The Swampland Program

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July 11, 2019
at Strings 2019, Brussels

Disclaimer

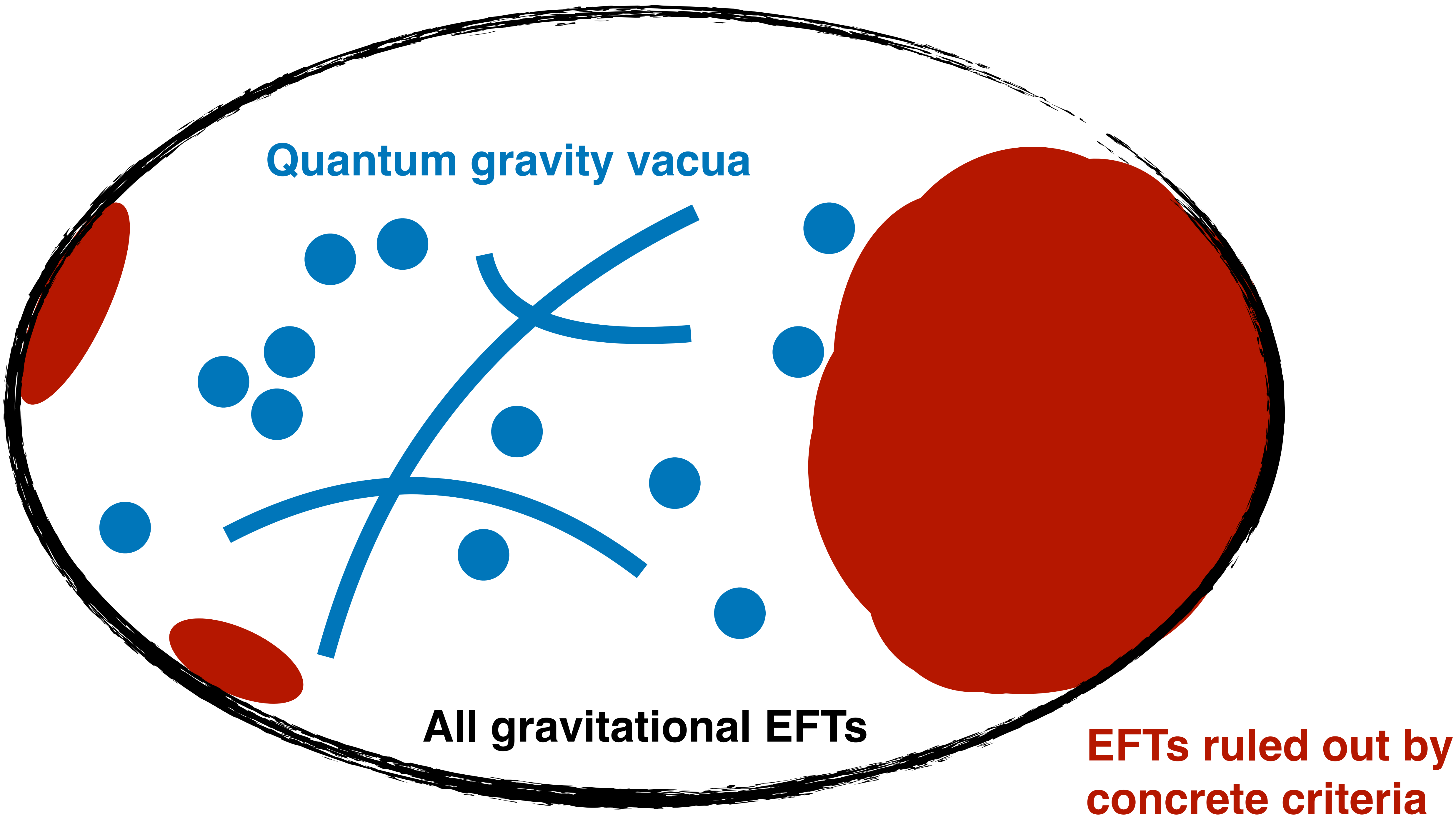
There has been much more happening in this field than I can possibly do justice to in this one talk.

I will mostly focus on some of the aspects I know best, from my joint work with Ben Heidenreich and Tom Rudelius and closely related work of others.

To read about other aspects: see
Brennan, Carta, and Vafa (1711.00864)
Palti (1903.06239).

Timo Weigand's talk immediately after mine will cover closely related material, as will Eran Palti's talk tomorrow.

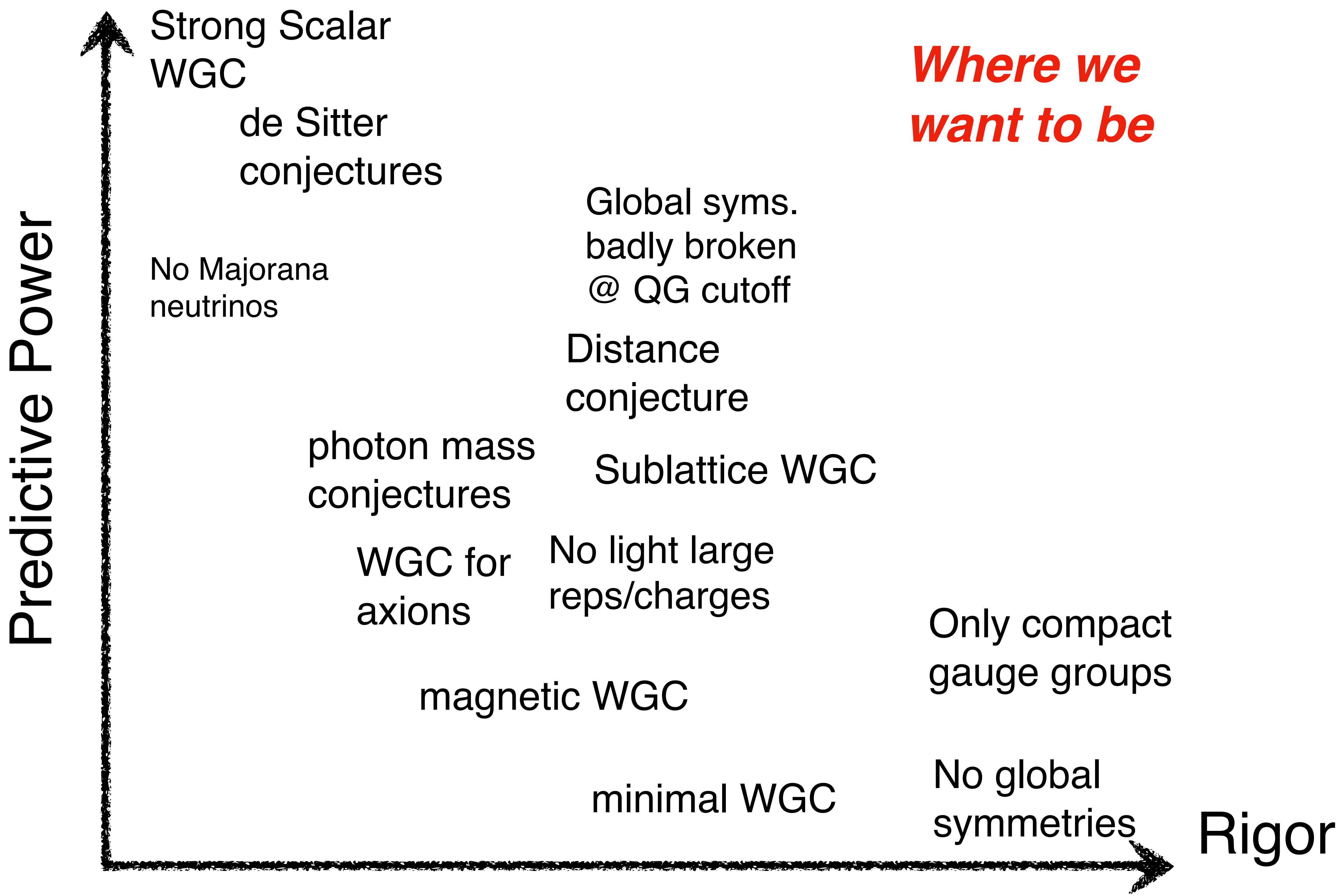
The Landscape vs. The Swampland



The Swampland is the complement of the Landscape.
Our goal is to characterize it. Many suggestions.

Predictivity vs. Rigor/Generality

(A subjective assessment)

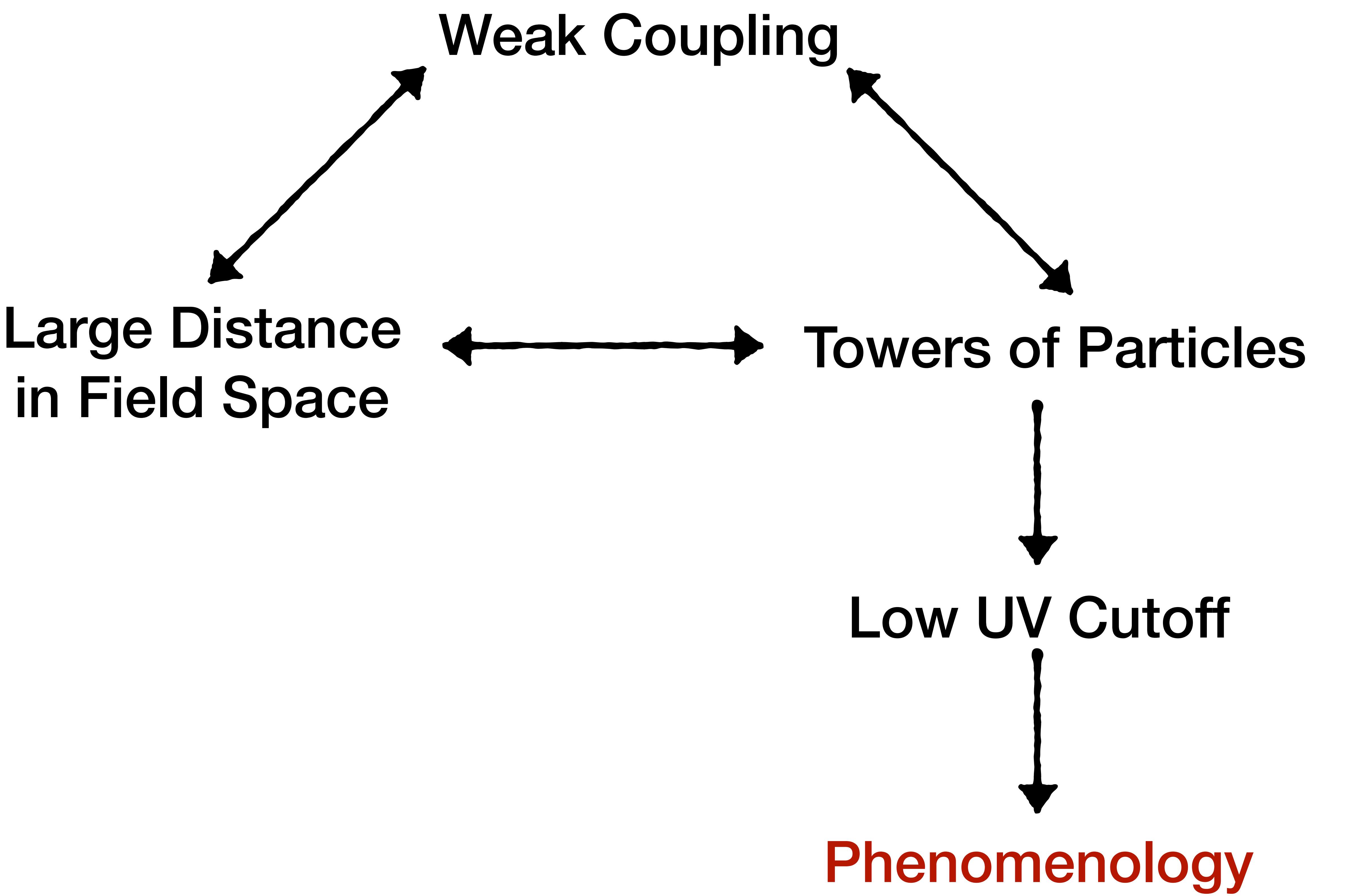


1. **Summary of main conjectures.**

2. Understanding the conjectures and their relationships.

3. Toward phenomenology.

Summary: Swampland, Towers, Cutoffs



Summary: Swampland, Towers, Cutoffs

Weak Coupling

Large Distance in Field Space

Towers of Particles

Low UV Cutoff

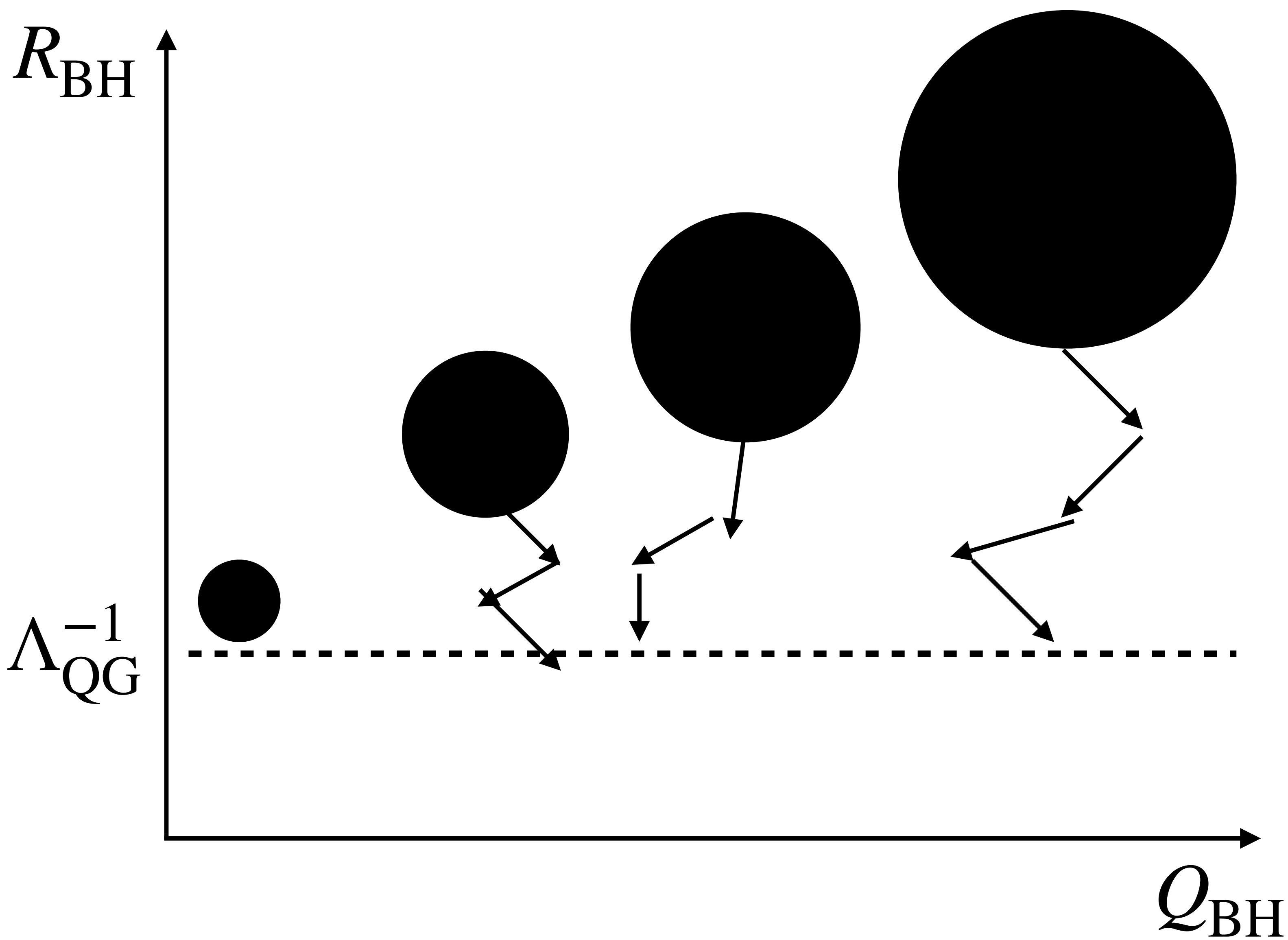
Phenomenology

Phenomenological lessons

- Low-energy physics constrains UV scales (inflation, SUSY breaking)
- “O(1) Naturalness”, not just “Technical” Naturalness

No global symmetries: continuous case

String worldsheet argument (Banks, Dixon ’88):
Conserved current $J(z) \Longrightarrow$ vertex operator $J(z)\bar{\partial}X^{\mu}(z,\bar{z})\exp(\mathrm{i}k^{\mu}X_{\mu}(z,\bar{z}))$
with $k^2 = 0$ creating a massless gauge boson.



Black hole Hawking evaporation would lead to infinite entropy in finite mass range.

Banks, Seiberg ’10

Earlier work includes Georgi, Hall, Wise ’81; Kamionkowski, March-Russell ’92; Holman, Hsu, Kephart, Kolb, Watkins, Widrow ’92; Kallosh, Linde, Linde, Susskind ’95; …

No global symmetries: general case

It is believed that quantum gravity allows **no global symmetries**, including **discrete** and **p-form** global symmetries.

In the asymptotically AdS context, this has been argued by Harlow and Ooguri (1810.05337/8).

They define a global symmetry carefully to involve a "**splittability**" condition that avoids various pathological counterexamples.

Then, the non-existence of global symmetries in the AdS bulk follows from an argument using entanglement wedge reconstruction.

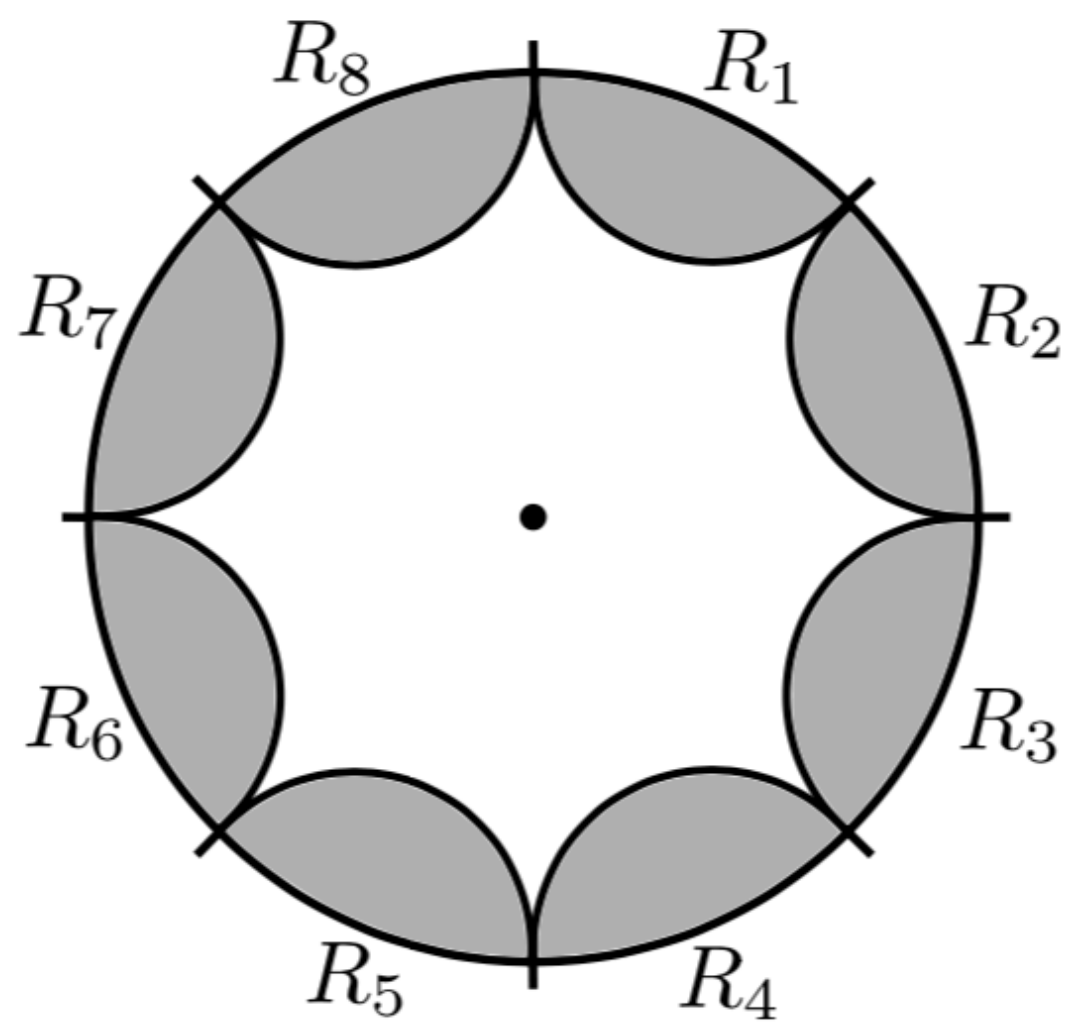
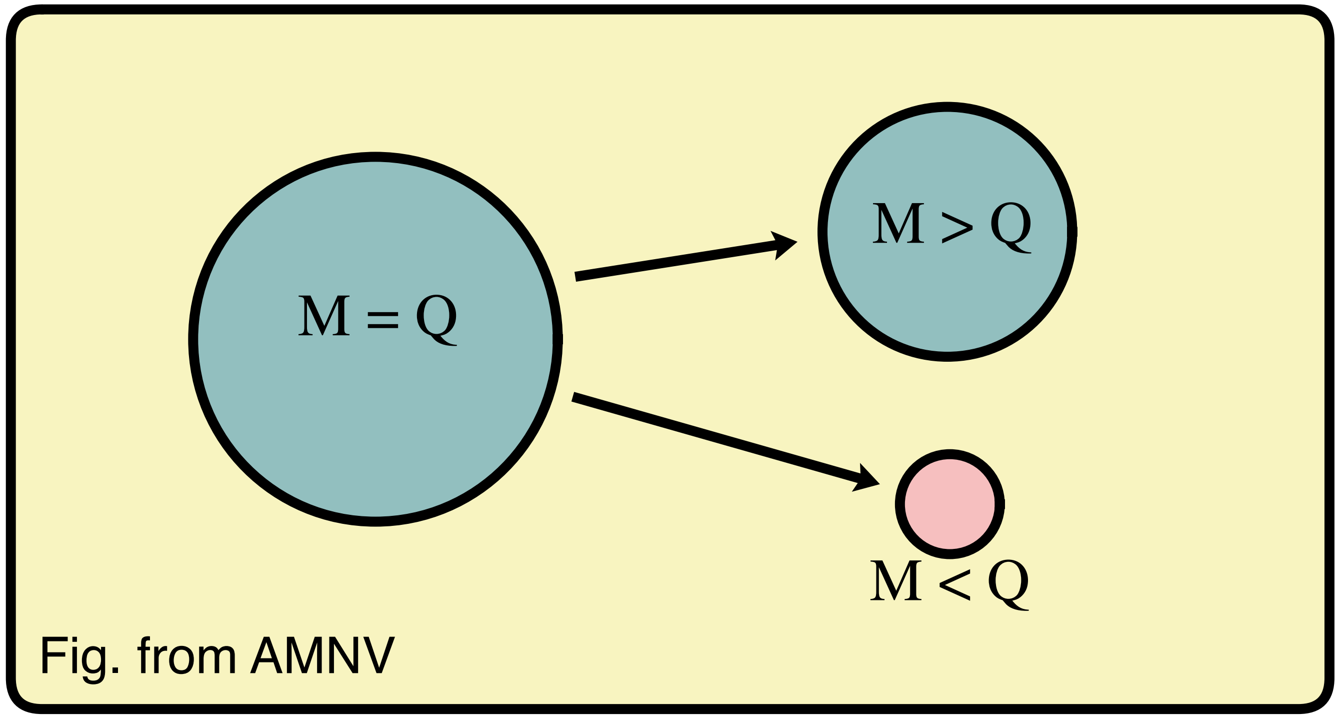


Fig. from 1810.05337 [Harlow/Ooguri]

What is the WGC? (Weak Gravity Conjecture)



Arkani-Hamed, Motl, Nicolis, Vafa ("**AMNV**") hep-th/0601001

Particle exists with M<Q (superextremal).

Extremal BHs can shed charge.

Repulsive Force Conjecture:

A charged particle exists which is (long-range) **self-repulsive**. Gauge repulsion overcomes gravitational attraction.

Distinct conjectures when massless scalars exist.

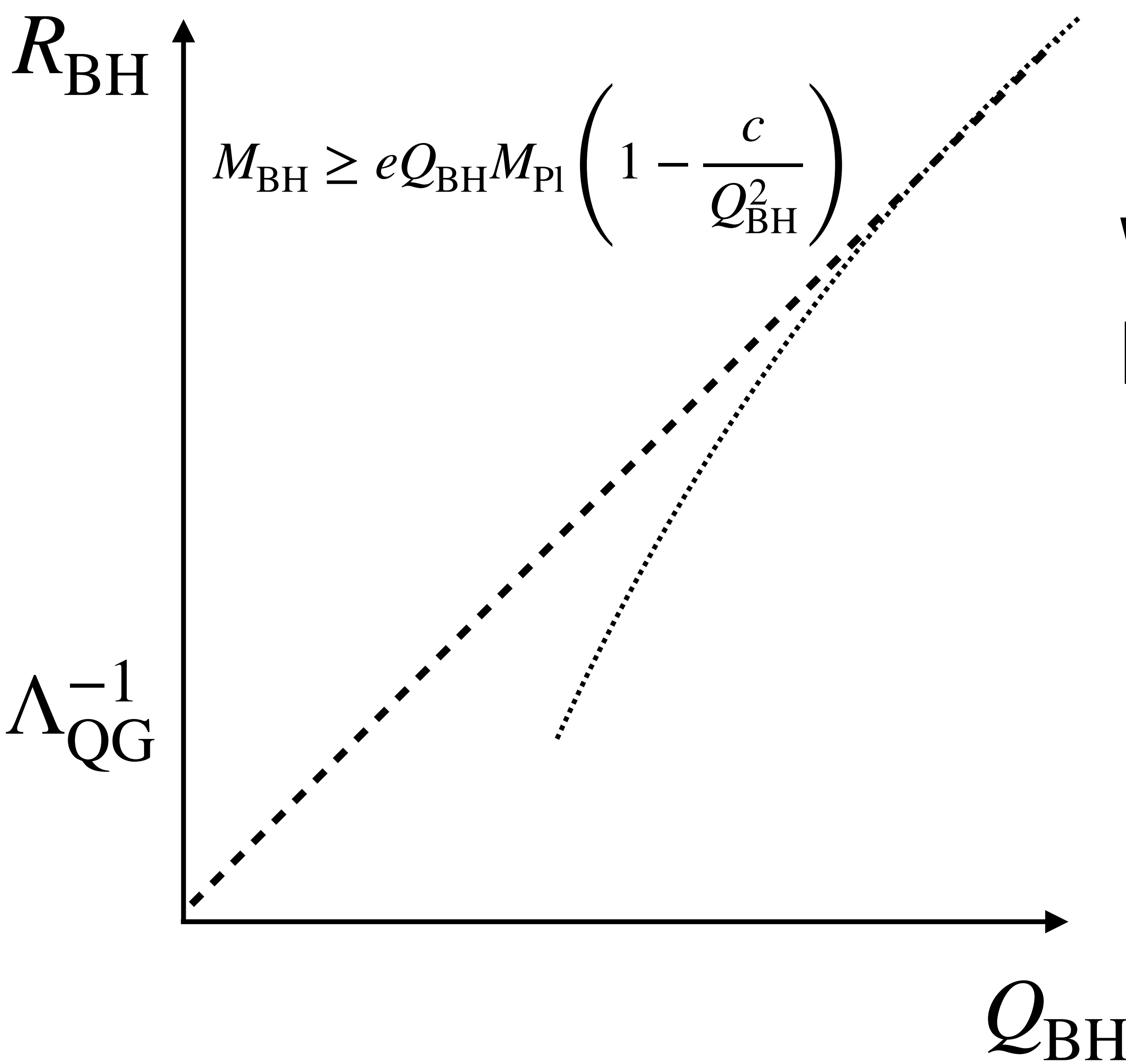
Palti '17; Lee, Lerche, Weigand '18; Heidenreich, MR, Rudelius '19

Is the minimal WGC obeyed by black holes?

Go beyond the 2-derivative action:

$$c_1(F_{\mu\nu}^2)^2 + c_2 F_{\mu\nu}F^{\nu\rho}F_{\rho\sigma}F^{\sigma\mu} + c_3 R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} + c_4 R_{\mu\nu\rho\sigma}F^{\mu\nu}F^{\rho\sigma}$$

AMNV; Kats, Motl, Padi '06



WGC obeyed by big black holes with small corrections!

Minimal WGC is **very weak.**

(Cheung, Remmen '18; Hamada, Noumi, Shiu '18; Bellazzini, Lewandowski, Serra '19; Mirbabayi '19; Arkani-Hamed, Huang, Liu, to appear)

How to make the WGC less weak?

For many applications we would like a stronger statement to be true: the WGC is obeyed by a particle with mass below the Planck scale.

However, some simple "**Strong WGC**" statements are **known to be false**: the WGC need not be satisfied by the particle of smallest charge or by the lightest charged particle (AMNV '06; Heidenreich, MR, Rudelius '16 [w/ suggestions from Vafa]).

AMNV gave an argument that **the WGC scale serves as a UV cutoff**, by combining **"Magnetic WGC"** with the statement that **the classical radius of a magnetic monopole is a UV cutoff:**

$$\Lambda \lesssim e M_{\mathrm{Pl}}$$

Sending $e \to 0$ to restore a global symmetry is then pathological.

Swampland Distance Conjecture

Moduli spaces in quantum gravity have infinite-distance regions.

EFT always breaks down in these regions.

Furthermore, it breaks down in a particular way: there exists a **tower** of **infinitely many particles** of decreasing mass,

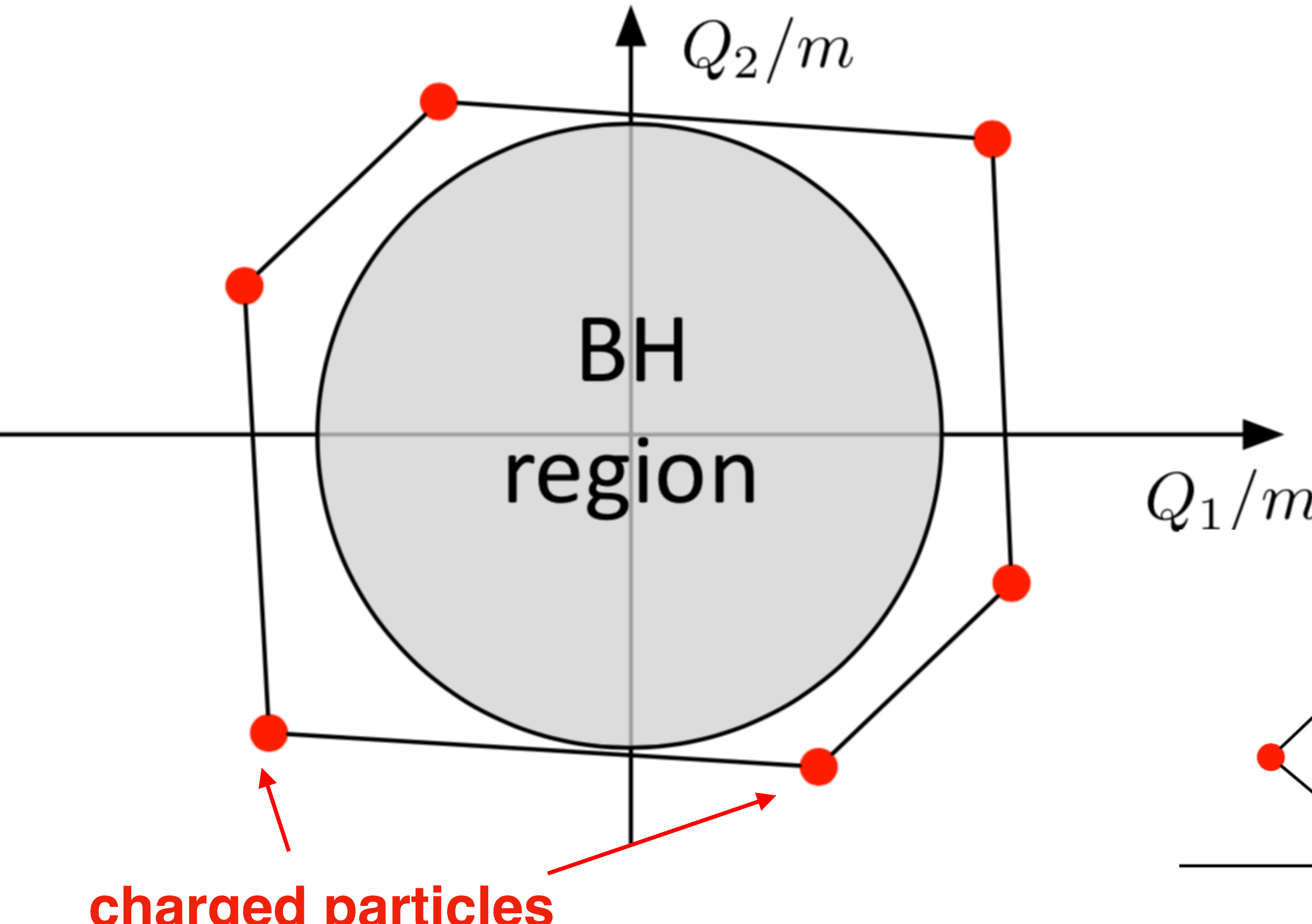
$$m_n(\phi) \sim m_n(0)\, \mathrm{e}^{-\alpha d(\phi)},$$

where α is some constant and $d(\phi)$ is the field-space distance (measured with the scalar field kinetic term).

Ooguri, Vafa ’06

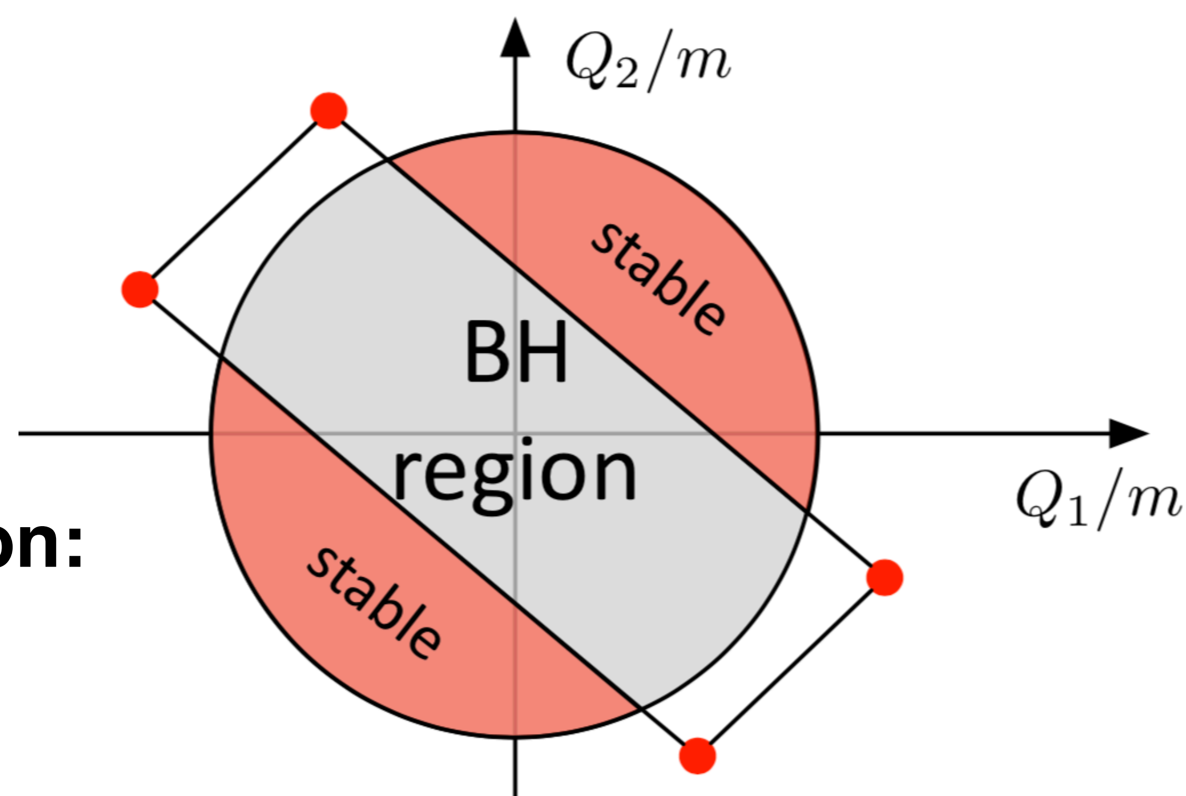
Convex Hull Condition (CHC)

WGC in the presence of multiple gauge groups: require that a general charged extremal BH can discharge.



Cheung, Remmen '14

WGC violation:

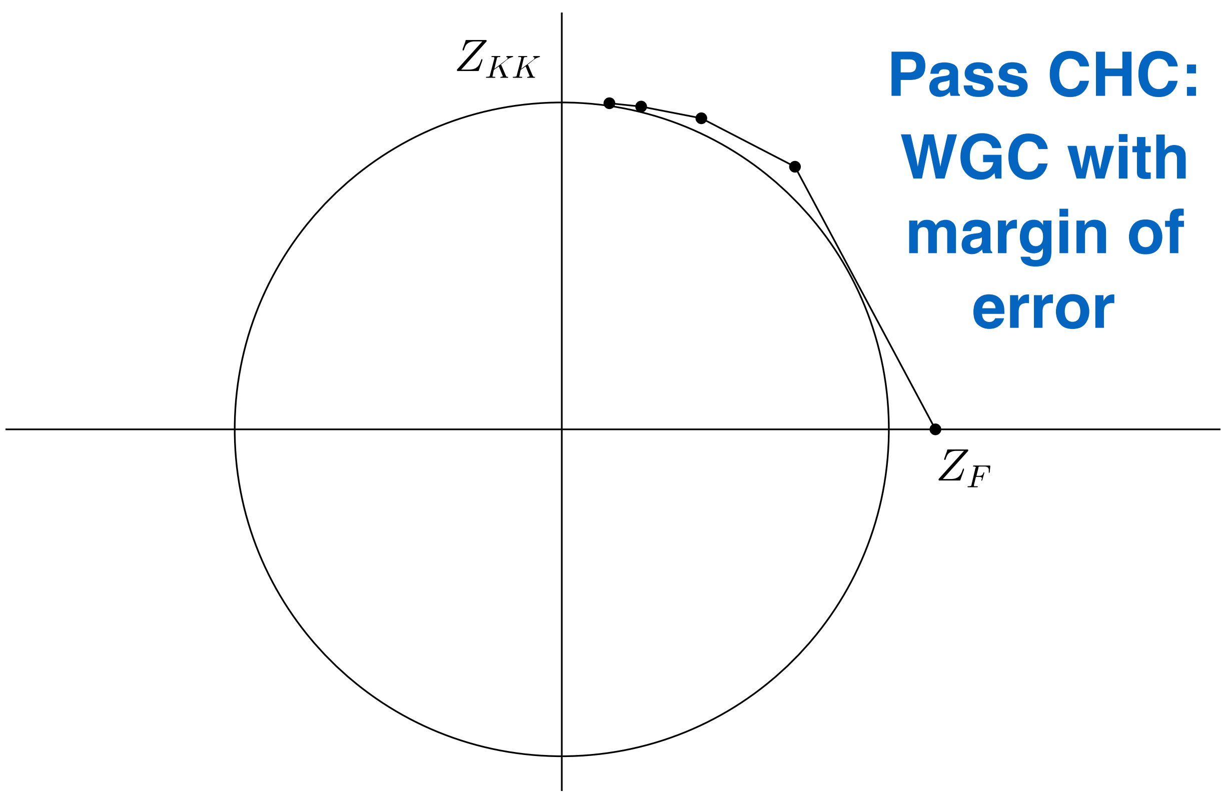


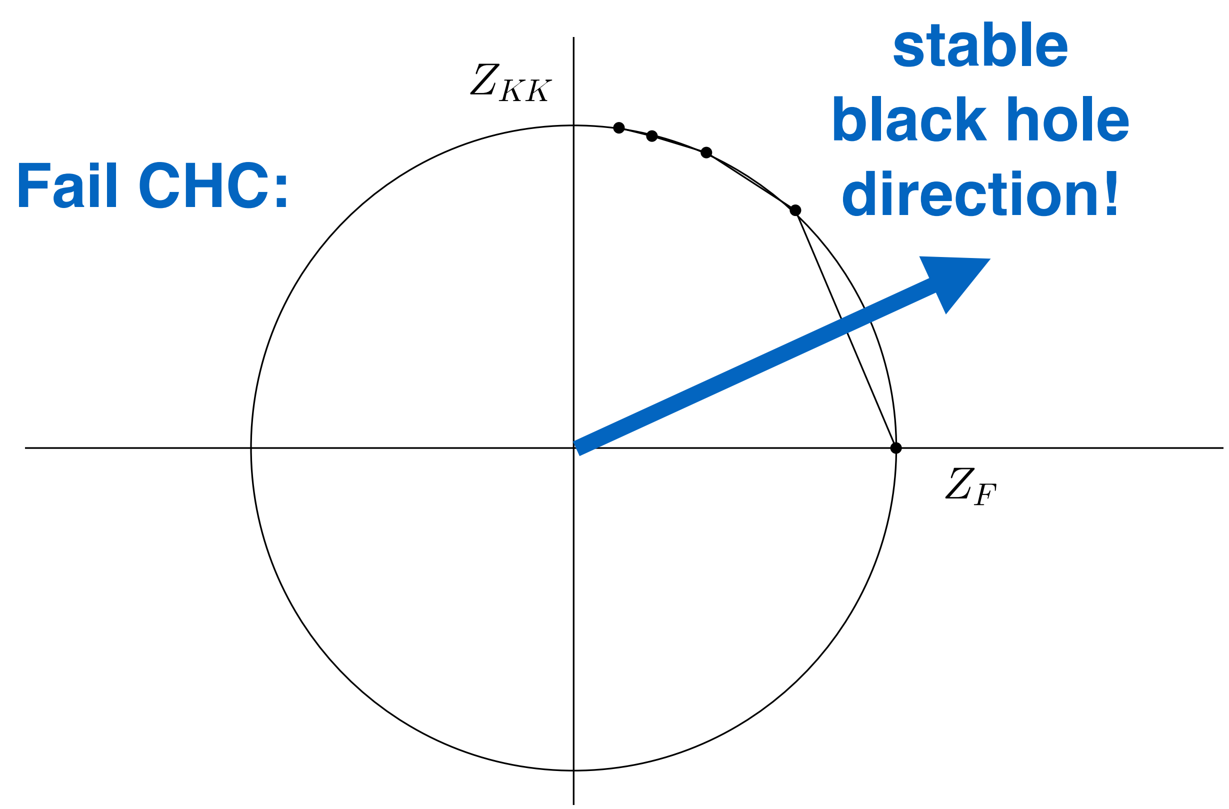
Figures by Ben Heidenreich

WGC and Dimensional Reduction

Compactify on a circle to get a new gauge theory with an **additional $U(1)_{KK}$** and consider black holes with general charges.

Infinite tower of superextremal KK modes. Mass-to-charge ratio **radius-dependent.**





Convex hull not guaranteed to contain the BH region!
CHC can fail, at least for some compactification radii.

Heidenreich, MR, Rudelius ’15, ’16

Tower & Sublattice WGCs

In known QG theories, the $e \to 0$ limit is an infinite-distance limit, so the Swampland Distance Conjecture predicts some sort of tower.

This, and robustness under dimensional reduction, can be arranged simultaneously with a **Tower WGC:**

There are infinitely many charged particles of *different* charges q_i, *each of which* obeys the bound

$$m_i \leq e q_i M_{\mathrm{Pl}} \,.$$

Stronger **Sublattice WGC (sLWGC)**: take the charges to lie in a sublattice (of the same dimension as full charge lattice).

(Tower WGC: Andriolo, Junghans, Noumi, Shiu ’18; Heidenreich, MR, Rudelius ’19; Sublattice WGC: Heidenreich, MR, Rudelius ’15/’16; Montero, Shiu, Soler ’16)

Example: Kaluza-Klein theory

For intuition, keep in mind the classic KK theory, with an extra dimension of radius *R*.

$$\sqrt{-g}\left[\frac{M_{\mathrm{Pl}}^2}{2}\mathscr{R}_4 - \frac{1}{2}(\partial\phi)^2 - \frac{1}{4e_{\mathrm{KK}}^2}\mathrm{e}^{\alpha\phi}F_{\mu\nu}^2\right]$$

gravity — radion — U(1) gauge field

$$e_{\mathrm{KK}}^2 = \frac{2}{R^2 M_{\mathrm{Pl}}^2}$$ large radius ⟺ small gauge coupling

$$m_n = \frac{n}{R} = \frac{e_{\mathrm{KK}}}{\sqrt{2}}M_{\mathrm{Pl}}$$ *infinite tower of* KK mode masses proportional to gauge coupling

$$R \propto \mathrm{e}^{\sqrt{3}\phi/(2M_{\mathrm{Pl}})}$$ radius *exponential* in canonically normalized radion (field space distance)

$$M_{5d} \sim e_{\mathrm{KK}}^{1/3}M_{\mathrm{Pl}}$$ UV cutoff exponentially small as well

1. Summary of main conjectures.
2. **Understanding the conjectures and their relationships.**
3. Toward phenomenology.

Hints of Organizing Principles?

There are many Swampland conjectures on a range of topics. Is there some new **underlying principle** that might help us to prove or at least organize them?

So far, we have some ***hints*** of ideas that subsume multiple Swampland conjectures. My personal ranking of some of the most intriguing:

- **Emergence of gauge theory and weak coupling**
  (Harlow ’15; Heidenreich, MR, Rudelius ’17; Grimm, Palti, Valenzuela ’18; Harlow, Ooguri ’18)
- **Universal strong coupling “quantum gravity” scale**
  (Dvali ’07; Dvali/Redi ’07; Heidenreich, MR, Rudelius ’17/’18; Grimm, Palti, Valenzuela ’18)
- ***All*** **global symmetries (including general *p*-form) badly broken at the quantum gravity scale**
  (Cordova, Ohmori, Rudelius, to appear)
- **Modular invariance**
  (Arkani-Hamed, Motl, Nicolis, Vafa ’06; Montero, Shiu, Soler ’16; Heidenreich, MR, Rudelius ’16; Lee, Lerche, Weigand ’18/’19)

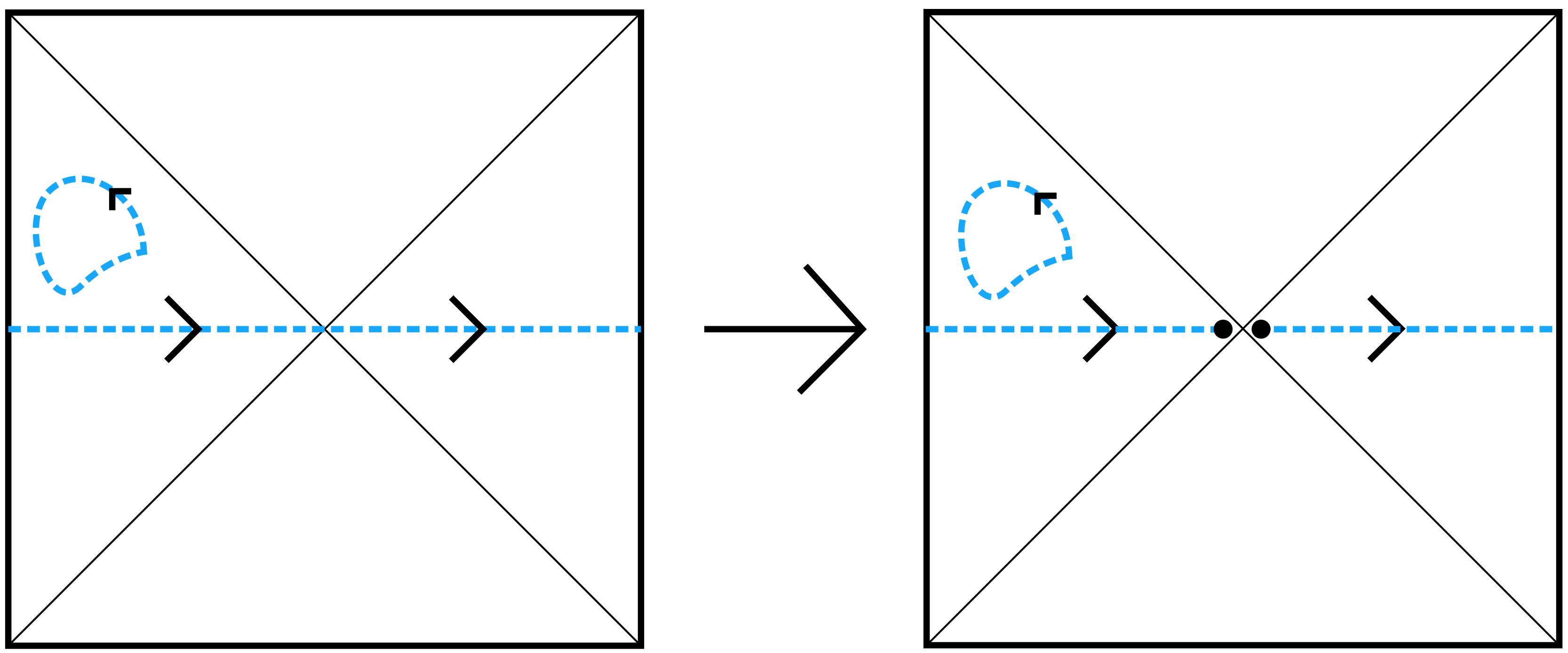
The first three appear to be closely related.

From Factorization to Emergence

Two-sided eternal AdS black hole vs. entangled state in the tensor product of two CFTs.

Require ***factorization*** of Wilson line through wormhole.

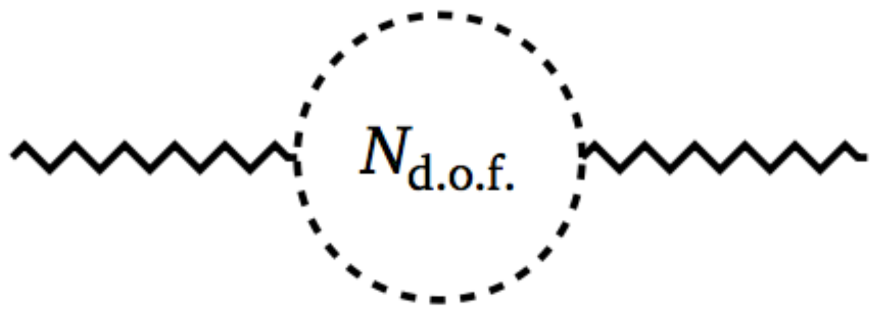
Daniel Harlow, 1510.07911.



The apparently problematic operator in the low-energy EFT really emerges from “nice,” factorizing operators in the UV completion. **CP^N** sigma model as toy example.

Towers and Strong Coupling

Towers of particles, as postulated by the Swampland Distance Conjecture or the Sublattice Weak Gravity Conjecture, lead to strong coupling in the UV through their loop effects:



For gravity, this leads to a cutoff below the Planck scale inferred from Newton's constant:

$$\Lambda_{\mathrm{QG}} \lesssim \frac{M_{\mathrm{Pl}}}{\left(N_{\mathrm{d.o.f.}}(\Lambda_{\mathrm{QG}})\right)^{1/(D-2)}}$$

e.g. G. Dvali, 0706.2050 and G. Dvali & M. Redi, 0710.4344

For gauge theory, there is again a cutoff (Landau pole).

A Universal Strong Coupling Scale

Intriguingly, towers of particles that saturate the (Lattice) WGC predict *parametrically the same UV cutoff* for gravity and gauge theory.

Single U(1):

$QeM_{\rm Pl}$ — $q = Q$

⋮

$3eM_{\rm Pl}$ — $q = 3$

$2eM_{\rm Pl}$ — $q = 2$

$eM_{\rm Pl}$ — $q = 1$

$$N_{\rm d.o.f}(\Lambda) \gtrsim \frac{\Lambda}{eM_{\rm Pl}}$$

$$\Lambda_{QG}^2 \lesssim \frac{1}{N_{\rm d.o.f}(\Lambda_{\rm QG})} M_{\rm Pl}^2$$

$$\Rightarrow \Lambda_{\rm QG} \lesssim e^{1/3} M_{\rm Pl}\,, \quad Q \sim e^{-2/3}$$

$$\frac{1}{e^2} = \frac{1}{e_{\rm UV}^2} + \sum_{q=1}^{Q} \frac{q^2}{12\pi^2} \log \frac{\Lambda}{eqM_{\rm Pl}}$$

Ignoring logs and constants, the sum is:

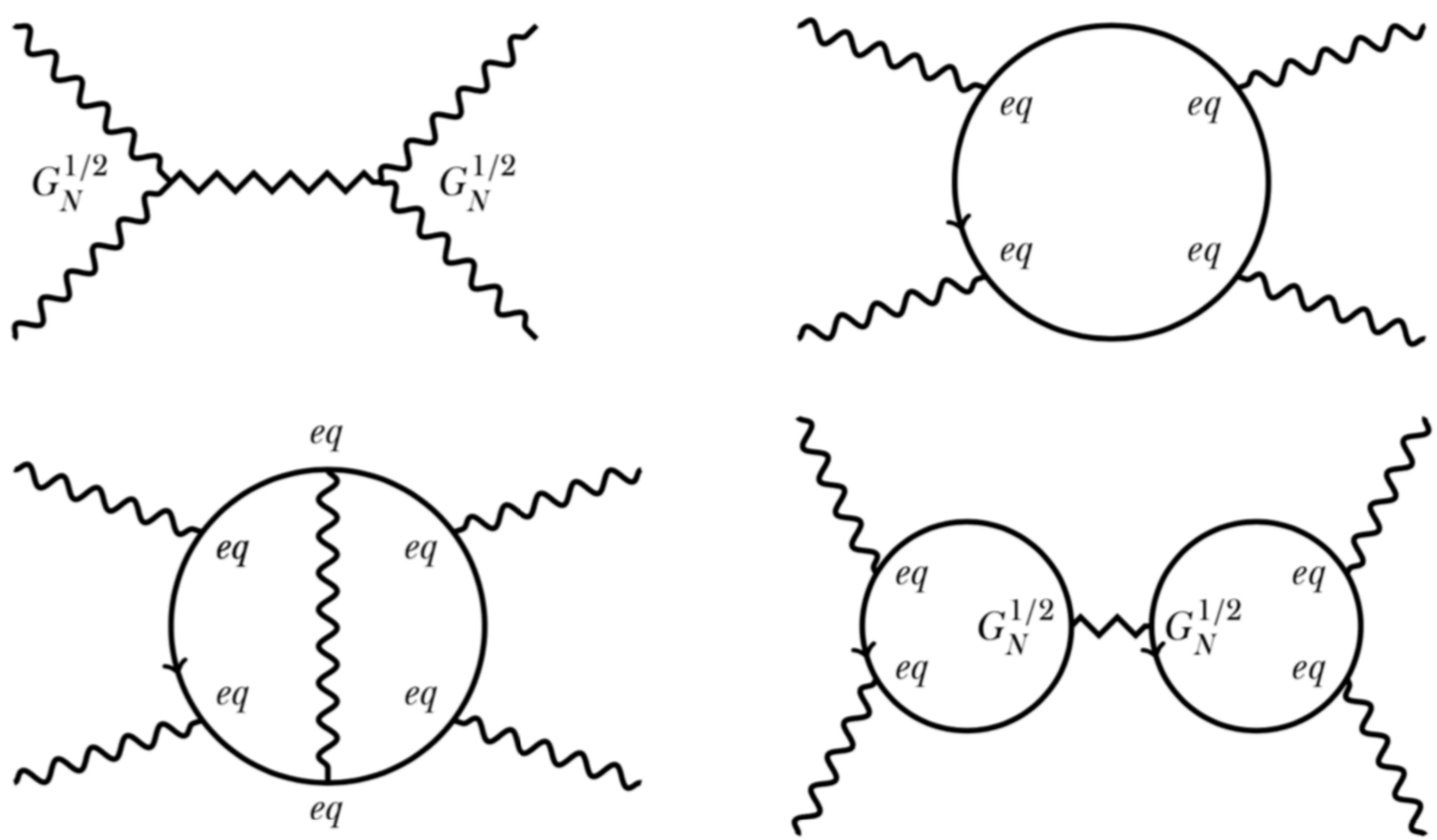
$$Q^3 \sim \frac{1}{e^2}$$

Same scale!

Heidenreich, MR, Rudelius ’17

Towers and Strong Coupling

If discussing *off-shell* 2-point functions bothers you, you can reach the same conclusions by considering **on-shell amplitudes**, e.g. photon-photon scattering.



All of this works for **general gauge groups** in a general number of spacetime dimensions. (s)LWGC **towers** are linked to **universal strong coupling**.

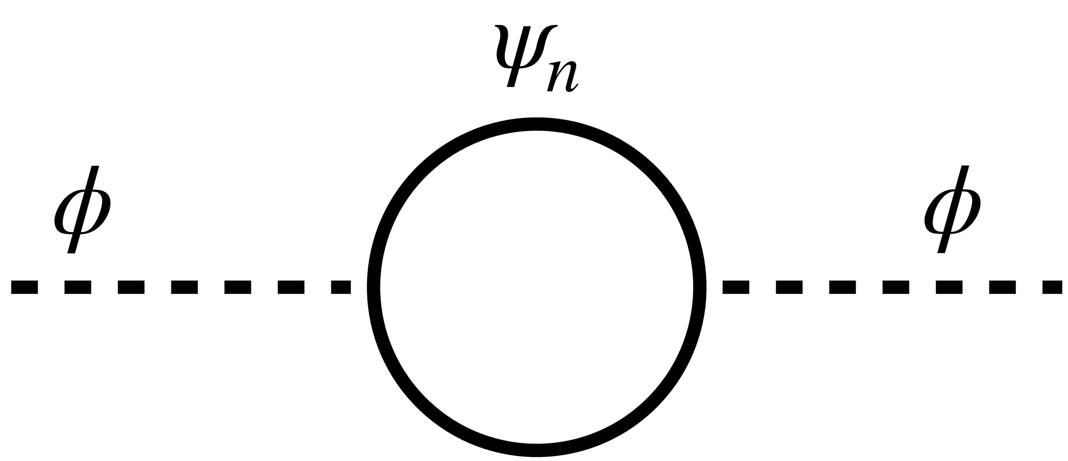
Heidenreich, MR, Rudelius '17

Moduli and the Quantum Gravity Scale

Assume fields becoming light at a special point $\phi = 0$.

$$\mathcal{L} = \frac{1}{2}K(\phi)(\partial\phi)^2 + \sum_n \bar{\psi}_n(\mathrm{i}\partial\!\!\!/ - m_n(\phi))\psi_n$$

Loops:



$$\sim \frac{1}{K(\phi_0)}\left(\frac{\partial m_n}{\partial \phi}\right)^2$$

Strong coupling at same scale as quantum gravity cutoff:

$$K(\phi_0) \sim \sum_{m_n < \Lambda_{\rm QG}} \left(\frac{\partial m_n}{\partial \phi}\right)^2 \sim \frac{1}{\phi_0^2}\sum_{m_n<\Lambda_{\rm QG}} m_n^2 \sim \frac{1}{\phi_0^2} N \Lambda_{\rm QG}^2 \sim \frac{M_{\rm Pl}^2}{\phi_0^2}$$

Heidenreich, MR, Rudelius '18; also Grimm, Palti, Valenzuela '18

Moduli and the Quantum Gravity Scale

Ooguri/Vafa 2006 *conjectured* towers become light at a rate exponential in field space distance.

Here we see it is an *output* of assuming a universal strong-coupling scale, implying a kinetic term:

$$\mathscr{L} \sim \frac{M_{\mathrm{Pl}}^2}{\phi^2} \partial_\mu \phi \partial^\mu \phi$$

Applying a similar argument to *axion* fields:

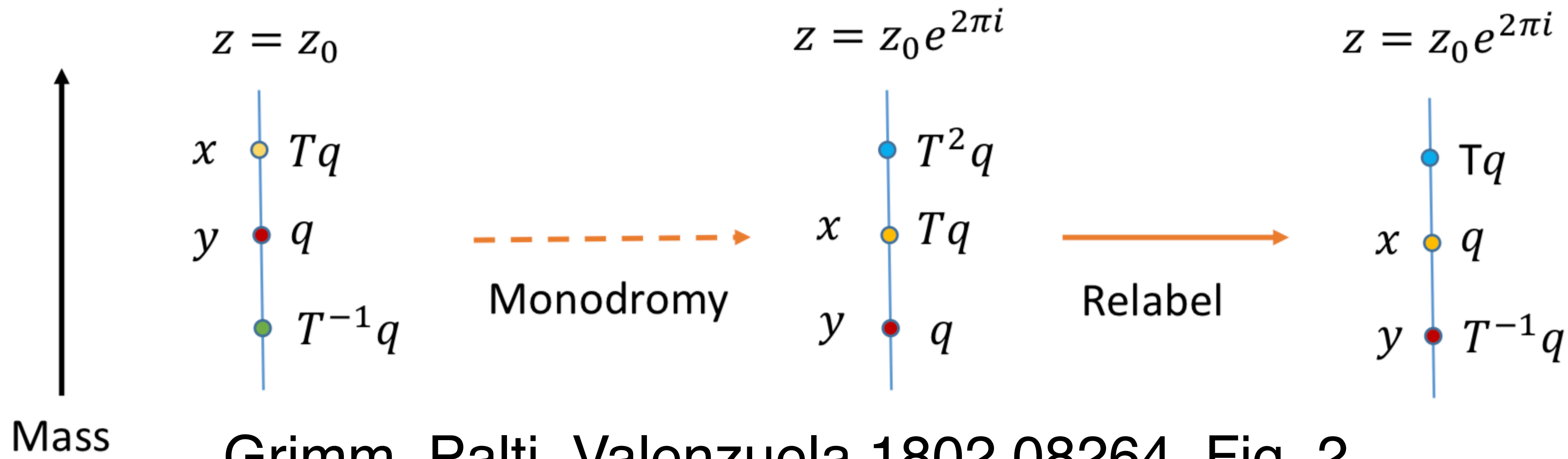
$$\left\langle (\Delta m)^2 \right\rangle \sim \Lambda_{\mathrm{QG}}^2 \frac{d(\phi)^2}{M_{\mathrm{Pl}}^2}$$

Super-Planckian field traversals require O(1) fraction of modes to pass through QG cutoff!

Heidenreich, MR, Rudelius '18

Infinite Distance and Infinite Monodromy

The Swampland Distance Conjecture is understood more concretely in the case of the Type IIB CY complex structure moduli space.



Grimm, Palti, Valenzuela 1802.08264, Fig. 2

There is a **monodromy** that rearranges the BPS spectrum when circling a singular point.

Infinite distances arise *only* when the monodromy orbit is infinite $\Longrightarrow$ infinite tower made up of BPS states of different charges.

Emergent infinite distance.

related: Grimm, Li, Palti ’18

Existence of charged particles vs. presence of global symmetries

Completeness Conjecture: all possible charges appear in QG theories (Polchinski, hep-th/0304042).
Related to "**no global symmetries.**" (Thomas Dumitrescu, …)

If there is a gauge group but no charged particles, there is a **global 1-form symmetry** that acts on Wilson lines:

$$U_g(S^{d-2})W(C) = \mathrm{e}^{\mathrm{i}\phi(g)}W(C)$$

Symmetry generator on sphere linking C, for group element *g*

Wilson line on C

phase associated with group element *g*

Gaiotto, Kapustin, Seiberg, Willett 1412.5148

Global symmetries badly broken at the QG cutoff

Clay Cordova, Kantaro Ohmori, Tom Rudelius (to appear)

Aim to test the relationship

$$U_g(S^{d-2})W(C) = \mathrm{e}^{\mathrm{i}\phi(g)}W(C)$$

by explicit calculation. For a true global symmetry, correlators of the $U_g(M)$ are ***topological***. In the presence of charged particles, this is no longer true. So, calculate distance-dependence.

$$U_g(S^{d-2}) \sim \exp\left(\mathrm{i}\phi(g)\int_{S^{d-2}} \frac{\star F}{e^2}\right), \quad W(C) \sim \exp\left(\mathrm{i}\int_C A\right)$$

The Ward identity can be ***explicitly*** checked in terms of **correlation functions of the gauge field A**!

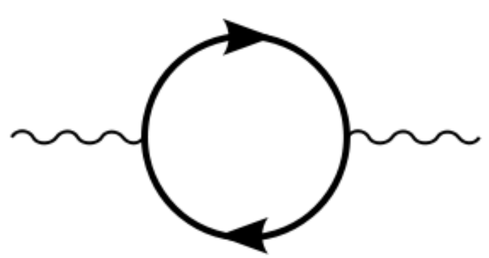
Global symmetries badly broken at the QG cutoff

Clay Cordova, Kantaro Ohmori, Tom Rudelius (to appear)

By expanding

$$U_g(S^{d-2})W(C) \stackrel{?}{=} e^{i\phi(g)}W(C)$$

in terms of correlators like $\langle F_{\mu\nu}(x)A_\lambda(x')\rangle$, can **quantify** the extent to which the presence of charged particles in the theory **breaks the global 1-form symmetry**.



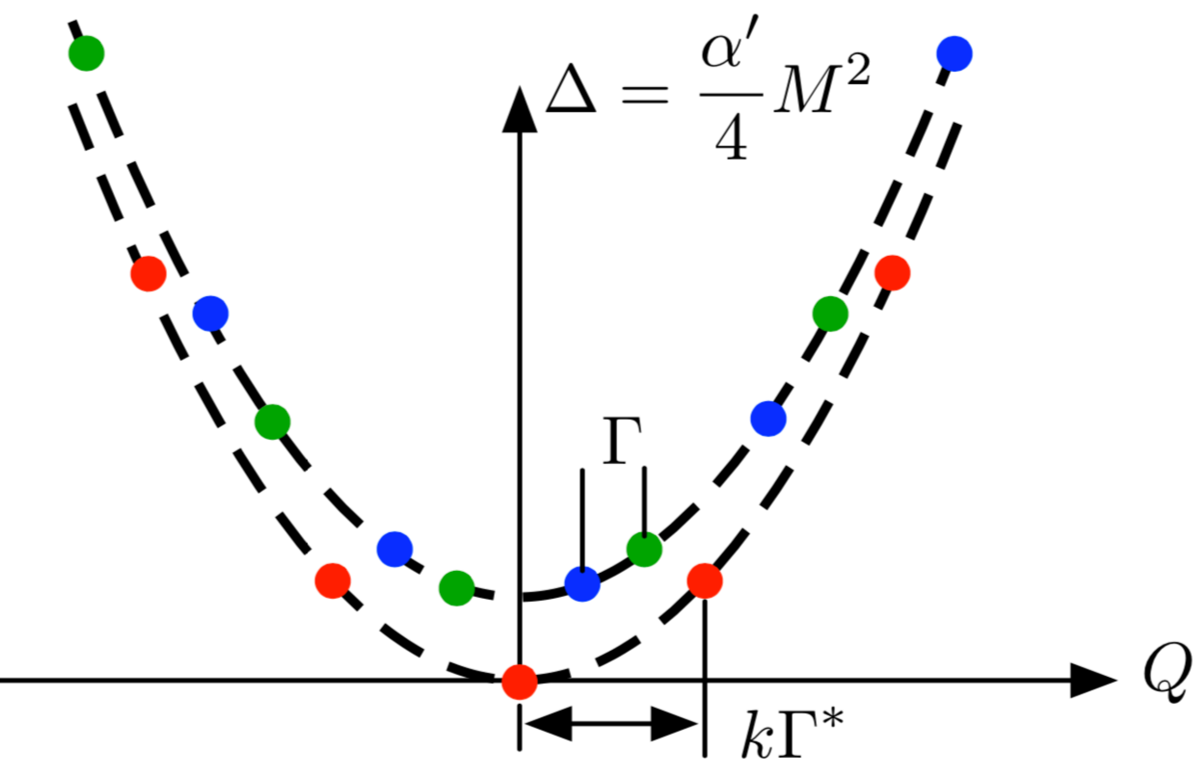
Check when the potential $V(r)$ between static sources deviates strongly from $1/r$.

A single charged particle does not **badly** break the symmetry at the cutoff, but a **tower of particles *does*.** Effectively, reproduce the strong coupling argument for Tower WGC from Heidenreich, MR, Rudelius ’17.

Extensions to Swampland Distance Conjecture, axion WGC, magnetic WGC—stay tuned!

Modular Invariance and the Sublattice WGC

Sublattice WGC proof in worldsheet string theory: Heidenreich, MR, Rudelius ’16.
Simultaneous argument in AdS_3/CFT_2: Montero, Shiu, Soler ’16



Partition function $Z(\mu, \tau)$ with a chemical potential has simple modular properties. Periodicity (**charge quantization**) together with **S-duality** implies partition function picks up a phase under a “quasi-period”

$$\mu \mapsto \mu + \tau\rho$$

where ρ is in the dual charge lattice.

“Spectral flow”

The quantity $\Delta - Q^2/2$ is invariant under shifts of *Q* by a dual charge. Thus the **graviton state** implies the existence of **infinitely many charged states**. These turn out to obey the Sublattice WGC! Lattice spacing = *k*, current algebra level. Similar results in F-theory: Lee, Lerche, Weigand ’18.

Figure: B. Heidenreich

also watch for Heidenreich, Lotito work in progress

1. Summary of main conjectures.

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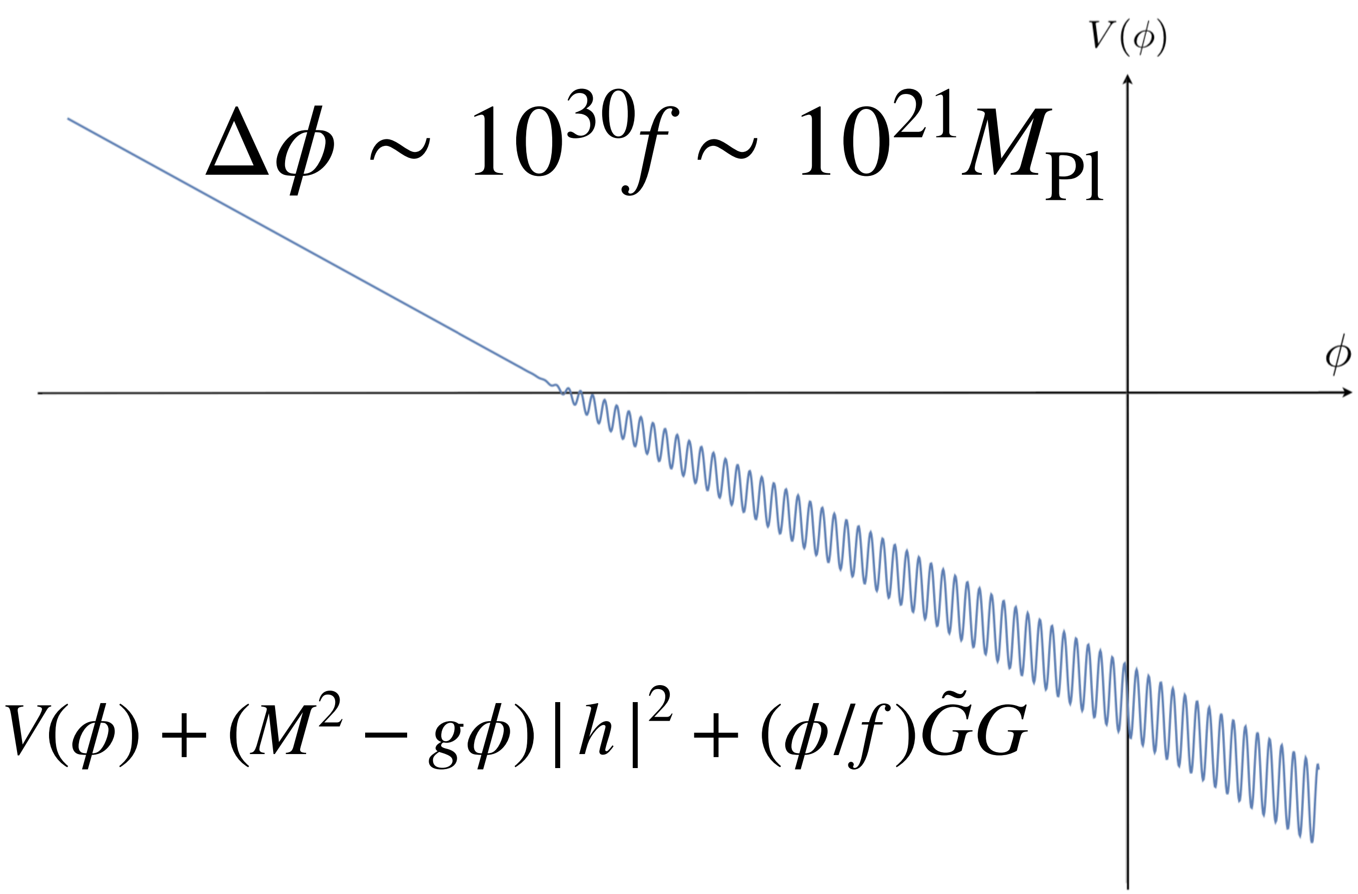
Swampland vs. Technical Naturalness

Some phenomenological models lean heavily on the notion of **“technical naturalness,”** allowing tiny numbers to be input by hand provided their value is radiatively stable.

An extreme example is the **relaxion** [Graham, Kaplan, Rajendran ’15]:

$$\Delta\phi \sim 10^{30} f \sim 10^{21} M_{\rm Pl}$$



$$\mathscr{L} \supset V(\phi) + (M^2 - g\phi)|h|^2 + (\phi/f)\tilde{G}G$$

The Swampland criteria suggest that quantum gravity will resist attempts to generate such small numbers.

Often will find **a tower of states** and a **low cutoff**.

Concrete backreaction effects in string constructions:
McAllister, Schwaller, Servant, Stout, Westphal ’16.
Modified models may be safer: Hook, Marques-Tavares ’16.

Axions and the WGC

Axions, periodic scalar fields, play many roles in phenomenology, not least in solving the strong CP problem (“QCD axion”) and giving candidate inflatons.

An appealing class of axion models obtain the axion by integrating a (*p*-form) gauge field over a *p*-cycle in extra dimensions,

$$\theta = \oint_\Sigma C_p$$

Helps solve the “axion quality problem”—why is the axion shift symmetry so good?—because corrections are exponentially suppressed instantons, e.g.

$$V(\theta) = \sum c_n \mathrm{e}^{-S_n} \cos(n\theta), \quad S_n \sim \int_\Sigma T_n$$

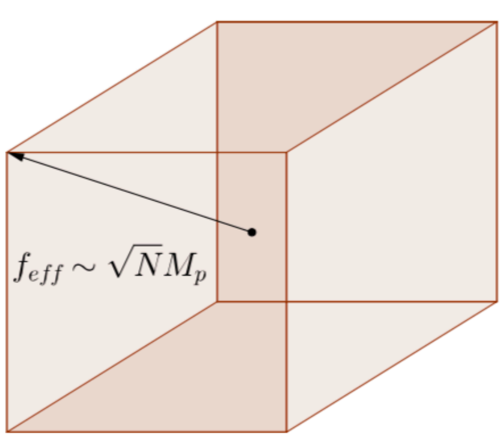
WGC vs. Axion Inflation

Because the instanton effects arise from higher-dimensional charged objects they are constrained by the WGC for the *p*-form gauge field.

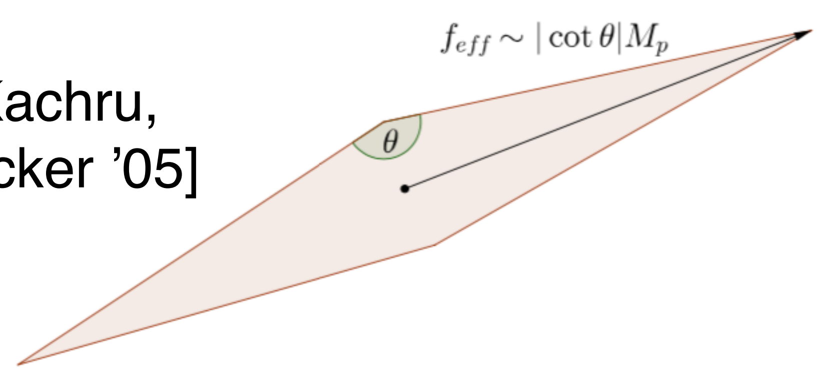
Axion WGC: $S_n \lesssim n M_{\mathrm{Pl}}/f$ (AMNV '06)

Naively rules out "Natural Inflation" (Freese, Frieman, Olinto '90) and explains observations about string constructions (Banks, Dine, Fox, Gorbatov '03).

Last five years: much activity extending the arguments and exploring loopholes.



N-flation
[Dimopoulos, Kachru, McGreevy, Wacker '05]



KNP Alignment / Clockwork
[Kim, Nilles, Peloso '04 / Choi, Kim, Yun '14, Choi, Im '15, Kaplan, Rattazzi '15]

WGC constraints:
[Rudelius '14, '15; de la Fuente, Saraswat, Sundrum '14; Montero, Uranga, Valenzuela '15; Brown, Cottrell, Shiu, Soler '15; Bachlechner, Long, McAllister '15; Hebecker, Mangat, Rompineve, Witkowski '15; Heidenreich, MR, Rudelius '15; … Heidenreich, Long, McAllister, Rudelius, Stout to appear]

Figures from Tom Rudelius

Photon Masses in QG

In effective field theory we can add masses to abelian gauge bosons and they're harmless. At small enough mass, the longitudinal mode is very weakly coupled. Good example of a **technically natural quantity.**

We can view a photon mass as a ***Stückelberg*** mass, introducing a Goldstone boson that shifts:

$$\frac{1}{2} f^2 (\partial_\mu \theta - e\hat{A}_\mu)^2$$

In string theory, such masses are ubiquitous. SUSY implies that a radial mode exists.
How is it different from Higgs mechanism? Kinetic term:

$$K(\Phi, \Phi^\dagger, V) = - M^2 \log(\Phi + \Phi^\dagger - cV)$$

Stückelberg in the Swampland

The point of zero photon mass lies at infinite distance,

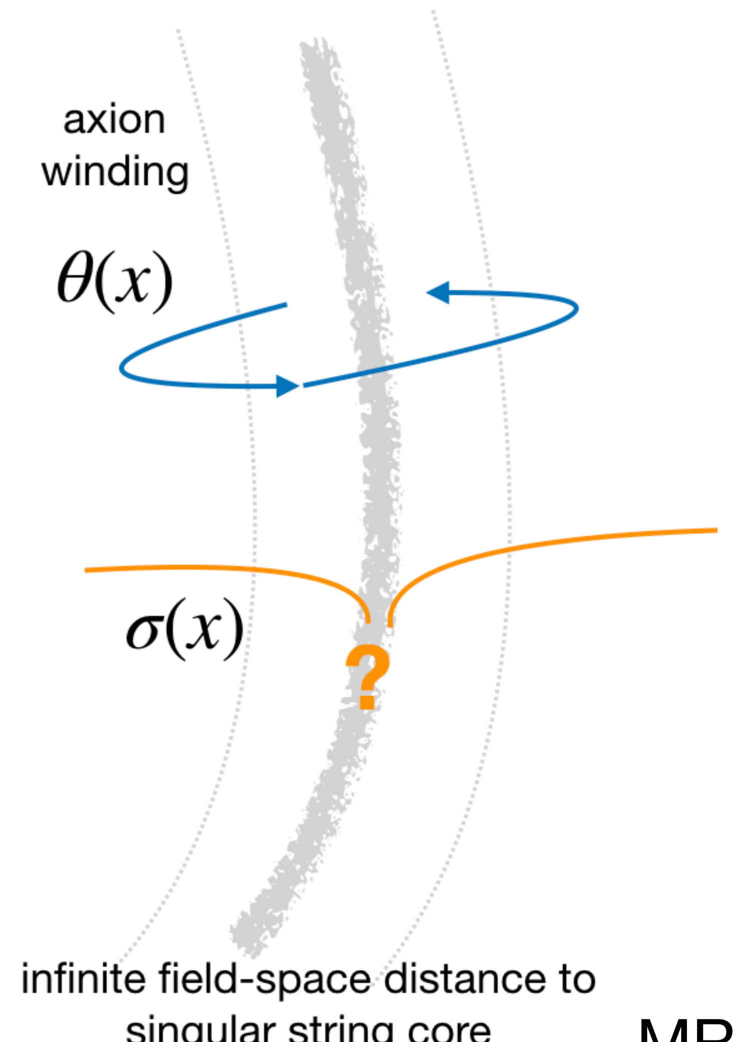
$$\mathrm{Re}\,\Phi \to \infty, \quad m_V \sim \frac{M^2}{(\Phi + \Phi^\dagger)^2}$$

Dualize the eaten Goldstone boson to a 2-form gauge field B:

$$\epsilon^{\mu\nu\rho\lambda}\partial_{[\mu}B_{\nu\rho]} = f^2\partial^\lambda\theta$$

Now apply the **WGC** to the B-field: charged strings exist with tension $T \lesssim f\, M_{\mathrm{Pl}}$. (see Hebecker, Soler '17)

For Stückelberg masses—**unlike the Higgs mechanism**—these are *fundamental* strings.



MR, '18

Can the photon have a mass?

For the SM photon, very simple kinematic bounds (from fast radio bursts) tell us

$$m_\gamma \lesssim 10^{-14}\ \mathrm{eV}$$

A Stückelberg mass at this scale leads to local EFT breaking down at low energies:

$$\Lambda_{\mathrm{QG}} \lesssim \sqrt{m_\gamma M_{\mathrm{Pl}}/e} \lesssim 10\ \mathrm{MeV}$$

So the SM photon can't have a Stückelberg mass.
Loophole is the unit of charge: suppose the electron charge is N, i.e. what we know as e is really $e_0 N$ for $N >> 1$.

We can push the UV cutoff above a TeV if $N \sim 10^{14}$.
(Or Higgs mechanism: Higgs is millicharged, similarly huge N.)

Does QG allow **enormous charge ratios** in light particles?

MR, '18

de Sitter

Attention-grabbing, phenomenologically powerful claim made recently: even ***metastable*** de Sitter vacua may not exist in QG.

Obied, Ooguri, Spodyneiko, Vafa ’18; Garg, Krishnan ’18; Ooguri, Palti, Shiu, Vafa ’18

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

Satisfied, e.g., by ubiquitous exponential potentials. **Is it true?**

Some possibilities, in increasing order of surprisingness:

- Refinement of the ***Dine-Seiberg problem***, and true only at the boundaries of moduli spaces.
- True in many cases as a way to satisfy some other deep principle, like “**No eternal inflation**” (Rudelius ’19*), which can also be satisfied in other ways (like sufficiently rapid tunneling out of metastable vacuum)
- Actually true—in which case many explicit constructions in the literature must be unreliable for one reason or another. **Surprising breakdown of effective field theory?**

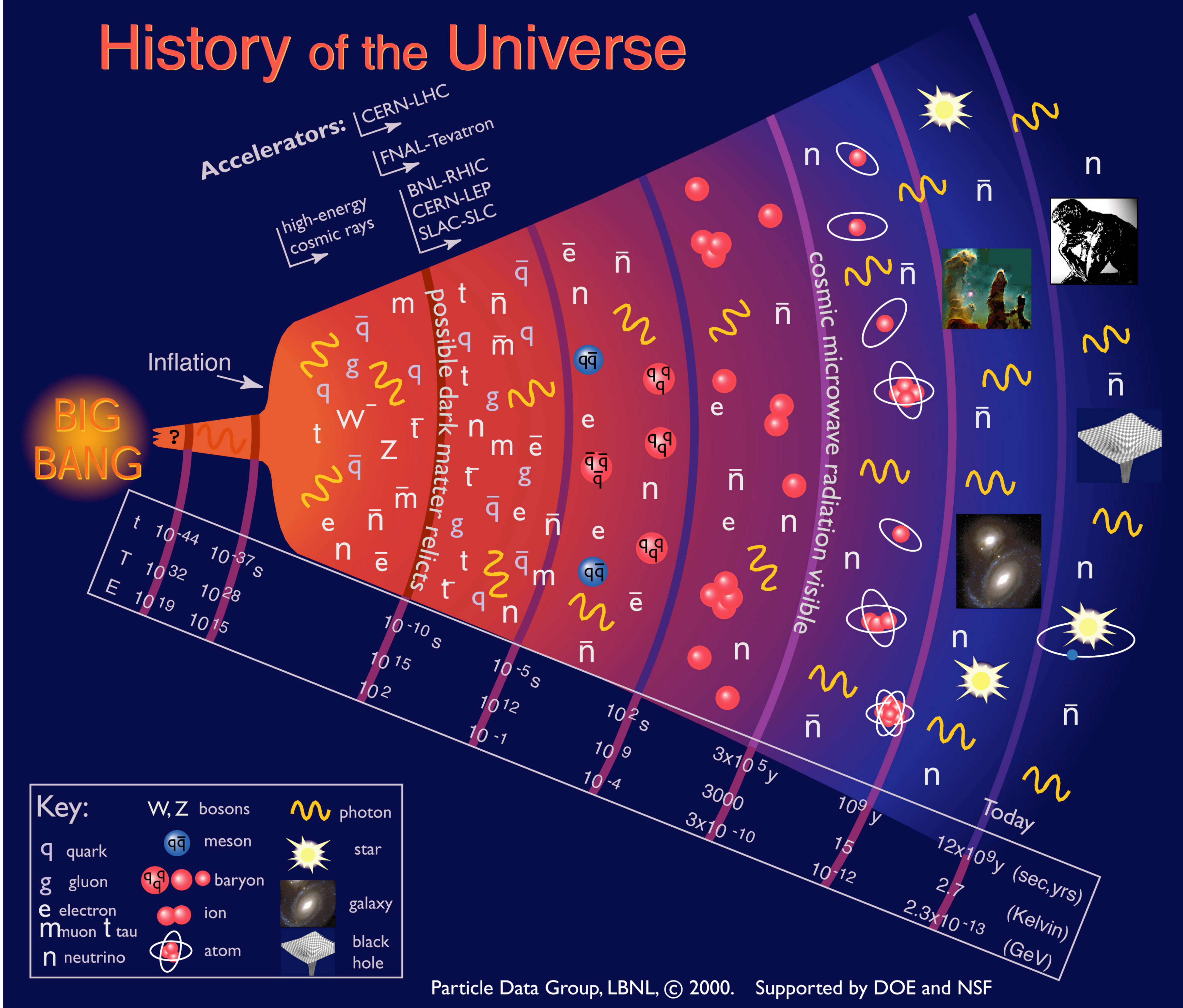
Liam McAllister’s talk tomorrow will update us on status of dS in string theory.

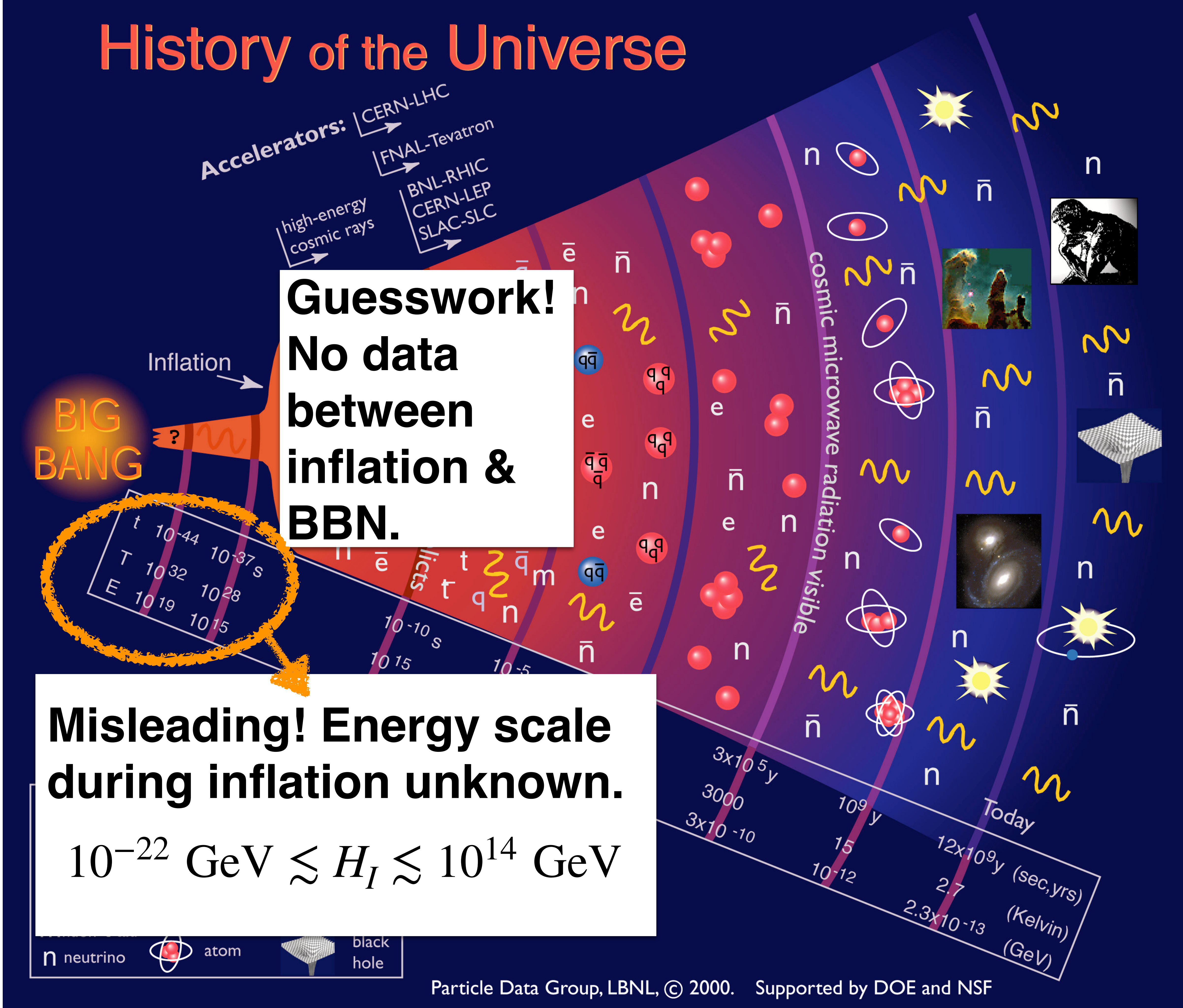
* also see Kinney ’18; Matsui, Takahashi ’18; Brahma, Shandera ’19

A phenomenologist's daydream

Even very loose, parametric bounds on the way that different fundamental scales in nature are related to each other might be very useful.

It's worth briefly recalling what a wide range of energies we are ignorant of.


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10^-44 10^-37 s
T 10^32 10^28
E 10^19 10^15
10^-10 s
10^15
10^2
10^-5 s
10^12
10^-1
10^2 s
10^9
10^-4
3x10^5 y
3000
3x10^-10
10^9 y
15
10^-12
Today
12x10^9 y (sec,yrs)
2.7 (Kelvin)
2.3x10^-13 (GeV)
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF



Guesswork! No data between inflation & BBN.

Misleading! Energy scale during inflation unknown.

$$10^{-22}\ \mathrm{GeV} \lesssim H_I \lesssim 10^{14}\ \mathrm{GeV}$$

The scales of nature

Planck scale	10^{18} GeV
string scale	10^{16} GeV?
KK scale	10^{15} GeV?
inflationary Hubble	10^{14} GeV?
gravitino (today)	10^{7} GeV?
lightest modulus	10^{5} GeV?
scalar superpartners	10 TeV?
gauginos	1 TeV?
Higgs	125 GeV
QCD	300 MeV
neutrino	100 meV(ish)
Hubble (today)	10^{-42} GeV

Red text = wild, generally optimistic guesses

Some Swampland claims about scales

A sprinkling of claims from the recent literature: mostly not yet subjected to serious scrutiny. Still early days for such ideas, but an interesting direction to go in.

Ibáñez, Martín-Lozano, Valenzuela ’17 (after Ooguri, Vafa ’16):
No metastable AdS, use Arkani-Hamed, Dubovsky, Nicolis, Villadoro ’07

$$\Lambda_4 \sim H_0^2 M_{\rm Pl}^2 \gtrsim m_\nu^4$$
$$\langle h \rangle \lesssim M_{\rm seesaw}^{1/2} H_0^{1/4} M_{\rm Pl}^{1/4}$$

(important caveat re: stability of vacuum)

Lüst, Palti, Vafa “AdS Distance Conjecture” ’19:

$$m_{\rm tower} \lesssim k_{\rm AdS}^{\alpha} M_{\rm Pl}^{1-\alpha}, \quad \alpha \sim \mathcal{O}(1)$$

(Likely clashes even with *SUSY* KKLT AdS vacua)

Noumi, Takeuchi, Zhou ’19:
Lüst, Palti ’19:

$$M_{\rm string} \gtrsim \sqrt{H_{\rm inf} M_{\rm Pl}}$$

Conclusions

Some messages to take away

The original, minimal WGC is satisfied by (corrected) black holes themselves, and is too weak to be useful.

There is substantial evidence for stronger statements: at the **“Magnetic WGC” cutoff** $\Lambda \sim eM_{\rm Pl}$ a **tower of charged states** appears.

Such towers are ubiquitous and may be a universal way that quantum gravity prevents a too-good approximate global symmetry from arising.

We are still in search of rigorous arguments.

Statements about *potentials* rather than *metrics* are more difficult and more controversial, but could be crucial for phenomenology.

Where are we and where are we going?