavior: important in conjectures
  - going beyond geometry: what else is there in the landscape?

Thank you for your attention!