A HIKE

THROUGH THE SWAMPLAND

Miguel Montero

Harvard

BIRS Online workshop "Geometry and the Swampland"

January 24th 2022

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with any Swamp rangers we might encounter along the way

Please interrupt me!!

(This is an interactive review talk!)

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Let us draw the space
of **all** EFT's
(finitely many fields, but
nonrenorm. couplings
etc allowed)

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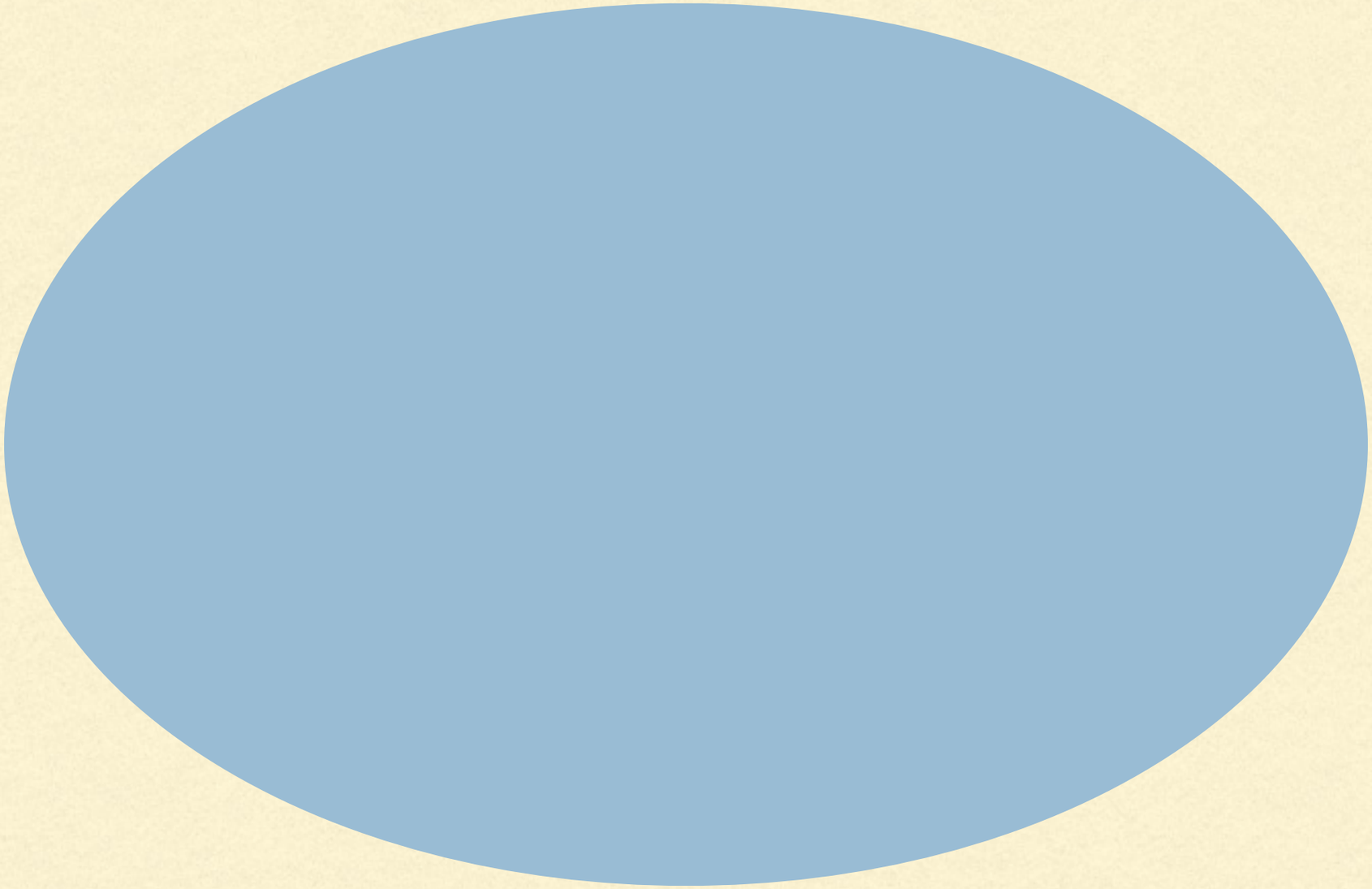

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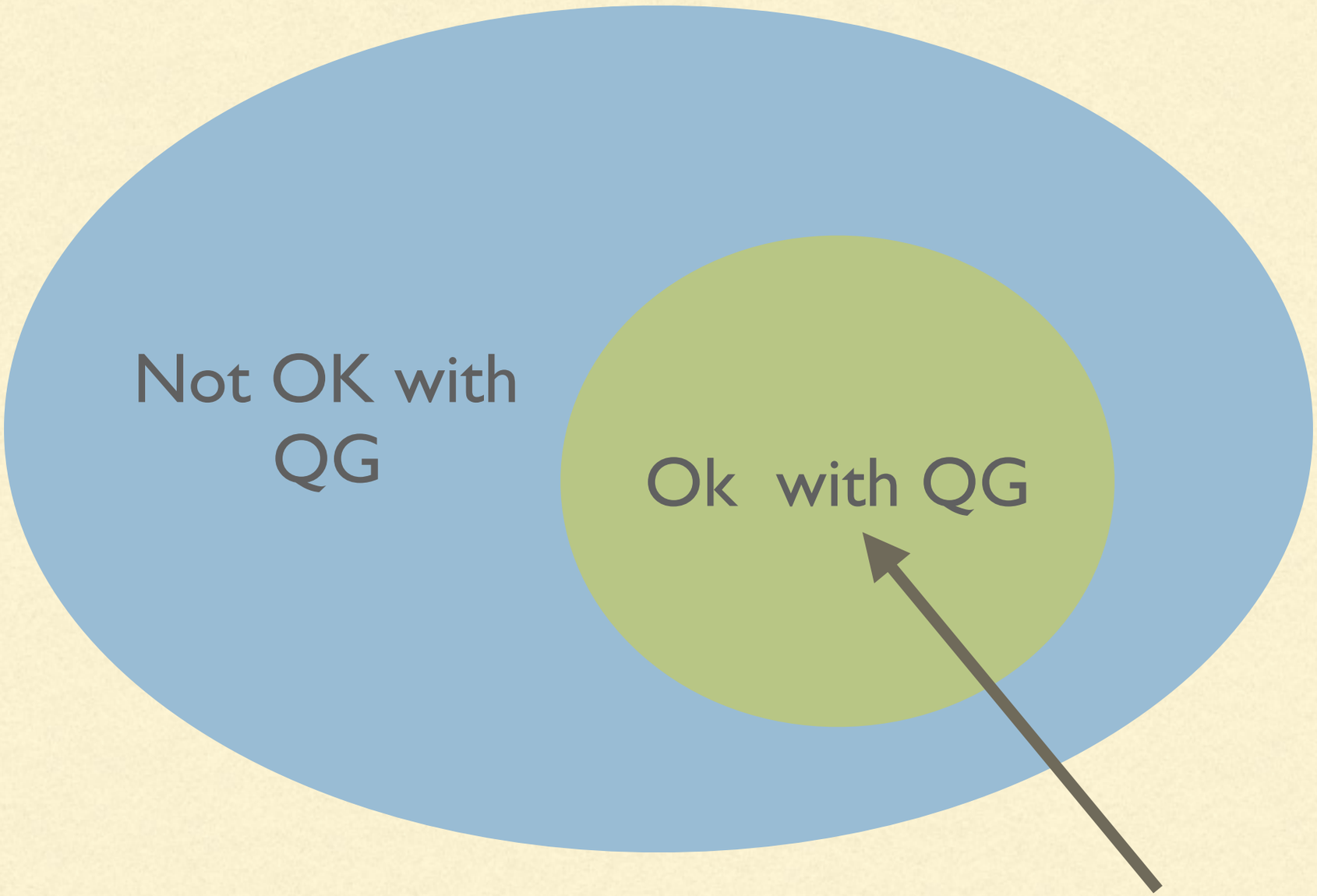

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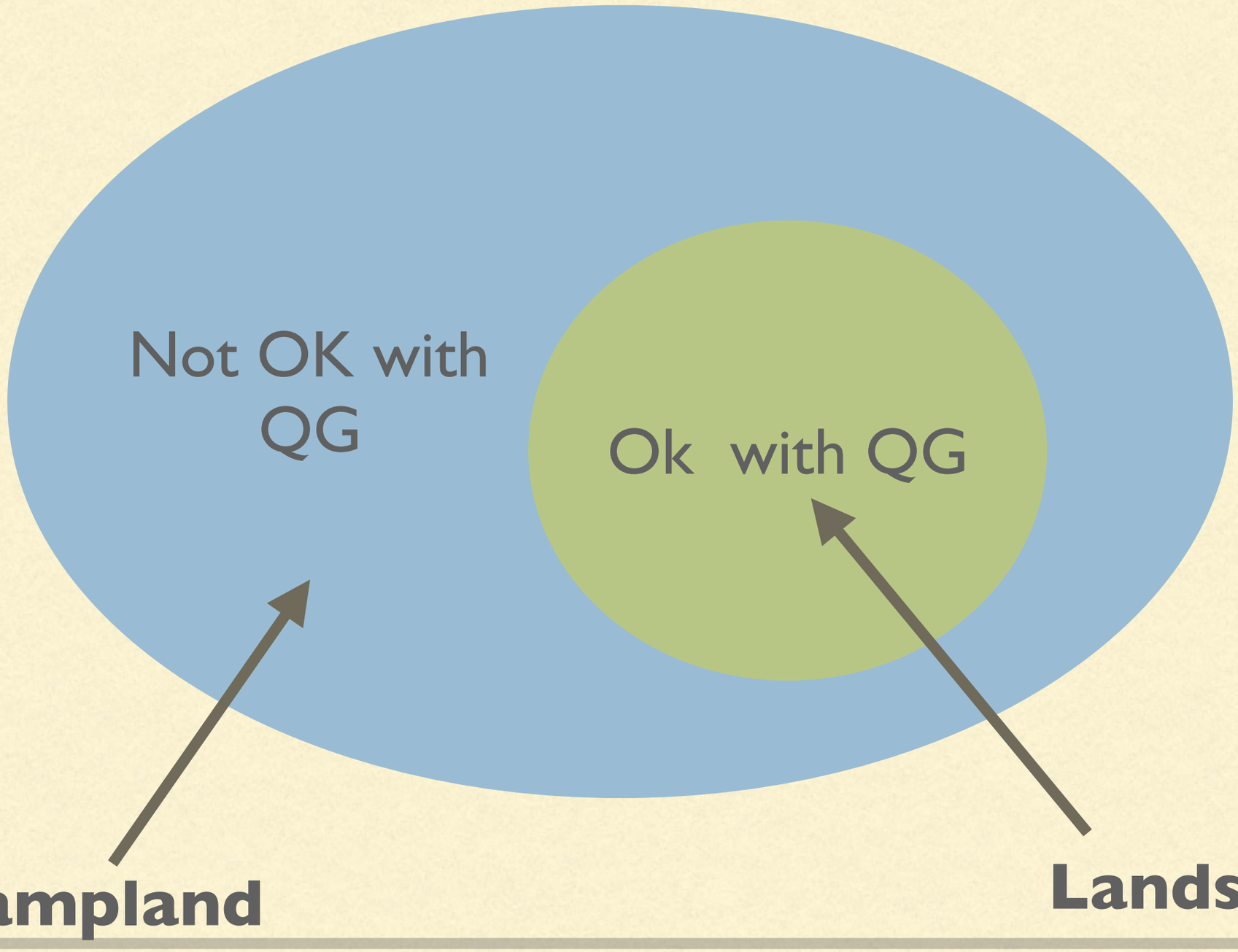

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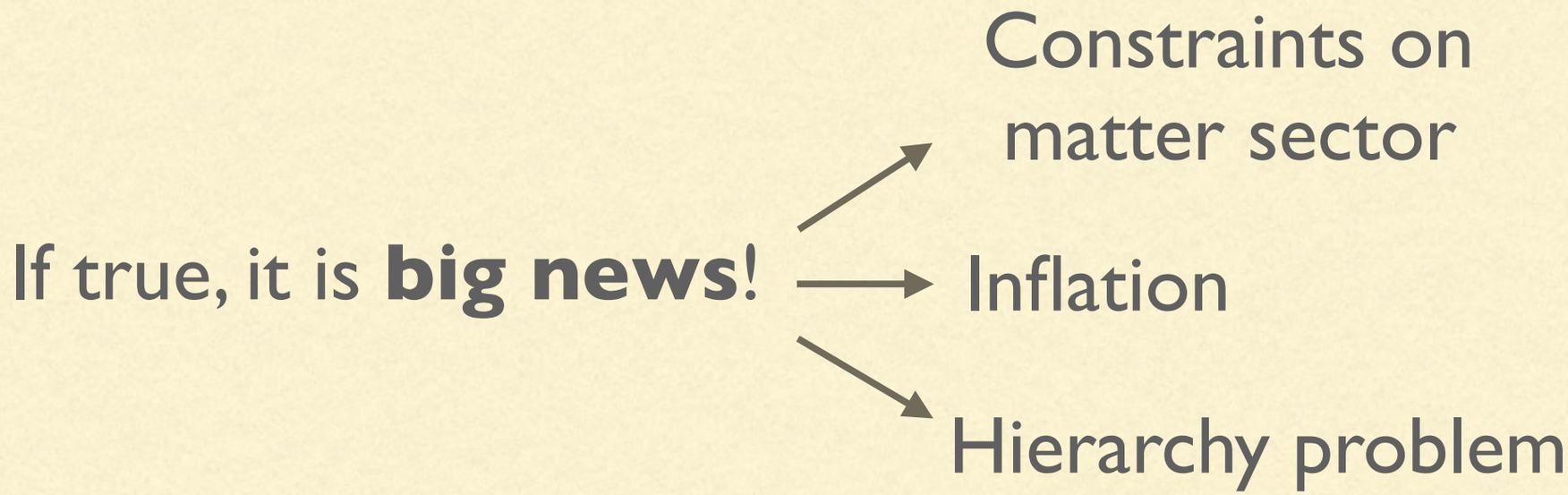

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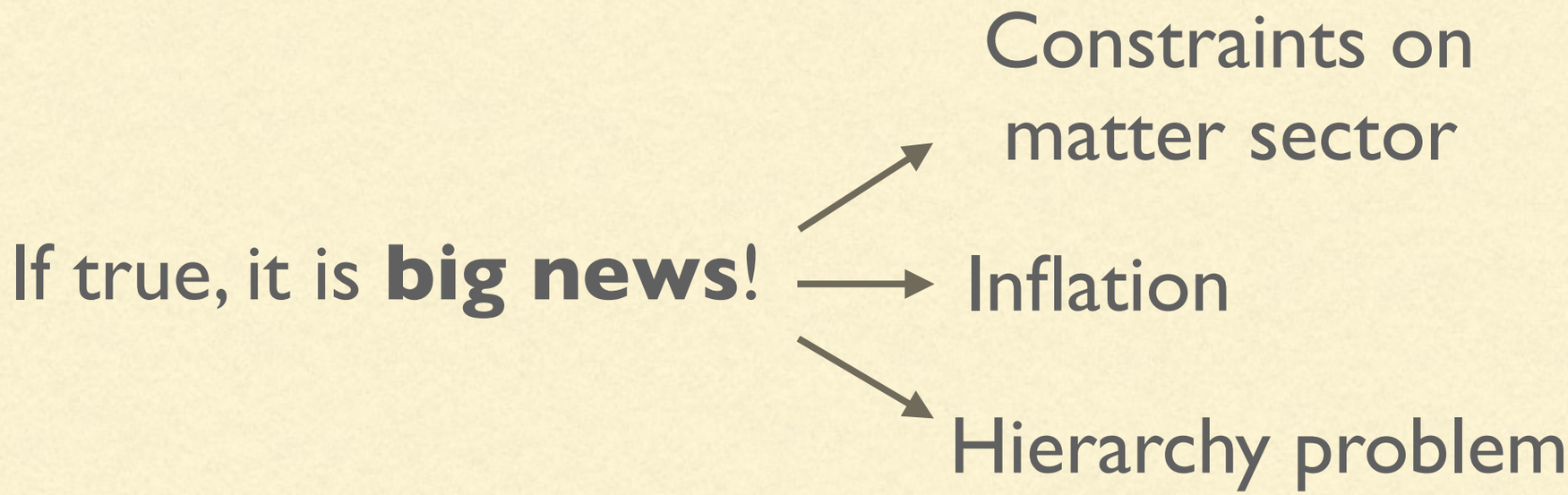

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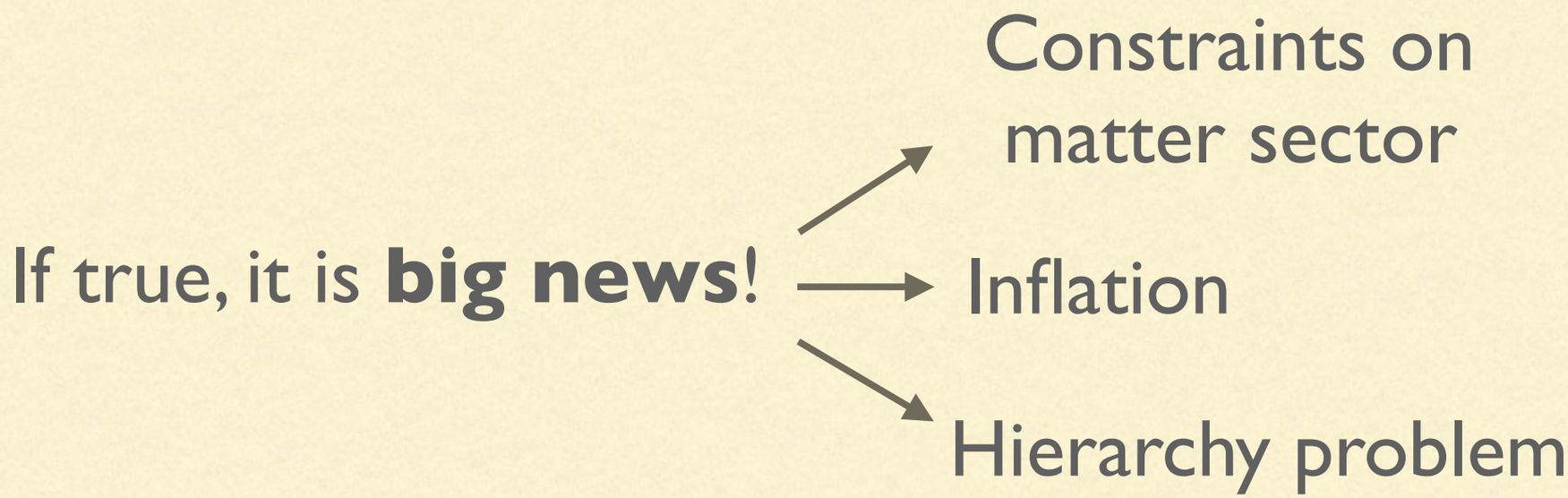

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- ``Empirical evidence'' coming from **string theory**

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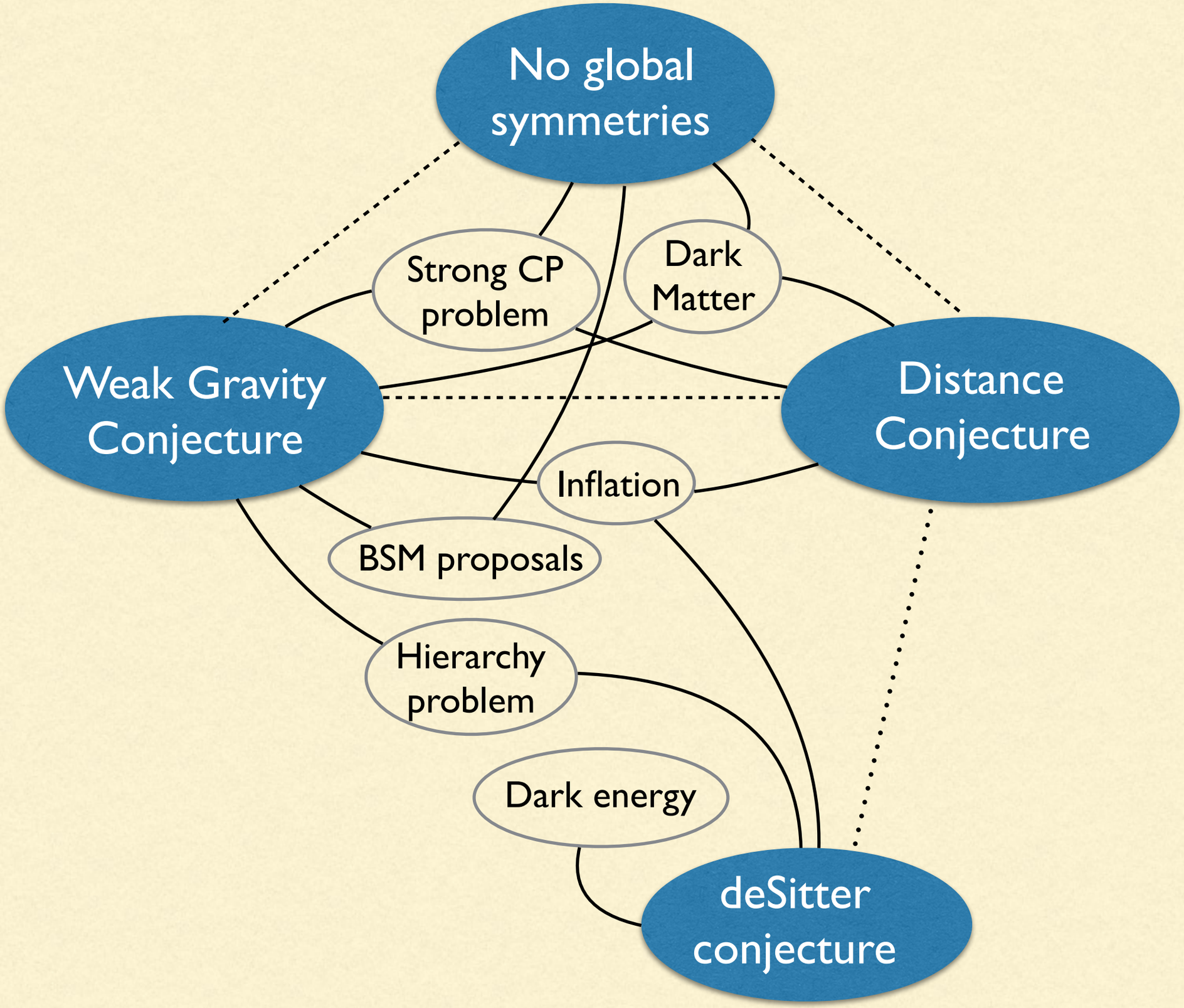
So we organize our knowledge in terms of **conjectures**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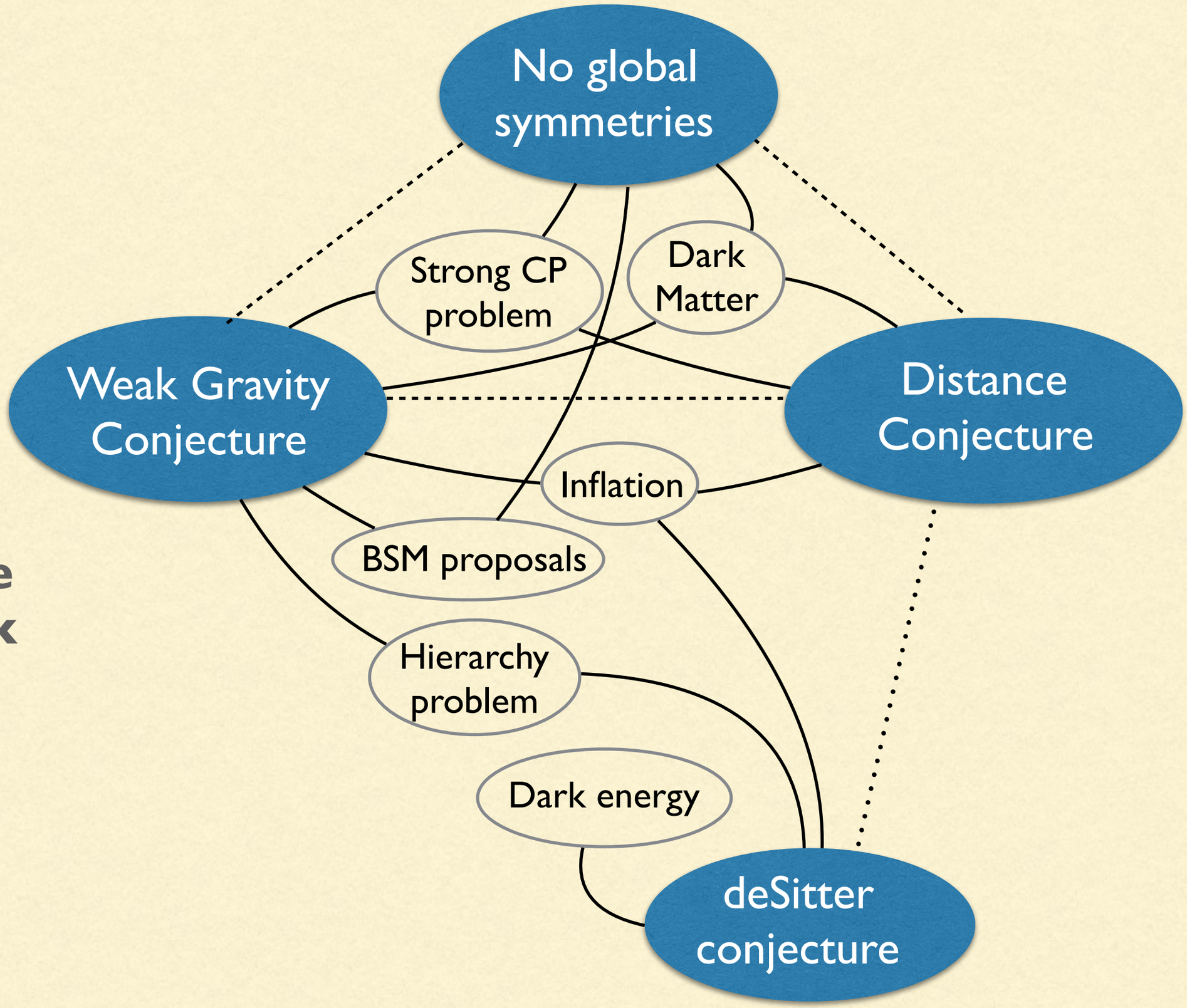
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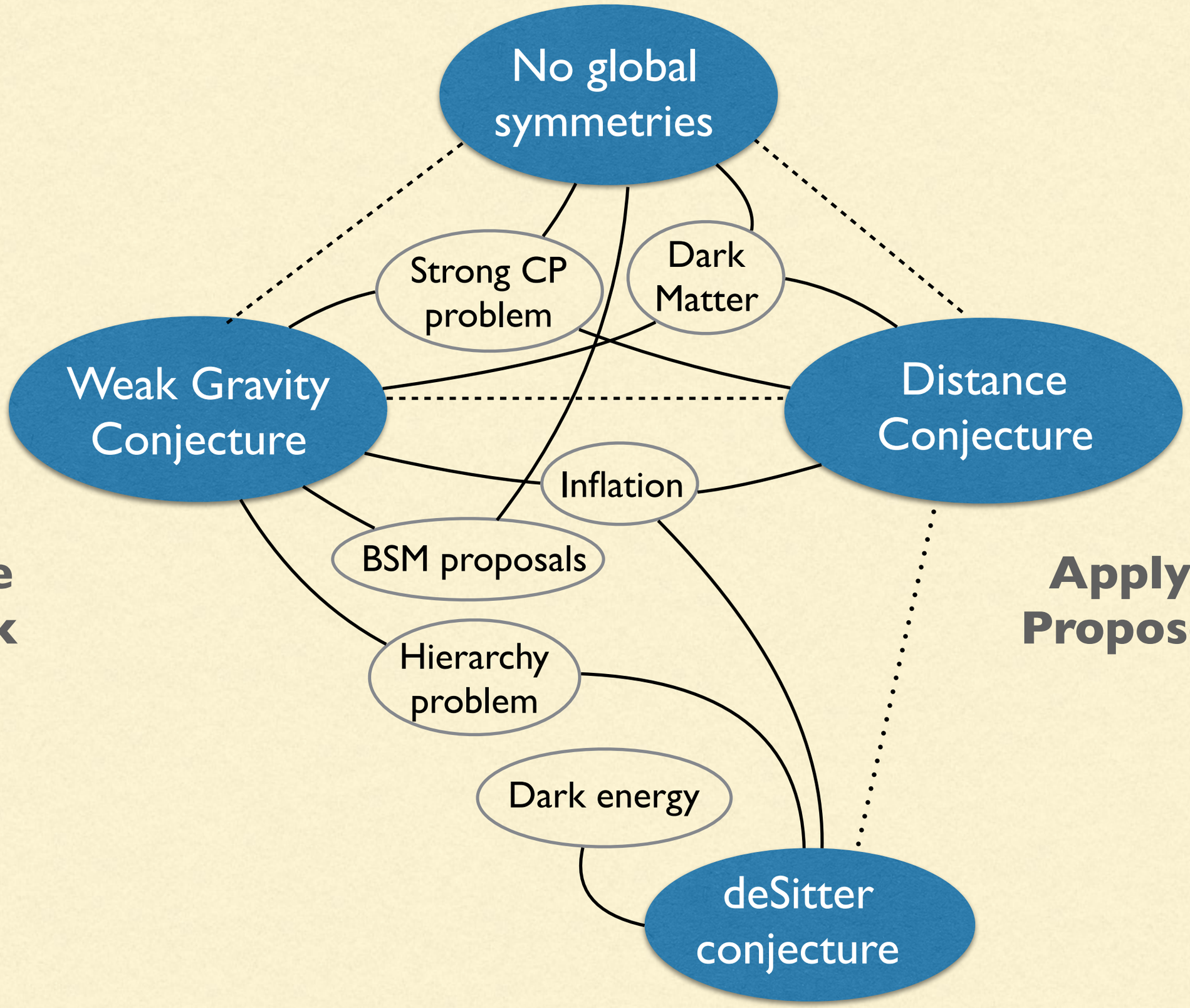

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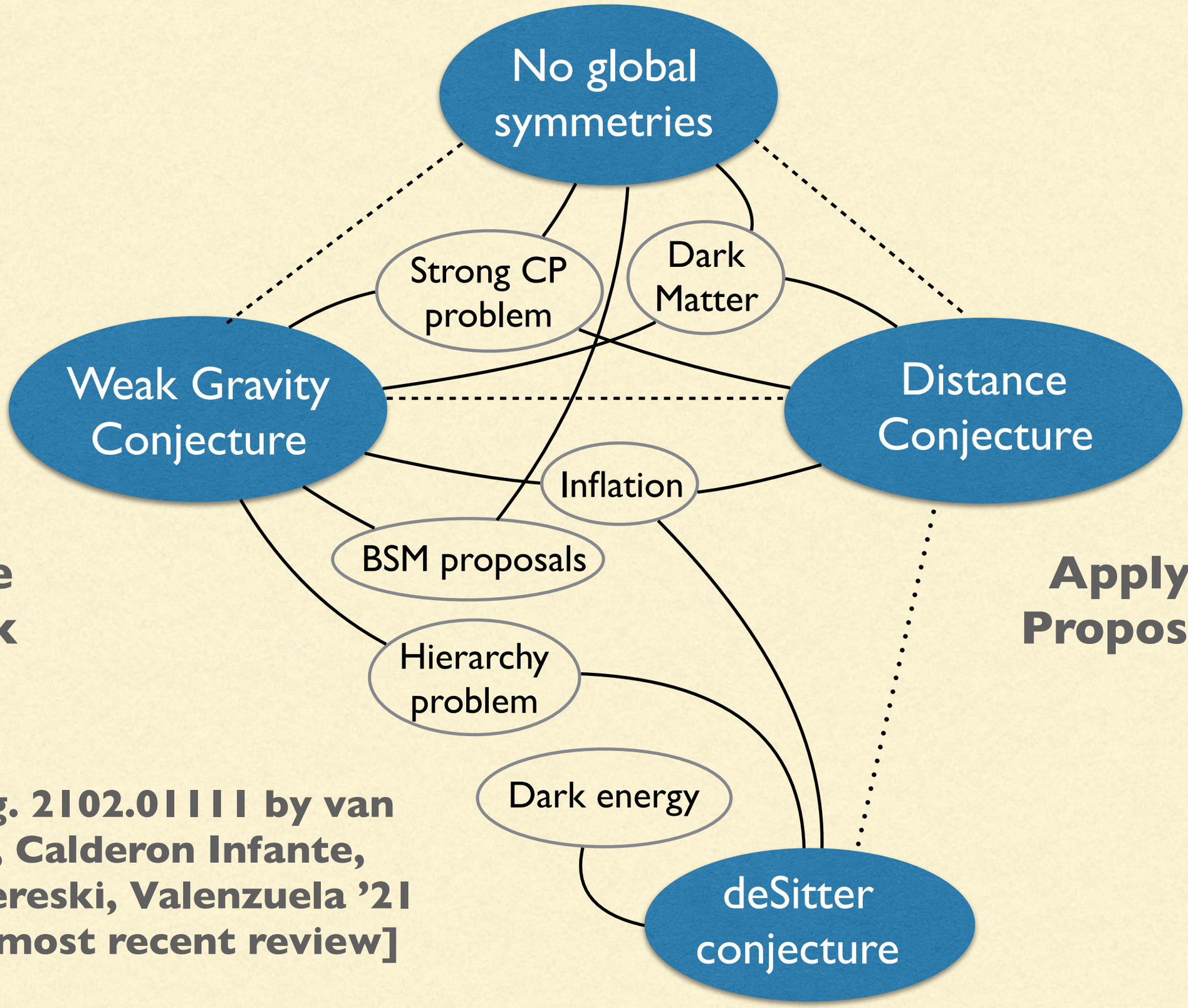

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[See e.g. 2102.01111 by van Beest, Calderon Infante, Mirfendereski, Valenzuela '21 for the most recent review]

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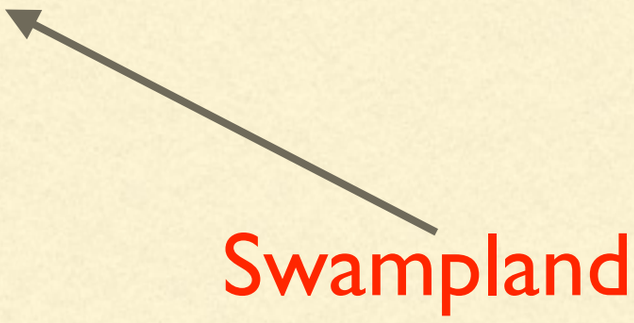

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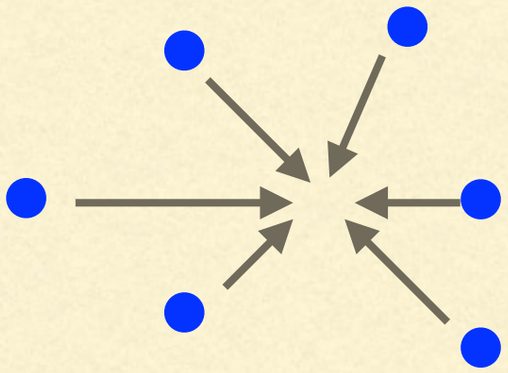

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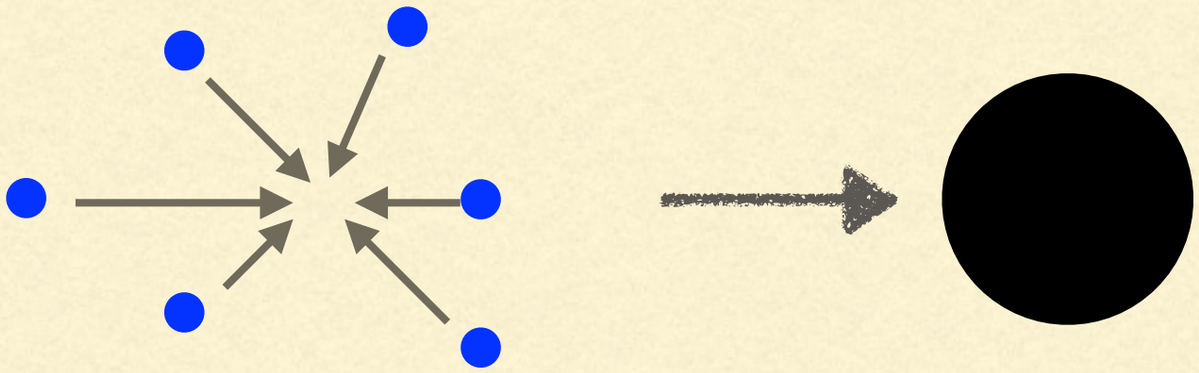

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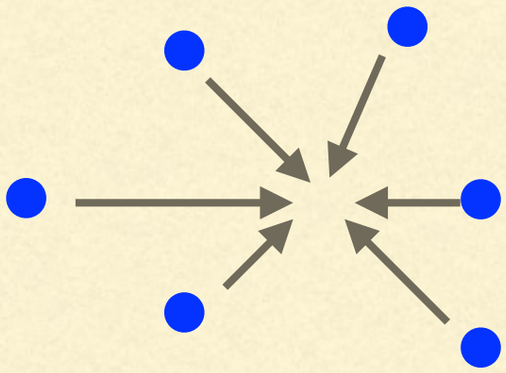

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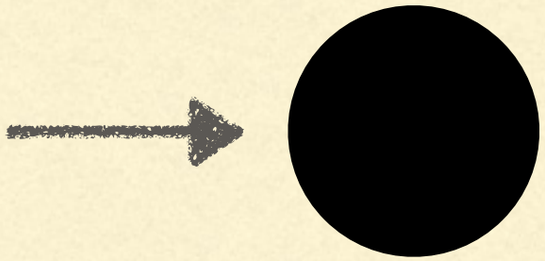

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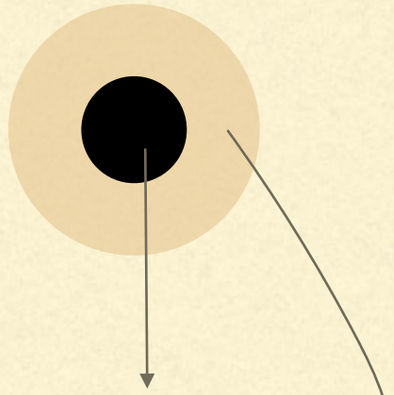

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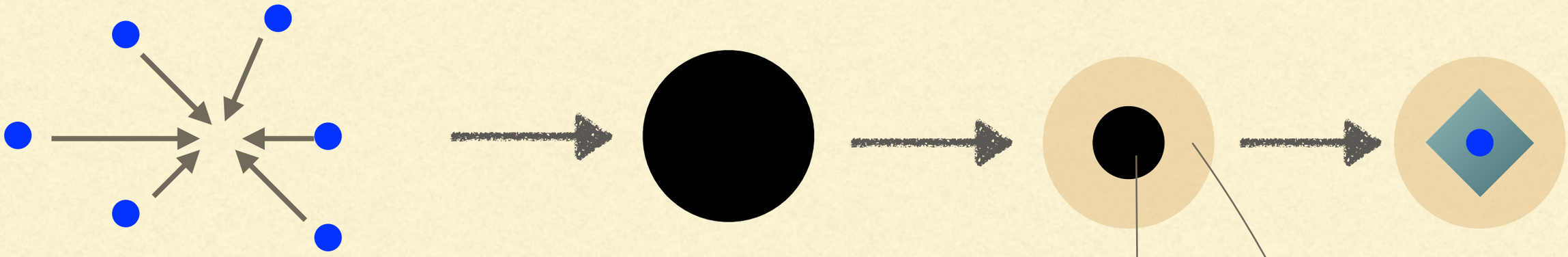

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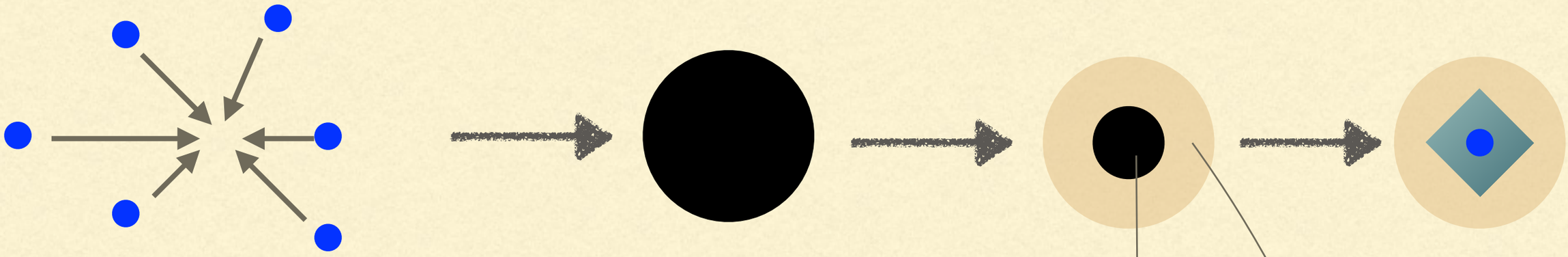

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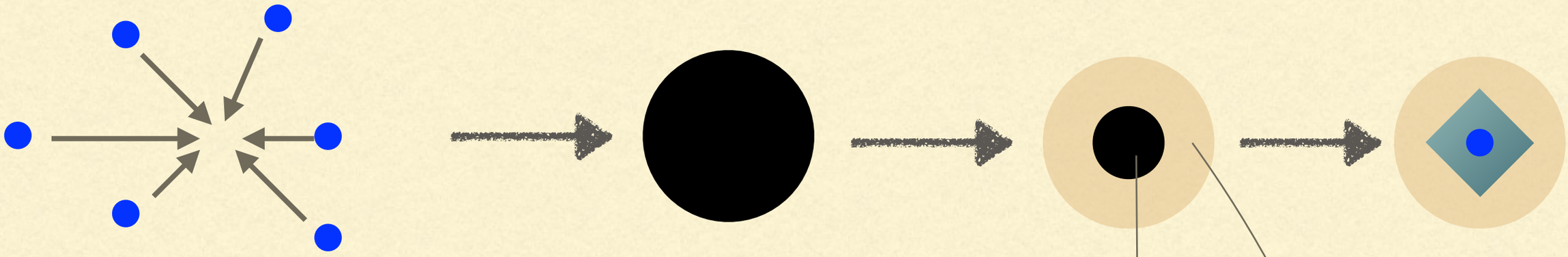

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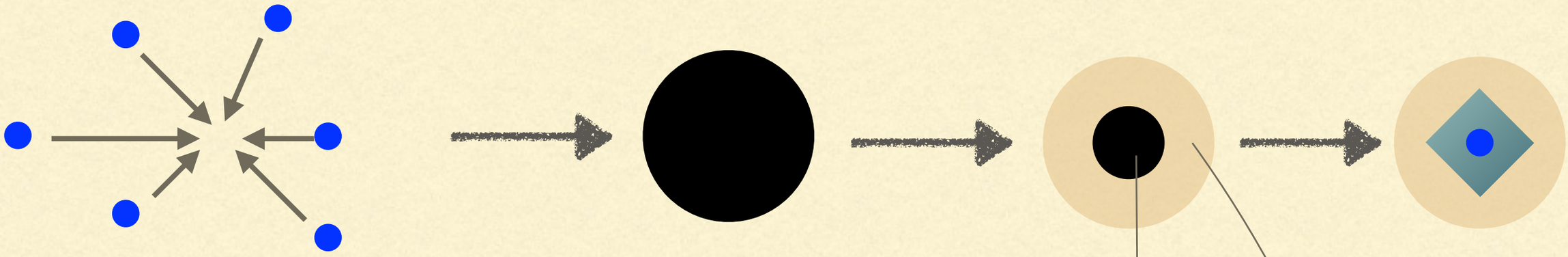

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Their contributions to loops would ruin any EFT

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Always true in every ST example

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But combined with supersymmetry + anomalies, it becomes **very strong**

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Swampland task is essentially **complete** in 8d, 9d at level of massless fields.

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Thus realizing **Coulomb branch** string universality

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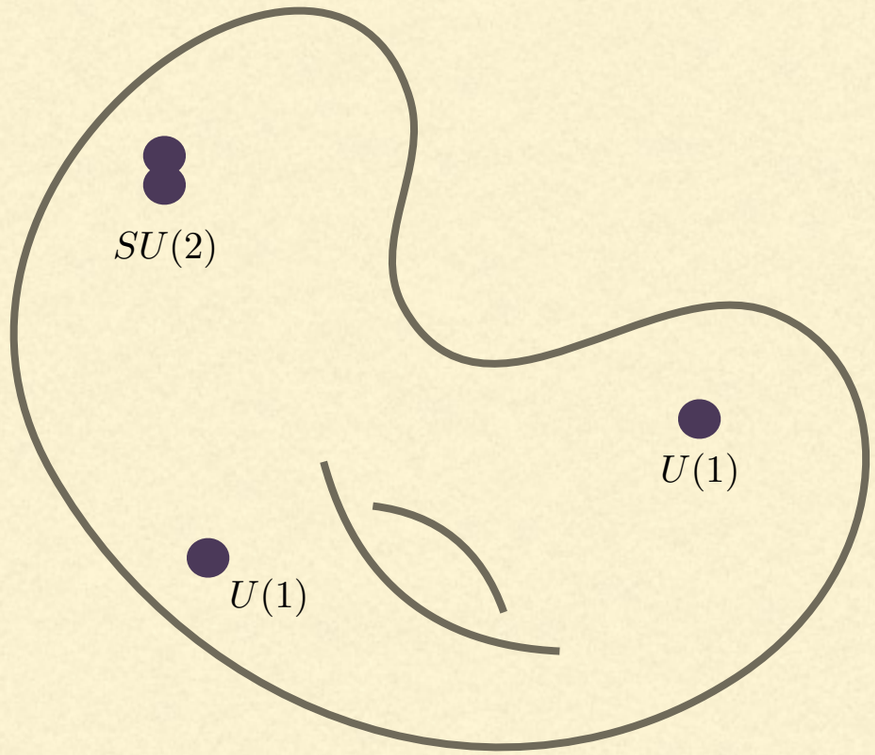

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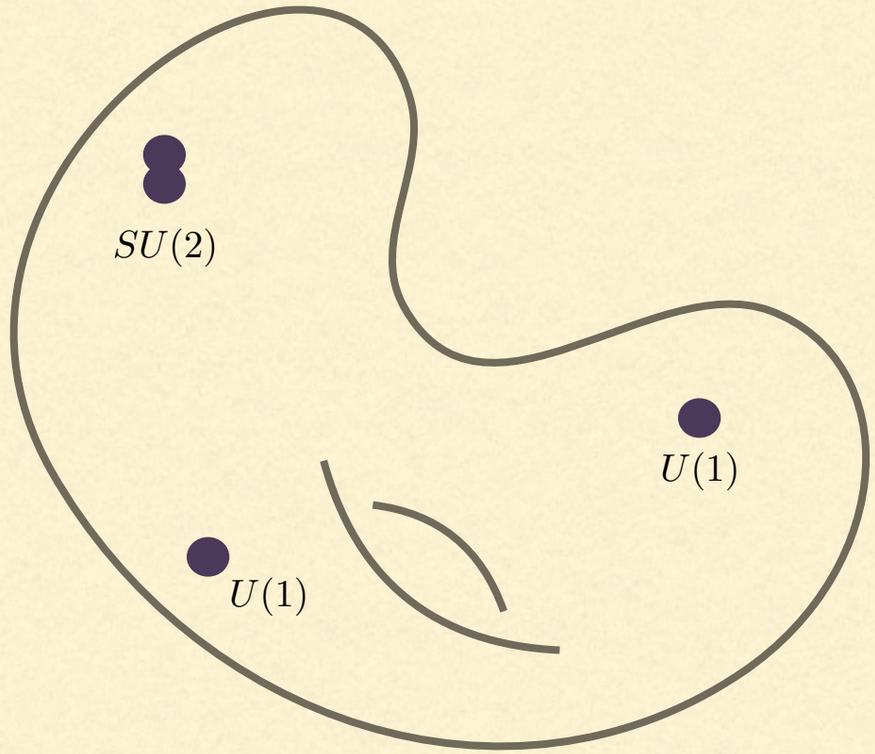

Algebra	$\dim(\mathfrak{g}) + \mathrm{rank}(\mathfrak{g})$	$\neq 0 \bmod 8$?	Group	Real reps?
A_k	k^2+3k	$k \neq 0, 5 \bmod 8$	$SU(k+1)$	✗
			$PSU(k+1)$	✓
B_k	$2k(2k+1)$	$k \equiv 1, 2 \bmod 4$	$Spin(2k+1)$	✗
			$SO(2k+1)$	✓
C_k	$2k(2k+1)$	$k \equiv 1, 2 \bmod 4$	$Sp(k)$	✗
			$Sp(k)/\mathbb{Z}_2$	✓
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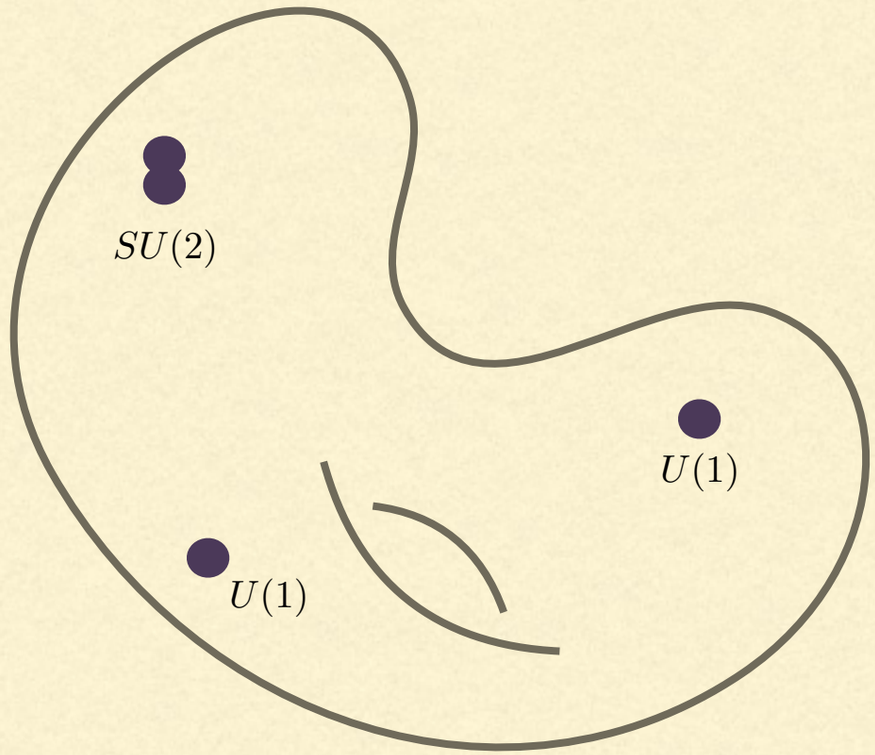
			$Spin(2k)/\mathbb{Z}_4$	✓
E_6	84	✓	E_6	✗
			$E_6/\mathbb{Z}_3$	✓
E_7	140	✓	E_7	✗
			$E_7/\mathbb{Z}_2$	✓
E_8	256	✗	E_8	✓
F_4	56	✗	F_4	✓
G_2	16	✗	G_2	✓

There are also nontrivial predictions for the patters of symmetry enhancement at special points in moduli space

So, **problem solved** at a generic point in moduli space.

But, at special points you get enhanced gauge symmetries (e.g. 2 D7's coinciding)



Algebra	$\dim(\mathfrak{g}) + \mathrm{rank}(\mathfrak{g})$	$\neq 0 \bmod 8$?	Group	Real reps?
A_k	k^2+3k	$k \neq 0, 5 \bmod 8$	$SU(k+1)$	✗
			$PSU(k+1)$	✓
B_k	$2k(2k+1)$	$k \equiv 1, 2 \bmod 4$	$Spin(2k+1)$	✗
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For e.g. rank 9 in 9d, this was a **Swampland prediction** which was later verified by ST calculations [Fraiman, Font, Graña, Parra '21]

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Recently, we have also uncovered connections between Swampland and **geometry** in these higher-dim. setups.

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Exact reconstruction of **bulk** moduli space

(e.g. only compact, hyperkahler manifolds are T4 and K3)

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Can we have **more than one string theory** with the exact same massless sugra?

(e.g. discrete theta angles in 11d M theory [Freed-Hopkins '19])

Massive states can be **attacked** via the **cobordism conjecture**

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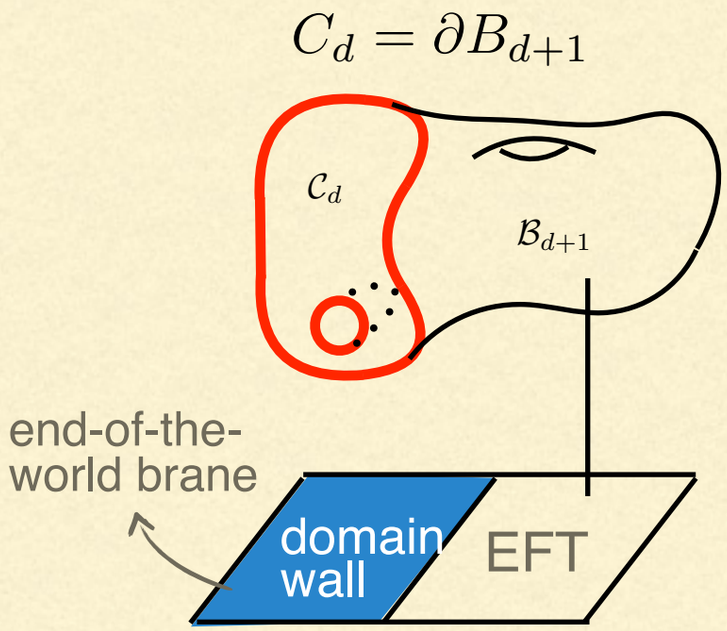

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$$\Omega^{\mathrm{QG}} = 0$$

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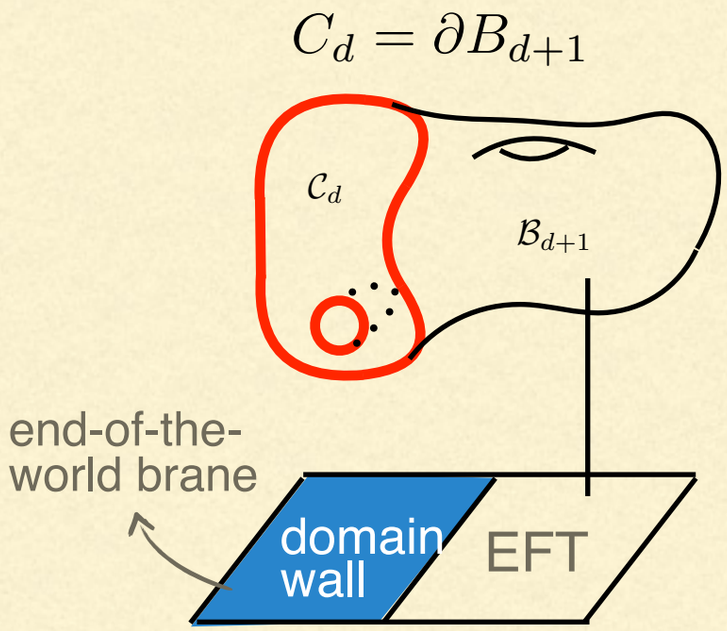

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Fun connections with anomalies & algebraic topology, K-theory… [Blumenhagen-Cribiori '21]

State-of-of-the art calculations in algebraic topology

The Weak Gravity Conjecture

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

There has to be a particle whose **electric charge** is bigger than its mass in Planck units:

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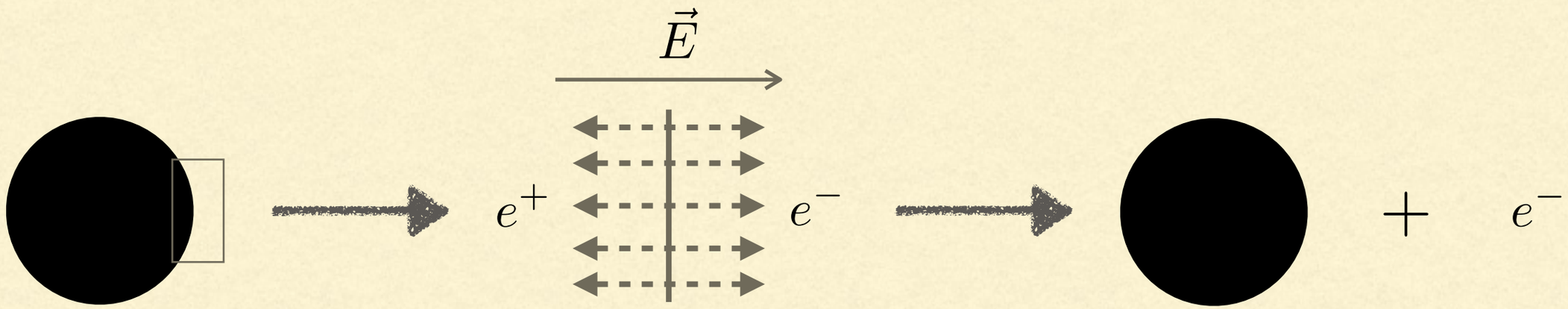
Satisfied in real world by **electrons**, and related to kinematics of black hole evaporation



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Last week's comprehensive review by Harlow, Heidenreich-Reece-Rudelius. Do check!

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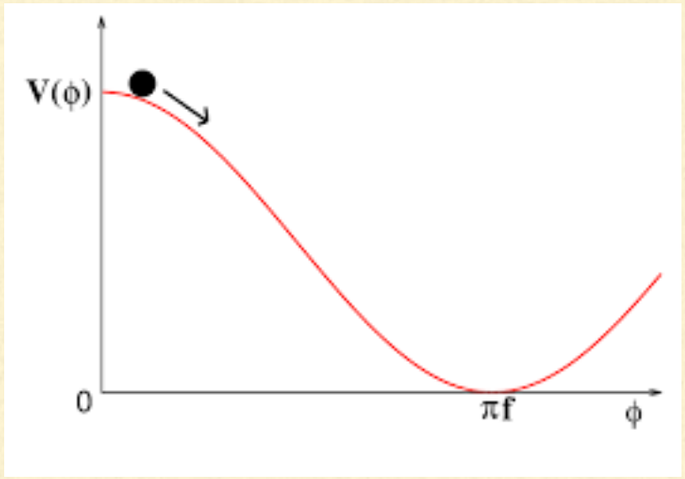
and models of **natural inflation**



$$V(\phi) \sim e^{-\frac{M_P}{f}} \cos(\phi/f)$$

puts upper bound on
cosmological observables

The Distance Conjecture

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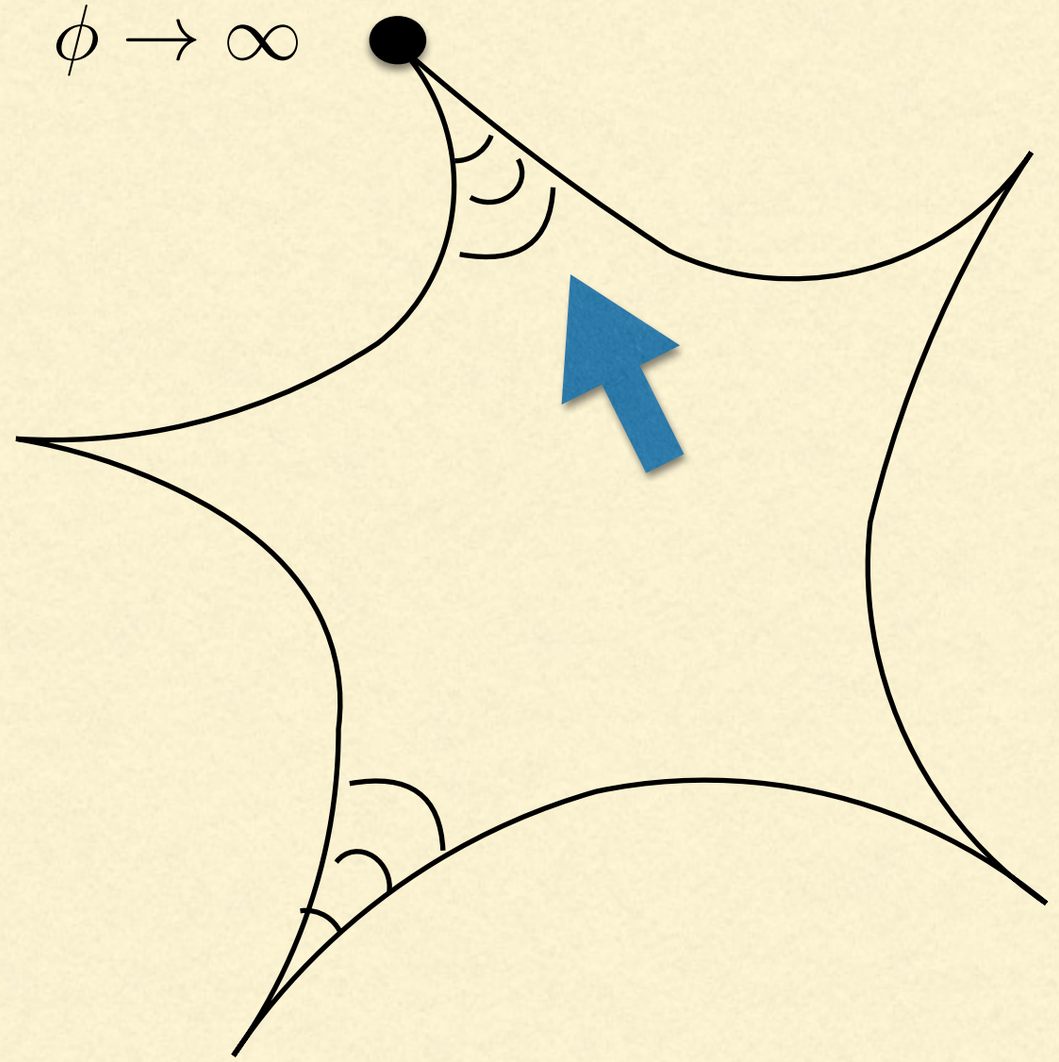

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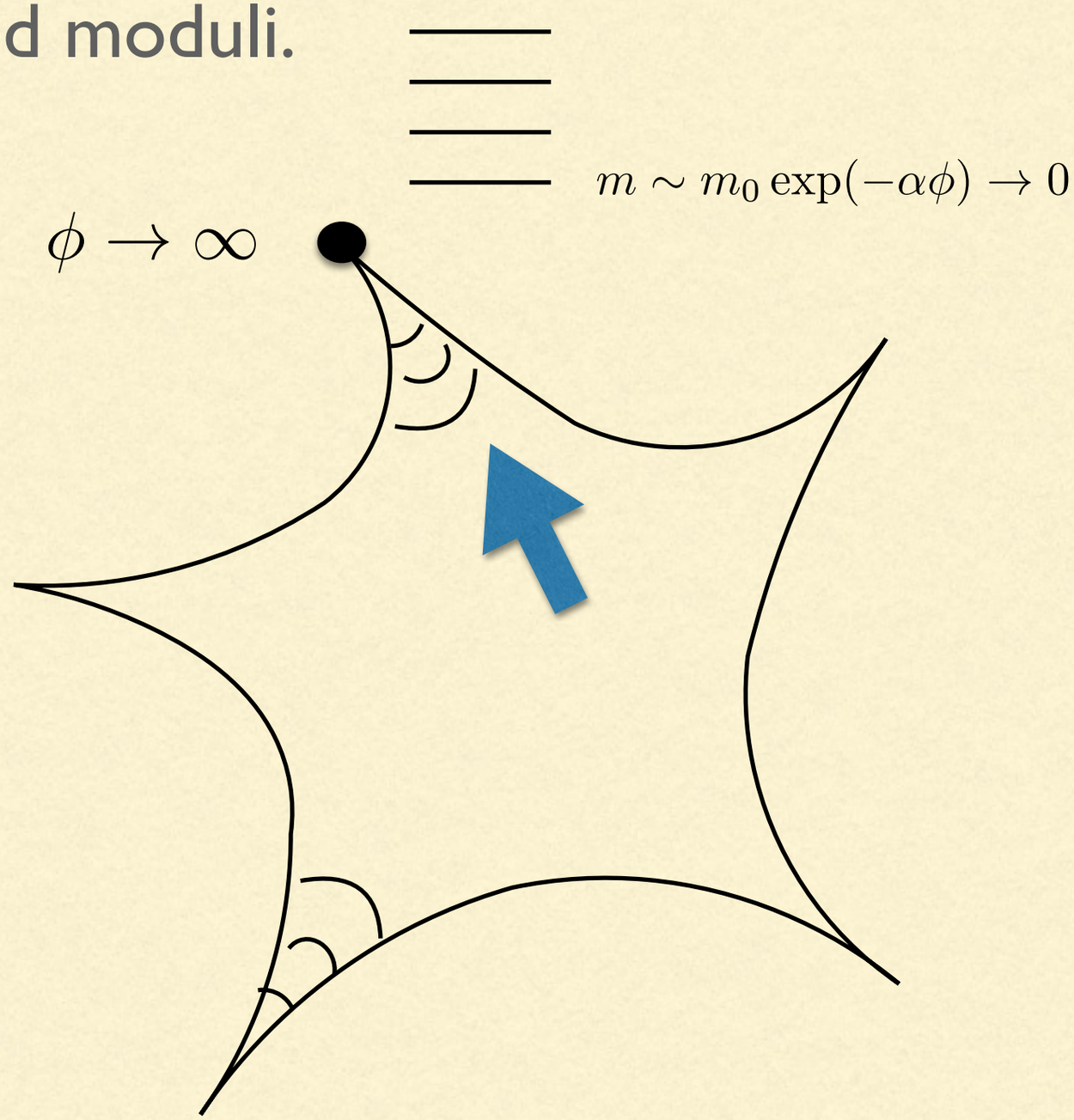
Empirical ST observation: As a scalar gets a very large vev, many states become light with respect to Planck mass and EFT breaks down



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In 4d, intriguing connection to codimension-2 axion strings in moduli space

[Lanza-Marchesano-Martuci-Valenzuela '20, '21]

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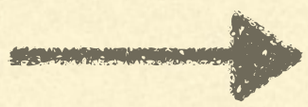
$$m(P) \sim m(Q) e^{-\alpha \Delta \phi}$$



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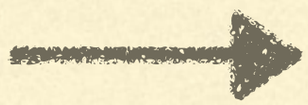

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Is it really so bad to have a light tower of states during inflation?

(SDC does not say anything about nature of coupling)
(topological gravity? [Obied, Agrawal, Gukov, Vafa '19,'20]

The SDC also leads to predictions about **black hole extremality bound**

[Heidenreich-Reece-Rudelius '18, Gendler-Valenzuela '19]

There is even a black hole argument supporting it for limits where a gauge coupling vanishes

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(Finiteness of QG amplitudes?)

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Emergence Proposal [Harlow-Heidenreich-Reece-Rudelius-Grimm-Palti-Valenzuela '15,'18]

Infinite distance arises due loops of the tower of states!

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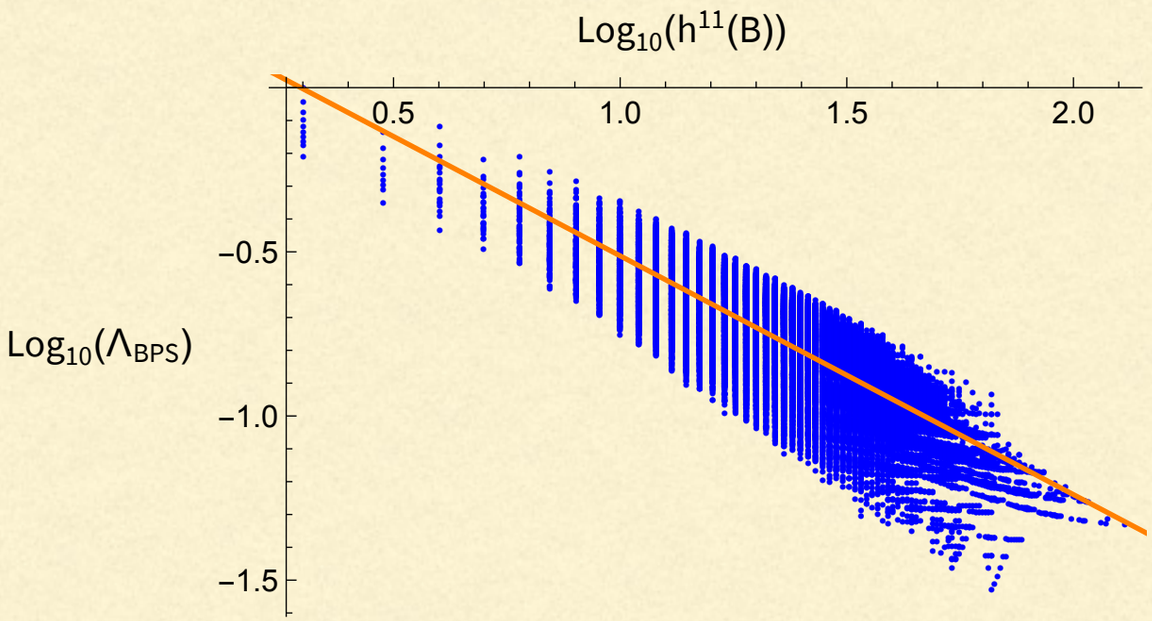

These points are generically **desert**-type scenarios

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This is true in every example we know of, but only **asymptotically**

(maybe there is dS far away from asymptotic limits)

The “no dS” conjecture is not very rigorous. It is only supported by arguments that work in parametric regimes.

[Grimm, Li, Valenzuela '19, Andriot '19-'21, Junghans, Shiu, Hebecker '19-21…]

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As an example of this, I will describe ongoing work on what is called the **tadpole conjecture**

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To do this, I will first describe the existing constructions of dS for string theory.

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Fun observation: #2 is way subtler that one might have thought, taking into account #4!

Tadpole Conjecture: In ST with a large number of complex structure moduli, not all of them can be stabilized with fluxes [Bena-Blaback-Graña-Lust '20]

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Is it true in general? Just violated at special points? Implications for dS?

Even if we forget about dS construction and just ask for scale-separated vacua, there is an **ongoing debate** about whether such vacua can be found in string theory!

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Intriguing observation [Conlon-Ning-Revello ’21]

Dual CFT operators to moduli have **integer dimensions** $m^2\ell^2 = \Delta(\Delta - 3)$

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Please, just ask during the Gather Town or any other time!

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and also why I am very excited to find out what we will **discover** together this week!

HOPE YOU ENJOYED THE HIKE!