
Sharpening the Swampland conjectures with less supersymmetry



Irene Valenzuela

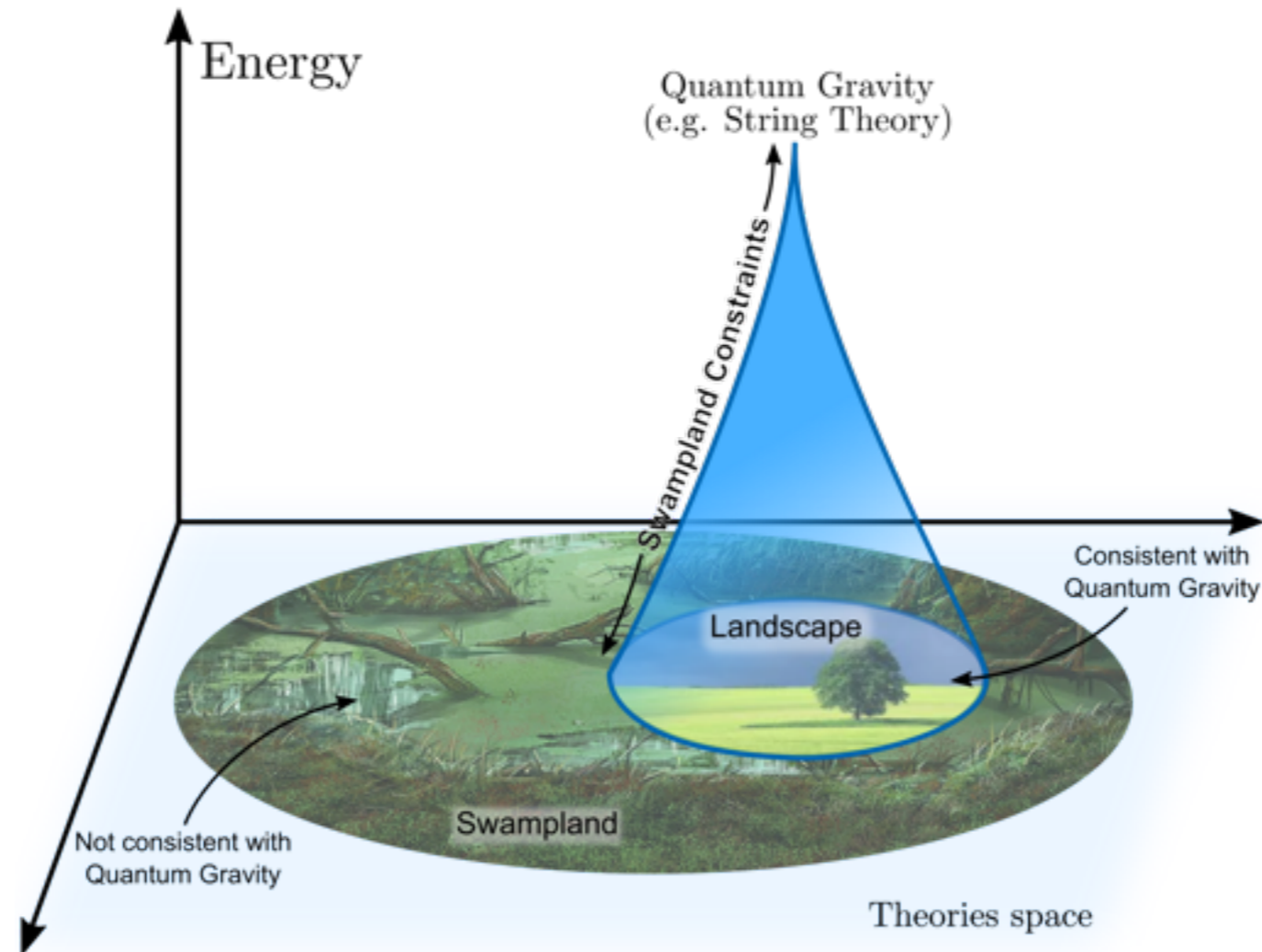
Harvard University

2006.15154 with Lanza, Marchesano, Martucci

+ previous work with Gendler, Grimm, Palti...

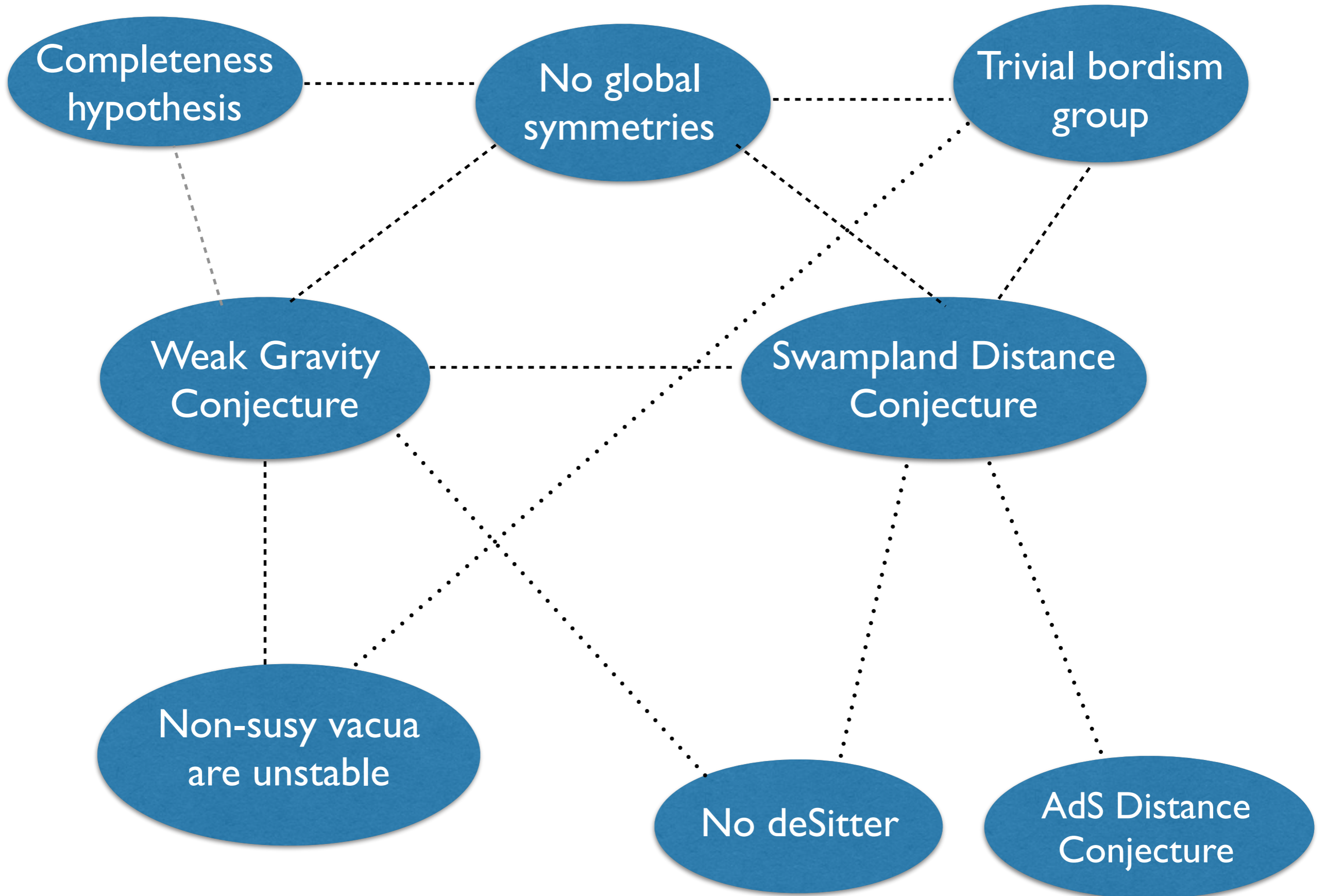
Dark World to Swampland workshop, IBS-IFT, Oct 2020

Swampland Conjectures

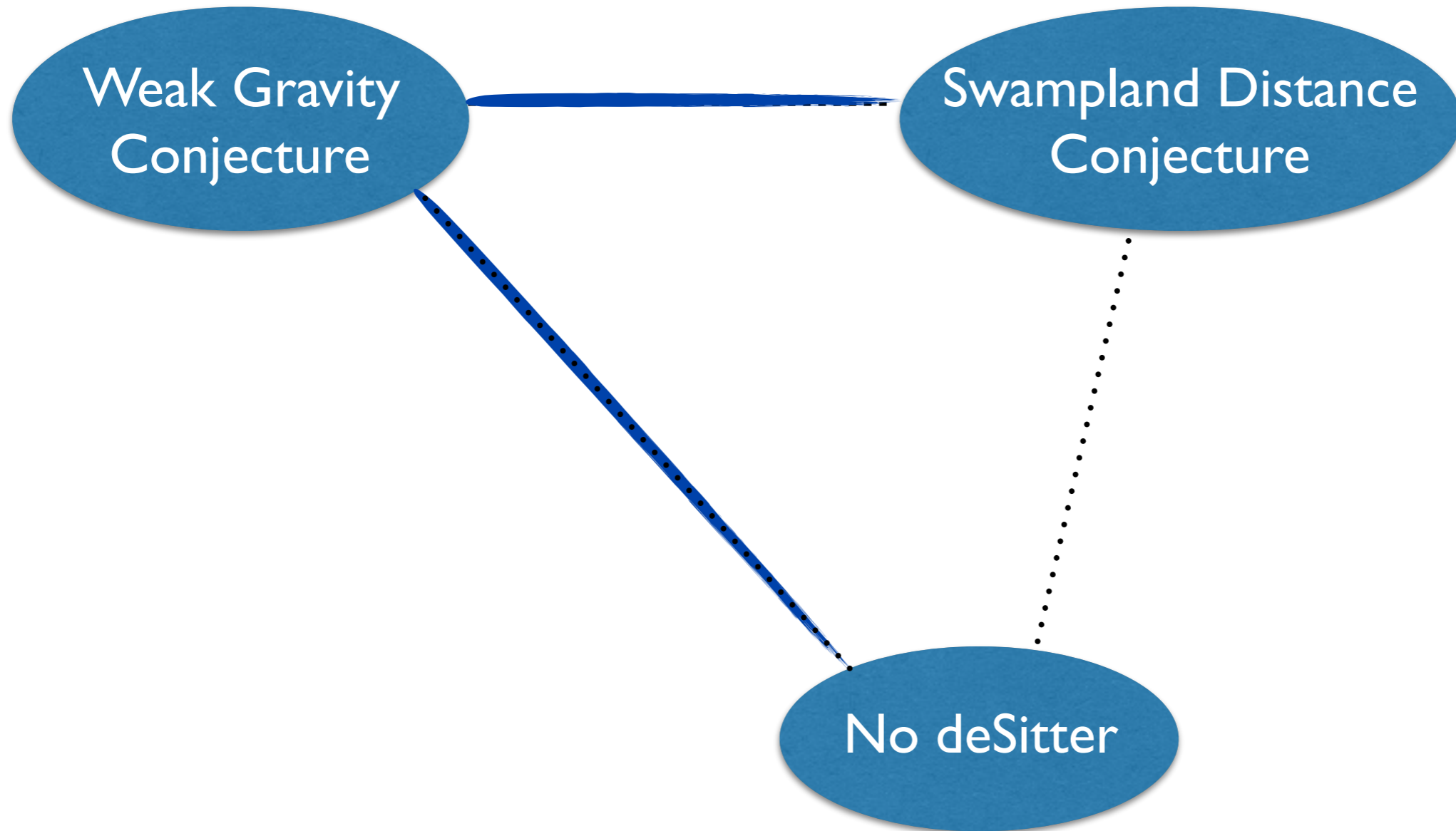


- 🎧 Guiding principles to construct BSM models (dark matter candidates, etc.)
- 🎧 New insights to solve naturalness issues in our universe

Swampland Conjectures



Swampland Conjectures



Swampland Conjectures

[Ooguri-Vafa'06]

There is an **infinite tower of states** becoming **exponentially light** at large field distances

$$m \sim m_0 e^{-\lambda \Delta\phi} \quad \text{as} \quad \Delta\phi \rightarrow \infty$$

Weak Gravity
Conjecture

Swampland Distance
Conjecture

Given an abelian gauge field, there must exist an **electrically charged state** with

$$\frac{Q}{m} \geq \frac{Q}{m} \Big|_{\text{extremal}} = 1$$

[Arkani-Hamed et al.'06]

[Obied et al'18]

[Ooguri,Palti,Shiu,Vafa '18]

Asymptotic behaviour
of the **potential**:

$$|\nabla V| \geq cV$$

with $c \sim \mathcal{O}(1)$

No deSitter

Relevant questions for phenomenology

- A lot of evidence for the WGC and SDC in theories with extended supersymmetry

What happens for lower supersymmetry, i.e. $N=1$ or $N=0$?

- Several undetermined $\mathcal{O}(1)$ factors in the conjectures.

$$\begin{aligned} m &\sim m_0 e^{-\lambda \Delta \phi}, & \lambda &\sim \mathcal{O}(1) \\ |\nabla V| &\geq cV, & c &\sim \mathcal{O}(1) \end{aligned} \qquad \frac{Q}{m} \geq \frac{Q}{m} \Big|_{\text{extremal}} \sim \mathcal{O}(1)$$

Can we be precise about their values?

Outline:

(1) Distance Conjecture in 4d $N=1$ EFTs

- Tower of states coming from BPS strings

Derivation of SDC from WGC

- Distance Conjecture in the presence of a potential

(2) Asymptotic behaviour of the potential 4d $N=1$ EFTs

Relation between dS conjecture and WGC

(2) Sharpening $O(1)$ factors in terms of WGC and geometry

(I) Distance conjecture in 4d $N=1$ EFTs

Tower of states from BPS strings

Summary of the overall picture

4D N=1 EFT:
$$S = \int \left(\frac{M_P^2}{2} R - M_P^2 K_{\alpha\bar{\beta}} d\phi^\alpha \wedge *d\bar{\phi}^{\bar{\beta}} - V \right)$$

At large field distances: an approximate axionic shift symmetry emerges

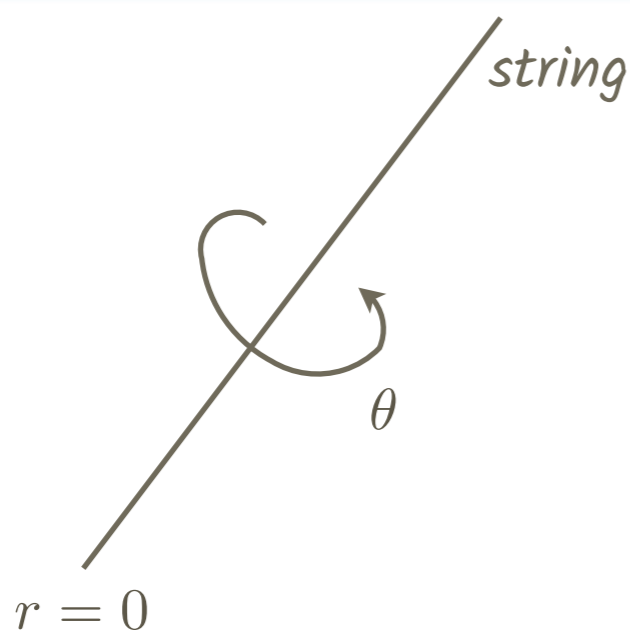
$$\phi^i = i s^i + a^i \quad (s^i, a^i) \xrightarrow{\text{dualize}} (l_i, B_{2i})$$

s^i ← saxion axion → a^i

$$l_i = -\frac{1}{2} \frac{\partial K}{\partial s^i}$$

l_i ← B_{2i} → 2-form gauge field

A weakly coupled axionic **string** becomes tensionless as $s^i \rightarrow \infty$



(charged under B_2)

If the string satisfies the WGC:

$$\Lambda_{max}^2 \equiv T_{max} \leq T_0 \exp(-\gamma d_{max})$$

We derive the SDC!

BPS Strings

We add BPS charged objects: $-\int d^{p+1}\xi T(\phi)\sqrt{-h} + e\int B_{p+1}$

Strings $\rightarrow T_e = M_P^2 |e^i \ell_i|, \quad Q_e = M_P \sqrt{G_{ij} e^i e^j}$ with $G_{ij} = \frac{1}{2} \frac{\partial^2 K}{\partial s^i \partial s^j}$

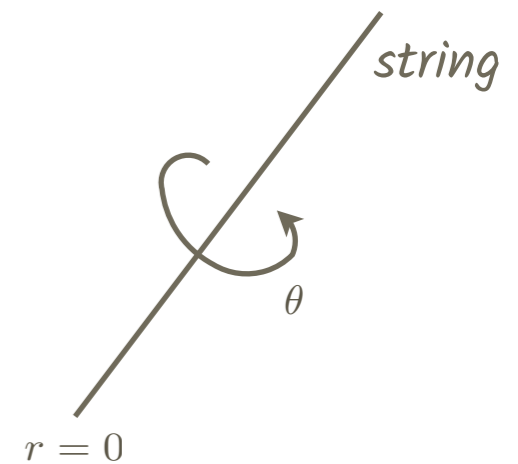
$$\|\partial T_{\text{str}}\|^2 = M_P^2 Q_e^2 \quad (\text{no force condition})$$

Strong back-reaction due to low codimension of the string:

$$ds^2 = -dt^2 + dx^2 + e^{2D} dz d\bar{z} \quad [\text{Greene, Saphere, Vafa, Yau'90}]$$

The string induces a flow of the scalars $\phi^i = i s^i + a^i$

$$s(r) = s_0 + \frac{e}{2\pi} \log \frac{r}{r_0}, \quad a = a_0 + \frac{e\theta}{2\pi}$$



Saxions are driven to infinite distance at the string core!

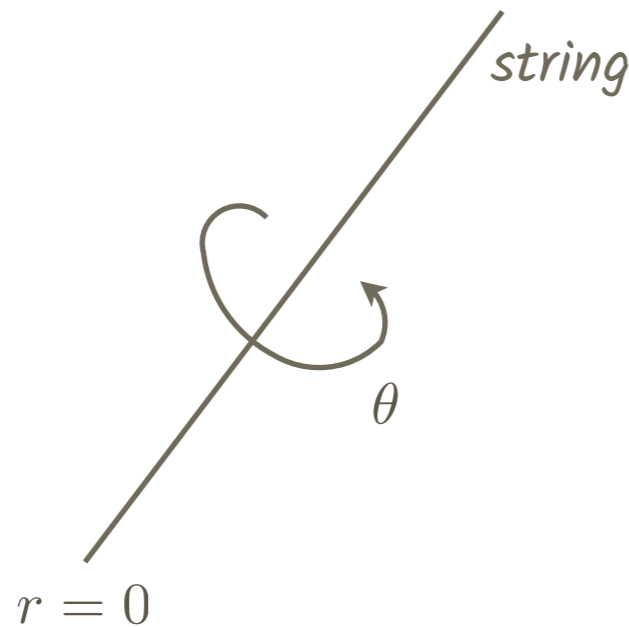
BPS Strings

String tension: $T(r) = M_p^2 e \ell(r)$, $\ell(r) = -\frac{1}{2} \frac{dK}{ds} \stackrel{K = -\log s}{=} \frac{1}{2s(r)}$

RG flow:
 $r_\Lambda = \Lambda^{-1}$

$$\frac{T(\Lambda)}{M_P^2} = \frac{e}{2s_0 + \frac{e}{\pi} \log(\Lambda r_0)}$$

Also: $Q \sim \frac{1}{s} \rightarrow 0$



As $\Lambda \rightarrow 0$ ($r \rightarrow \infty$): $T(\Lambda) \rightarrow \infty$

EFT breaks down at $\Lambda_{strong} = \Lambda \exp\left(-\frac{\pi M_p^2}{T(\Lambda)}\right)$

[Polchinski'14]

String Backreaction \longleftrightarrow RG flow \longleftrightarrow trajectory in field space

BPS Strings

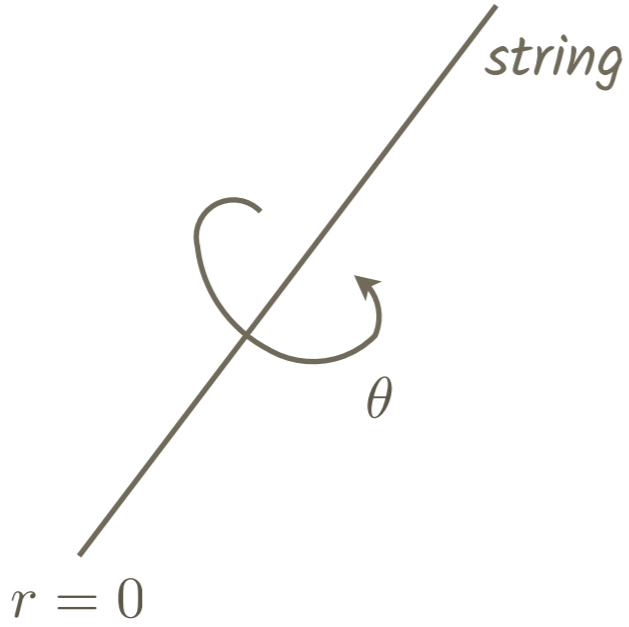
String tension: $T(r) = M_p^2 e \ell(r)$, $\ell(r) = -\frac{1}{2} \frac{dK}{ds} \equiv \frac{1}{2s(r)}$

$K = -\log s$

RG flow:
 $r_\Lambda = \Lambda^{-1}$

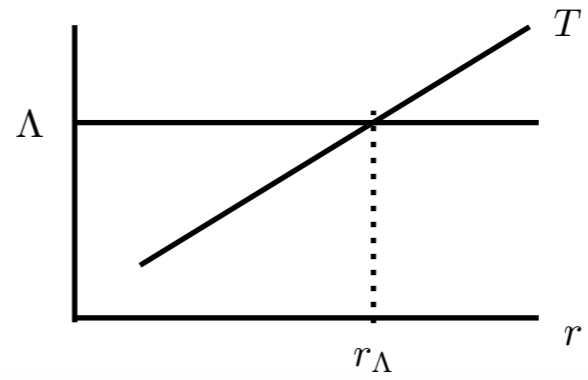
$$\frac{T(\Lambda)}{M_P^2} = \frac{e}{2s_0 + \frac{e}{\pi} \log(\Lambda r_0)}$$

Also: $Q \sim \frac{1}{s} \rightarrow 0$



As $\Lambda \rightarrow \infty$ ($r \rightarrow 0$): $T(\Lambda) \rightarrow 0$, $s(r_\Lambda) \rightarrow \infty$

EFT breaks down at $\Lambda_{max} = T(\Lambda_{max})^{1/2}$



[Polchinski'14]

String Backreaction ↔ RG flow ↔ trajectory in field space

DASC

Weakly coupled axionic strings → Infinite field distance limits

DASC

Weakly coupled axionic strings \longleftrightarrow Infinite field distance limits

Distant Axionic String Conjecture (DASC):

All infinite distance limits of a 4d EFT can be realised as an RG flow endpoint of a fundamental axionic string

Evidence from String theory: [Lanza, Marchesano, Martucci, IV'to appear]

Higher dimensional spaces: only a subset of BPS strings are weakly coupled

$$\mathcal{C}_S^{\text{EFT}} = \{ \mathbf{e} \in N_{\mathbb{Z}} \mid \langle \mathbf{m}, \mathbf{e} \rangle \geq 0 \ \forall \mathbf{m} \in \mathcal{C}_I \} \subset \mathcal{C}_S$$

instanton charges \longleftarrow \longrightarrow string charges

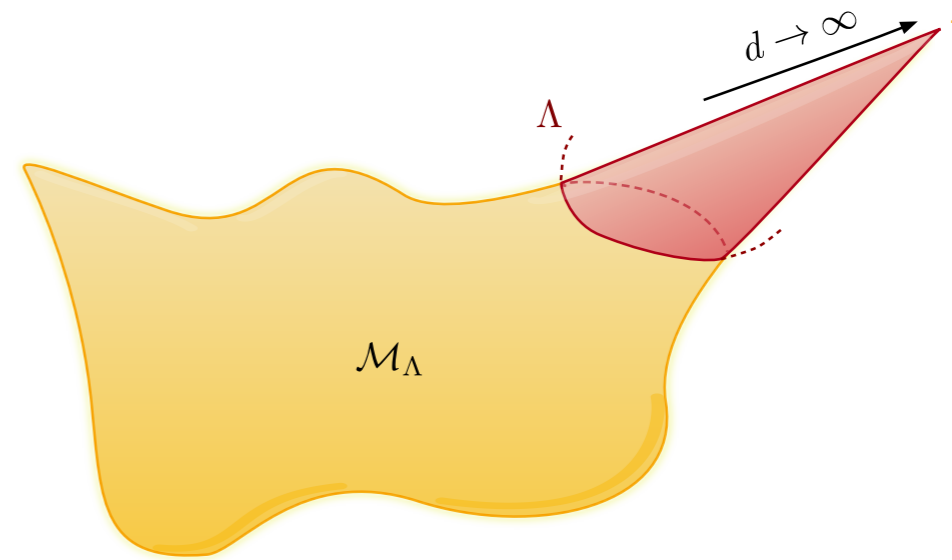
If $\mathbf{e} \in \mathcal{C}_S^{\text{EFT}}$ \longrightarrow weakly coupled string : tensionless at infinite distance

If $\mathbf{e} \in \mathcal{C}_S - \mathcal{C}_S^{\text{EFT}}$ \longrightarrow strongly coupled string : tensionless at finite distance

Derivation of SDC

For a given Λ , the moduli space accessible by the EFT is finite since it breaks down when

$$\Lambda_{max}^2 = T(\Lambda_{max})$$



Field distance from r_0 to $r_{max} = \Lambda_{max}^{-1}$:

$$d_{max} = \int_0^{\sigma_{max}} Q_s(\sigma) d\sigma = \frac{1}{M_p} \int_{T_{max}}^{T_0} \frac{1}{Q} dT \leq \frac{1}{\gamma} \log \frac{T_0}{T_{max}}$$

field = gauge metric = coupling
 $G_{ij} = \frac{1}{2} \partial_{ij}^2 K$

RG flow + no-force condition: $Q^2 = -\frac{dT}{d\sigma}$

WGC
 $QM_p \geq \gamma T$

Max cut-off: $\Lambda_{max}^2 \equiv T_{max} \leq T_0 \exp(-\gamma d_{max})$

SDC!

WGC for strings \rightarrow SDC with $\lambda = \gamma/2$

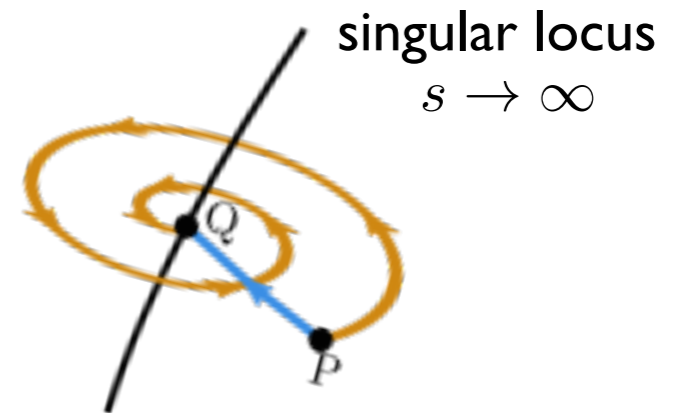
(I) Distance conjecture in 4d $N=1$ EFTs

Axionic trajectories

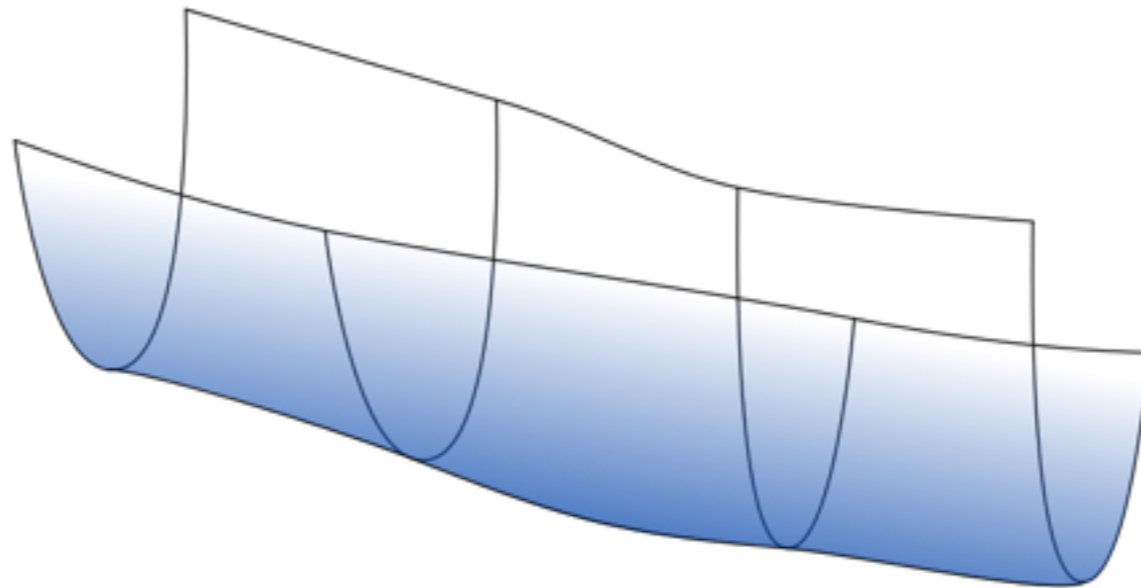
SDC in axion monodromy

Distance Conjecture: $\Delta s \lesssim \frac{1}{\lambda} \log \left(\frac{M_p}{\Lambda} \right)$

*Upper bound for purely saxionic trajectories
but what about turning (axionic) trajectories?*



SDC expected to apply to nearly flat trajectories



➔ It constrains the effective potentials consistent with quantum gravity

Evidence in string theory

We find: The asymptotic form of the flux potential in Calabi-Yau string compactifications behaves as an homogeneous function at large field:

[Grimm,Li,IV'19]

$$V(\beta s^i, \beta \phi^i) \simeq \beta^{d_i} V(s^i, \phi^i)$$
$$\partial_{s_i} V = 0 \rightarrow s^i = \kappa \phi^i + \dots$$

with κ a **flux-independent** parameter.

This backreacts on the kinetic term for the axion:

[Baume,Palti'16] [I.V.,'16]

$$\mathcal{L} \supset \frac{1}{s^2} (\partial\phi)^2 \sim \frac{1}{\kappa^2 \phi^2} (\partial\phi)^2 \quad \rightarrow \quad \Delta\phi \leq \frac{1}{\lambda\kappa} \log \frac{M_p}{\Lambda}$$

Hence, the SDC also constraints axionic trajectories!

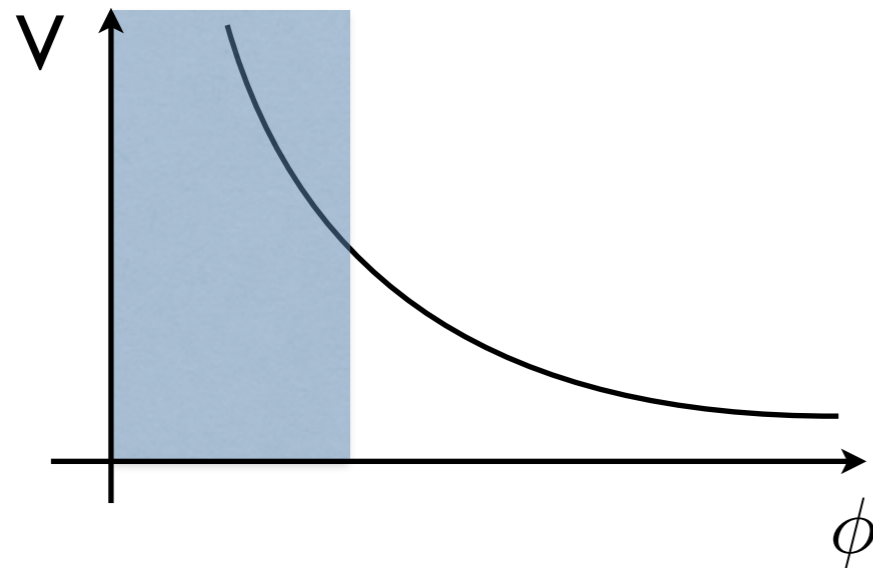
Open question: is this a general feature beyond CY's?

(2) Asymptotic behaviour of the potential in $N=1$ 4d

Asymptotic de Sitter conjecture

When the tower becomes light, it induces a **runaway for the scalar potential**

[Ooguri,Palti,Shiu,Vafa '18]



*Dine-Seiberg problem for every scalar
(every direction in field space)*

(asymptotic)

deSitter conjecture:

$$|\nabla V| \geq cV \quad \text{with} \quad c \sim \mathcal{O}(1)$$

[Obied,Ooguri,Spodyneik,Vafa'18]

[Ooguri,Palti,Shiu,Vafa '18]

at any asymptotic field space limit (at large field)

No-go's for dS in string theory

Test the conjecture in string theory:

Consistent with known no-go's for classical vacua in Type IIA

[Hertzberg, Kachru, Taylor, Tegmark '08]

[Flauger, Paban, Robbin, Wrase '09]

[Wrase, Zagermann '10] ...

[Wrase, Junghans, ... '19]

[Andriot et al '19-20]



We analyse asymptotic structure of flux-induced potential for F-theory on CY_4

No-go theorem: [Grimm, Li, IV'19]

Why?

There is no dS vacua at parametric control near any two large field limit of a CY_4 in the strict asymptotic approx if $V \rightarrow 0$ at the large field limit

(generalizes previous no-go's by going beyond the string weak coupling limit)

Dual formulation in terms of 3-forms

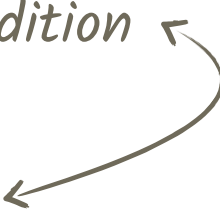
The flux-induced scalar potential can be written in terms of field strengths of 3-form gauge fields

$$V = \frac{1}{2} T^{ab} f_a f_b \quad \longleftrightarrow \quad S \supset - \int \frac{1}{2} T_{ab} F_a^a * F_4^b$$

Constraints on the scalar potential can be translated to properties of BPS membranes charged under the 3-form gauge fields

Membranes \rightarrow $T_{\mathbf{q}} = 2M_{\text{P}}^3 e^{\frac{1}{2}K} |q_a \Pi^a|$, $Q_{\mathbf{q}} = M_{\text{P}} \sqrt{T^{ab} q_a q_b} = \sqrt{2V(q)}$

$$\|\partial T_{\text{m}}\|^2 - \frac{3}{2} T_{\text{m}}^2 = M_{\text{P}}^2 Q_{\text{m}}^2 \quad \text{no-force condition}$$

$$e^K (\|DW\|^2 - 3W^2) = V(q) \quad N=1 \text{ sugra}$$


(see also [Herraez'20])

Membranes and no-dS

Satisfying WGC is a non-trivial constraint on K and W :

If $\partial_\alpha T_{\mathbf{q}} = K_\alpha \sigma_\alpha T_{\mathbf{q}} \rightarrow Q_m(\Lambda) M_p = \gamma T_m(\Lambda)$

extremal with $\gamma = \frac{|\alpha^2|}{4} - \frac{3}{2} = \sum_i 2n_i \sigma_i^2 - \frac{3}{2}$

scalar contribution $T_{ab} \sim e^{-\alpha\phi}$

These extremal membranes satisfy $\|\partial Q_m^2\| = c Q_m^2$

$\rightarrow \|\partial V^2\| = c V^2$ with $c = |\alpha|$

dS conjecture!

WGC-saturating membranes \rightarrow dS conjecture

(3) Sharpening the order one factors

In terms of extremality factors

Recall, WGC:

$$\exists \text{ } p\text{-dim state with } QM_p \geq \gamma T \quad \text{and} \quad \gamma^2 \equiv \left. \frac{Q}{T} \right|_{\text{extr.}} = \frac{p(2-p)}{2} + \frac{|\alpha|^2}{4}$$

- SDC tower coming from BPS string in N=1 4d:

$$m \sim m_0 e^{-\lambda \Delta \phi} \quad \rightarrow \quad \lambda = \frac{\gamma}{2} = \frac{|\alpha_s|}{4}$$

- Flux induces N=1 potential dual to the charge of a BPS membrane:

$$|\nabla V| \geq cV \quad \rightarrow \quad c = |\alpha_m|$$

if membrane is extremal

- SDC tower coming from BPS particles in N=2 4d: [Gendler, IV' 20]

$$m \sim m_0 e^{-\lambda \Delta \phi} \quad \rightarrow \quad \lambda = \frac{|\alpha_p|}{2}$$

In terms of geometric data

Recall, WGC:

$$\exists \text{ } p\text{-dim state with } QM_p \geq \gamma T \quad \text{and} \quad \gamma^2 \equiv \left. \frac{Q}{T} \right|_{\text{extr.}} = \frac{p(2-p)}{2} + \frac{|\alpha|^2}{4}$$

- SDC tower coming from BPS string in N=1 4d: *using* $K = -\log(s_1^{n_1} s_2^{n_2} \dots)$

$$m \sim m_0 e^{-\lambda \Delta \phi} \quad \rightarrow \quad \lambda = \frac{\gamma}{2} = \frac{|\alpha_s|}{4} \geq \frac{1}{\sqrt{2n_i}}$$

- Flux induces N=1 potential dual to the charge of a BPS membrane:

$$|\nabla V| \geq cV \quad \rightarrow \quad c = |\alpha_m| \geq \frac{2}{n_i} \quad \frac{|\nabla m|^2}{m^2} \sim \frac{|\nabla V|}{V} ?$$

if membrane is extremal *(see also [Andriot et al'20])*

- SDC tower coming from BPS particles in N=2 4d: [Gendler, IV' 20]

$$m \sim m_0 e^{-\lambda \Delta \phi} \quad \rightarrow \quad \lambda = \frac{|\alpha_p|}{2} \geq \frac{1}{\sqrt{2n_i}}$$

Summary

• Swampland conjectures get **connected** by the physics of **strings and membranes** in 4d $N=1$ EFT's (their charges parametrise the axionic kinetic terms and scalar potential).

- Infinite distance limits realised as RG flow endpoints of strings

WGC for strings → *SDC*

- Potential parametrised by charge of BPS membranes

WGC-saturating membranes → *No dS*

• $O(1)$ factors in the conjectures are fixed by:

- Extremality factors of charged objects
- Discrete data characterising the asymptotic geometry

Thank you!

back-up slides

Dual formulation in terms of 2,3-forms

4D N=1 EFT:
$$S = \int \left(\frac{M_{\text{P}}^2}{2} R - M_{\text{P}}^2 K_{\alpha\bar{\beta}} d\phi^\alpha \wedge *d\bar{\phi}^{\bar{\beta}} - V \right)$$

$$(s^i, a^i) \rightarrow (l_i, B_{2i})$$

$$f_a \rightarrow C_3^a$$

$$-\frac{1}{2} \int G^{ij} \left(M_{\text{P}}^2 dl_i \wedge *dl_j + \frac{1}{M_{\text{P}}^2} H_{3i} \wedge *H_{3j} \right)$$

$$G_{ij} \equiv \frac{1}{2} \frac{\partial^2 K}{\partial s^i \partial s^j}$$

$$-\int \frac{1}{2} T_{ab} F_a^a * F_4^b$$

$$V = \frac{1}{2} T^{ab} f_a f_b$$

Field metric = 2-form gauge couplings

Potential = 3-form gauge couplings

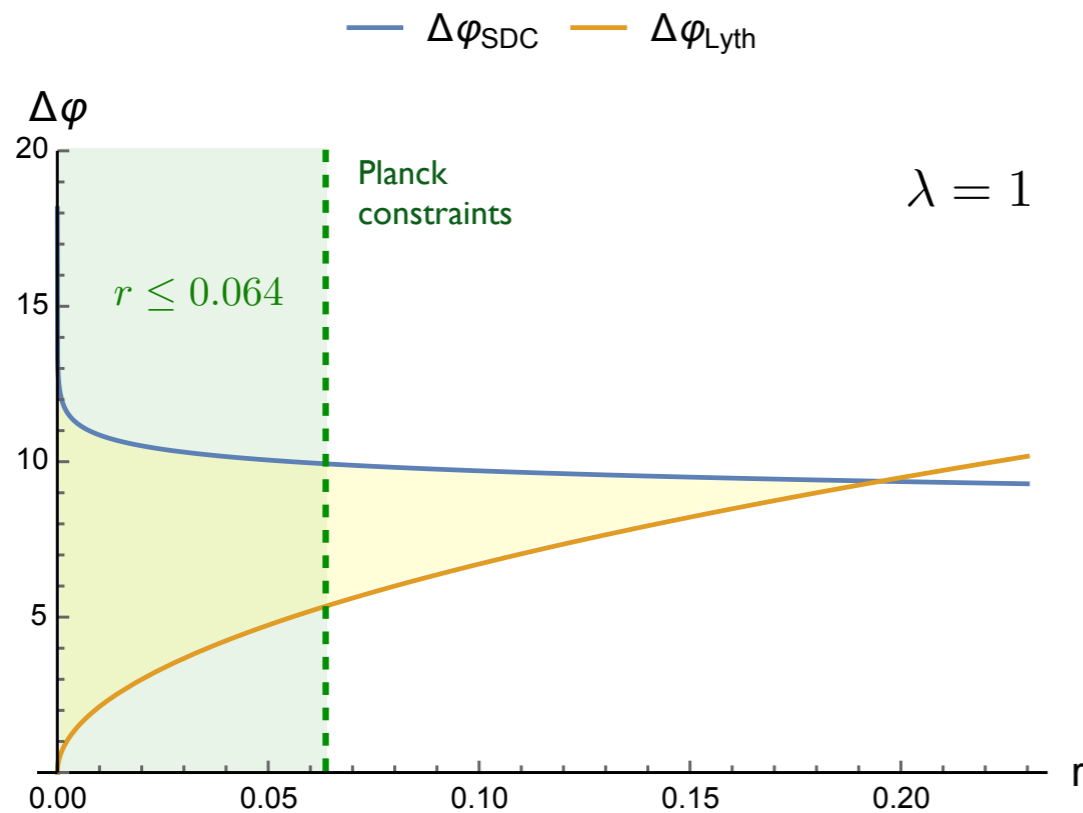
Implications for Inflation

SDC:

$$\Delta\phi \lesssim \frac{1}{\lambda} \log\left(\frac{M_p}{\Lambda}\right) \xrightarrow{H \leq \Lambda} \Delta\phi \leq \frac{1}{\lambda} \log\frac{M_p}{H} = \frac{1}{\lambda} \log\sqrt{\frac{2}{\pi^2 A_s r}}$$

Opposite scaling than Lyth bound!

[Scalisi, IV'18]



Large field inflation is not ruled out but constrained

Evidence in String Theory

Great progress in EFTs with 8 supercharges!

We get an universal bound for SDC factor in CY string compactifications:

(using limiting mixed hodge structures) $m \sim m_0 e^{-\lambda \Delta \phi}$

We find: λ is related to the properties of a **discrete infinite symmetry** generating the tower of BPS states

$$\lambda = \left| \frac{\nabla_i M}{M} u_i \right| \geq \frac{1}{\sqrt{2d}}$$

unit vector along geodesic



$$\lambda \geq \frac{1}{\sqrt{6}}$$

For CY3: $d = 1, 2, 3$

$d \equiv$ integer associated to discrete symmetry

(it characterises the type of asymptotic limit)

- One field [Grimm, Palti, IV'18]
- Multi-field [Gendler, IV'20]