Swampland Conjectures

Masahito Yamazaki
(IPMU, Univ. Tokyo)

PPP2019, Aug/2/2019, YITP Kyoto

Swampland : recently very popular

1. **Distance and de Sitter Conjectures on the Swampland**
Hirosi Ooguri (Caltech & Tokyo U., IPMU), Eran Palti (Munich, Max Planck Inst.), Gary Shiu (Wisconsin U., Madison), Cumrun Vafa (Harvard U., Phys. Dept.). Oct 12, 2018. 5 pp.
Published in **Phys.Lett. B788 (2019) 180-184**
DOI: 10.1016/j.physletb.2018.11.018
e-Print: **arXiv:1810.05506 [hep-th]** | **PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service; Link to Article from SCOAP3
Detailed record - Cited by 138 records 100+

2. **De Sitter Space and the Swampland**
Georges Obied (Harvard U., Phys. Dept.), Hirosi Ooguri (Caltech & Tokyo U., IPMU), Lev Spodyneiko (Caltech), Cumrun Vafa (Harvard U., Phys. Dept.). Jun 21, 2018. 21 pp.
CALT-TH-2018-020, IPMU18-0100
e-Print: **arXiv:1806.08362 [hep-th]** | **PDF**
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record - Cited by 245 records 100+

But not just fashion!

Fundamental questions / ideas

on QG

But not just fashion!

Fundamental questions / ideas

on QG

... and <u>our</u> Universe

myself:

phenomenological constraints / implications

on swampland conjectures

"Pheno / String Collaboration"

村山－柳田－MY 1809.00478

福田－斉藤－白井－MY 1810.06532

伊部－柳田－MY 1811.04664

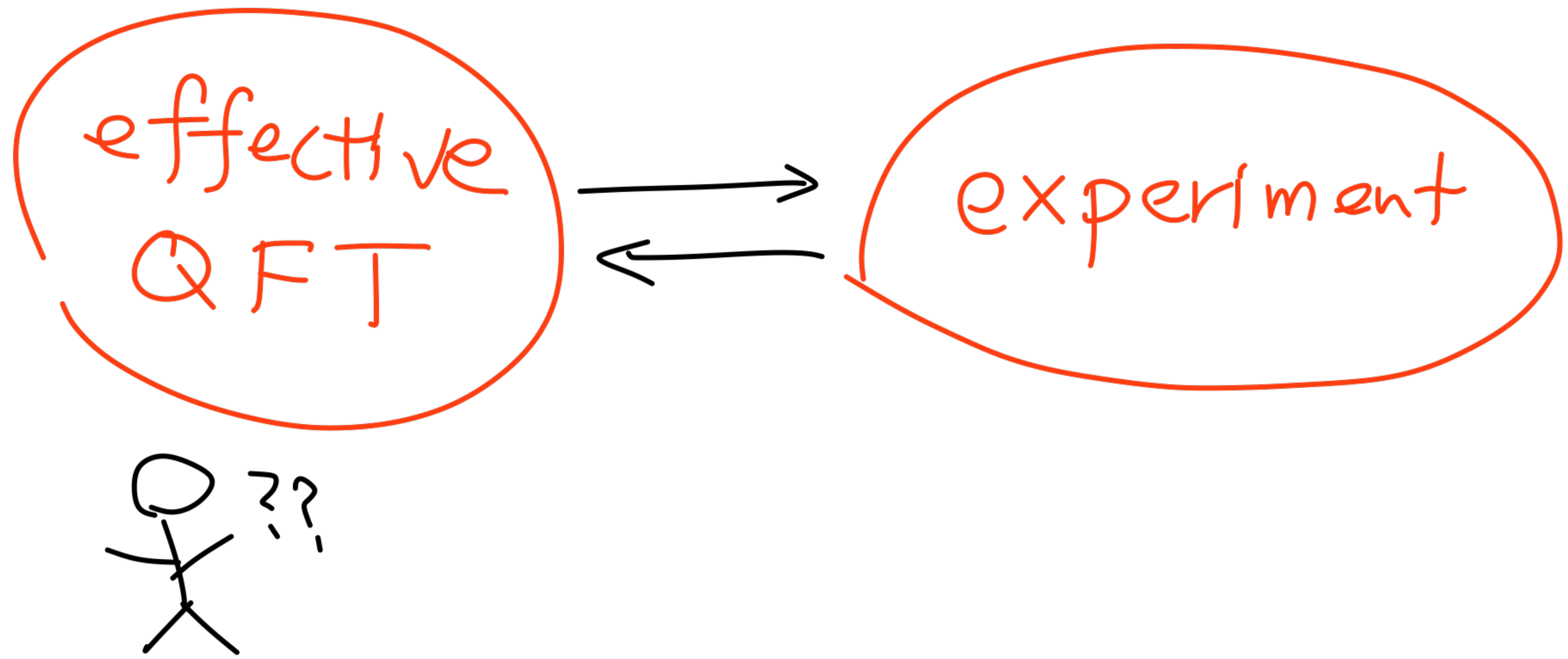
MY 1904.053576 ← Moriond proceeding

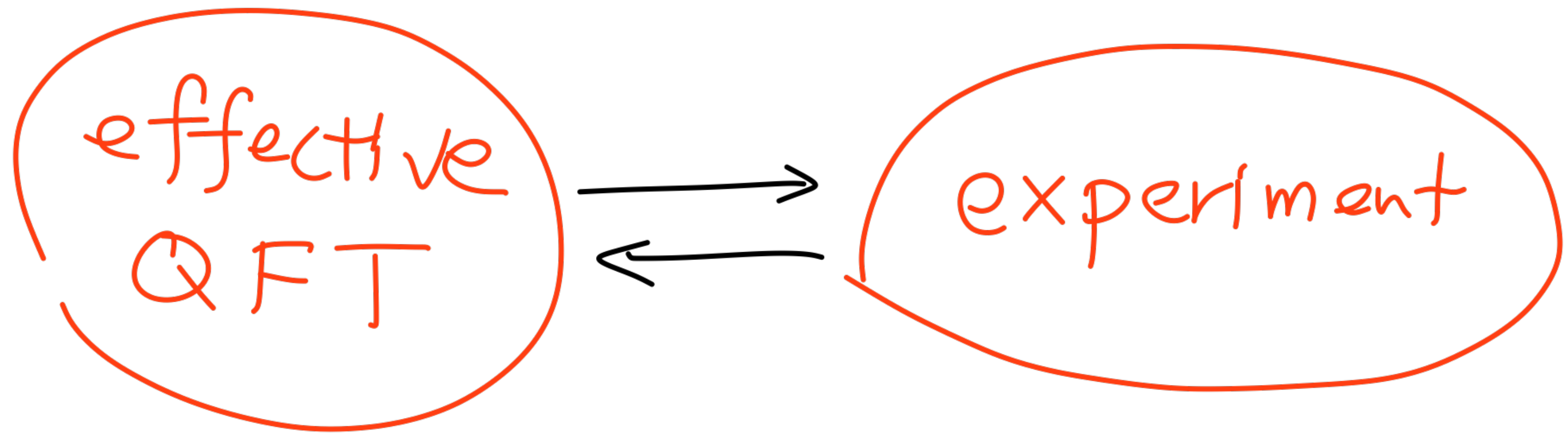
4,5 pages + ref.

白井－MY 1904.10577

Why Swampland?

experiment


effective
QFT
experiment
??


effective
QFT
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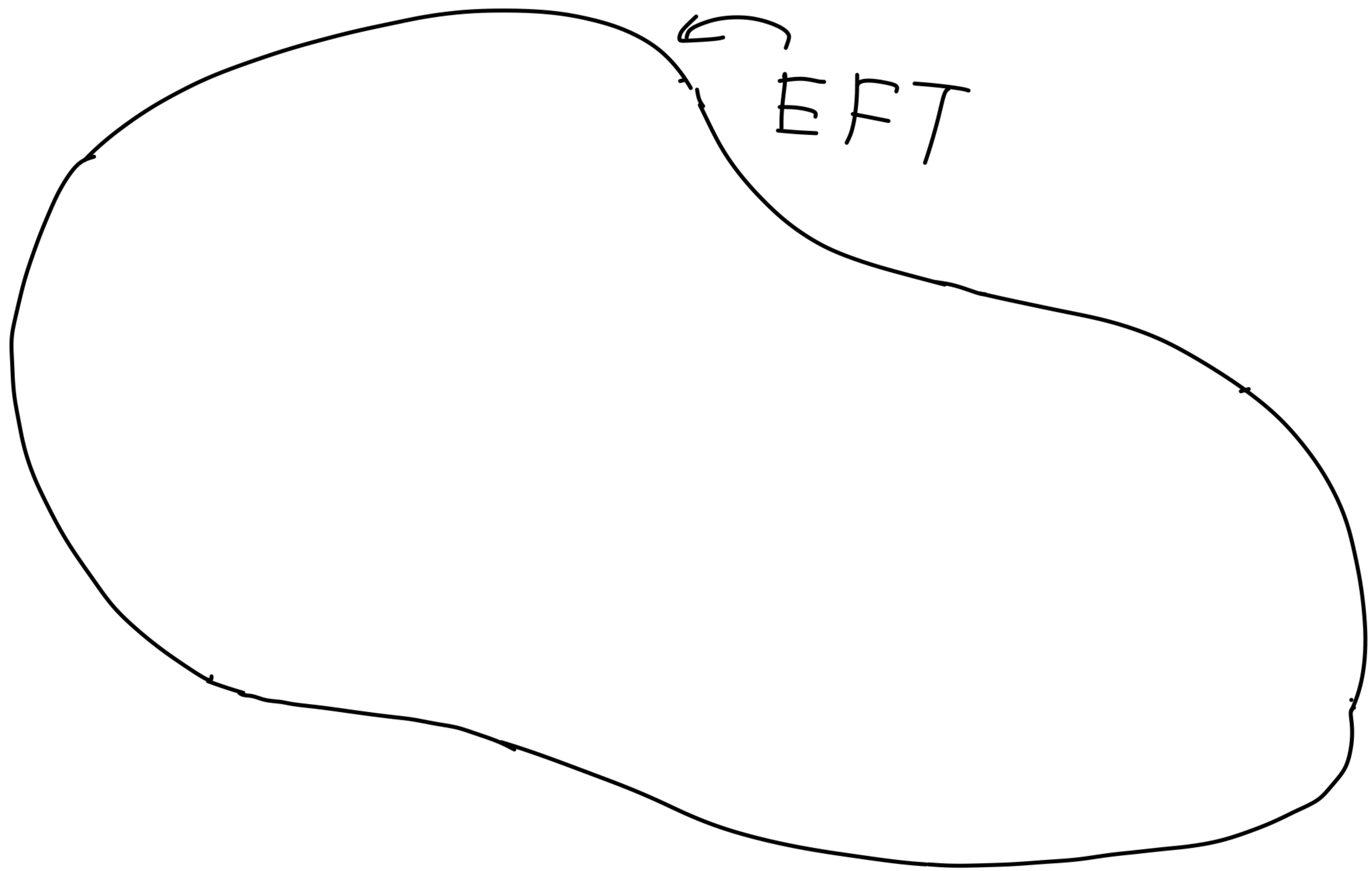
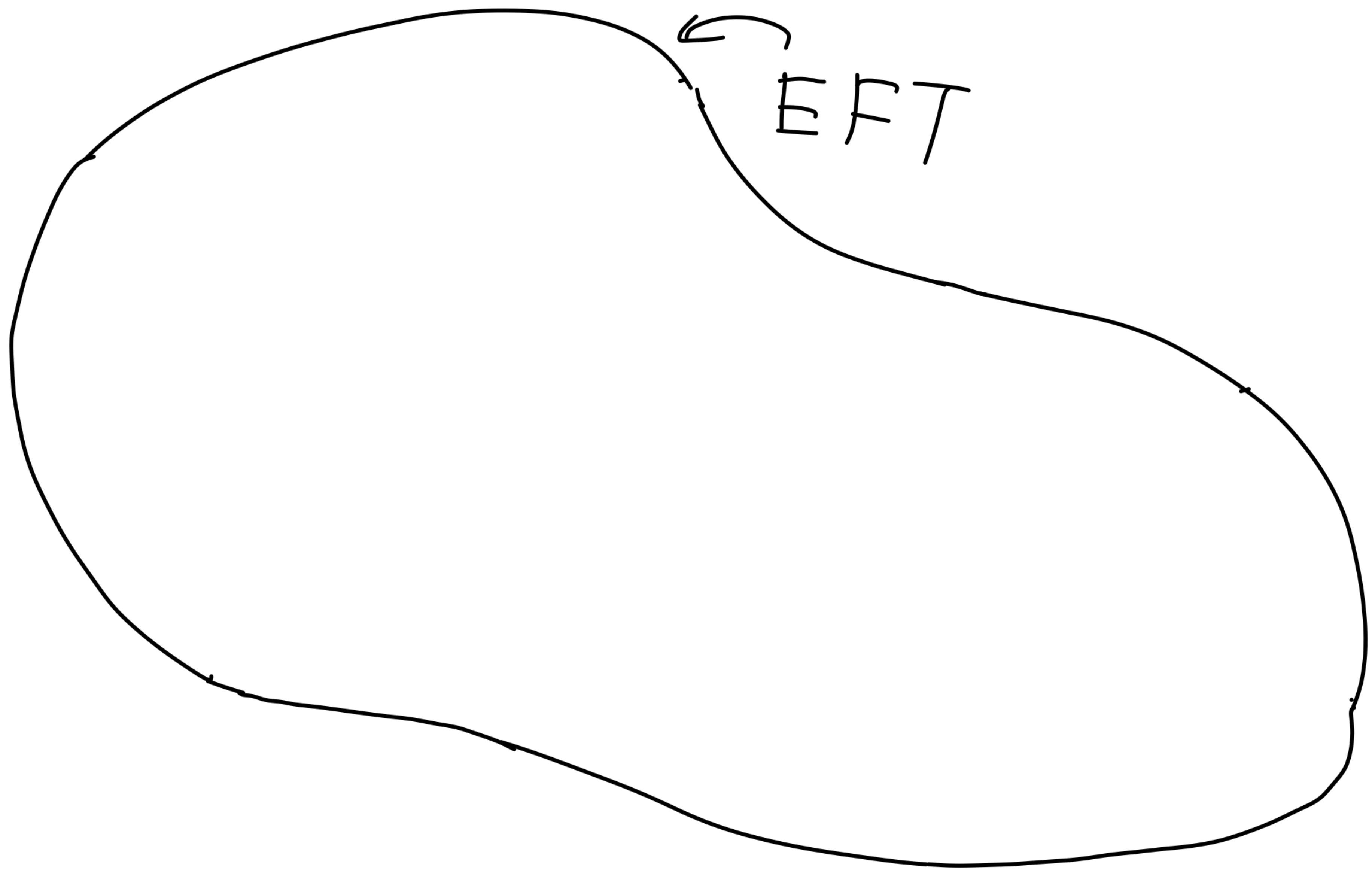

EFT


Quantum Gravity
effective QFT
experiment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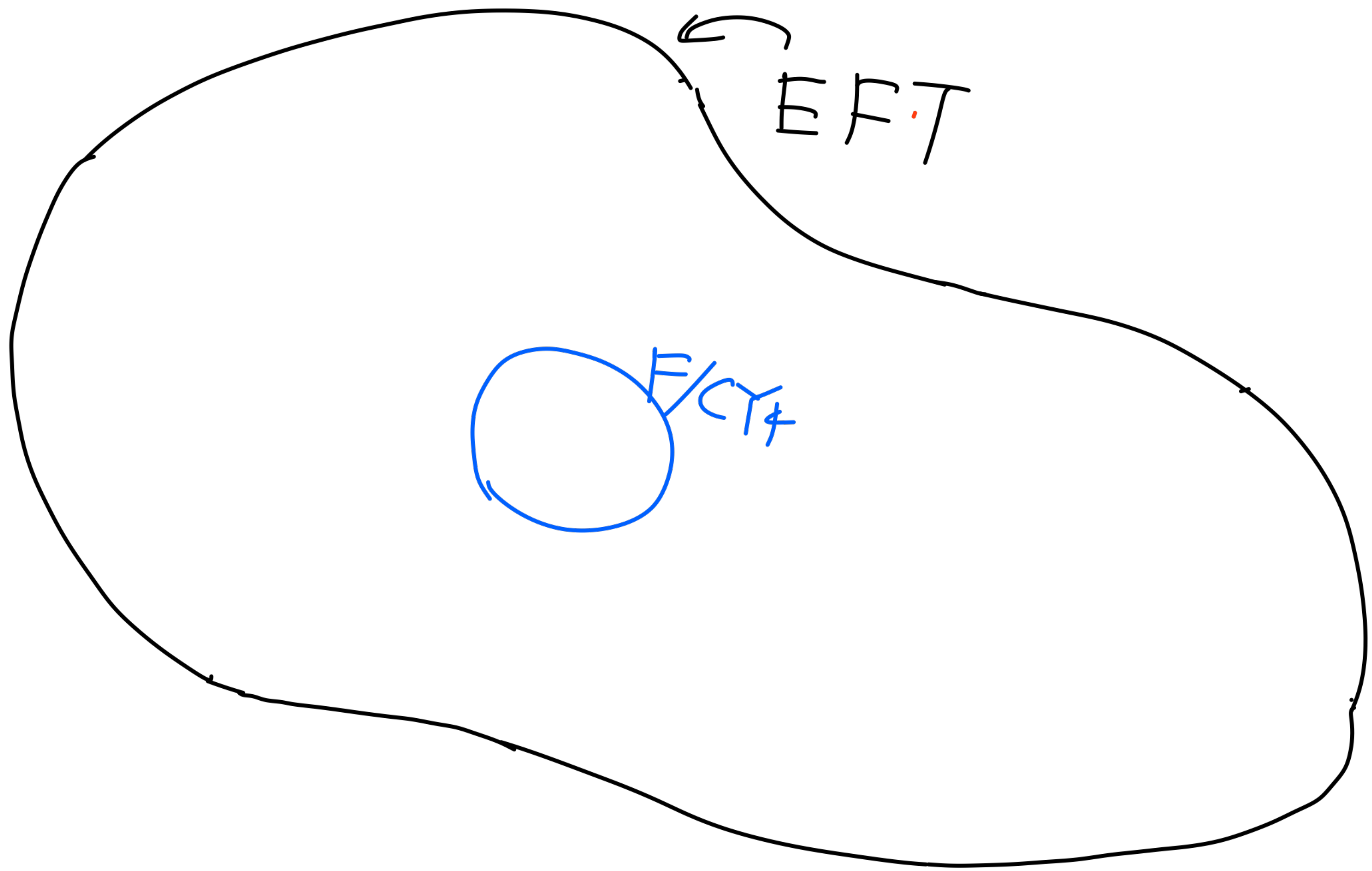
EFT


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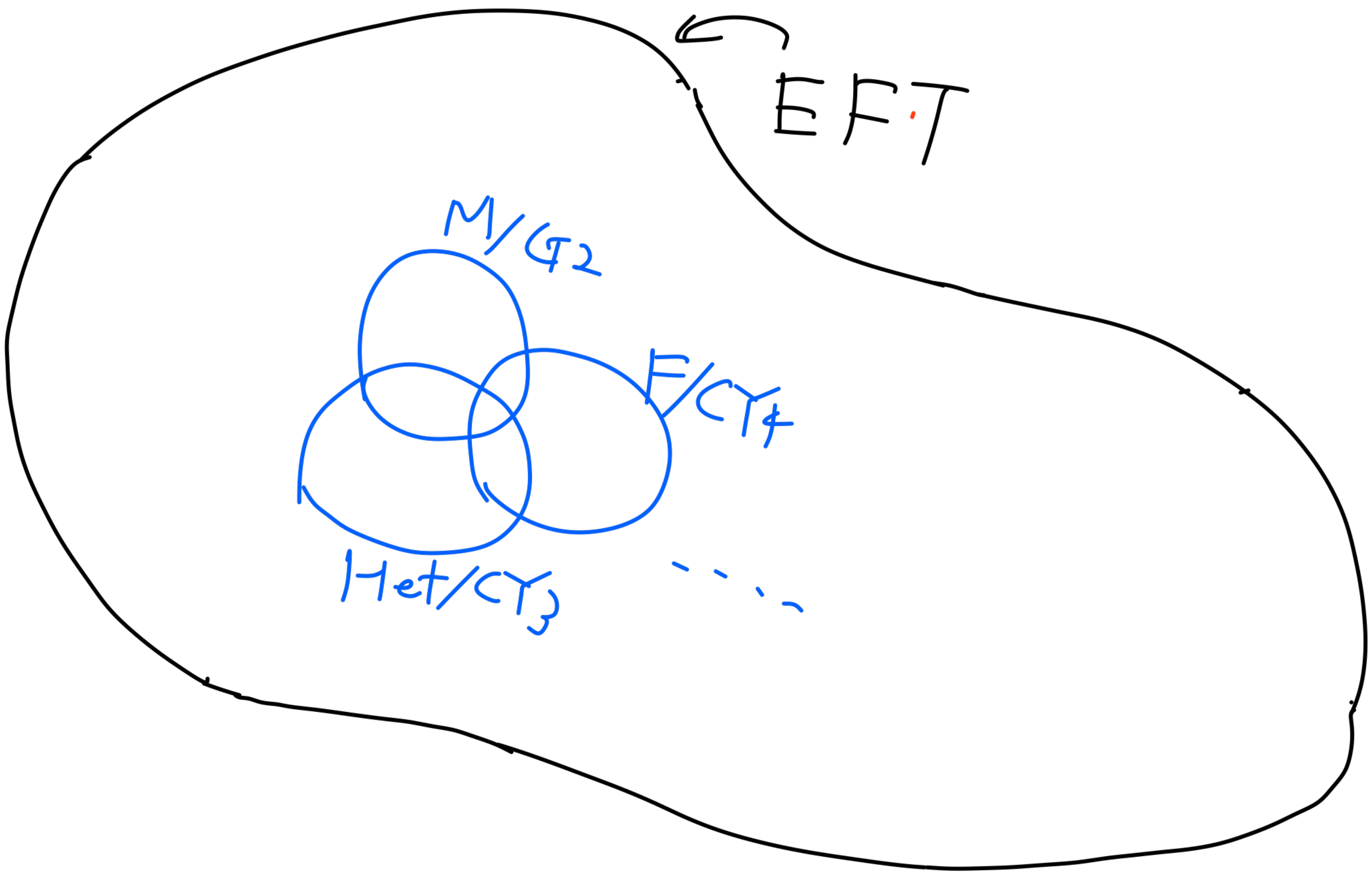
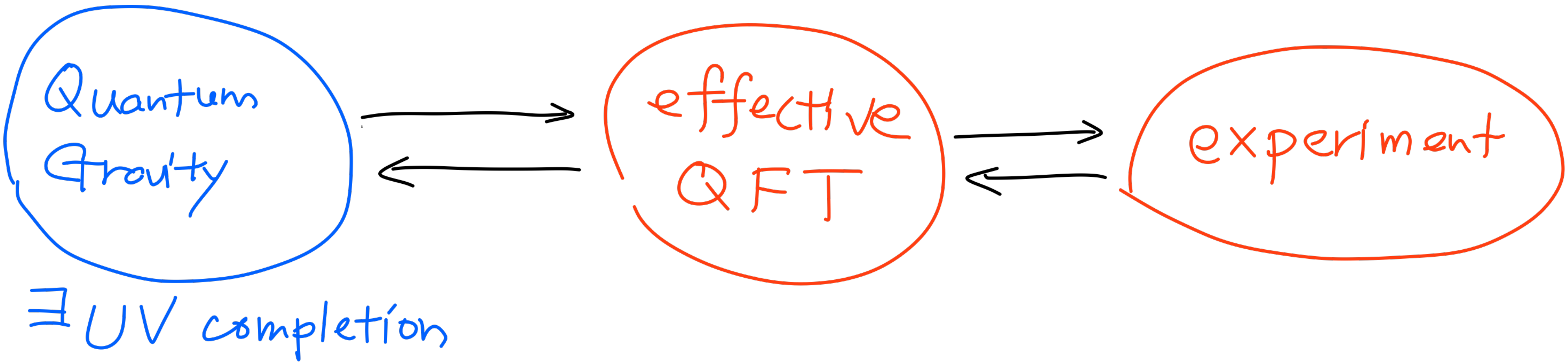
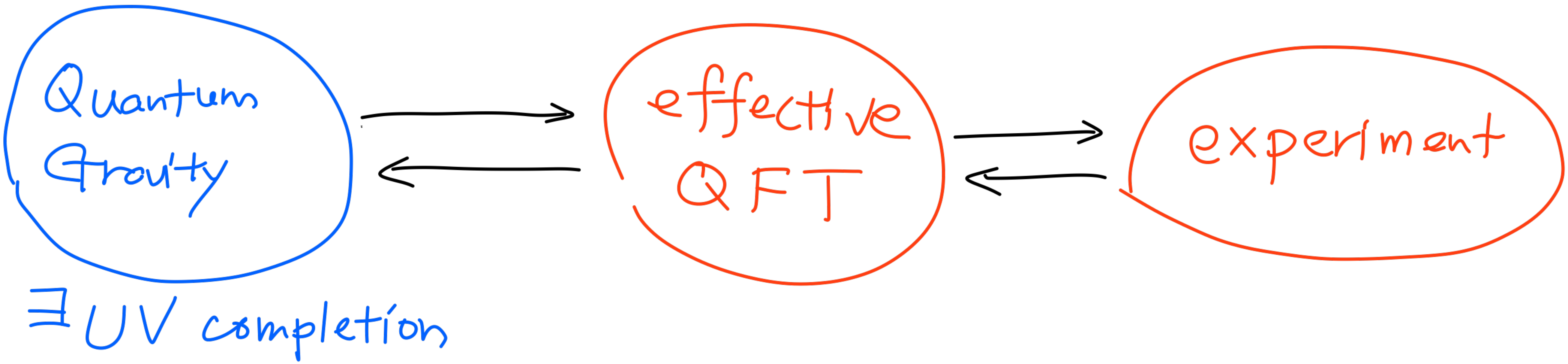

EFT
M/G_2
F/CY_4
Het/CY_3
. . . .


Quantum Gravity
effective QFT
experiment
∃ UV completion


EFT
M/G2
F/CY4
Het/CY3
. . . .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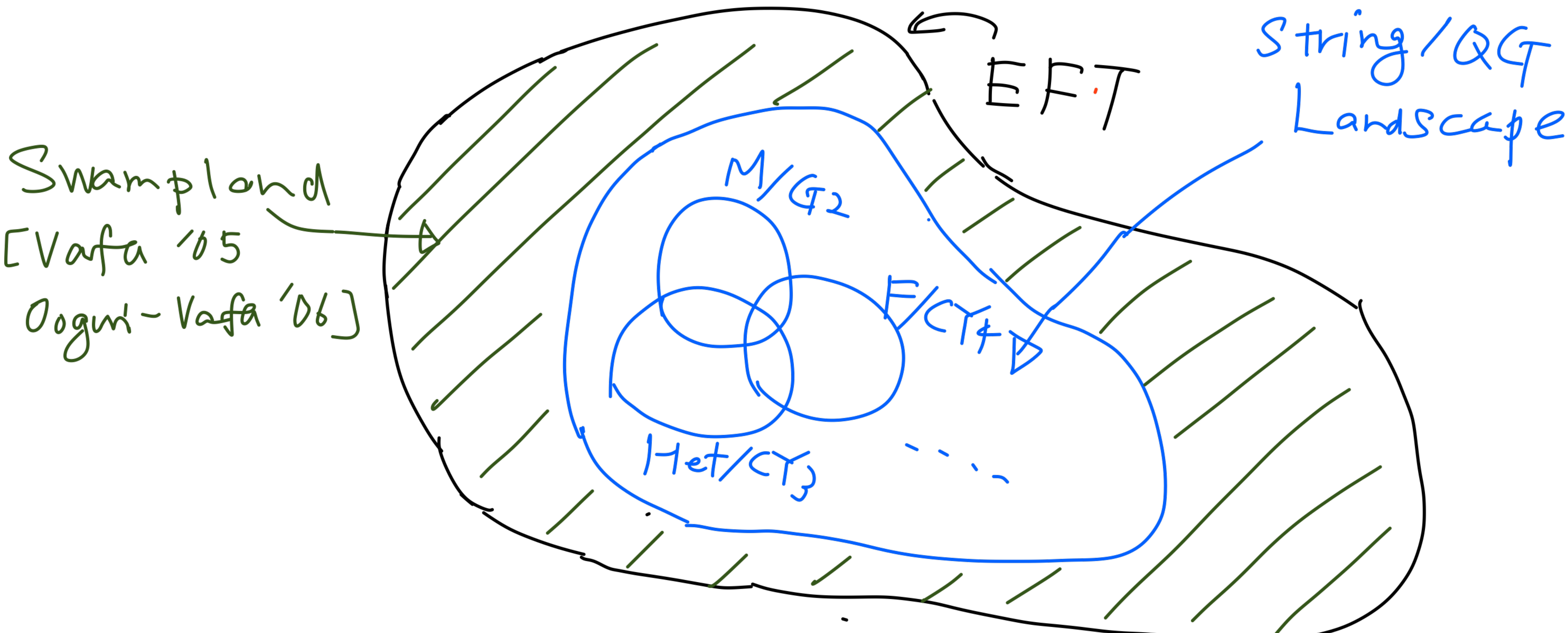

EFT
String/QG Landscape
Swampland [Vafa '05 Ooguri-Vafa '06]
M/G2
F/CY4
Het/CY3
. . . .

Quantum Gravity $\rightleftarrows$ effective QFT $\rightleftarrows$ experiment

$\exists$ UV completion

[Vafa '05
Ooguri-Vafa '06]
Swampland

EFT

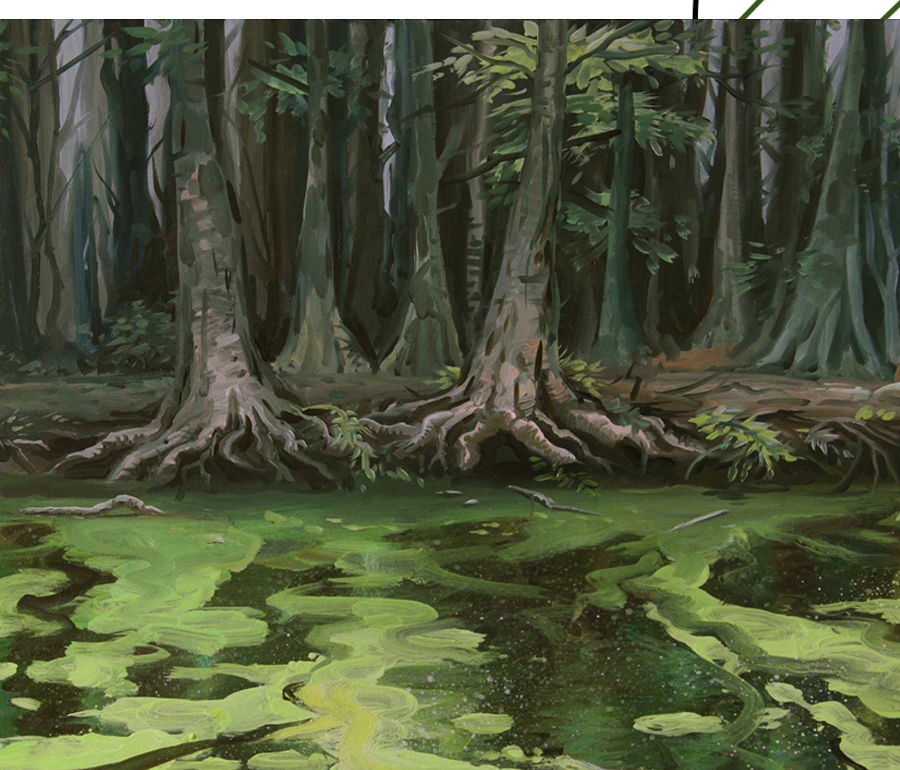
String/QG
Landscape

M/G_2

F/CY_4

Het/CY_3

. . .



To recap:

given a low-energy EFT

Swampland Conjectures:

Necessary (but NOT sufficient) condition for existence of UV completion in QG (such as string theory)

attempts towards universal prediction from QG

Of course, QG is notoriously difficult

Of course, QG is notoriously difficult

clue

- (Semiclassical) GR — e.g. Black Hole (entropy, Hawking radiation)
- String theory — many examples/data; duality, AdS/CFT, ...; precise mathematical checks
- phenomenology

Points to keep in mind

* Gravity is <u>very</u> crucial (M_{pl} finite)

* Often refer to higher-dim. non-renormalizable operators

* All swampland conjectures: conjectures/ hypothesis

Points to keep in mind

* Some solid, some speculative

* Combination/ Consistency of conjectures crucial

* Some conjectures might not hold generally, but could still be useful

Swampland Conjectures

: Examples

Many conjectures on the market

[review: Brennan, Carta, Vafa '17
Palti '19]

today's focus:

$$\begin{tikzcd}
 & \text{no global sym.} \arrow[dl] \arrow[dr] & \\
\text{Weak gravity conj.} \arrow[rr, leftrightarrow] & & \text{distance conj.} \arrow[dl, dashed] \\
 & \text{de Sitter conjecture} &
\end{tikzcd}$$

「No Global Symmetry」

many many works

Misner - Wheeler '57

Polchinski '03

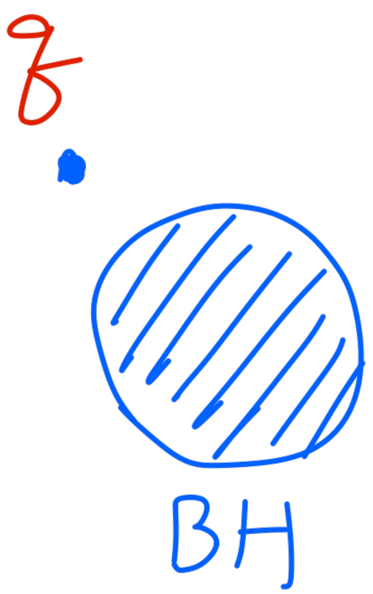
Banks - Seiberg '10

Harlow - Ooguri '18

「No exact global sym. in QG」

argument: Consider $U(1)$ global sym.

$\exists$ a state w/ charge $q \gg 1$



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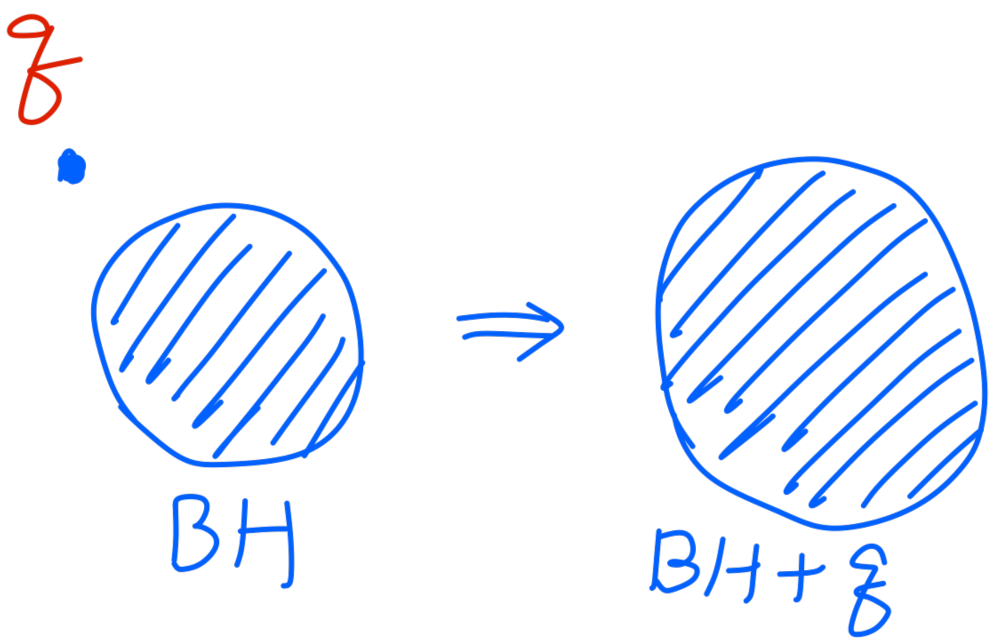

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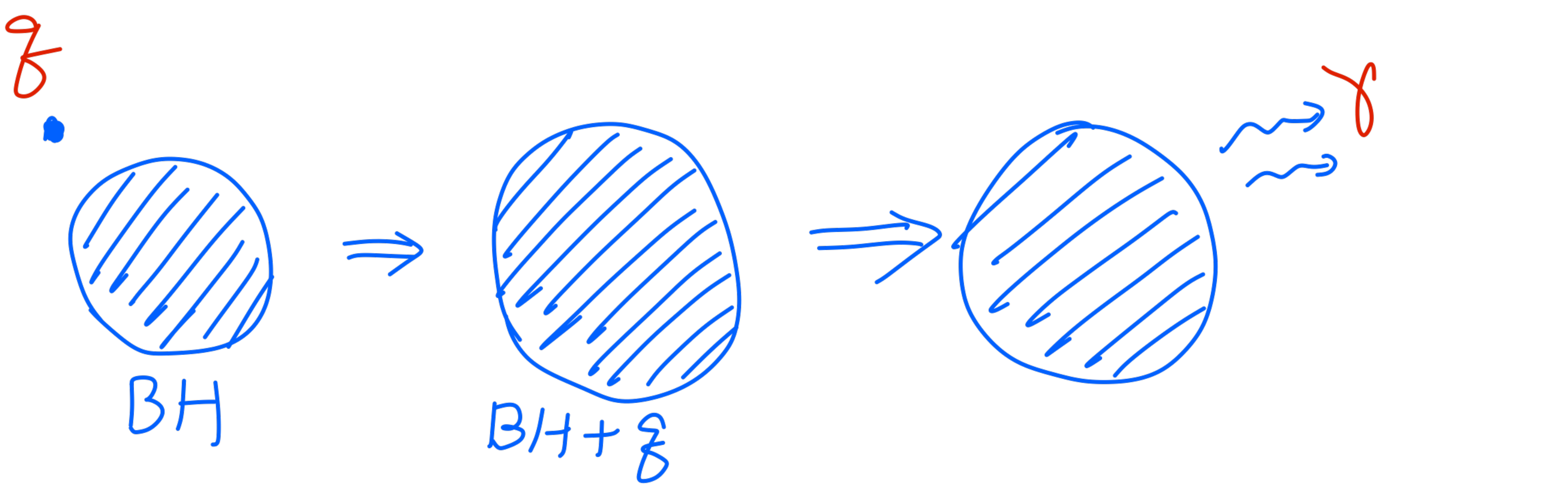

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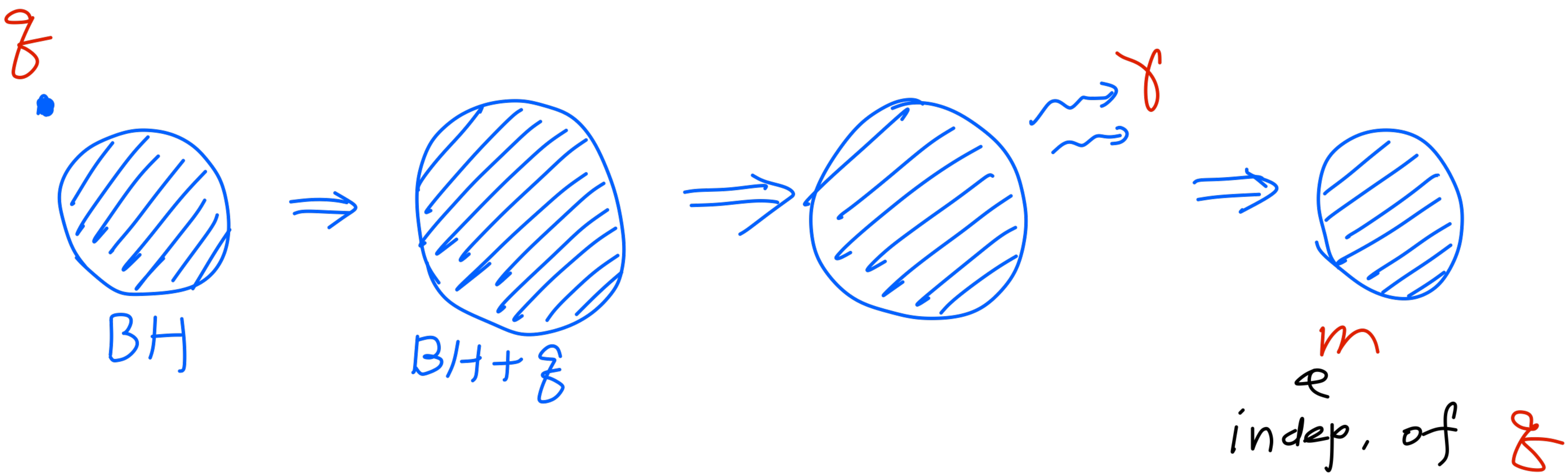

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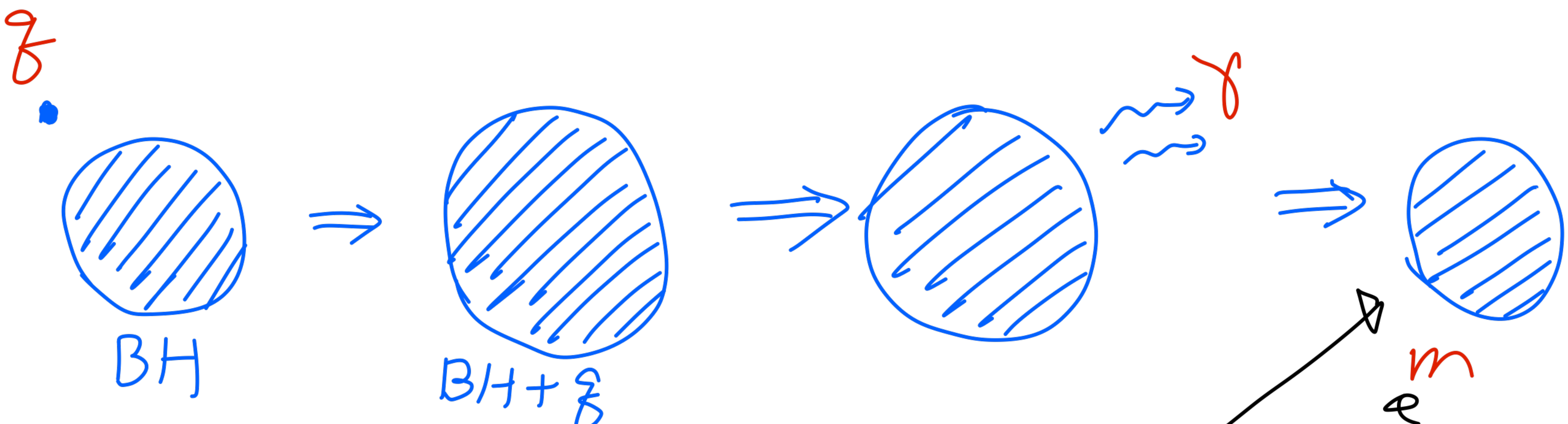


e^{m} indep. of q

q should be in BH

but S_{BH} finite $\Rightarrow$ contradiction for q very large

「No exact global sym. in QG」

e.g. $U(1)_{B-L}$ in SM must be broken

by higher-dim. operator e.g. $\bullet \dfrac{\nu\nu\nu\ell}{\Lambda^2}$

$\boxed{\text{no constraint (if } \neq 0)}$

「No exact global sym. in QG」

e.g. $U(1)_{B-L}$ in SM must be broken

by higher-dim. operator e.g. $\frac{qqq\ell}{\Lambda^2}$

$\boxed{\text{no constraint (if} \neq 0\text{)}}$

※ approximate global sym.
exact gauge sym.
} OK

global sym. = ∞ fine-tuning No free luch!

「No exact global sym. in QG」

* BH argument does not apply to
  discrete sym. (such as $\mathbb{Z}_2$)

  but holography argument does

  [Harlow-Ooguri '18]

* even applies to p-form sym.

  [Córdova-Ohmori-Rudelius]

「 Weak Gravity Conjecture 」

[Arkani-Hamed, Motl, Nicolis, Vafa '06]

Global Sym.

$e \to o$

NOT ALLOWED

Gauge Sym. $\xrightarrow[\text{limit}]{}$ Global Sym.

e : finite $\qquad e \to 0$

ALLOWED $\qquad$ NOT ALLOWED

Q: Can we choose e to be arbitrary small?

WGC :

$\exists$ a particle w/ charge q
mass m

s.t.

$$\boxed{eq \geq \sqrt{2} \frac{m}{M_{pe}}}$$

WGC:

$\exists$ a particle w/ charge q
mass m

s.t.

$$\boxed{eq \geq \sqrt{2}\,\frac{m}{M_{pl}}}$$

"Gravity as weakest force"

$$F_{gauge} = \frac{(eq)^2}{4\pi r^2} > F_{gravity} = \frac{m^2}{8\pi M_{pl}^2}$$

WGC:

$\exists$ a $\left\langle \begin{matrix} \text{particle} \\ \text{state} \end{matrix} \right\rangle$ w/ charge q
mass m

can be BH (extremal BH
+ higher curvature correction)
[Kats-Motl-Padi '06, ...]

s.t. $$\boxed{eq \geq \sqrt{2}\, \frac{m}{M_{pl}}}$$

* original argument: decay of extremal BH
[AMNV '06]

* checks in string theory compactifications

* many subsequent works, e.g.

connection with

cosmic censorship [Crisford-Horowitz-Santos '17]

holography [e.g. Nakayama-Nomura '15, Montero '19]

Tower/Sublattice WGC [Heidenreich-Rudelius-Reece '15, Montero-Shiu-Soler '16, ...]

(Roughly Speaking)

$\exists$ ∞-many charges $g_1, g_2, \cdots$ s.t.

$\exists$ a particle w/ charge g_i
mass m_i

s.t. $\boxed{e g_i \geq \sqrt{2}\,\frac{m_i}{M_{pl}}}$ for $\forall i$

「Distance Conjecture」

[Ooguri – Vafa '06
Baume – Palti '16
⋮]

Distance Conjecture

Example of global sym.:

shift sym. $\phi \to \phi + c$.

[e.g. many moduli in SUSY]

Can we quantify QG-breaking of shift sym?

Distance Conjecture

Example of global sym. :

shift sym. $\phi \to \phi + c$.

[e.g. many moduli in SUSY]

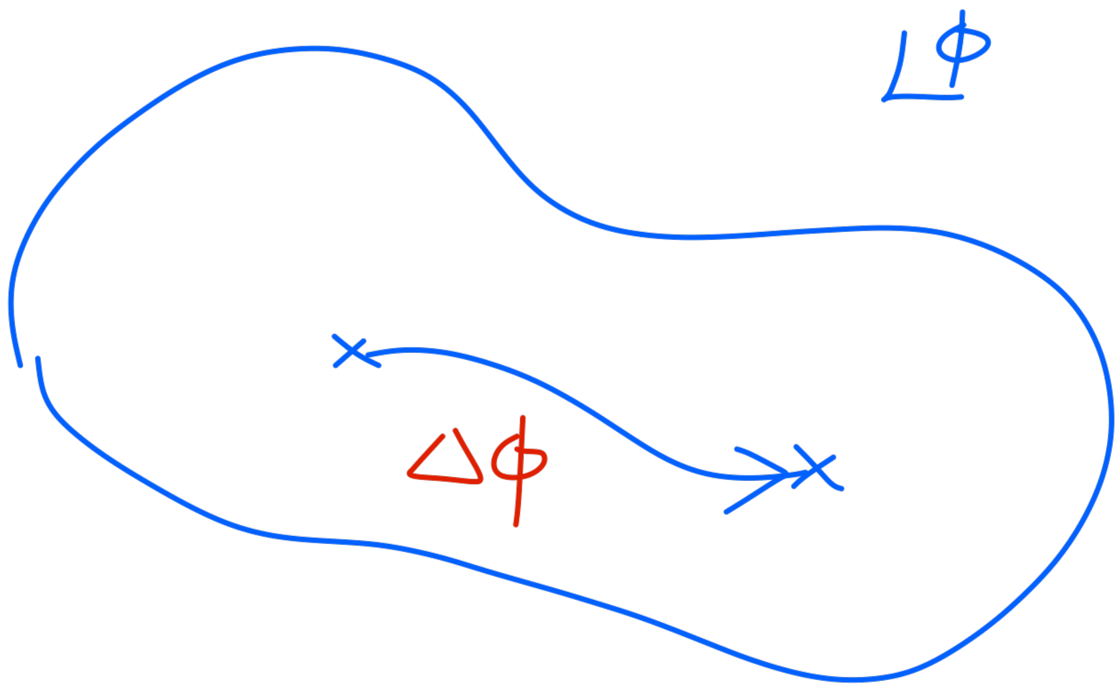
Can we quantify QG-breaking of shift sym?

(cf. monodromy infl. relaxion)

Claim:

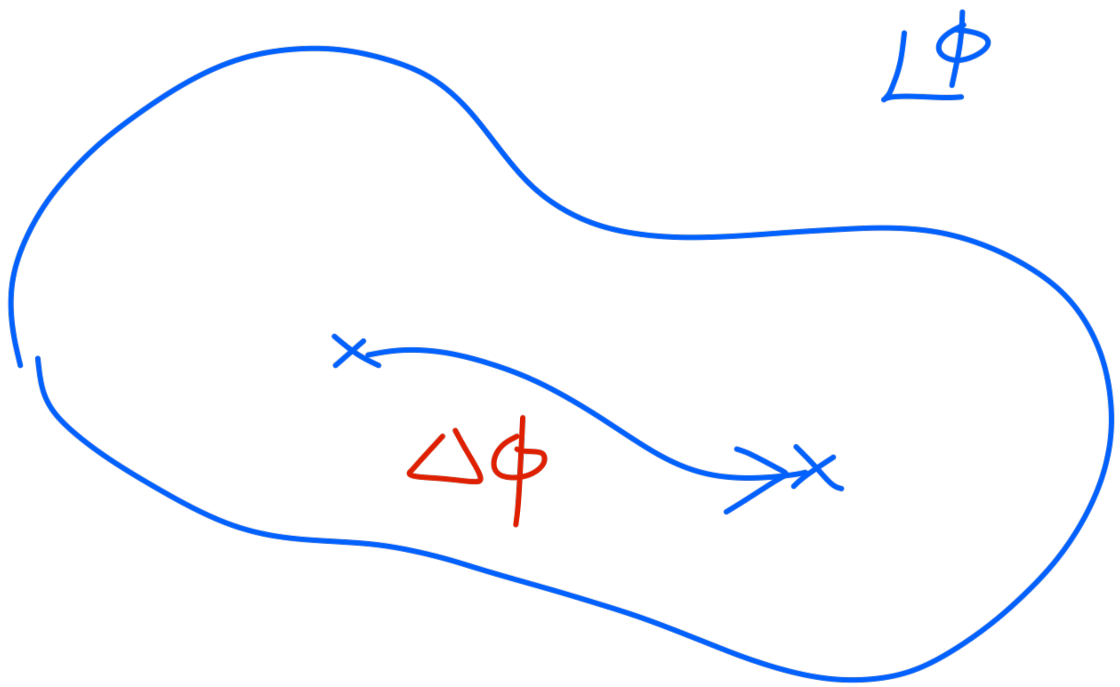
$$\boxed{\Delta\phi \lesssim \mathcal{O}(1)\, M_{Pl}}$$

Distance Conjecture



field range $\Delta\phi$ large

Distance Conjecture



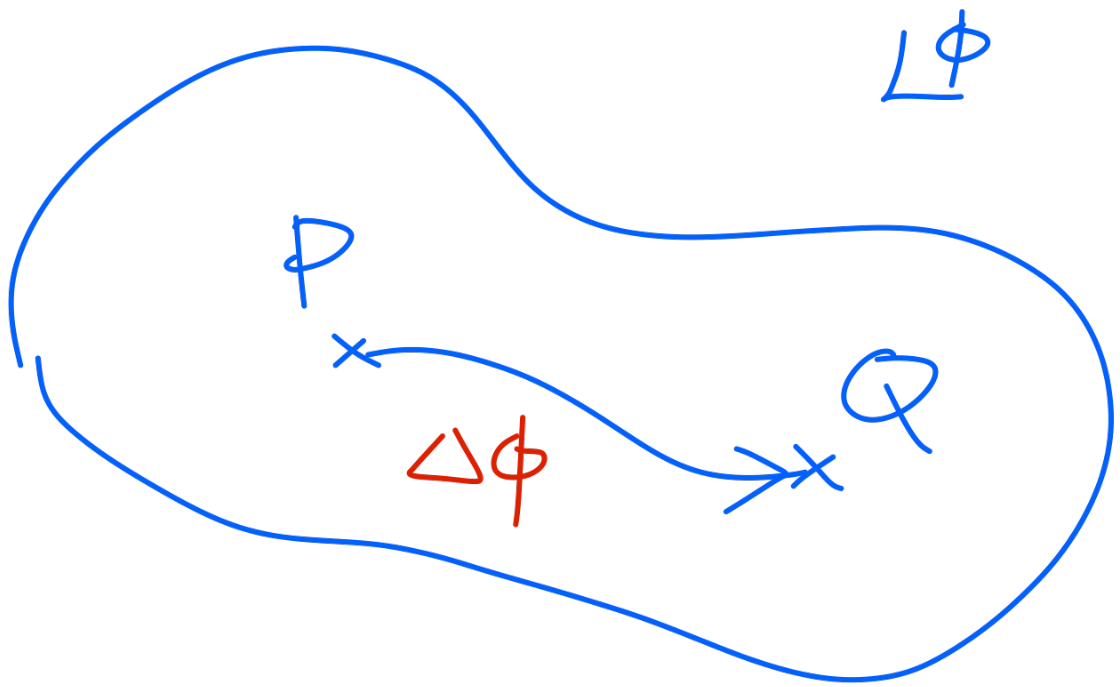
field range $\Delta\phi$ large

$\left(\begin{array}{c} \text{particles} \\ \text{string} \\ \vdots \end{array}\right)$

$\rightsquigarrow$ an infinite tower of massless states

$$m_n \sim n M_{pl} e^{-\mathcal{O}(1)\frac{\Delta\phi}{M_{pl}}} \quad (n=1,2,\cdots)$$

Distance Conjecture



field range $\Delta\phi$ large

(particles, string, $\vdots$)

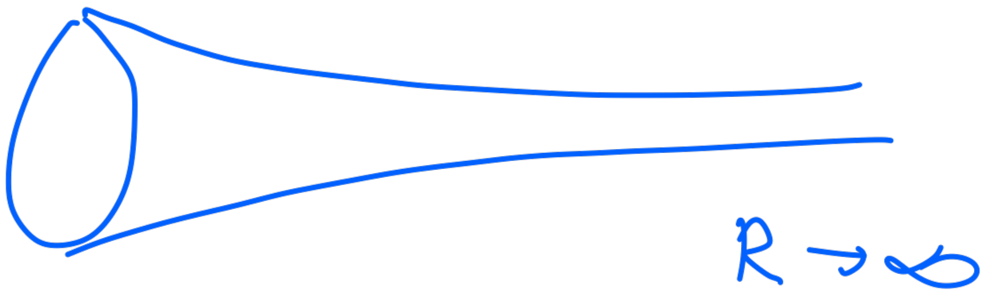
$\rightsquigarrow$ an infinite tower of massless states

$$m_n \sim n M_{pl} e^{-\mathcal{O}(1)\frac{\Delta\phi}{M_{pl}}} \quad (n=1,2,\cdots)$$

$\rightsquigarrow$ breakdown of EFT at $\Delta\phi \sim M_{pl}$

e.g.: Compactify on S^1 with size $\underbrace{R}_{\text{modulus}}$

Can we take $R \to \infty$?



$$ds^2 = \left(\frac{dR}{R}\right)^2$$

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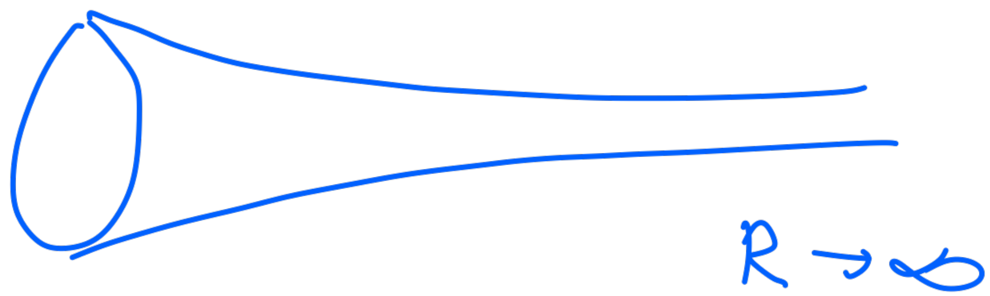


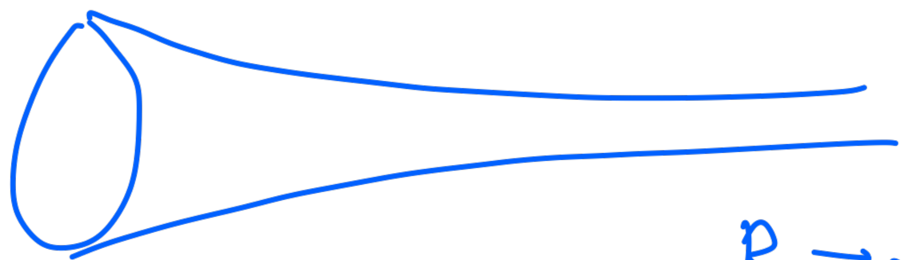
$$ds^2 = \left(\frac{dR}{R}\right)^2$$

Answer: $R \to \infty$ then KK modes light:

$$m_n \sim \frac{n}{R} \to 0$$

e.g.: Compactify on S^1 with size $\underbrace{R}_{\text{modulus}}$

Can we take $R \to \infty$?



$R \to \infty$

$$ds^2 = \left(\frac{dR}{R}\right)^2 = d\tau^2$$

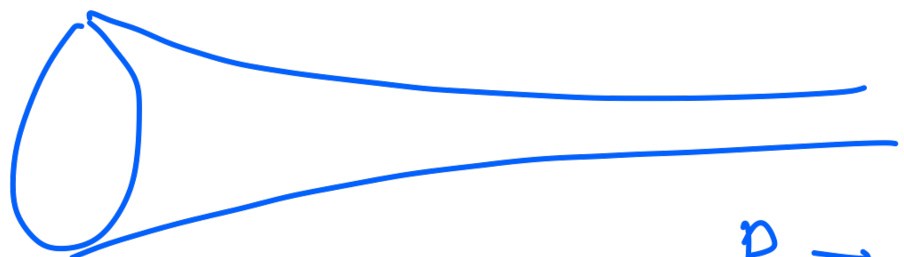
$$R = e^{\tau}$$

Answer: $R \to \infty$ then KK modes light:

$$m_n \sim \frac{n}{R} = n\, e^{-\tau} \to 0$$

e.g.: Compactify on S^1 with size $\underbrace{R}_{\text{modulus}}$

Can we take $R \to \infty$?



$R \to \infty$

$$ds^2 = \left(\frac{dR}{R}\right)^2 = d\tau^2$$

$$R = e^{-\tau}$$

Answer: $R \to \infty$ then KK modes light:

$$m_n \sim \frac{n}{R} = n e^{-\tau} \to 0$$

(※ $R \to 0$: winding strings become light) originally string-motivated

Distance Conjecture is

related with Tower Weak Gravity Conjecture

originally gravity-motivated

$$m_n \lesssim n M_{pl}\, e \sim n M_{pl}\, e^{-\mathcal{O}(1)\Delta\phi}$$

(lattice WGC w/ $q_n = n$)

$$\frac{1}{e^2} \sim e^{\mathcal{O}(1)\Delta\phi}$$

(gauge coupling: VEV of ϕ)

today's focus:

$$
\begin{tikzcd}
& \text{No global sym.} \arrow[dl] \arrow[dr] & \\
\text{Weak gravity conj.} \arrow[rr, leftrightarrow] & & \text{distance conj.} \arrow[dl, dashed] \\
& \text{de Sitter conjecture} &
\end{tikzcd}
$$

de Sitter Swampland Conjecture

例：de Sitter swampland conjecture

[Obied – Ooguri – Spodyneiko – Vafa ('18)]

$$M_{Pl} |\nabla V| \geq c\, V$$

例：de Sitter swampland conjecture

[Obied-Ooguri-Spodyneiko-Vafa ('18)]

$$\overbrace{M_{Pl}}^{2\times 10^{18}\,\mathrm{GeV}} \underbrace{\left|\nabla \overbrace{V}^{\text{scalar potential}}\right|}_{\text{size of gradient}} \geq \underbrace{c}_{O(1)\text{ positive constant}} \overbrace{V}^{\text{scalar potential}}$$

$$\sqrt{\sum_{i,j} g^{ij}\partial_i V \partial_j V}$$

* dS vacua excluded ($\nabla V = 0$, $V > 0$)

* no constraint for $V < 0$

(many known (SUSY) AdS vacua in string theory)

Idea: e.g. 11D SUGRA

$$\mathcal{L} \sim \int \sqrt{-g} \left(\underset{\substack{\uparrow \\ g_{\mu\nu} \\ \text{metric}}}{R} + \underset{\substack{\uparrow \\ C_3 \ (dC_3 = G_4) \\ \text{3-form}}}{|G_4|^2} \right) + \cdots$$

Idea: e.g. 11D SUGRA

$$\mathcal{L} \sim \int \sqrt{-g}\,\big(\underset{\substack{g_{\mu\nu} \\ \text{metric}}}{R} + \underset{\substack{C_3 \ (dC_3 = G_4) \\ \text{3-form}}}{|G_4|^2} \big) + \ldots$$

compacify on manifold X w/ overall modulus τ

$$ds_{11}^2 = ds_d^2 + e^{2\tau}\, ds_{11-d}^2$$

Idea: e.g. 11D SUGRA

$$\mathcal{L} \sim \int \sqrt{-g}\left(R + |G_4|^2 \right) + \dots$$

$g_{\mu\nu}$ metric

C_3 $(dC_3 = G_4)$ 3-form

compactify on manifold X w/ overall modulus τ

$$ds_{11}^2 = ds_d^2 + e^{2\tau} ds_{11-d}^2$$

$$\rightsquigarrow \quad V(\hat{\tau}) = V_R e^{-\lambda_1 \hat{\tau}} + \underset{V_0}{V_G} e^{-\lambda_2 \hat{\tau}} \qquad (\lambda_1 < \lambda_2)$$

Idea: e.g. 11D SUGRA

$$\mathcal{L} \sim \int \sqrt{-g}\,\big(\underset{\substack{\uparrow \\ g_{\mu\nu} \\ \text{metric}}}{R} + \underset{\substack{\uparrow \\ C_3\ (dC_3 = G_4) \\ \text{3-form}}}{|G_4|^2} \big) + \ldots$$

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$$ds_{11}^2 = ds_d^2 + e^{2\tau} ds_{11-d}^2$$

$$\rightsquigarrow \quad V(\hat{\tau}) = V_R\, e^{-\lambda_1 \hat{\tau}} + \underset{V_0}{V_G}\, e^{-\lambda_2 \hat{\tau}} \qquad (\lambda_1 < \lambda_2)$$

$$\rightsquigarrow \quad \frac{|\partial_{\hat{\tau}} V|}{V} \geq \min(\lambda_1, \lambda_2) = \lambda_1 = \sqrt{\frac{6}{(d-2)(11-d)}}$$

Assumption

- GR (no α'/g_s correction)
- extra dimension

(cf. dS no-go thm [Maldacena-Nunez '00, Steinhardt-Wesley '08]

no-go on slow-roll inflation
[Hertzberg-Kachru-Taylor-Tegmark '07, ...])

Assumption

- GR (no α'/g_s correction)
- extra dimension

(cf. dS no-go thm [Maldacena-Nunez '00, Steinhardt-Wesley '08]

no-go on slow-roll inflation [Hertzberg-Kachru-Taylor-Tegmark '07, ...])

[OOSV] claimed this holds generally/anywhere even when various corrections are important

If true, dS conjecture has dramatic consequences

* multiverse gone? [cf. Takahashi-Matsui '18
Kinney '18 Redelius '19]

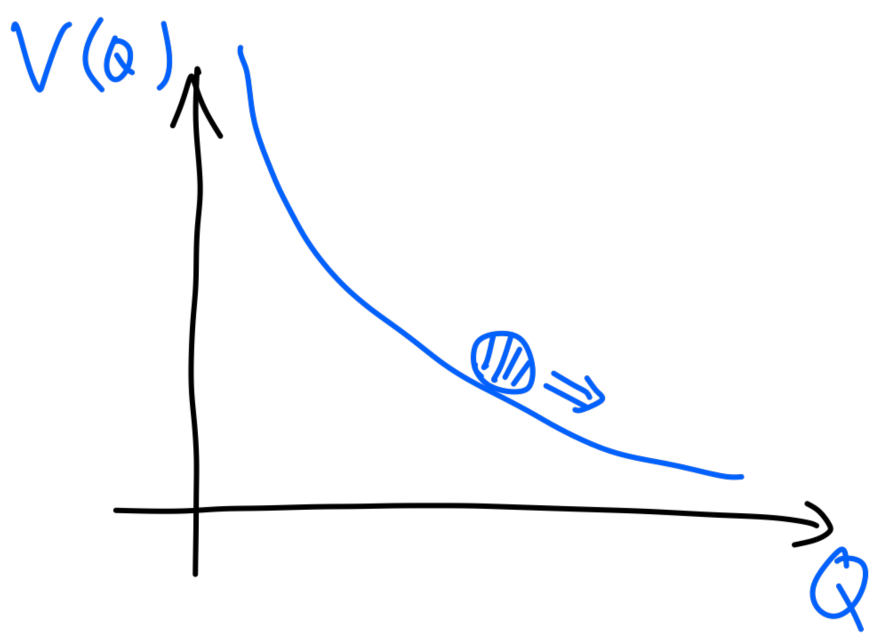
eternal inflation

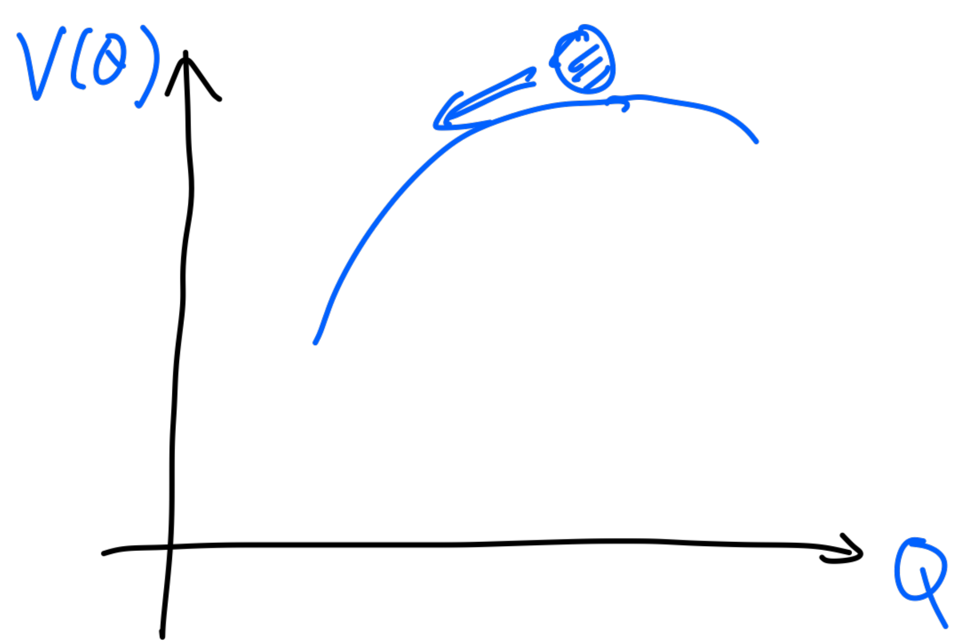
If true, dS conjecture has dramatic consequences

* multiverse gone? [cf. Takahashi-Matsui '18, Kinney '18, Rudelius '19]

eternal inflation

* quintessence? [Ratra-Peebles '88, Wetterich '88, Caldwell-Dave-Steinhardt '97]





Future observation (e.g. Euclid/WFIRST/LSST, ...)

"Controversy"

SPACE

String Theory May Create Far Fewer Universes Than Thought

Some physicists claim the popular landscape of universes in string theory may not exist

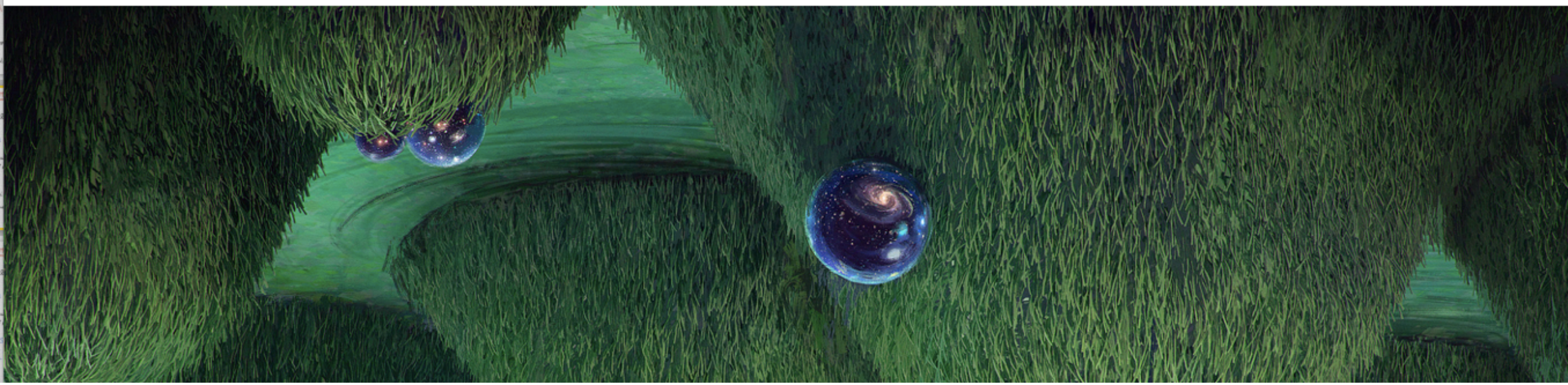
By Clara Moskowitz on July 30, 2018 أعرض هذا باللغة العربية

THEORETICAL PHYSICS

Dark Energy May Be Incompatible With String Theory

130

A controversial new paper argues that universes with dark energy profiles like ours do not exist in the "landscape" of universes allowed by string theory.



dS conjecture is in sharp tension w/ claimed construction of metastable dS vacua

e.g. [Kachru-Kallosh-Linde-Trivedi '03]

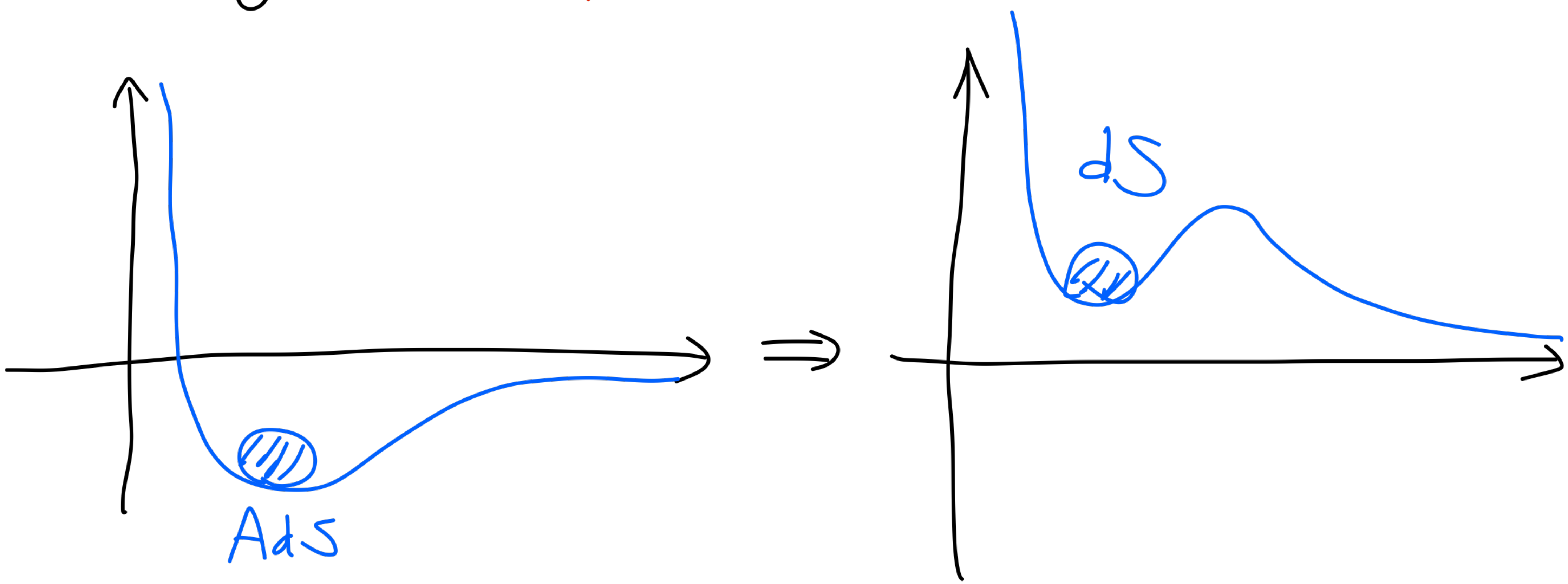
dS conjecture is in sharp tension w/

claimed construction of $\underbrace{\ }_{\text{metastable}}$ dS vacua

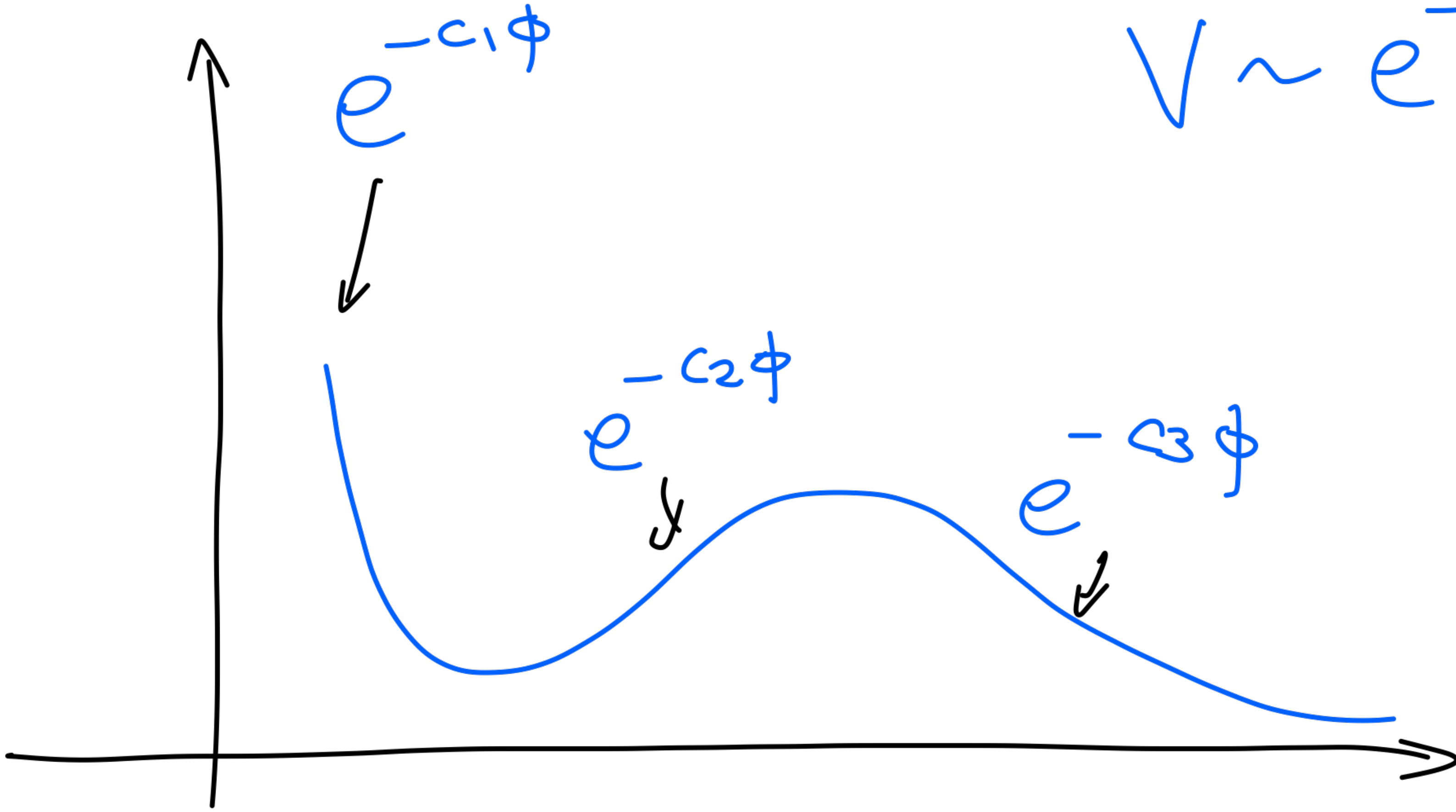
e.g. [Kachru-Kallosh-Linde-Trivedi '03]

It is true that KKLT has many subtle parts

e.g. $\overline{\text{D3}}$ uplift / ~~SUSY~~ (no SUSY dS)



Technically: difficult to control corrections



$$V \sim \underbrace{e^{-c_1\phi} + e^{-c_2\phi} + e^{-c_3\phi} + \cdots\cdots}_{\text{same order?}}$$

[Dine-Seiberg '85]

(※ Proposal of classical dS in IIA + O8 [Córdova-De Luca-Tomasiello '18]

seem to be removed by Maldacena-Nunez-type no-go [Cribiori-Junghans '19])

I myself do not see sharp-enough argument

against metastable vacua

dS conjecture as a general statement

rather speculative

I myself do not see sharp-enough argument against metastable vacua

dS conjecture as a general statement rather speculative

.... but can still be useful in asymptotic/weak coupling corner of QG landscape

[I prefer a positive approach: an opportunity to learn something]

Bottom-up constraints

Higgs

$$V_H = \lambda (H^2 - v^2)^2$$

has local maximum @ $H = 0$

$$\partial_H V_H = 0 \qquad V > 0$$

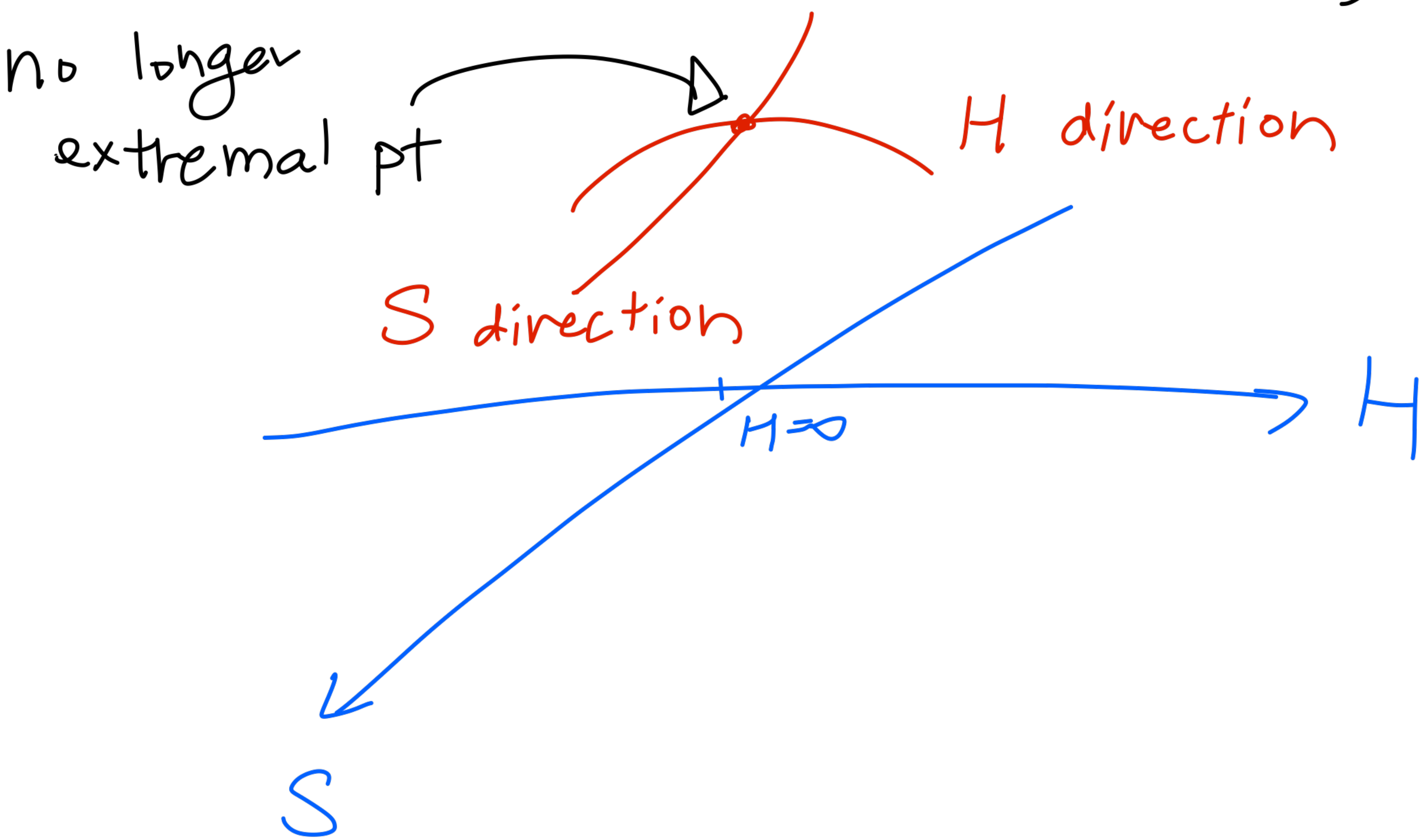
already in tension with dS conjecture

[Denef-Hebecker-Wrase '18]

EW modification? [Murayama-Yanagida-Y '18]

e.g. real scalar S in addition to H

$$V_{H,S} = \lambda (H^2 - v^2)^2 + \underbrace{\kappa (S-a)(H^2-\omega^2)}_{(\partial_S V \neq 0 \ @\ H=0)} + \frac{m^2}{2} S^2 + \lambda s^4$$



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minimum

- $H_{(a)}^2 = \dfrac{\kappa^2\omega^2 - \kappa m^2 u - 2\lambda m^2 v^2}{\underset{\overset{\text{IV}}{0}}{\kappa^2 - 2\lambda m^2}}$, $S_{(a)} = \dfrac{\kappa^2 u + 2\kappa\lambda v^2 - 2\kappa\lambda\omega^2}{\kappa^2 - 2\lambda m}$

- $V|_{H(a),S(a)} = 0$

but another extremal point $(\nabla V = 0)$: $H_{(b)}^2 = 0$, $S_{(b)} = \dfrac{\omega^2\kappa}{m^2}$

We need

- $V|_{H(b),S(b)} \leq 0$

(3 conditions incompatible!!)

EW modification? [Murayama-Yanagida-Y '18]

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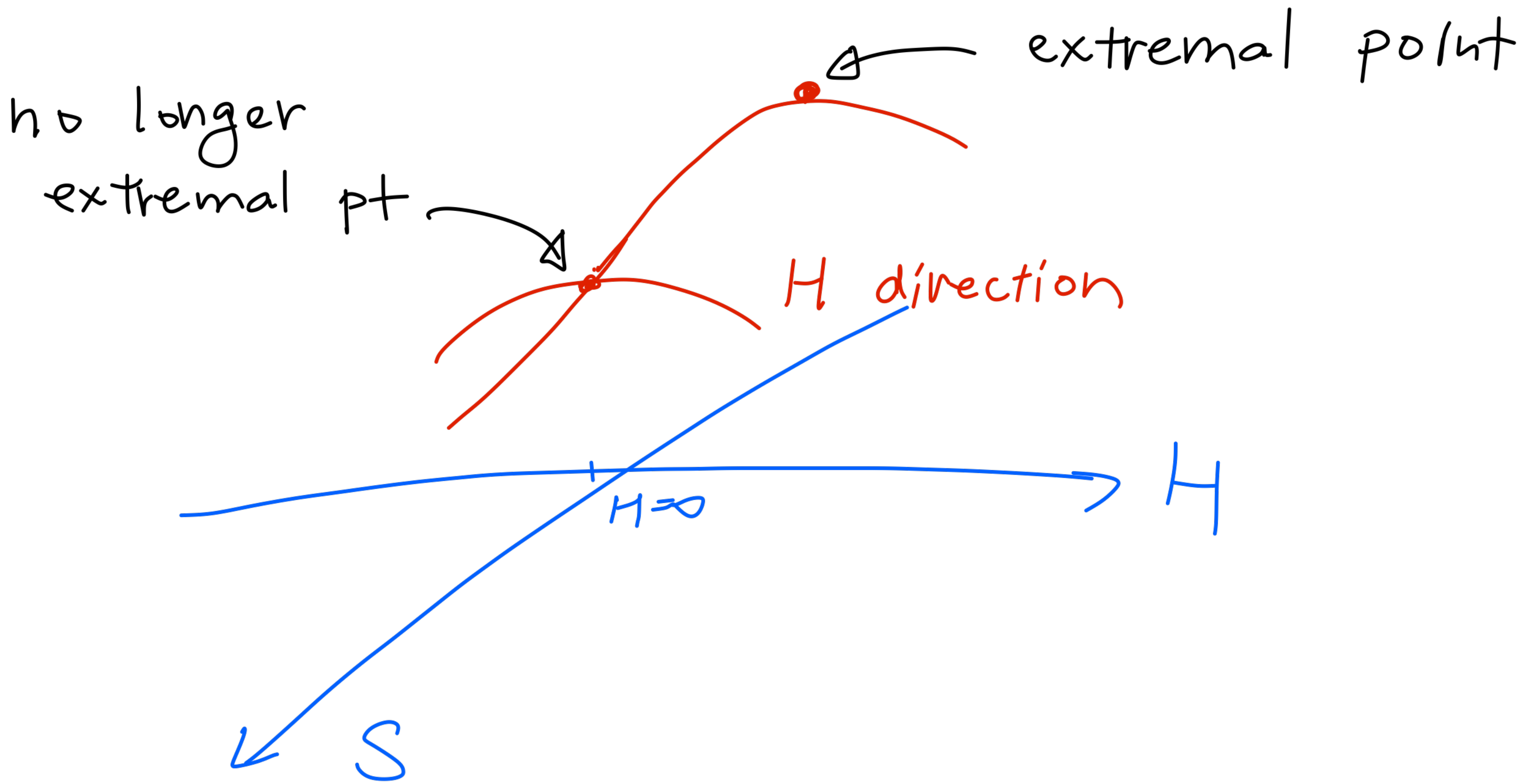

More generally no-go thm
against EW modification
even for multiple fields

[Murayama-Yanagida-Y '18]

(※ still contrived loopholes, but unlikely)

Coupling to Quintessence: [Denef-Hebecker-Wrase '18]

$$V_{H,Q}(H,Q) = \underbrace{e^{-c\frac{Q}{M_{pl}}}} V_H(H)$$

always rolls in Q-direction

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But then Higgs VEV depends on Q

and hence time-dependent

quantum correction

(m_p/m_e time variation
fifth force searches)

[Ibe-Hamaguchi-Moroi '18]

$\Longrightarrow$ original dS conjecture "excluded"

Refined dS Conjecture

Modify the condition s.t.

$V > 0, \quad \nabla V = 0, \quad \nabla^2 V < 0$ allowed

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* [Garg-Krishnan, Ooguri-Palti-Shiu-Vafa '18]

$$|\nabla V| \geq c\, V \quad \text{or} \quad \min(\nabla_i \nabla_j V) \geq -c' V$$

$(c, c' : \text{positive } \mathcal{O}(1))$

$(c' = 0)$

* [Murayama-Yanagida-Y '18]

$$|\nabla V| \geq c\, V \quad \text{when} \quad \nabla^2 V \geq 0$$

Distance Conj. $\longrightarrow$ dS Conj. ?

* distance conjecture required for dS conj

$$\left(\begin{array}{l} V(\phi) = m^2\phi^2 \\ \partial_\phi V > V \end{array} \rightsquigarrow \phi \lesssim M_{pl} \right)$$

Argument by [Ooguri-Palti-Shiu-Vafa '18]

Consider quasi-dS $\quad \partial_\phi V \sim c\, V$

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$$S \leq S_{GH} \sim R^2 \sim \frac{1}{H^2} \sim \frac{1}{V}$$

$$S = S(N, R) \sim N^p R^\delta$$

# of species

dS Radius

$N, R \gg 1$

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# of species $\qquad$ dS Radius $\qquad$ $N, R \gg 1$

When $\Delta\phi$ large, tower of states $\frac{m_n}{M_{pl}} \sim n e^{-b\Delta\phi}$

$$\rightarrow \quad N \sim \frac{\Lambda_{cutoff}}{e^{-b\Delta\phi}} \sim e^{b\Delta\phi}$$

[※ assume light states dominates (a fraction of) entropy]

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$$\left(c \sim \frac{2bp}{2-q} \right)$$

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For absence of tachyons

$$\min(\nabla^2 V) \geq -\frac{O(1)}{R^2} \sim -c' V$$

← curvature coupling

Argument by [Hebecker-Wrase ('18)]

* distance conjecture : tower of light states

$$n m \sim n M_{pl} e^{-b\phi} \quad (n = 1, 2, \cdots)$$

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$$\rightsquigarrow \frac{V}{M_{pl}^4} \lesssim e^{-\frac{2b\phi}{3}}$$

* Since we use distance conjecture,

asymptotic region $\Delta\phi \sim M_{pl}$

* Inequality :

$$V \lesssim e^{-\mathcal{O}(1)\Delta\phi}$$ [cf. Dine - Selberg]

saturated ?

today's focus:

No global sym.

Weak gravity conj.

distance conj.

de Sitter conjecture ???

In refined version
no constraint on Higgs / axion / SSB

Inflation : $\left(\epsilon_V \geq c^2/2 \text{ or } \eta_V \leq -c' \right)$

[Fukuda - Saito - Shirai - Y '18, ...]

* e-folding OK (concave region)

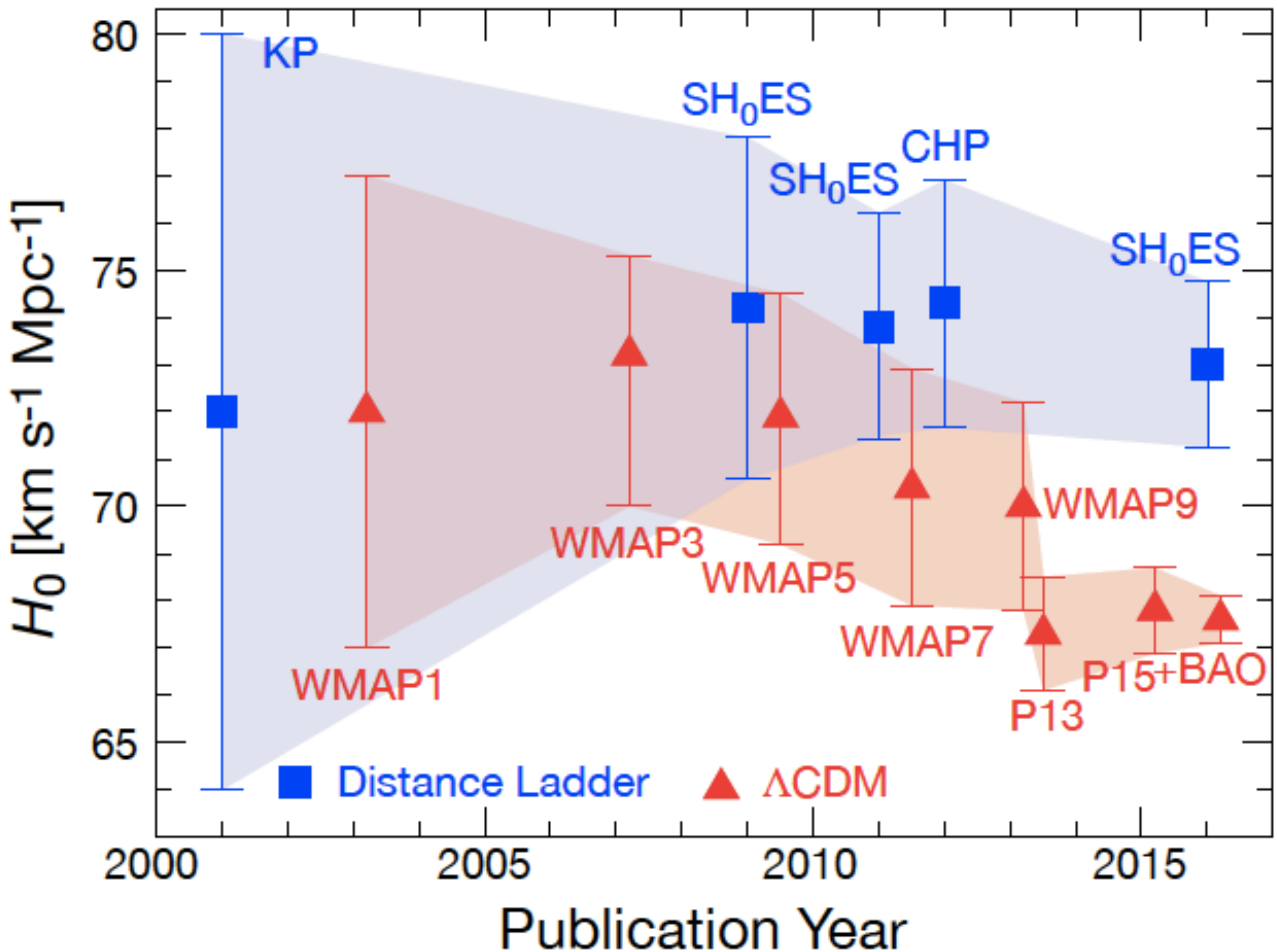
* n_s, r difficult for single-field (canonical kinetic term)

$r = 16\epsilon \lesssim 0.064$

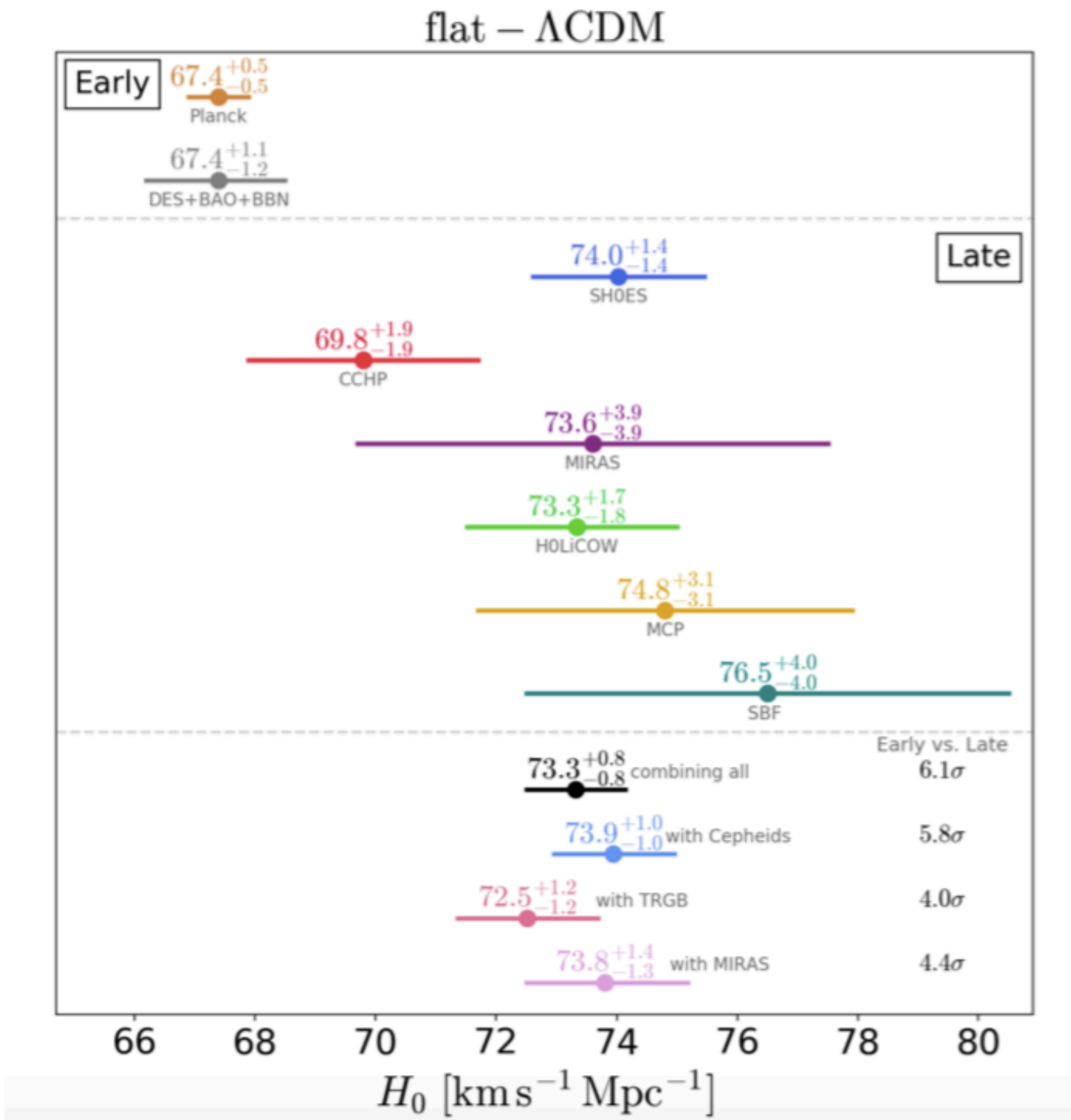
$n_s - 1 \simeq -6\epsilon + 2\eta \simeq 0.03 - 0.04 \rightsquigarrow \eta \simeq -0.01$ $(c' \lesssim 0.01)$

* $c, c' \sim 1$ OK for multi-field (e.g. curvaton)

Ho Tension


80
75
70
65
H_0 [km s^{-1} Mpc^{-1}]
KP
SH0ES
SH0ES
CHP
SH0ES
WMAP1
WMAP3
WMAP5
WMAP7
WMAP9
P13
P15+BAO
Distance Ladder
ΛCDM
2000
2005
2010
2015
Publication Year

(Freedman '17)



[Verde-Treu-Riess '19]

Is H_0 tension

consequence of distance conj.??

Early-time solution

「Early Dark Energy」 [Poulin-Smith-Karwal-Kamionkowski '18]

- Behaves as DE to raise CMB H_0
- then decays rapidly (faster than radiation) @ $z \sim 5000$

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- then decays rapidly (faster than radiation) @ $z \sim 5000$

e.g. $V(\phi) \sim \left(1 - \cos\frac{\phi}{f}\right)^n \sim \phi^{2n}$ near $\phi \sim 0$ (e.g. $n = 3$)

[※ matter $V(\phi) \sim \phi^2$ has $\Gamma \ll m \sim H_{z=5000}$]

Consider instead ultralight axion [Kaloper '19]

$f \sim M_{pl}$ (WGC $f \lesssim M_{pl}$)

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distance conj. $\left(\mathcal{L} \supset e^{-\Delta\phi} \chi\chi \right)$

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Late-time solution

distance conjecture for

Quintessence Dark Energy Q

tower of states = Dark Matter

$$\rho_{DM}(Q) \sim \rho_{DM}\, e^{-Q}$$

Late-time solution

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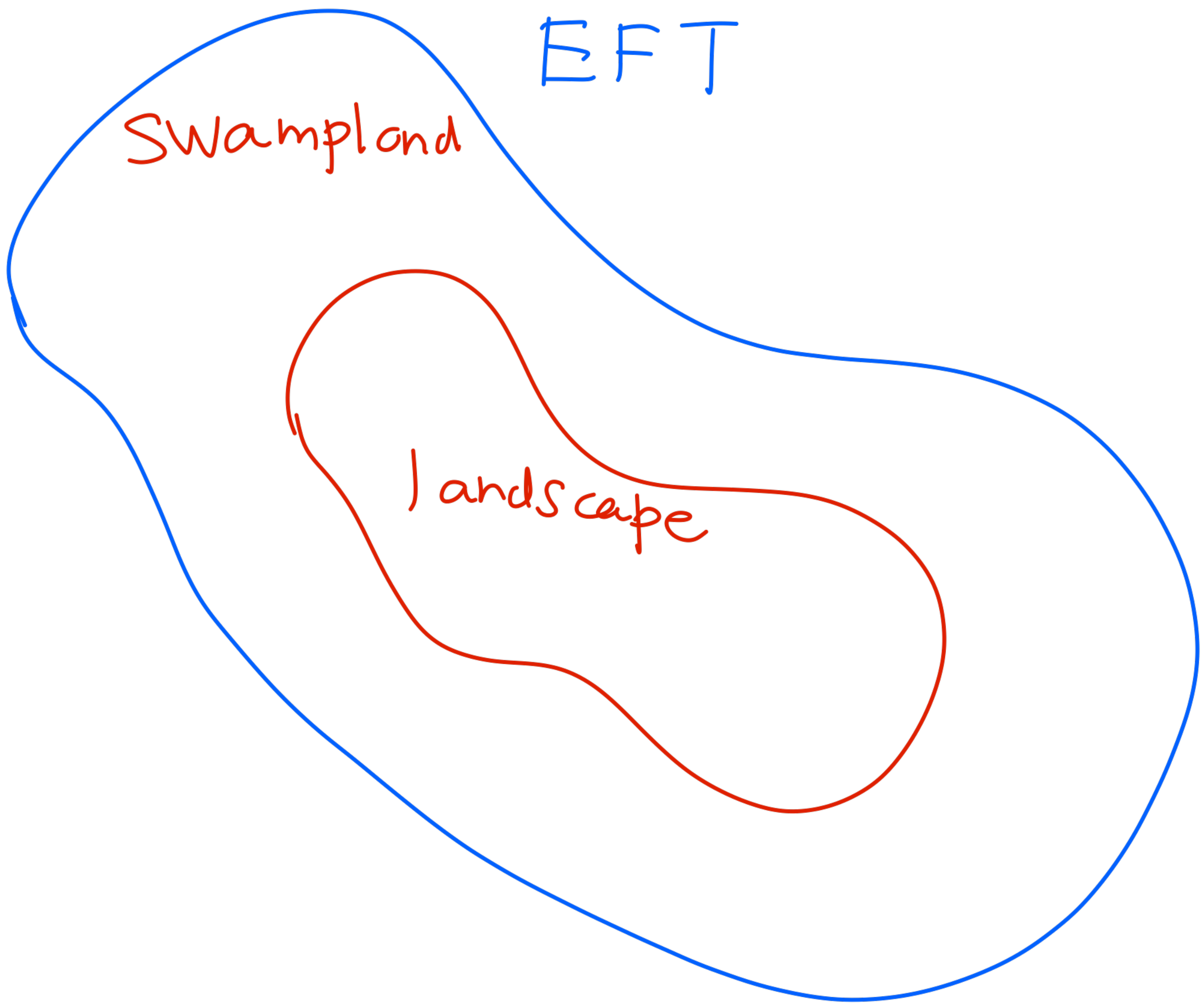
※ fifth-force constraint marginal

※ improves H_0 tension

[Agrawal-Obied-Vafa '19]

Naturalness?

naturalness needs to be revisited:



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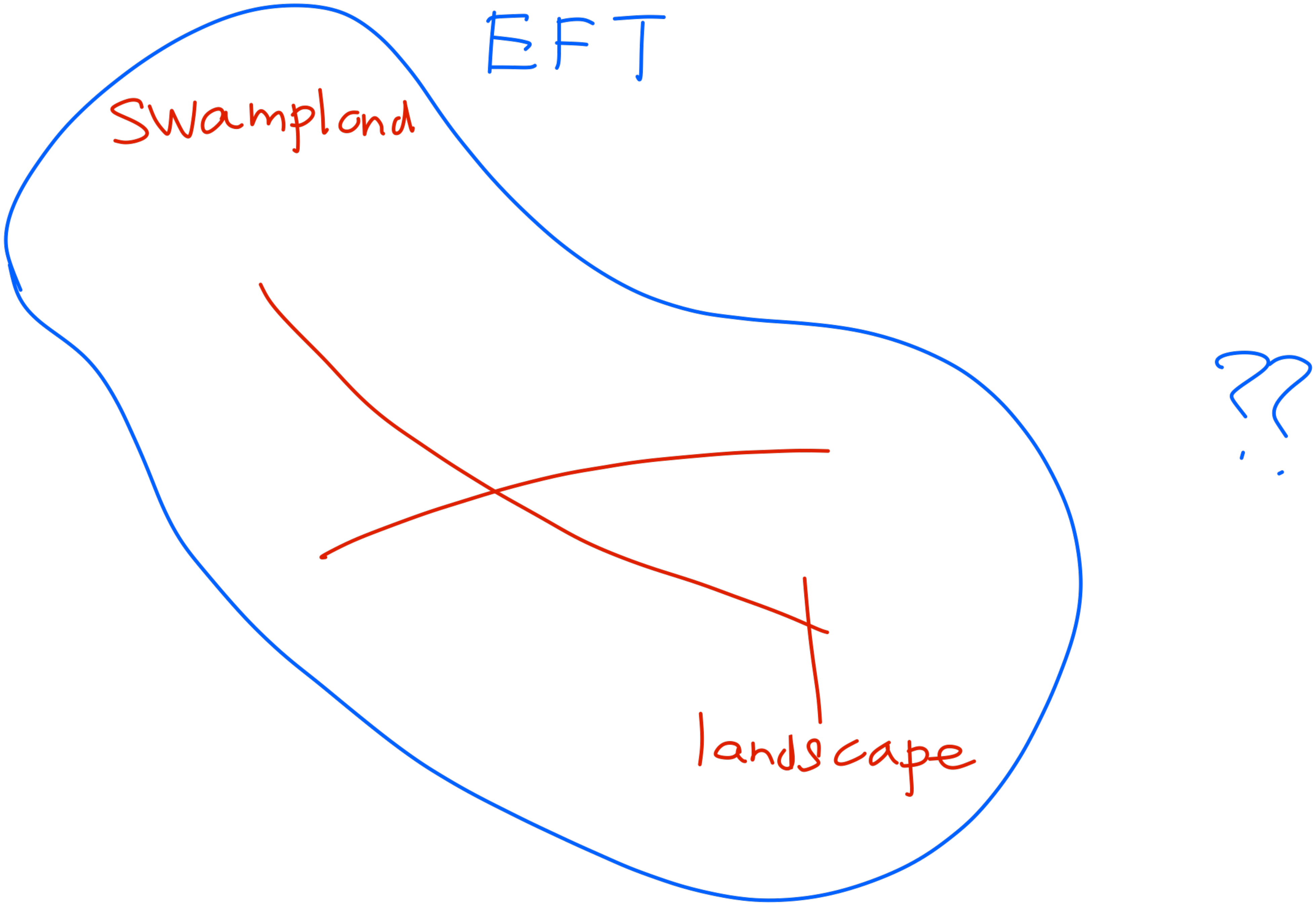
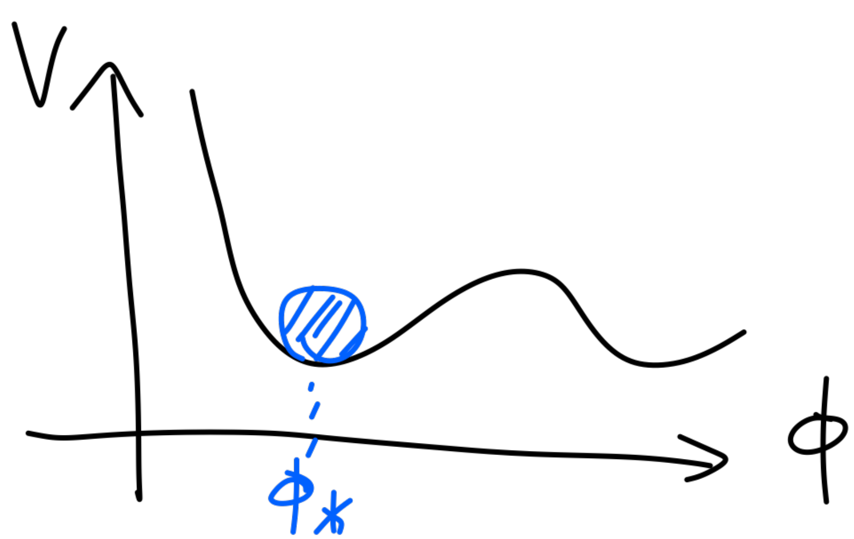


「No Free Parameter in QG」

Any parameter (e.g. Y_{quark}, θ_{QCD}, ⋯):

VEV of moduli (e.g. axion)

dynamically determined



(or fixed by some (QG) consistency)

「 Finite # of Moduli in QG 」

(typically $\sim \mathcal{O}(100)$)

$\Longrightarrow$ ∞ - relations for higher-dim. op.

$$\mathcal{L} = \mathcal{L}_0 + \sum_i \lambda_i \frac{\mathcal{O}_i}{M_{Pl}^{\Delta_{\mathcal{O}_i}-4}}$$

only finite independent

[cf. Heckman-Vafa '19]

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only finite independent

No global sym, but "fine-tuned"
There IS free lunch!

Summory

Swampland Conjectures :

QG constraints on low-energy physics

essence of QG / string $\Longrightarrow$ phenomenology of EFT

essence of QG / string $\Longleftarrow$ phenomenology of EFT

Please do use the conjectures in your next paper !!

(esp. young folks!)


緊急告知!!

Today:

Covered only limited aspects of "standard" material...

＊ 名古屋大学にて集中講義

「沼地予想とその現象論」

2019年 9月30日(月) ～ 10月2日(水)

(4×3 ≃ 12h)

(※詳細は追って名大物理HPより)

＊ 科研費研究員公募(予定)!!

(予定) 2019年秋公募

2020年4月以降 ~ 2023年3月 (3年)

IPMU 1人, KEK 1人

KEK

北野

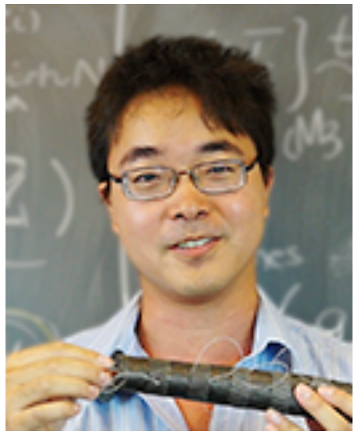
hep-ph

山田

hep-lat

IPMU

山崎



hep-th