

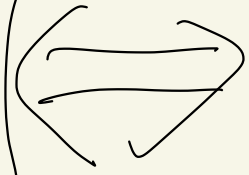
Swampland Conjecture &

Cosmology / Particle Physics

2021 / Mar / 17 Zoom

若手による重力 / 宇宙論研究会

String Theory
Quantum Gravity



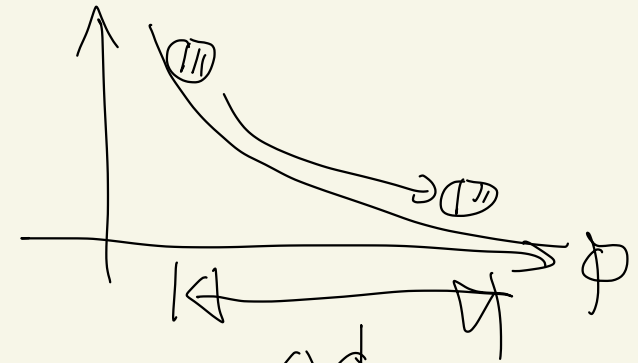
Cosmology
Particle Physics

Swampland

Distance Conjecture

Distance conjecture [Ooguri-Vafa, Klaewer-Palti]

$$\Delta\phi \lesssim \theta(M_{\text{pl}})$$



* a tower of light particles appear

$$\Lambda_{\text{QG}} = M_{\text{pl}} e^{-\lambda \Delta\phi / M_{\text{pl}}}$$

$\theta(1)$ coefficient

- relaxation
- quintessence
- inflation

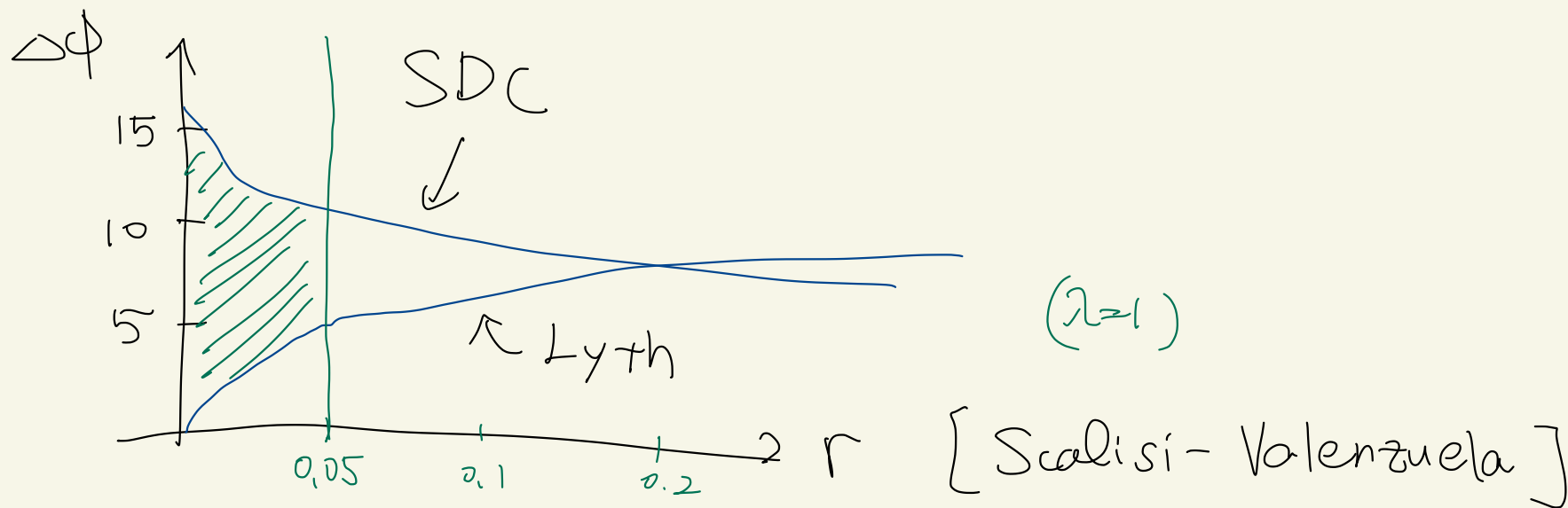
⋮

$$\mathcal{L} \supset (\partial\phi)^2$$

* constraints on large-field inflation models

$$H \leq \Lambda_{QG} \rightsquigarrow \Delta\phi \lesssim -\frac{1}{2\lambda} \left(\log \frac{\pi^2 A_S}{2} + \log r \right)$$

Lyth bound $\rightsquigarrow \Delta\phi \geq 3\sqrt{\frac{r}{0.01}} M_{pl}$ ← 逆向走



* Check/Prove DC? $\mathcal{O}(1)$ coefficient?

* ∞ -distance

decompactify into high dim. (M-theory)
(KK modes)

Weakly coupled string (tensionless string)

(* in general quantum correction (eg. D-instanton)
to manifold important)

* "CFT dual" [Perlmutter, Rastelli, Vafa, Valenzuela]

∞ -distance in conformal manifold

\leadsto higher-spin current $\Delta \sim e^{-d}$

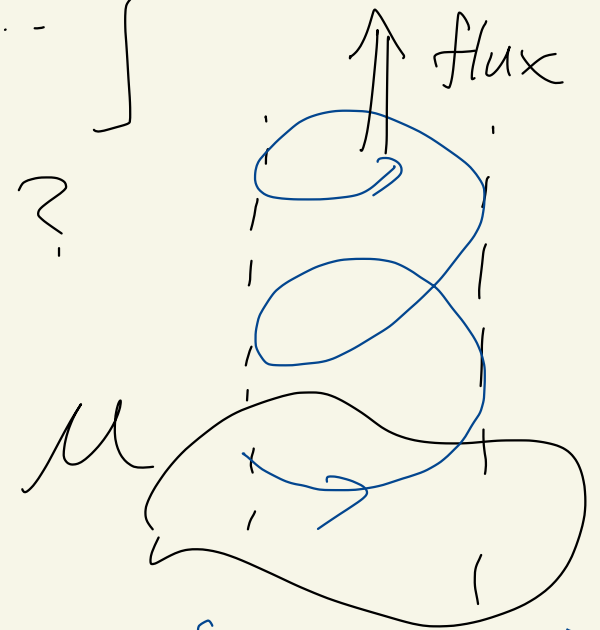
bootstrap constraints?

Axion Monodromy?

[Silverstein - Westphal ...
Kaloper - Sorbo ...]

* What if potential is multi-valued?

$$\Delta\phi \rightarrow N\Delta\phi?$$



* $N(\text{flux})$ large \rightsquigarrow backreaction important [eg. Baume - Palti]

$$\left(\begin{array}{l} \text{eg } K = -2\log S' - 3\log U - 3\log T \\ W = \textcircled{1} + \textcircled{2} S + \textcircled{3} U + e T + g T^2 + \textcircled{10} T^3 \end{array} \right)$$

\uparrow flux

* physical vacuum gone away for $a \gtrsim a_*$

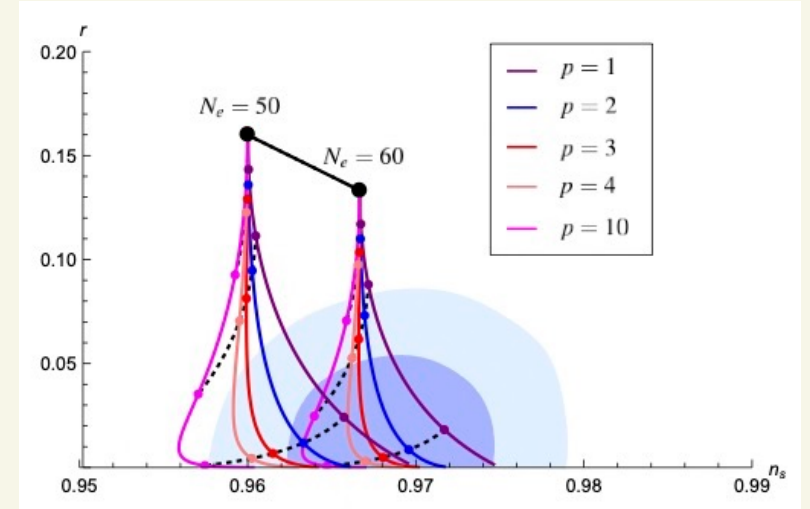
* a_* can be large, but $\Delta\phi \sim \frac{\Delta a_*}{a_*} \sim \mathcal{O}(1)$

Multi-Valued Axion Potentials:

Pure Natural Inflation [Nomura-Watanabe-Y] ³

$$V(a) \sim M^4 \left[1 - \left(1 + \left(\frac{a}{F_a} \right)^2 \right)^p \right]$$

↑
holography



Chromonatural ($a \sim a + 2\pi F_a$)

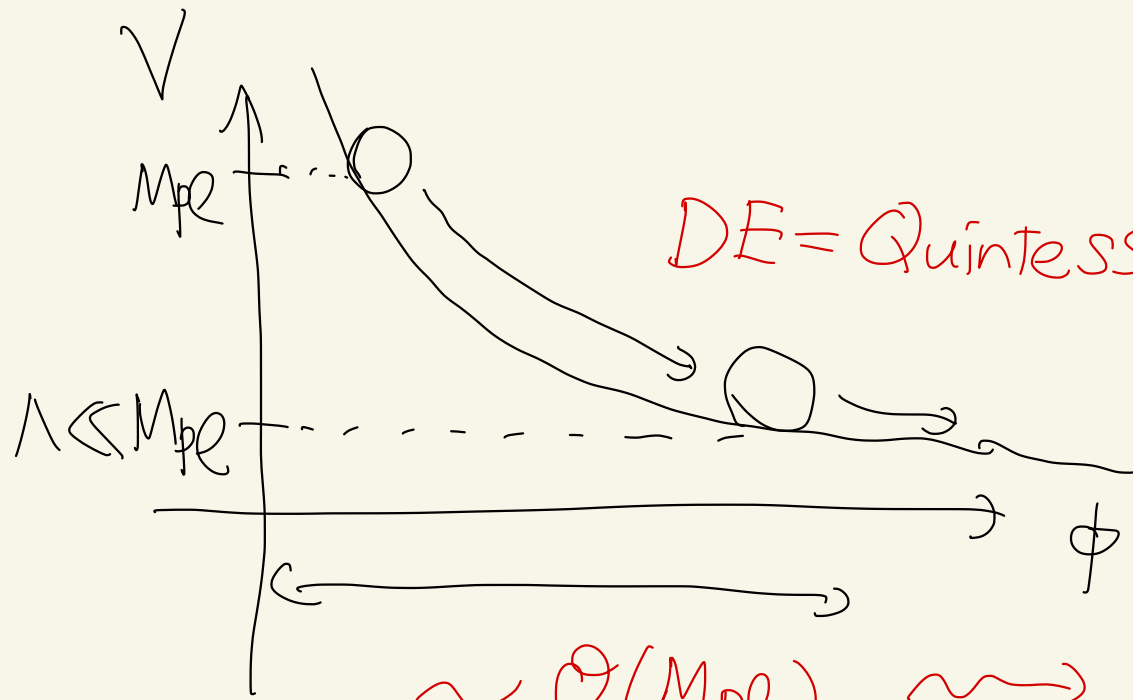
$$V(a) \sim M^4 \cos\left(\frac{a}{F_a j}\right) + k \frac{\alpha}{8\pi} \frac{a}{F_a} \mathbb{F} \mathbb{F} \quad [\text{Adshedd-Wyman} \dots]$$

$j, k \gg 1$ often needed but how?

Large PQ charge / kinetic mixing / clockwork?
but constrained [Agrawal, Fan, Reece]

[cf. [Dror-Leedom] for ultralight axions]

Coupled DM + DE mode



DE = Quintessence

ϕ

$$e^{-c\phi}$$

\int

$$\mathcal{L} \supset \overbrace{m c \phi} \bar{\psi} \psi$$

$\sim \mathcal{O}(M_{pl})$

distance conjecture

DM = tower of states

$$\bar{\psi} \psi$$

* [Agrawal, Obied, Vafa] better for H_0 tension?

* [Desmond, Ferreira] ruled out by galaxy morphology?

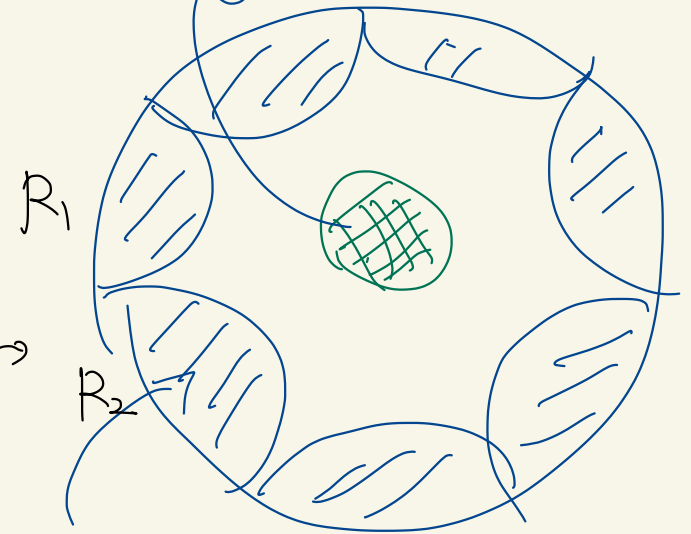
($\Delta G_N / G_N \sim 10\%$ ruled out)

No Exact Global Sym.

Violation of Global Symmetry

- * Arguments from BH evaporation, ...
- Holography** [Harlow-Yoon]

We can put the charged operator here



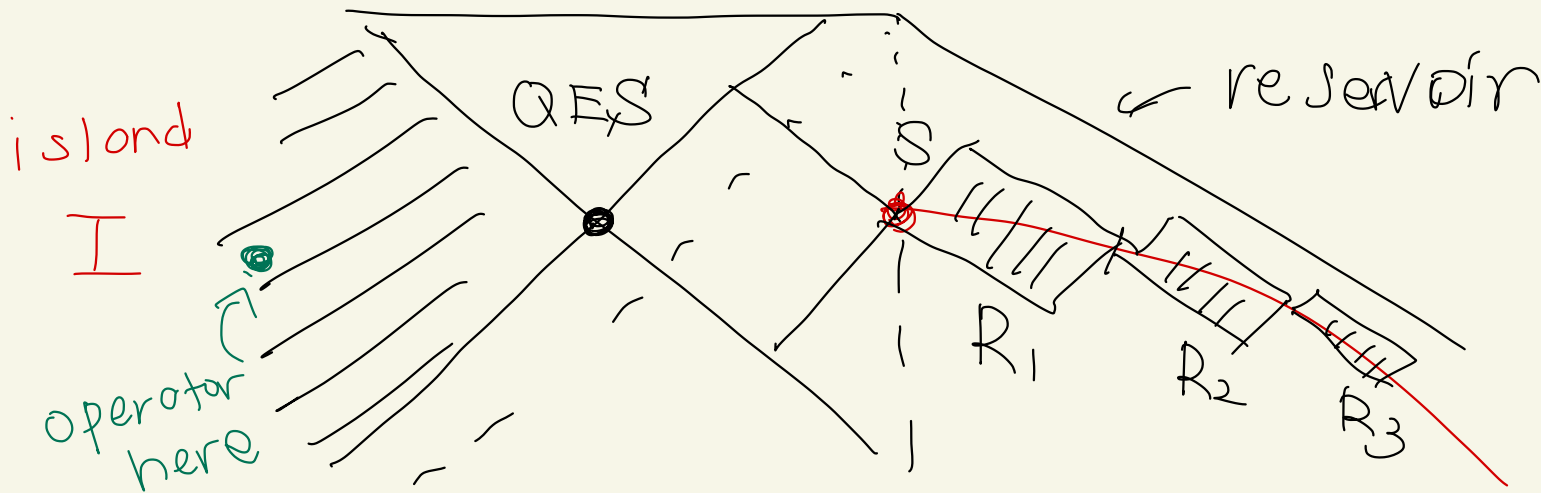
$$\bigcup_i R_i \rightsquigarrow$$

- * Similar argument for
- Evaporating Black Holes**

entanglement wedge

[Harlow-Shaghoulian]

BH



$$S \sim \left(\bigcup_i R_i \right) \cap R$$

$$\left(I \subset EW(R) \right) \neq \bigcup_i EW(R_i)$$

* Q: How to quantify \mathcal{A} ?

[← could be related eg. to
stability of DM]

Warmhole suggests

$$c \sim e^{-\frac{M_{\text{pl}}^2}{\Lambda^2}} \sim e^{-\frac{1}{c_{\text{NH}} \Lambda^2}}$$

[Giddings- Strominger, ..]

∴ global symmetry can be

"gauge-derived" / "accidental" / "fine-tuned"

↑
landscape

we can also consider gauge sym.

Weak Gravity Conjecture

* Spin 1
[AMNV]

$$\exists \sqrt{2} g \geq \frac{m}{M_{pl}}, \quad \Lambda \lesssim g M_{pl}$$

* Spin 2
[Klaewer-Lust-Palti]

$$\Lambda \lesssim \frac{m}{M_*} M_{pl} \quad \leftarrow \text{Homework}$$

* axion (0-form)

$$\left(\mathcal{L} \ni \frac{a}{f} F \tilde{F} \right)$$

[AMNV]

$$\frac{1}{f} \gtrsim \frac{S_I}{M_{pl}} \quad \rightsquigarrow \quad f \lesssim \frac{M_{pl}}{S_I}$$

↑ charge

↙ mass

(p-form version: suggested by dimensional reduction
[Heidenreich, Reece, Rudelius])

Axionic WGC [Hebecker - Soler]

* Axionic Hair of BH

axion $a \rightarrow$ 2-form B , $H = dB$
dualize

BH w/ charge $\int_{S^2} H = b$

* BH evaporate, w/ $R \sim \Lambda^{-1}$ $r_s \sim M/M_{pl}^2$

$$E \sim \frac{b^2}{f^2 R^3} \lesssim E_{tot} = M_{pl}^2 R \sim \Lambda \lesssim \sqrt{f} M_{pl}$$

* relation w/ \mathcal{G}

[Dons - Hebecker - Leonhardt
- March-Russel]

$$S_I \lesssim \frac{M_{pl}}{f}$$

$$e^{-S_I} \gtrsim e^{-\frac{M_{pl}^2}{\Lambda^2}}$$

Photon mass

$$\mathcal{L} \supset m^2 (A_\mu - \partial_\mu \phi)^2$$

Suppose γ has mass m_γ from Stückelberg mechanism

conj:

[Reece]

also

[Hebecker - Soler]

$$\Lambda_{UV} \lesssim \min \left(\sqrt{\frac{m_\gamma M_{pl}}{e}}, e^{\frac{1}{3}} M_{pl} \right)$$

* Idea: m_γ small \leadsto large distance \leadsto tower of states beyond EFT

* $m_\gamma \lesssim 10^{-14}$ eV (FRB) $\leadsto \Lambda_{UV} \lesssim 5$ MeV excluded

* constrains dark photon

(Gauge) WGC :

$$F_{\text{gauge}} \geq F_{\text{gravity}}$$

With Scalar ?

[Palti, Heidenreich - Reece - Rudelius]

$$F_{\text{gauge}} \geq F_{\text{scalar}} + F_{\text{gravity}}$$

[Palti, Gonzalo - Ibanez, Shirai - Y]

$$F_{\text{scalar}} \geq F_{\text{gravity}}$$

(likely not always
but can be "generic"?)

fifth-force constraint [Shirai - Y]

implications for Q-balls, PBH, axion, GW, ...

[Kusenko - Takhistov - Yamada - Y]

Cosmic Censorship vs Weak Gravity Conjecture

* Violation of **Weak Cosmic Censorship** (no naked sing.)

in 4D Einstein-Maxwell - $\Lambda < 0$

[Horowitz, Santos, Woy, Crisford, ...]

* ^{AdS} **WGC** $\leadsto \exists$ particle w/ $q \geq m$

Now 4D Einstein-Maxwell - Charged Scalar - $\Lambda < 0$

WGC removes the counterexample to CC.

[Crisford, Horowitz, Santos, ...]

More on Axioms

* Axions: "Generic" in String Theory

$\mathcal{O}(100)$ axions — string axiverse

inflation / QCD axion / ultralight axion — DM
 \ — DE

IB

eg. D7-brane CS coupling

$$\mathcal{L} \supset \int_{\substack{D7 \\ R^4 \times 4\text{-cycle}}} C_4 \wedge \text{Tr}(F \wedge F) \rightsquigarrow \int \underbrace{a}_{\parallel} \text{tr}(F \wedge F)$$

$$\int C_4$$

4-cycle

Het.

$(H_3 = dB_2)$

Bionchi

$$\mathcal{L} \supset dH_1 \wedge dH_1 + a \left(dH_1 + \frac{1}{16\pi^2} \text{tr}(F_1 F_1 - R_1 R_1) \right)$$

\downarrow
 $H d a$ integrate out H

... However axions are subtle! phase difference

QCD axion

$$V = m_{\pi}^2 f_{\pi}^2 \cos \frac{a}{f_{\pi}} + M^4 e^{-S_{\text{inst}}} \cos \left(\frac{a + \psi}{f} \right)$$



worldsheet instanton

D-brane instanton

gravity instanton
(wormhole)

for QCD axion

$$e^{-S_{\text{inst}}} \lesssim 10^{-10} \frac{F_{\pi}^2 m_{\pi}^2}{M^4} \quad M = M_{\text{pl}}$$

$$S_{\text{inst.}} \gtrsim 200$$

subtle

[Svrcek-Witten]

EW Quintessence Axion

{ Nomura - Watari - Yanagida,
McLerran - Pisarski - Skokov }

(DE)

$$\Lambda^4 \sim M_{\text{pl}}^4 e^{-\frac{2\pi}{\alpha_{\text{EW}}(M_{\text{pl}})}} \sim 10^{-120} \sim \Lambda_{\text{c.c.}}$$

* constrained by WGC, but better w/ SUSY
[Ibe - Yanagida - Y]

* Explicitly stringy quintessence models hard
but attempts [eg. Pando - Sumitomo - Trivedi]
 ↑
 moduli

Some More Conjectures

"Transplanckian censorship" [Bed roya - Vafa]

$$l_p e^{N_e} \lesssim \frac{1}{H}$$

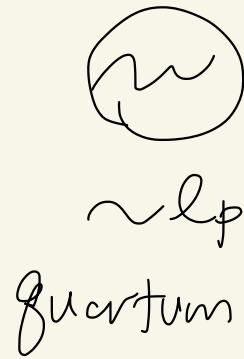


$$r \lesssim \mathcal{O}(10^{-30})$$

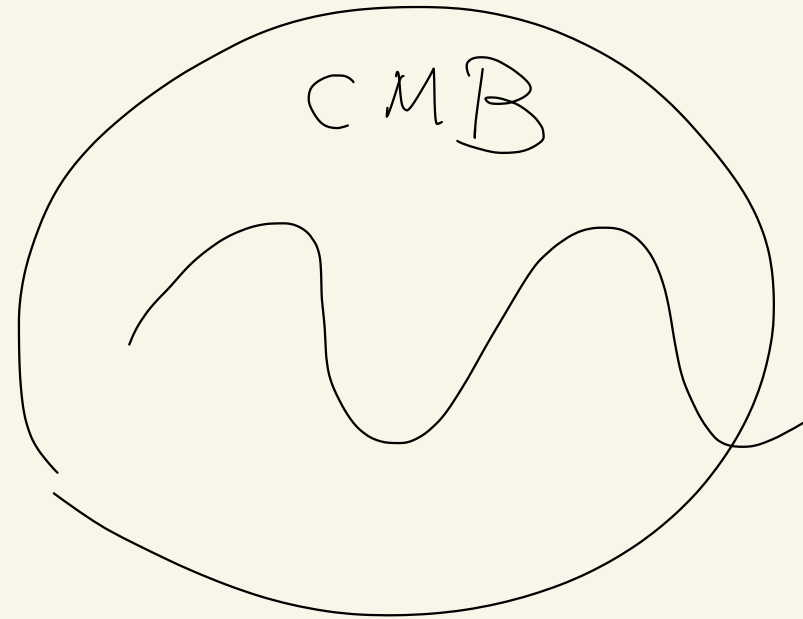
or

$$r \lesssim \mathcal{O}(10^{-8})$$

[Mizuno - Mukohyama - Pi - Zhang]



$\sim l_p$
quantum



macroscopic
fluctuation

My take: TCC : not a swampland conjecture

[Scito - Shirai - Y]

No AdS Conjecture [Ooguri - Vafa]

"No non-SUSY AdS"

[Ibanez - Martin-Lozano - Valenzuela]: $4D$ SM \rightarrow $3D$ AdS³ x S²

" $\Lambda \sim m_{\text{pl}}^4$, Majorana + (no new phys) excluded"

AdS distance Conjecture

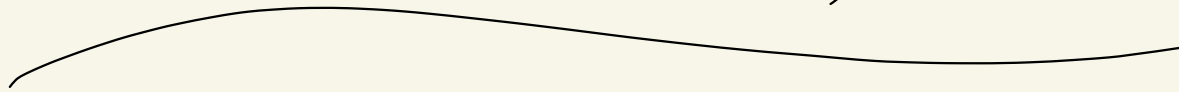
AdS w/ Λ

as $\Lambda \rightarrow \infty$ tower w/ $m \sim |\Lambda|^{-\alpha}$ $\alpha > 0$

(hard to get scale separation between

R_{AdS} & R_{KK})

Summary



* String/QG: difficult

but some important lessons:

"Research topic for the young"

* interplay of

