
A SURVEY OF GLOBAL SYMMETRY BREAKING IN STRING THEORY & HOLOGRAPHY



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IFT UAM-CSIC



Quantum spacetime and the Renormalization Group
Heidelberg University
April 1, 2025





Please interrupt me!!

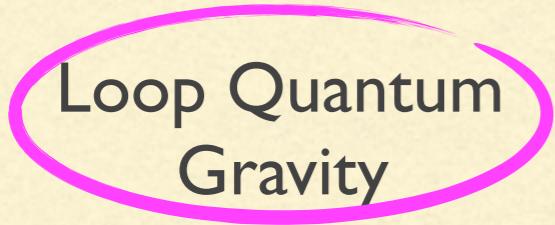
(at any point with questions, comments, whatever!)



**Asymptotic
safety**



Asymptotic
safety



Loop Quantum
Gravity

Asymptotic
safety

String
theory

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Causal sets

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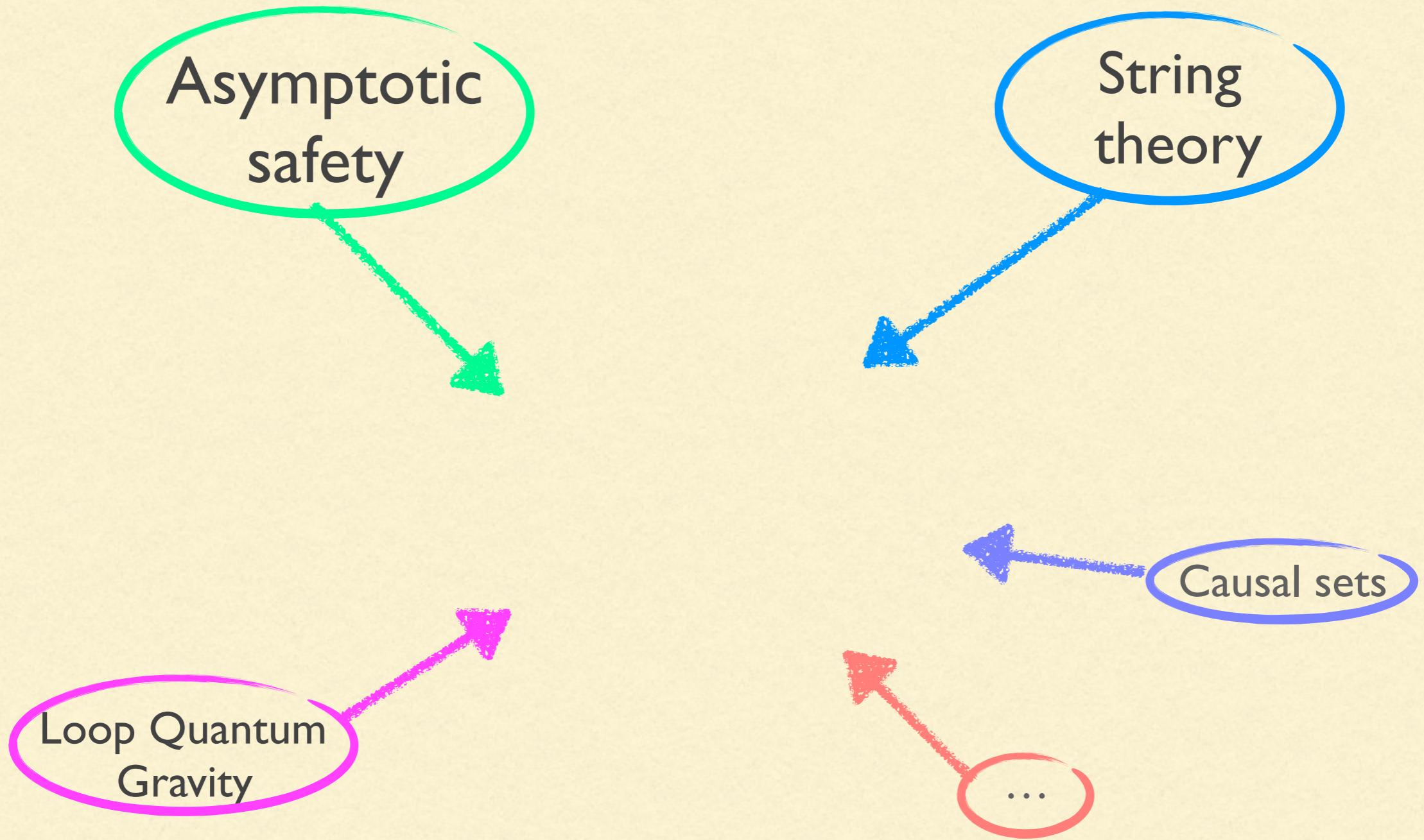
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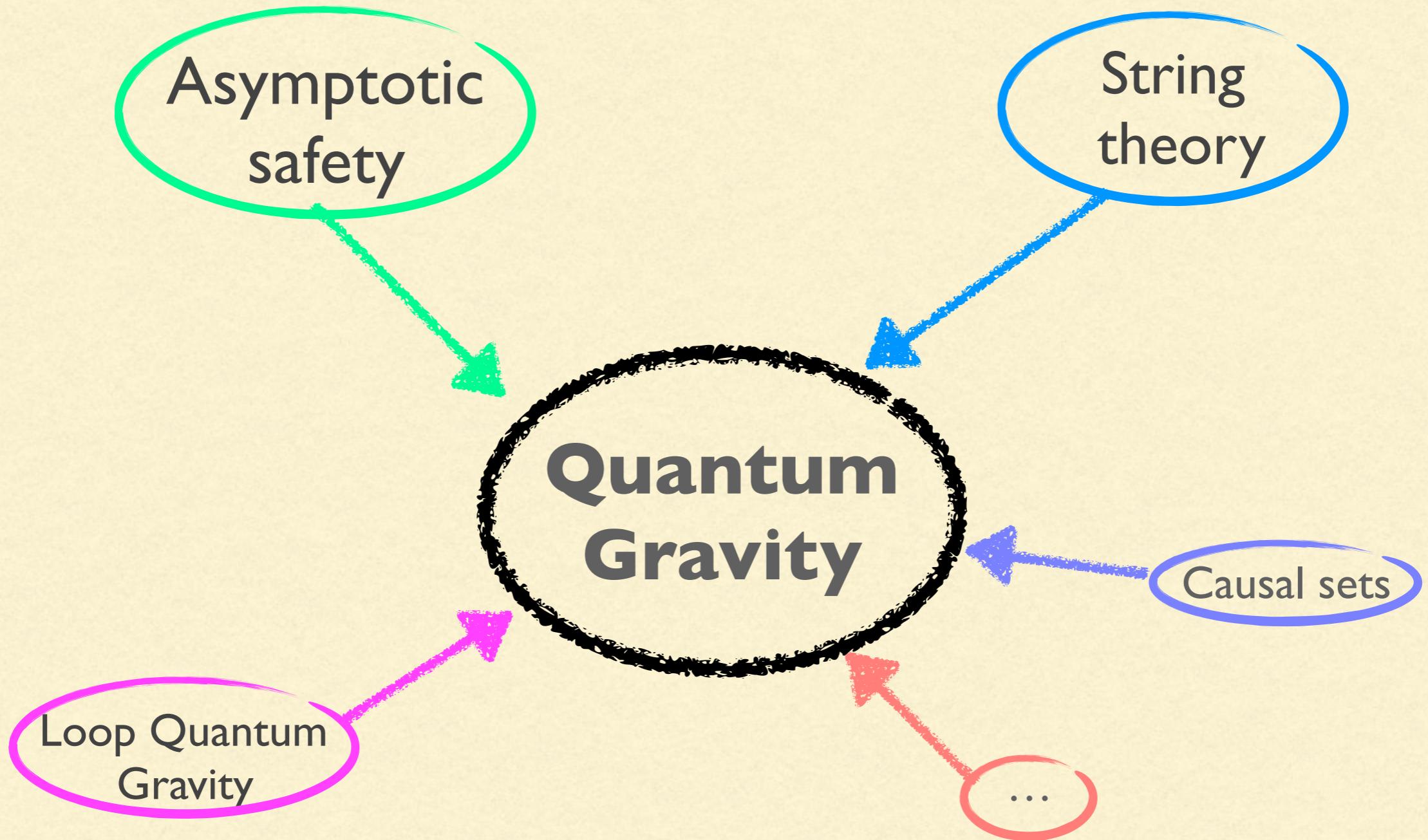
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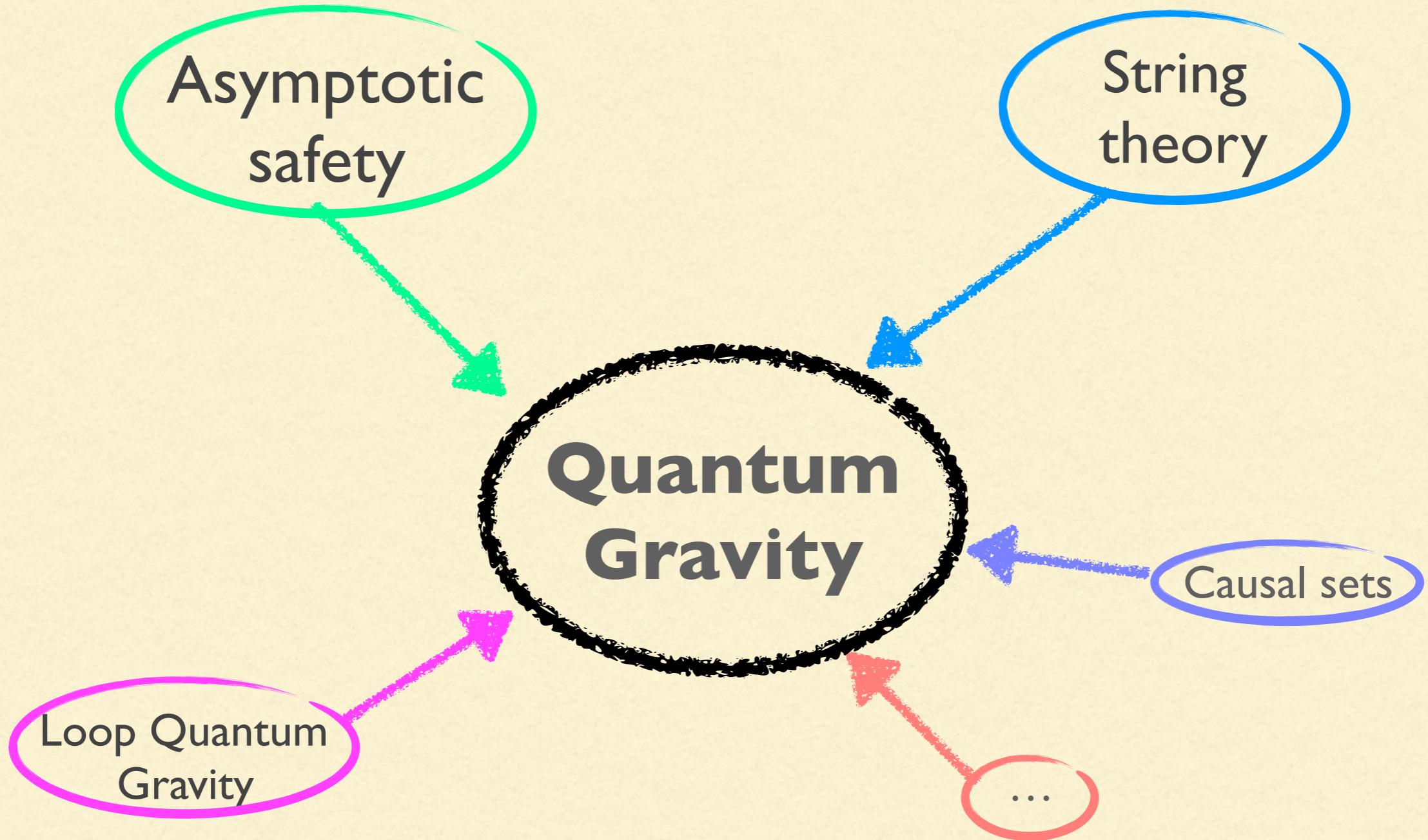
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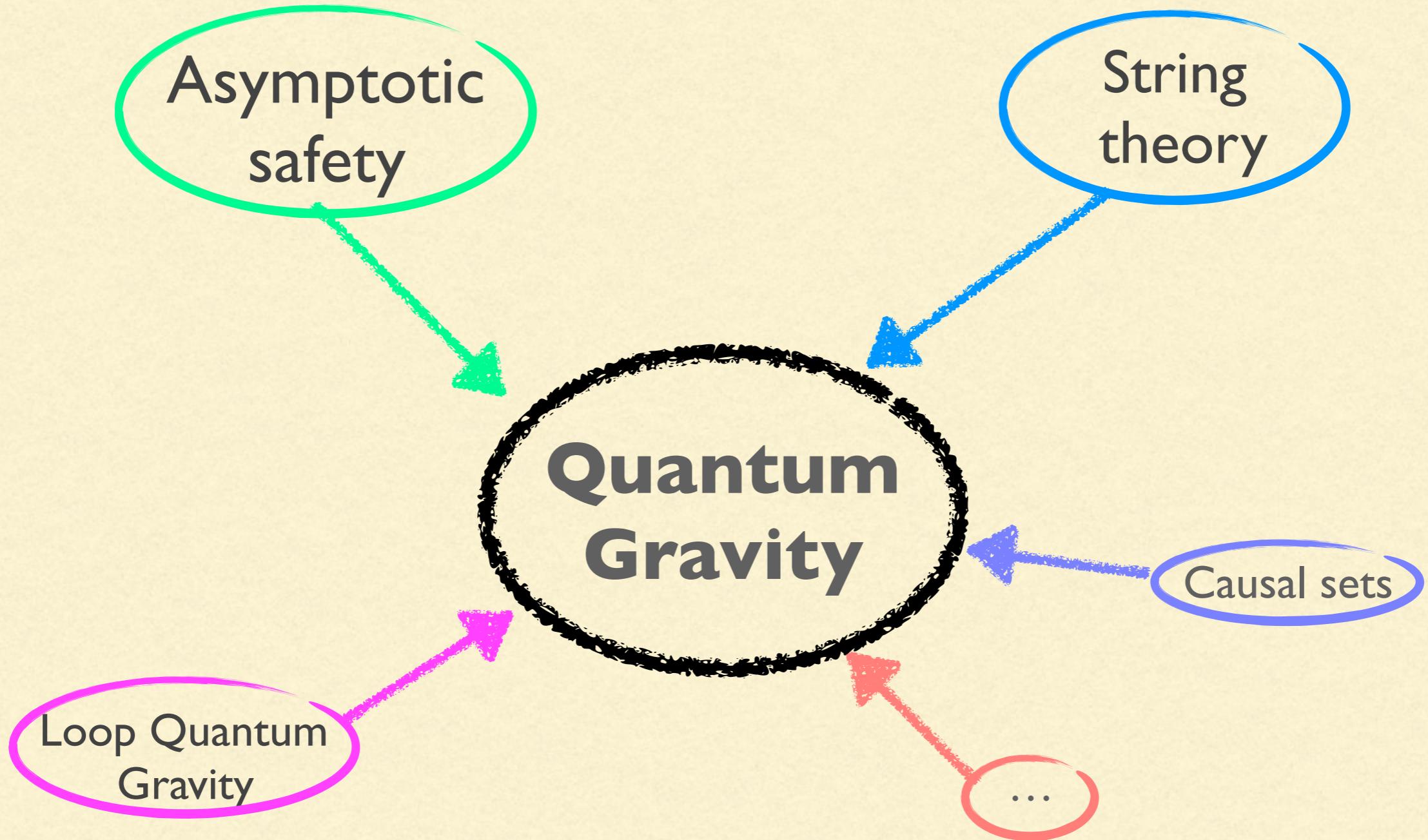








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(tough: $M_P = 10^{19} \text{ GeV} \gg E_{\text{Today}} \sim 10^3 \text{ GeV}$)

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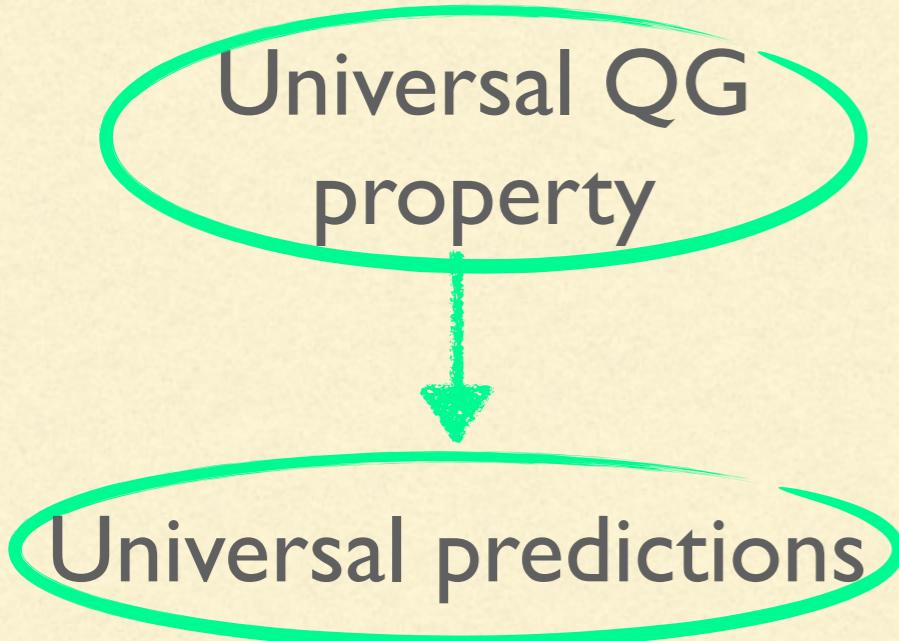
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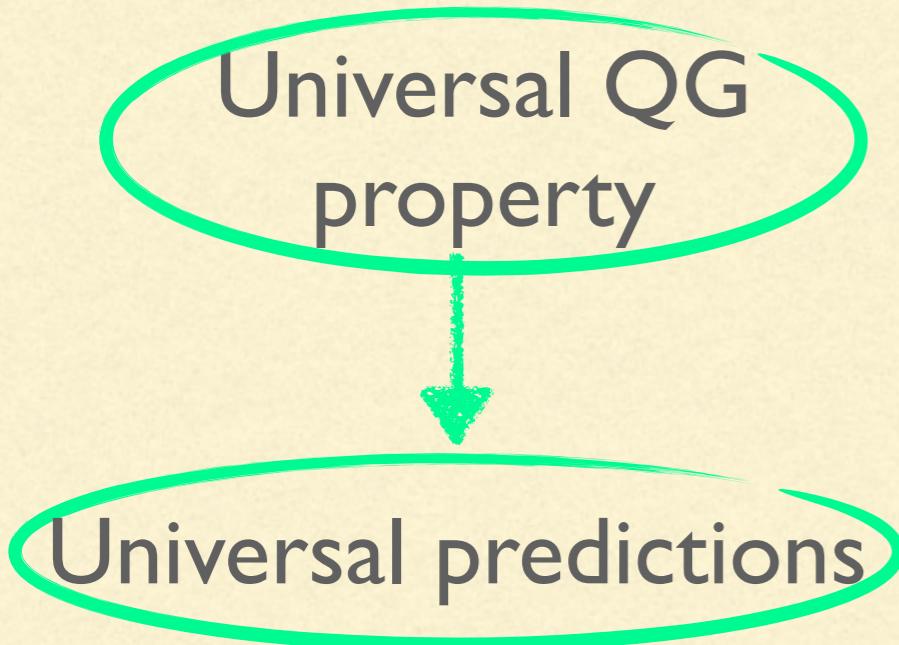
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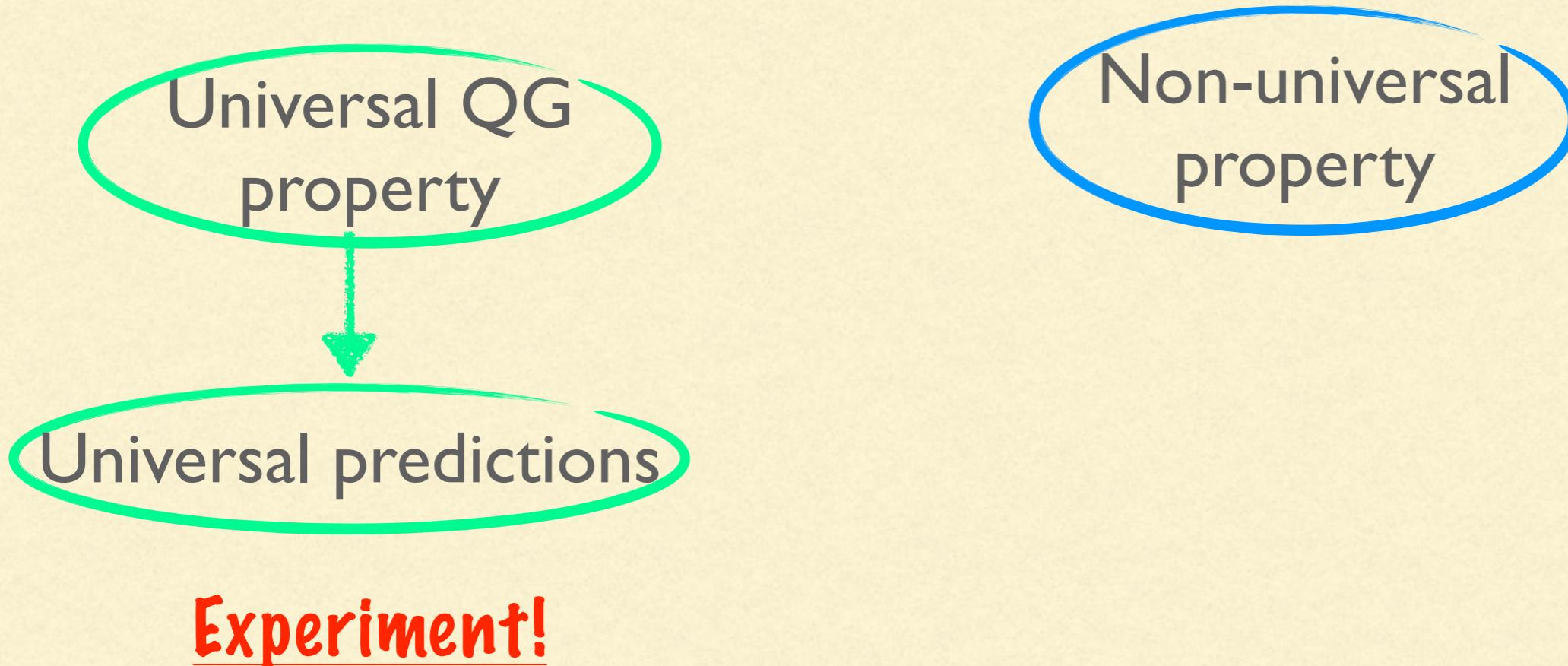


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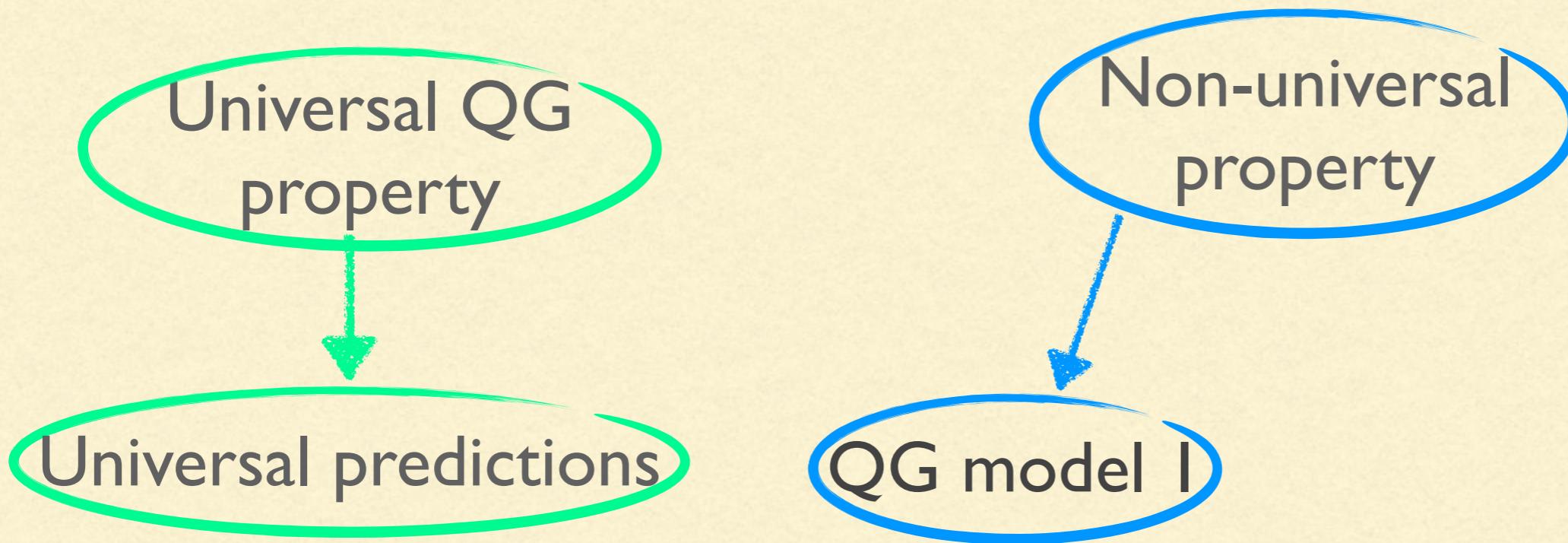


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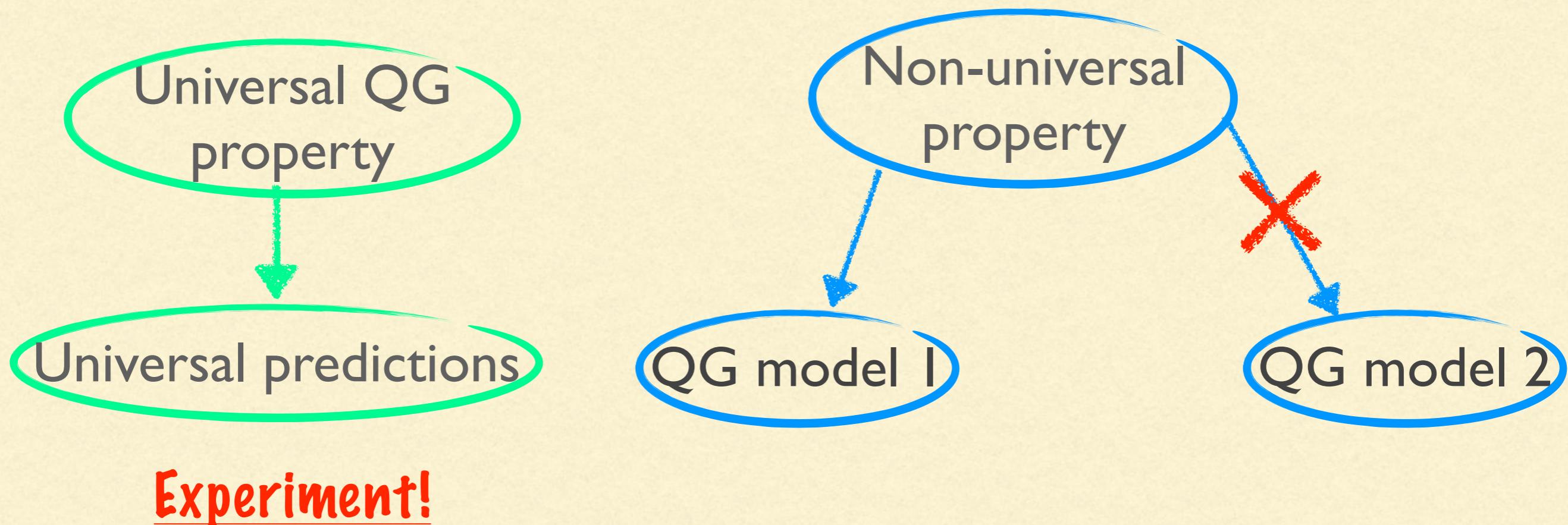


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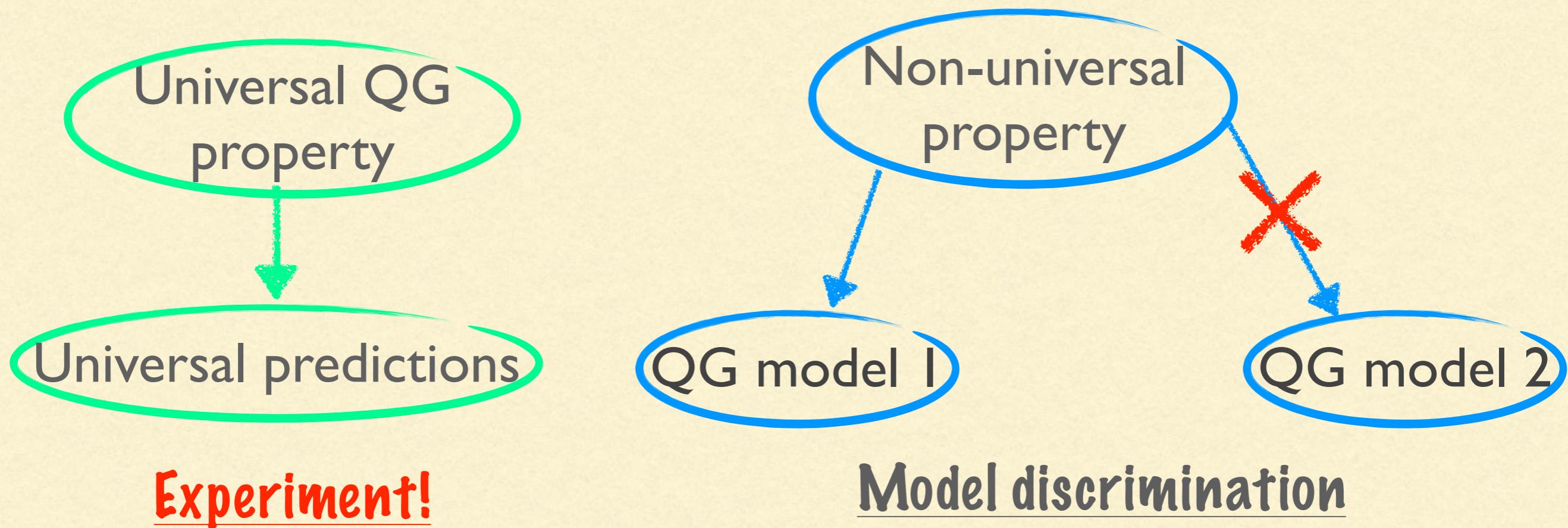


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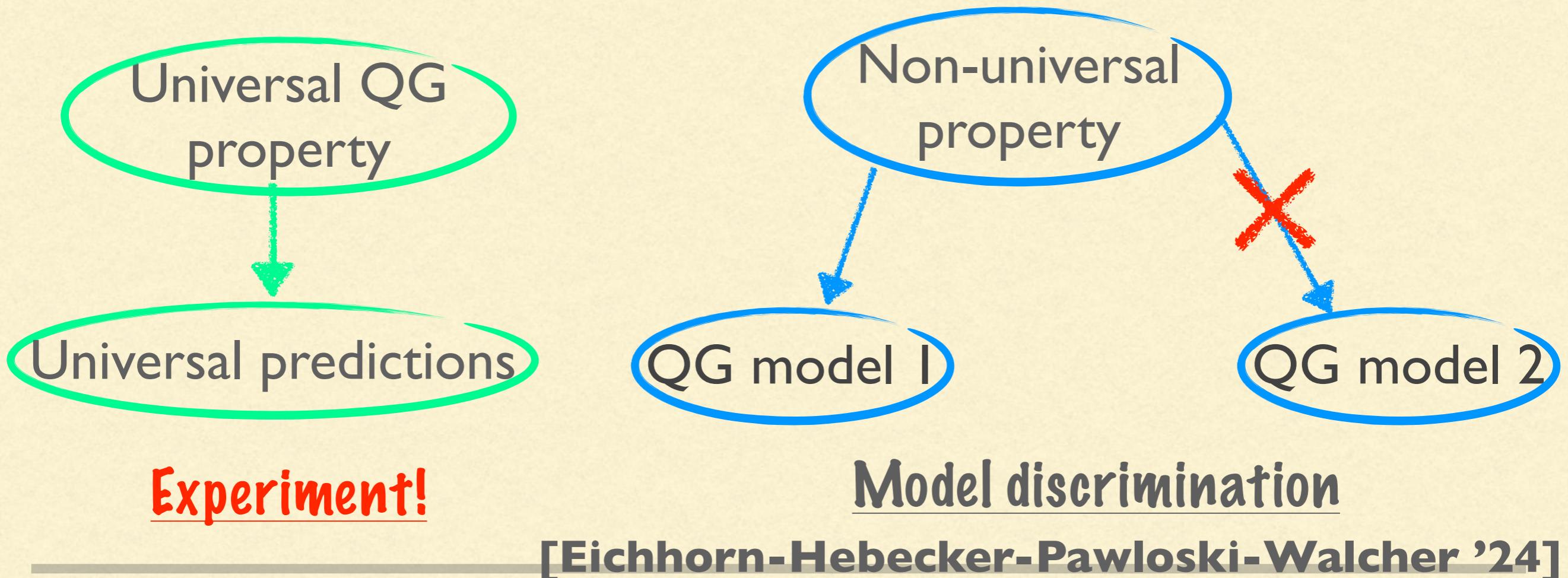
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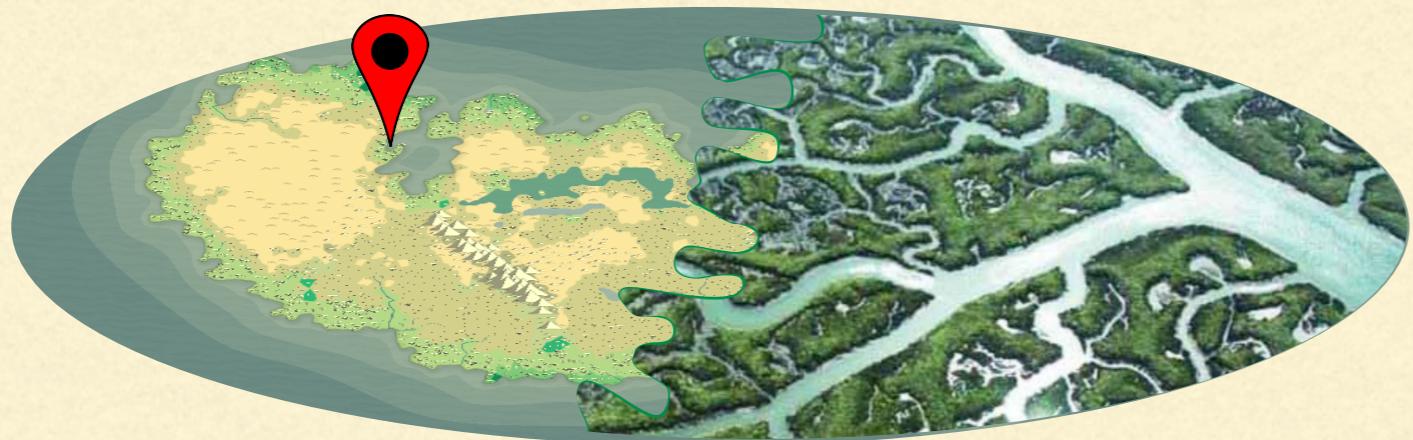
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Finding these **universal/discriminating** properties of QG is what the



Swampland Program

is all about.

[**Palti '19, Van Beest-Calderon Infante -Mirfendereski-Valenzuela '21, Eichhorn-Pauly '20, Basile-Platania '21, Eichhorn-Hebecker-Pawloski-Walcher '24, Basile-Knorr-Platania-Schiffer '25]**

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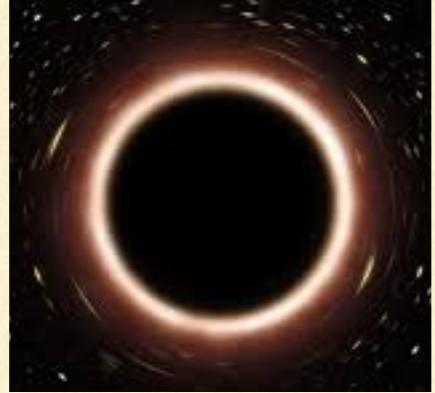
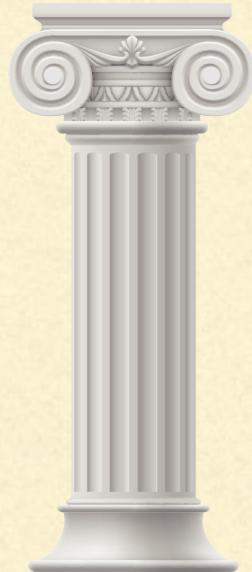
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Gravity forbids exact global symmetries

[Banks, Dixon '88, Polchinski, Wheeler??...]

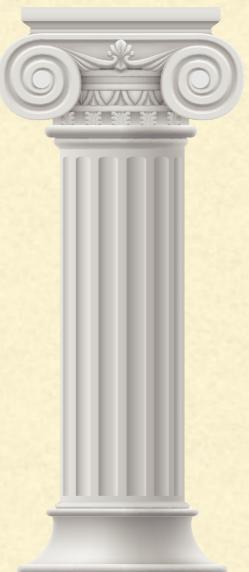
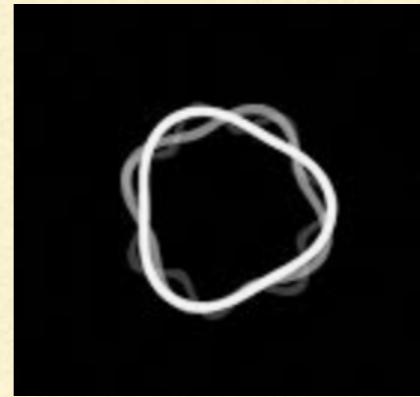
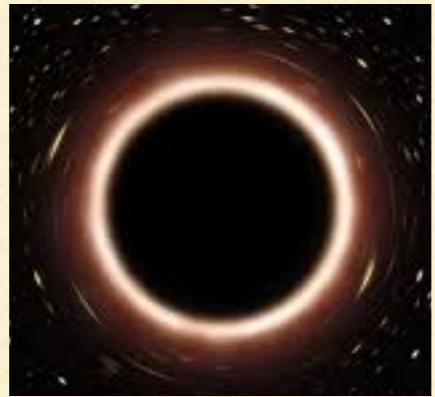
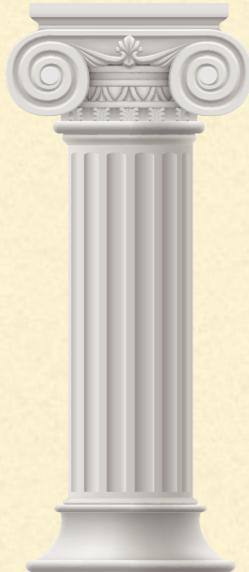
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General arguments
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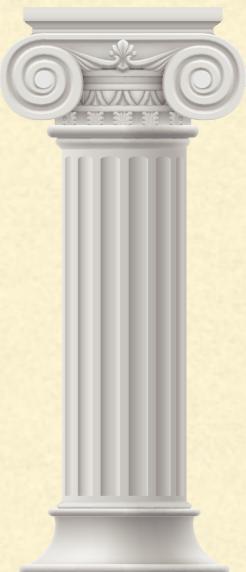
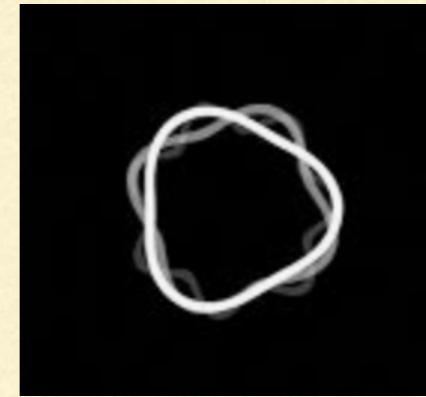
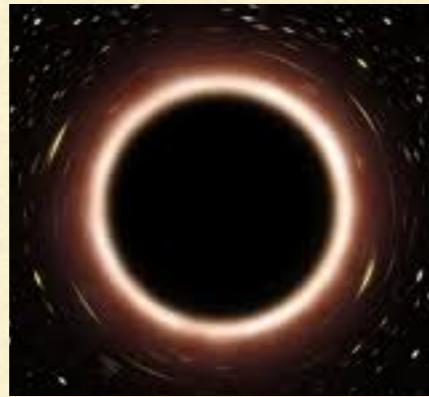
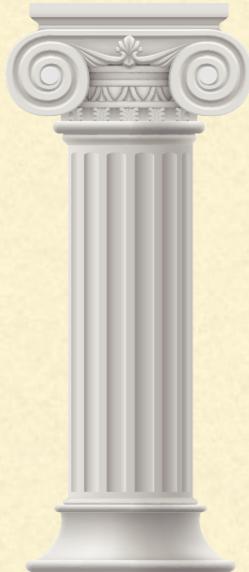
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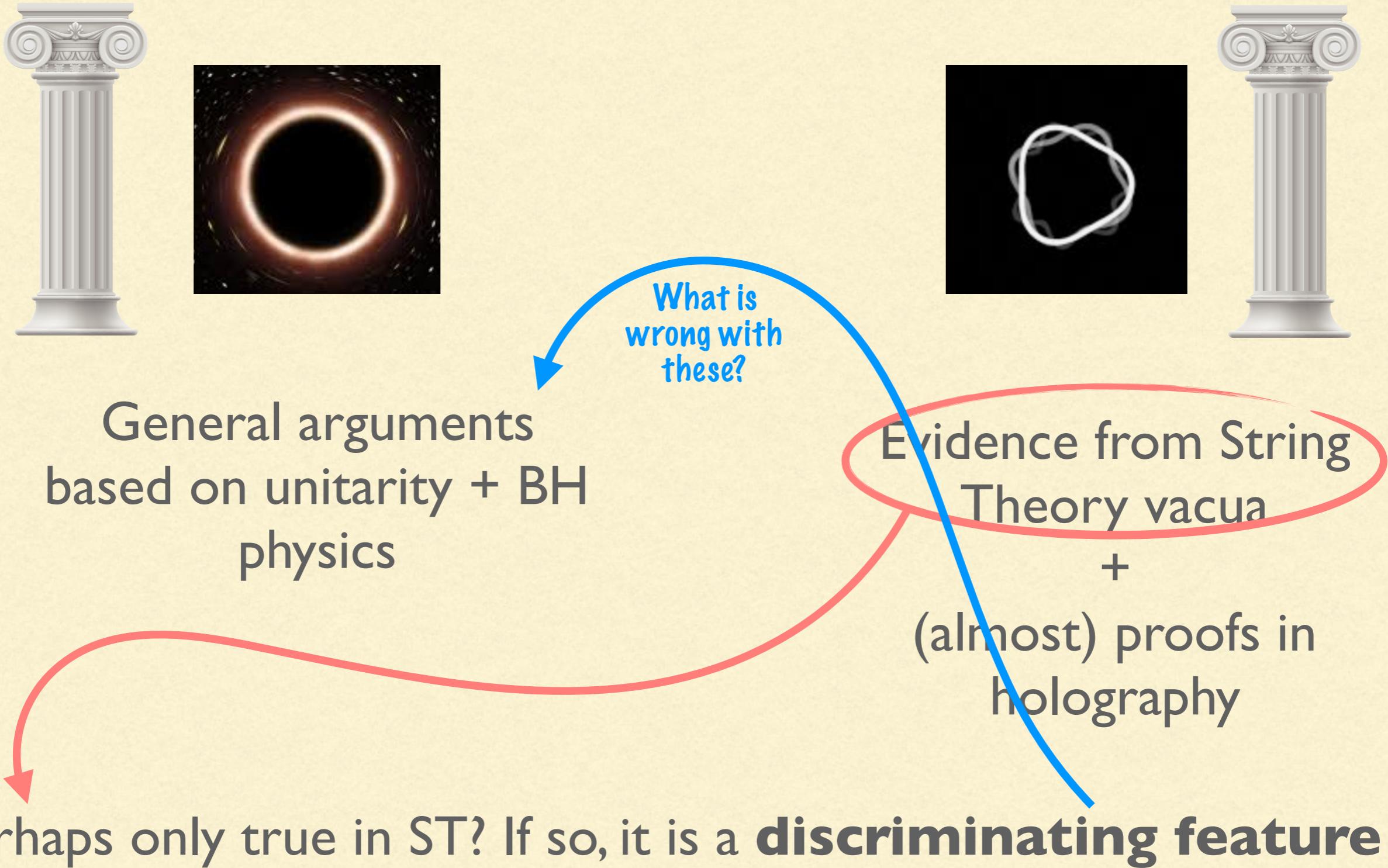
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Perhaps only true in ST? If so, it is a **discriminating feature**

The no GS conjecture is supported on **two pillars**:



Plan of the talk

Precise statement
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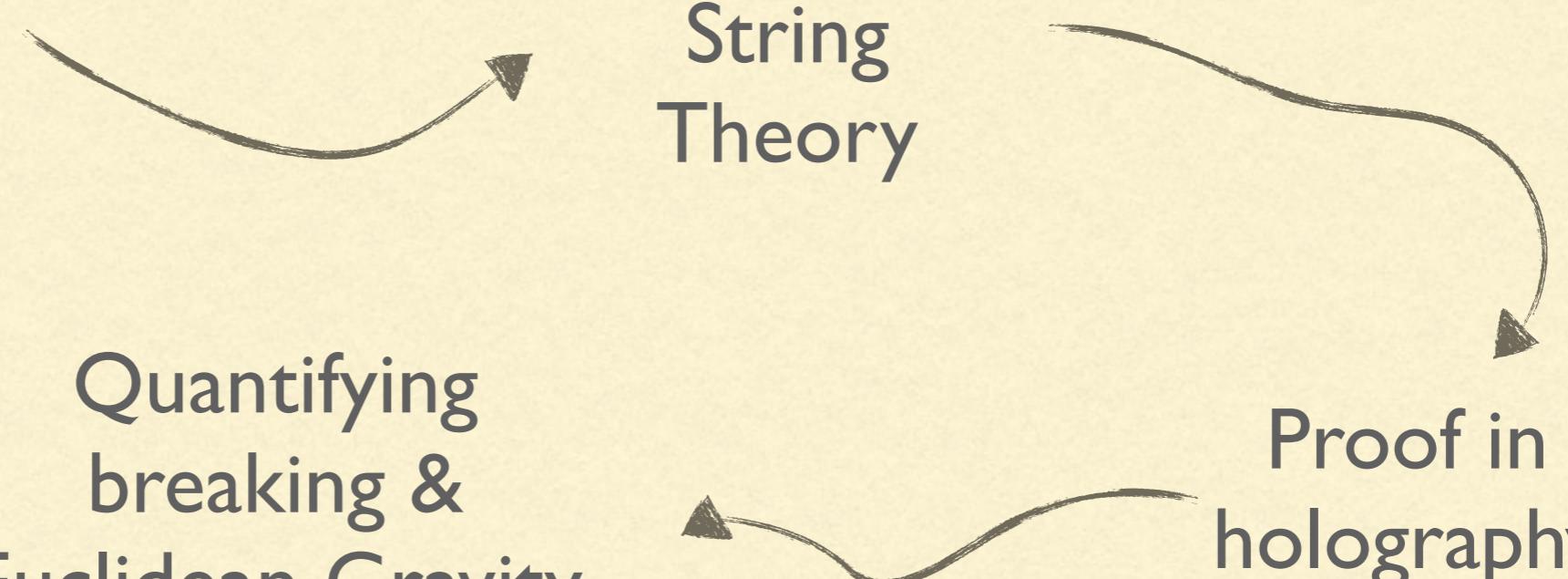
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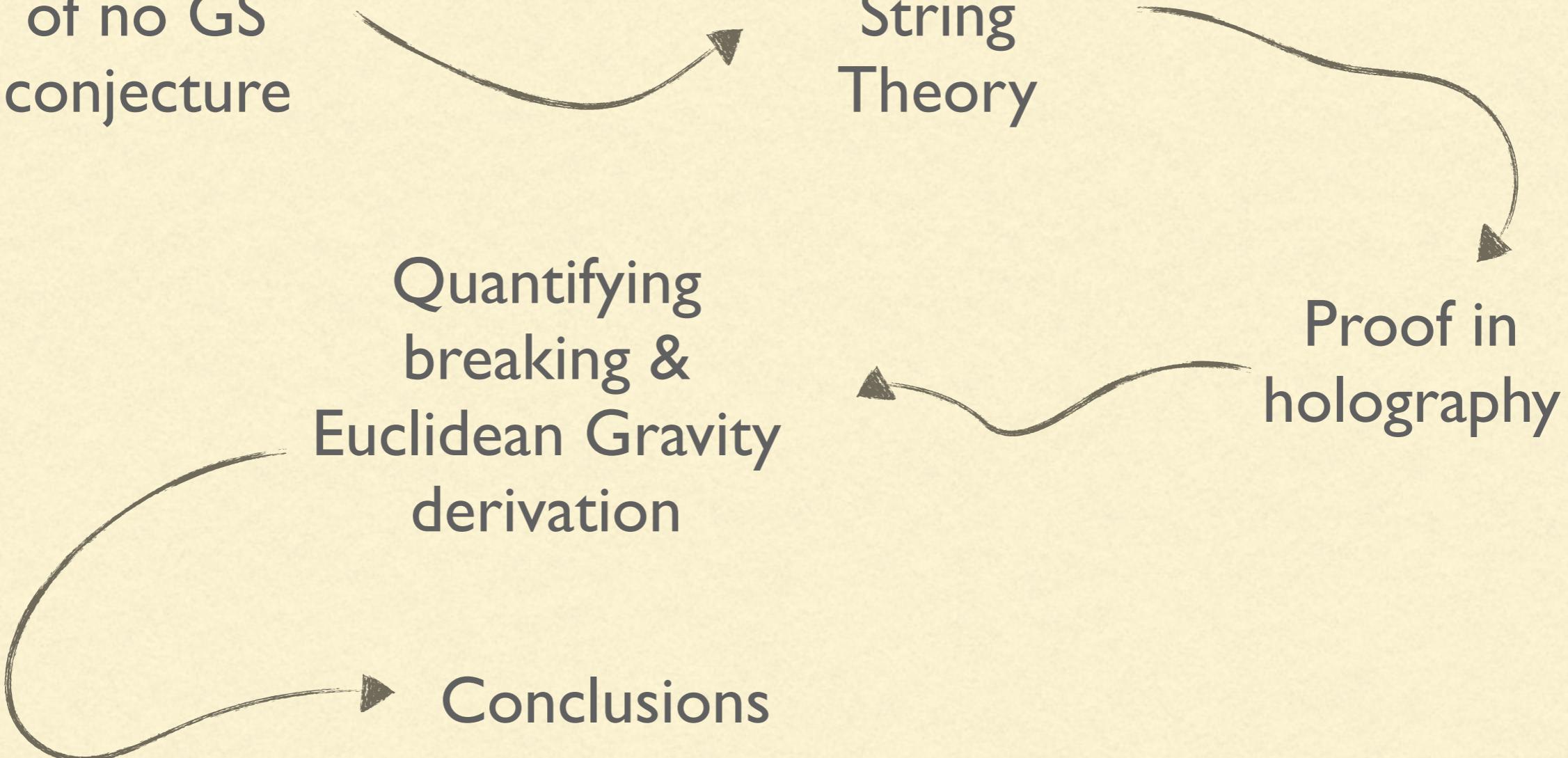
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Final discussion

No global symmetries

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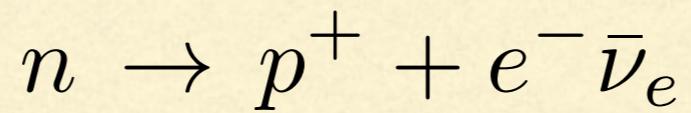
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(long range) **gauge symmetry** if the charge can be measured from far away (via electric field)

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Slogan/mantra/mnemonic:

“No GS = All exactly conserved charges couple to a gauge field”

This has **real-world** consequences: B-L is a global sym. in
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[See Ray's talk]

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So it is either coupled to a (yet unseen) **fifth force**

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It is not a real symmetry, it is **broken**

Double beta decay, proton decay

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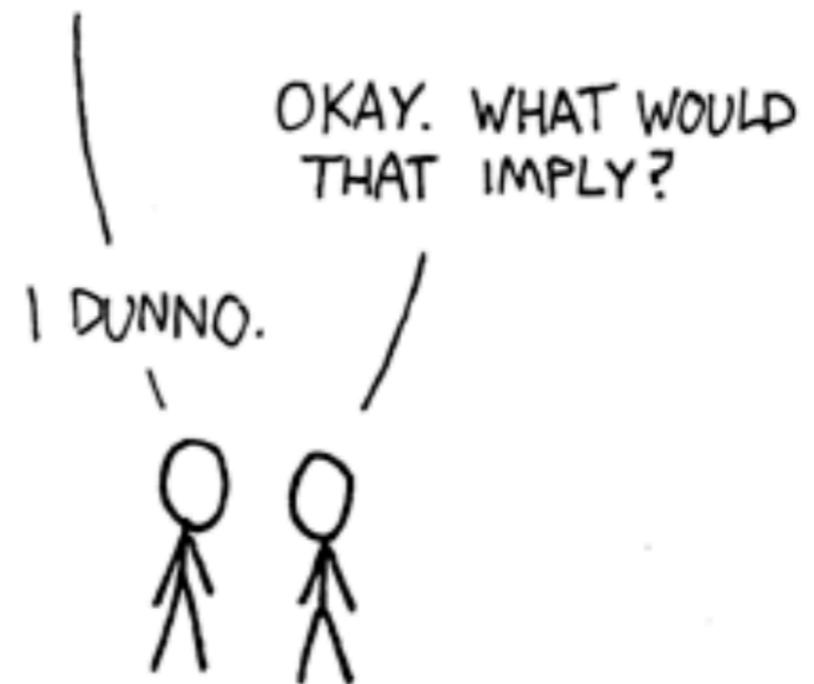
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STRING THEORY SUMMARIZED:

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(Actually, discovered “by accident” while looking for perturbative theory of the QCD string)

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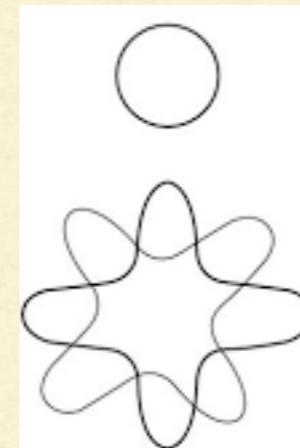
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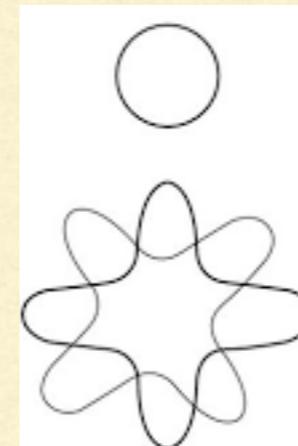
I DUNNO.



Different vibration modes
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= different particles

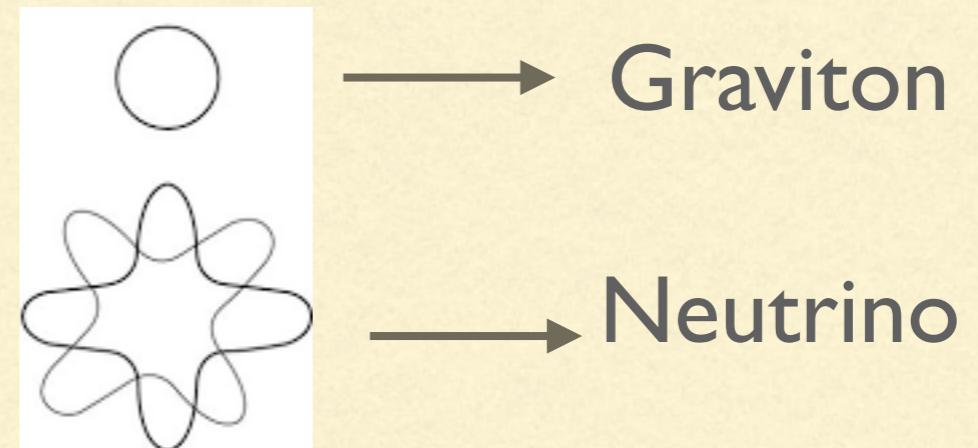


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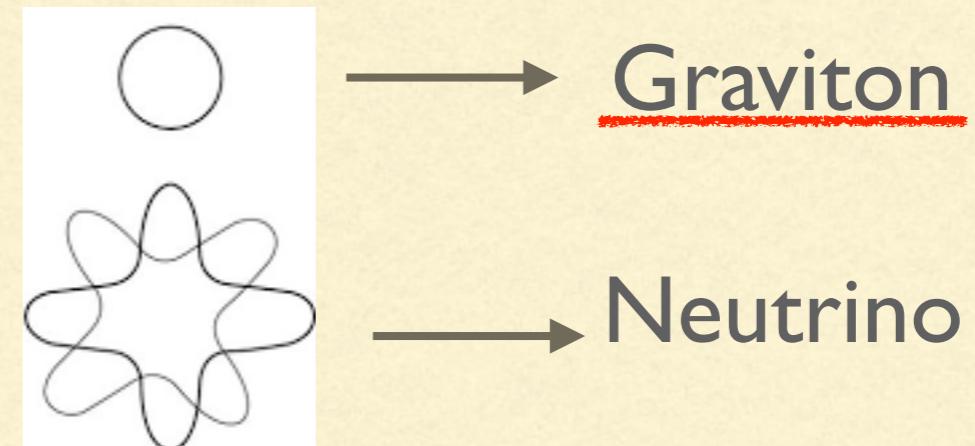


→ Graviton

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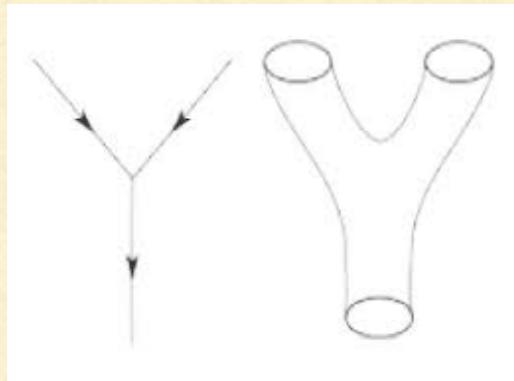
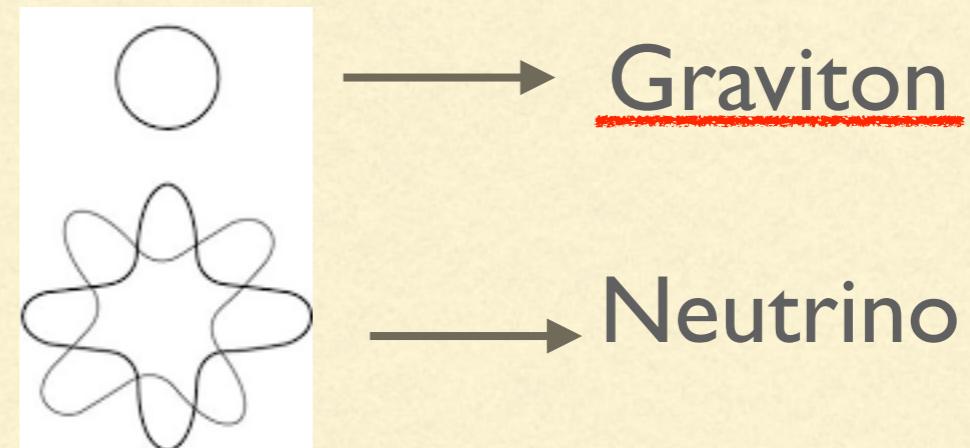
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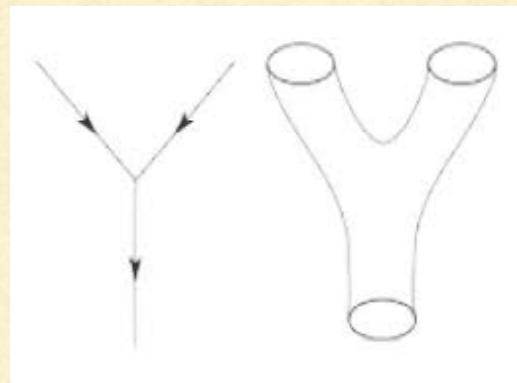
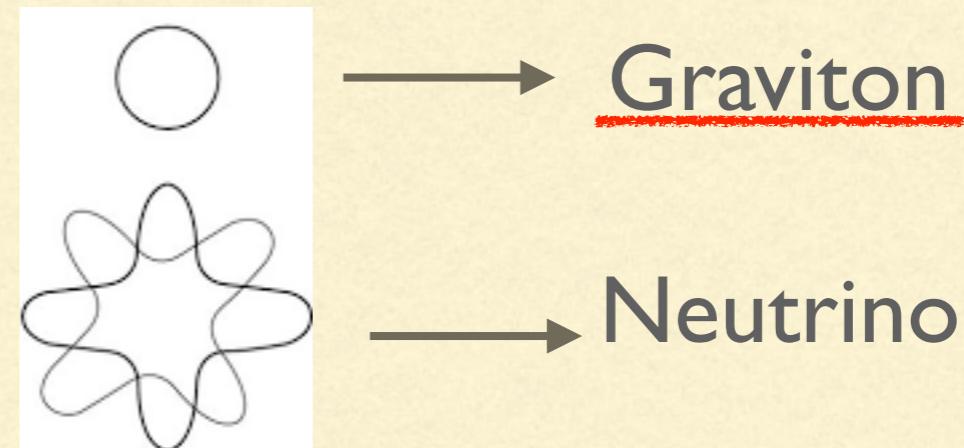
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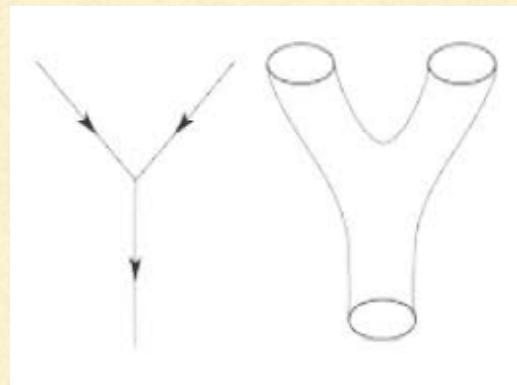
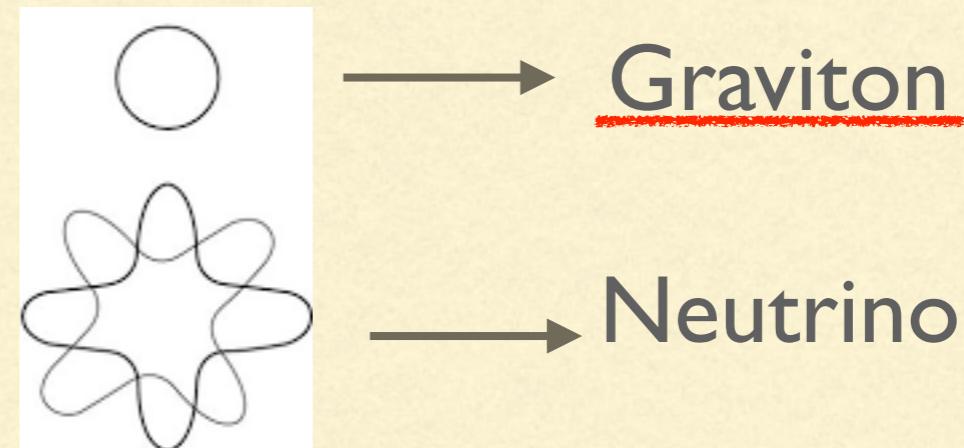
Consistent, UV-finite,
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Consistent, UV-finite,
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General Relativity

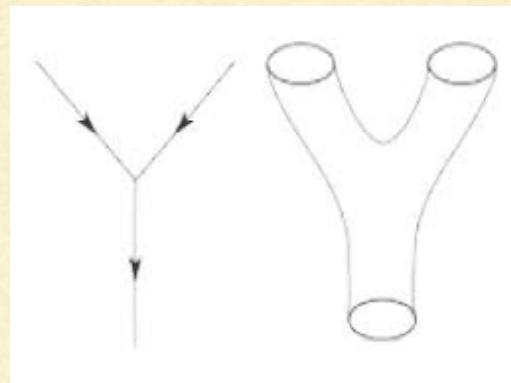
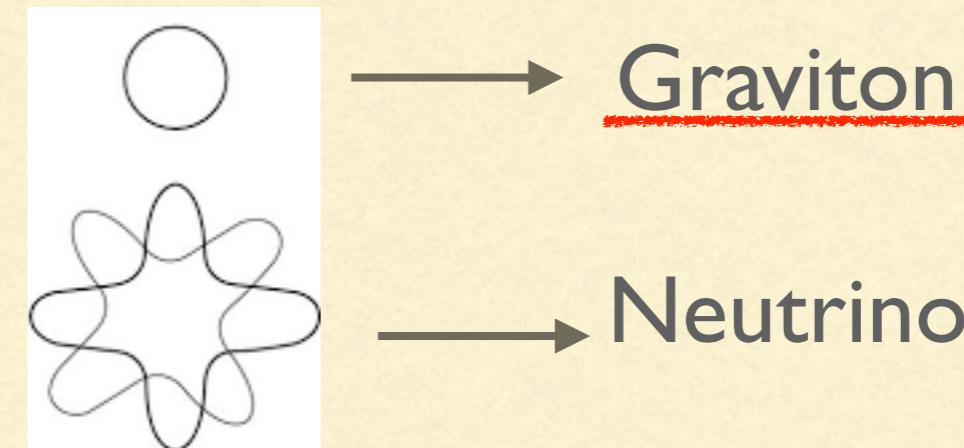
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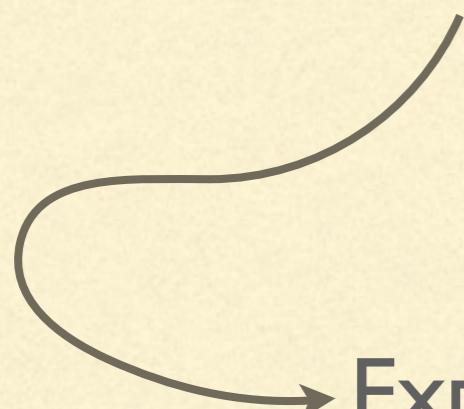
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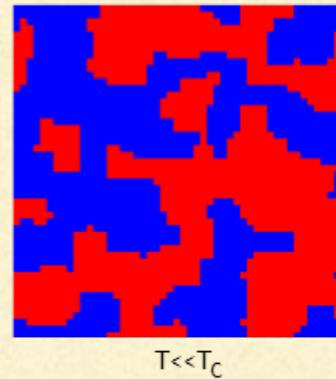


Explicit counting of BH microstates (entropy)

[**Strominger-Vafa, ...**]

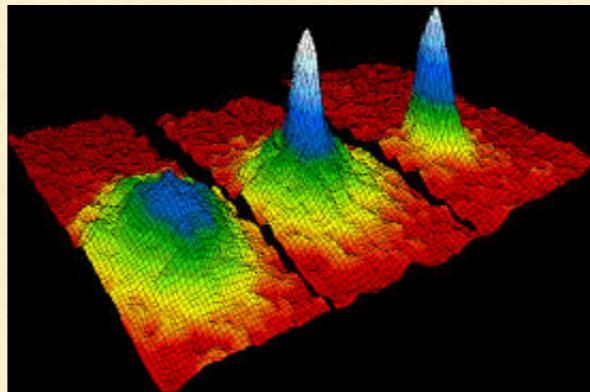
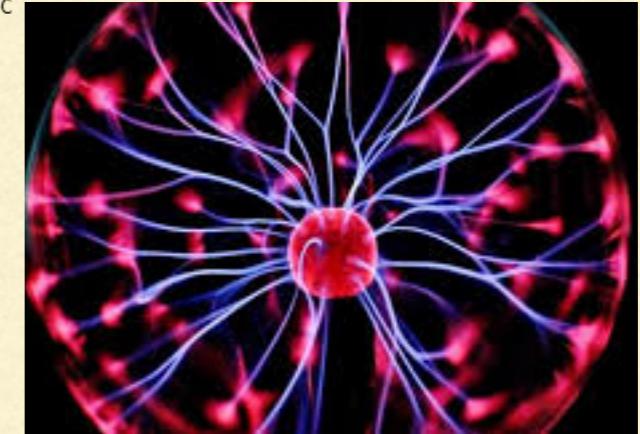
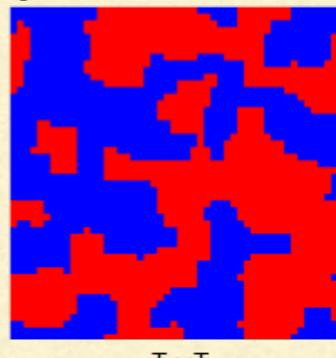
$$S = \frac{A}{4}$$

Just like many physical systems (e.g. ferromagnets, water...) can have many different **phases**,

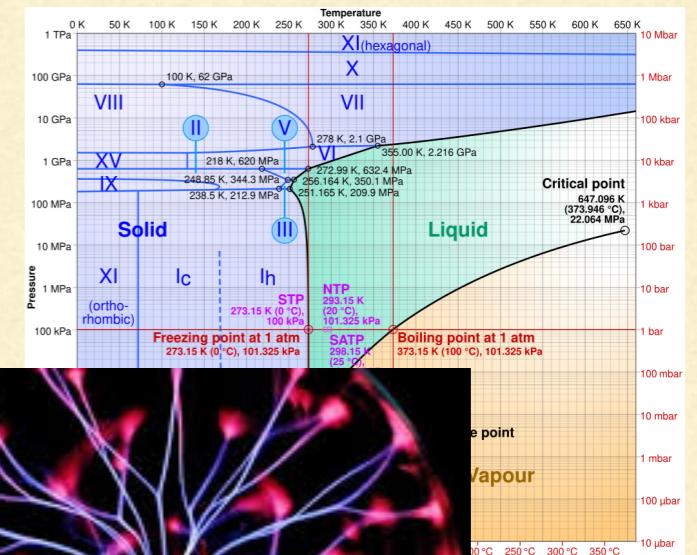
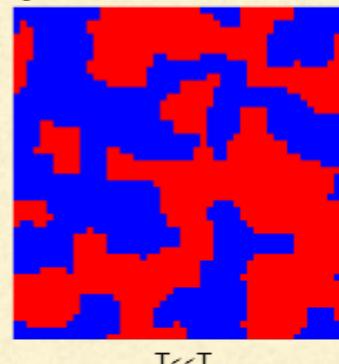
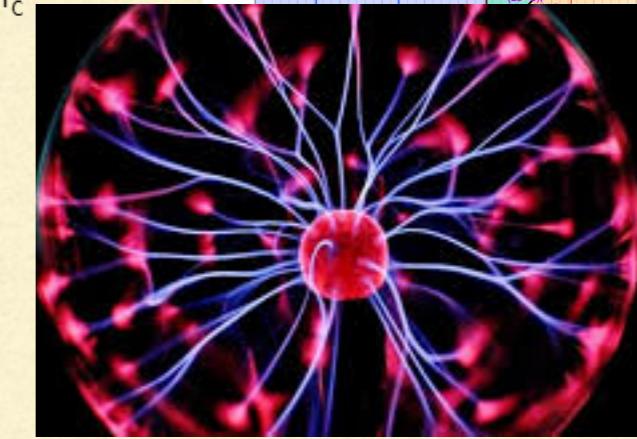
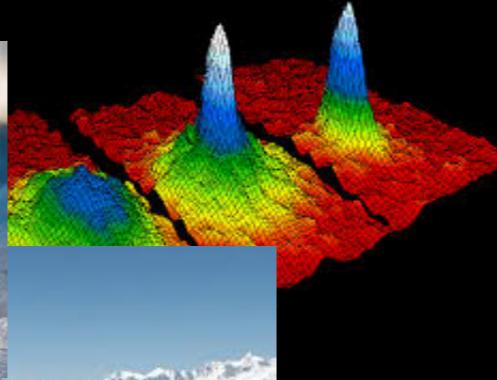


$T \ll T_c$

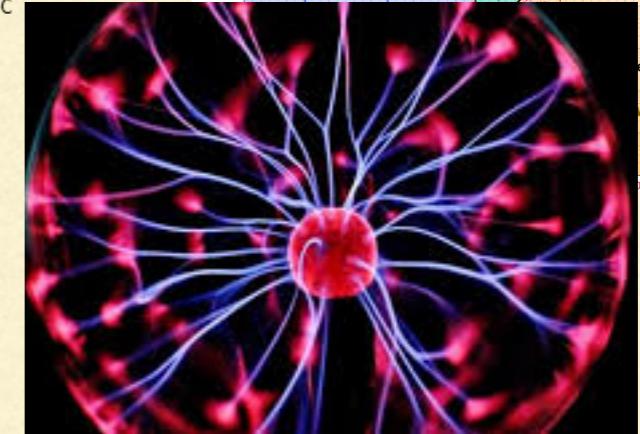
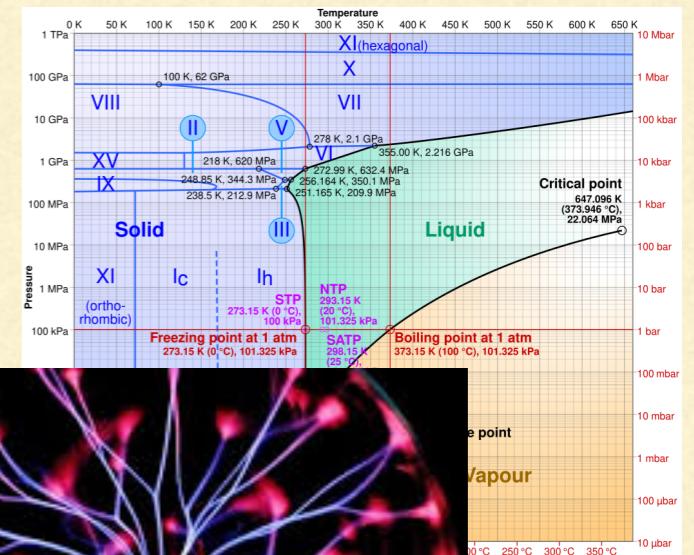
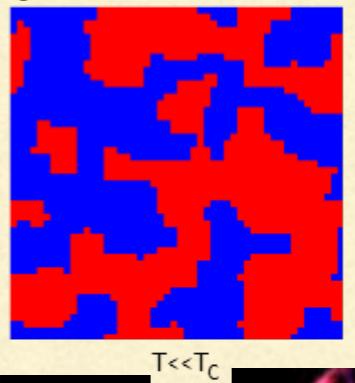
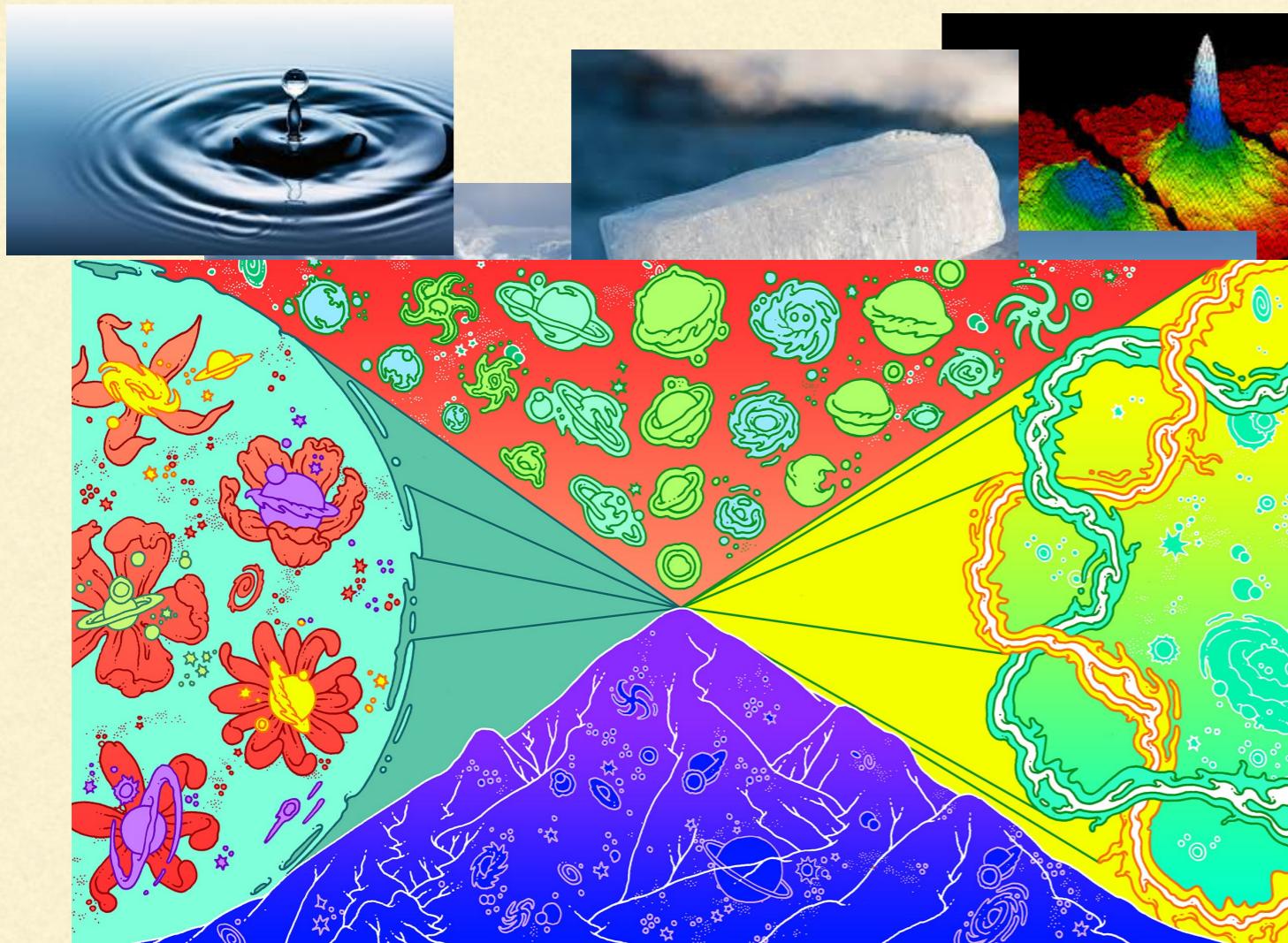
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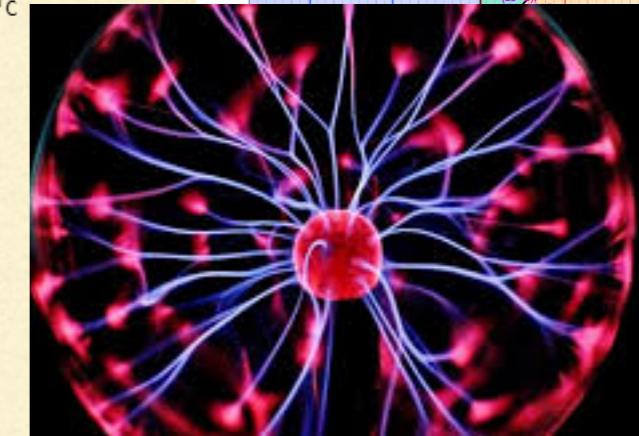
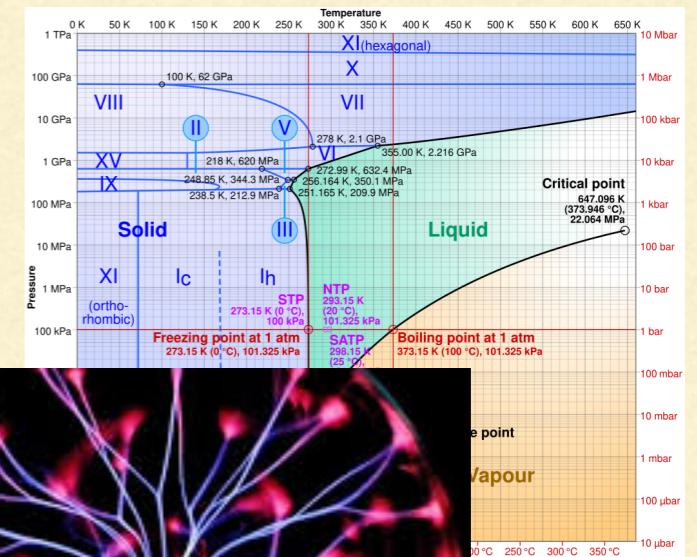
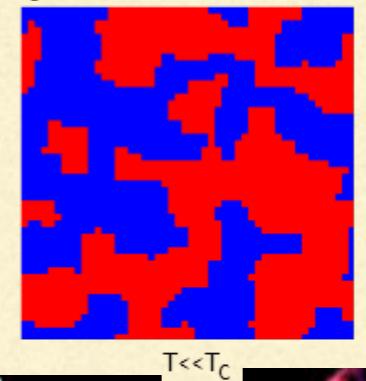
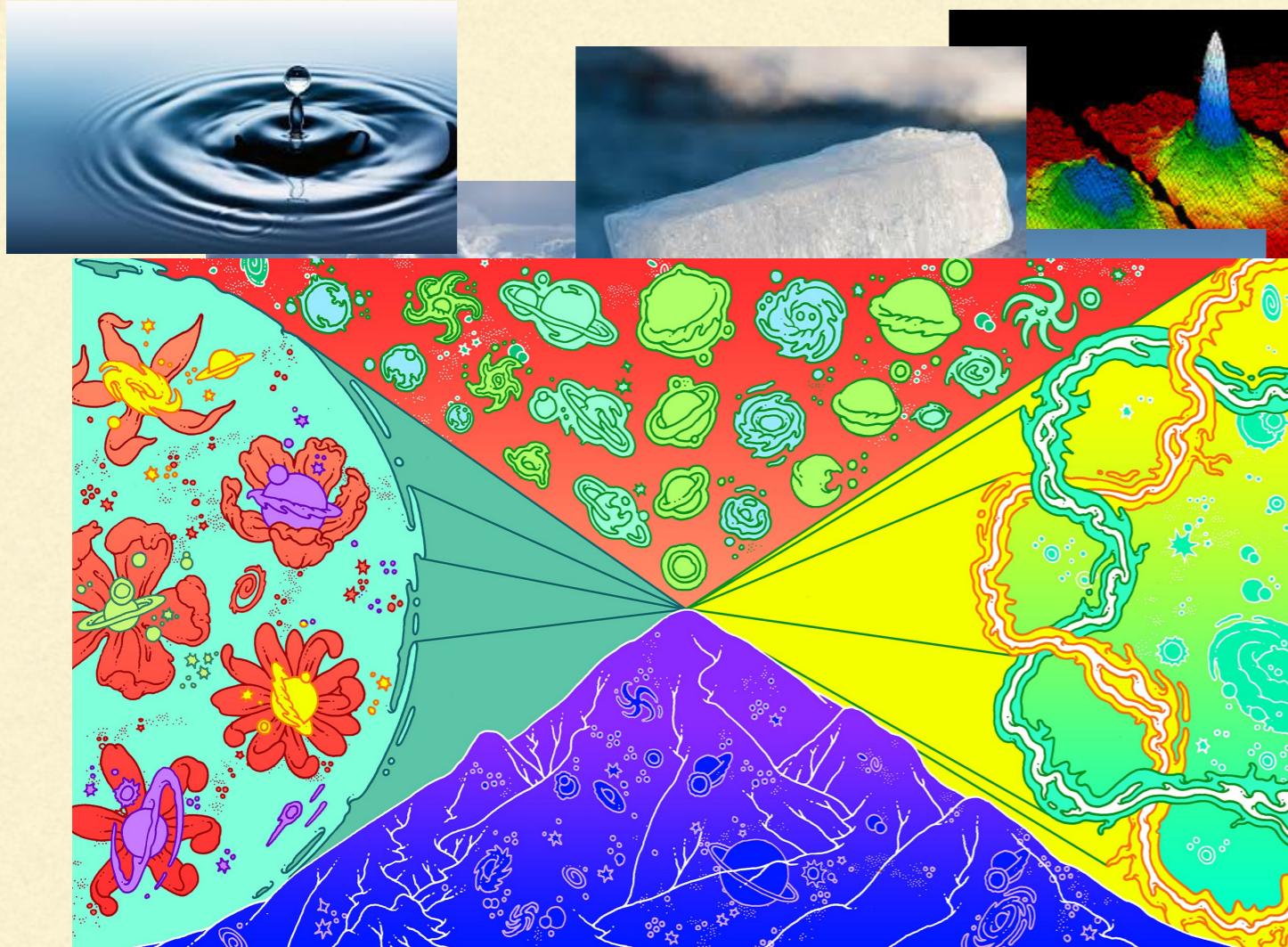


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At low energies, most phases look like **Einstein gravity + matter** in some # of dimensions, $d \leq 11$

(No such upper bound in QFT or other QG approaches)

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No GS in the ST Landscape

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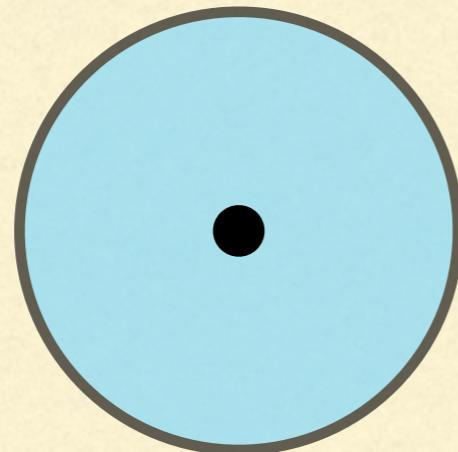
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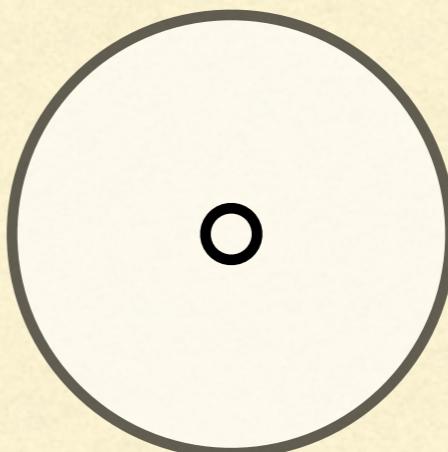
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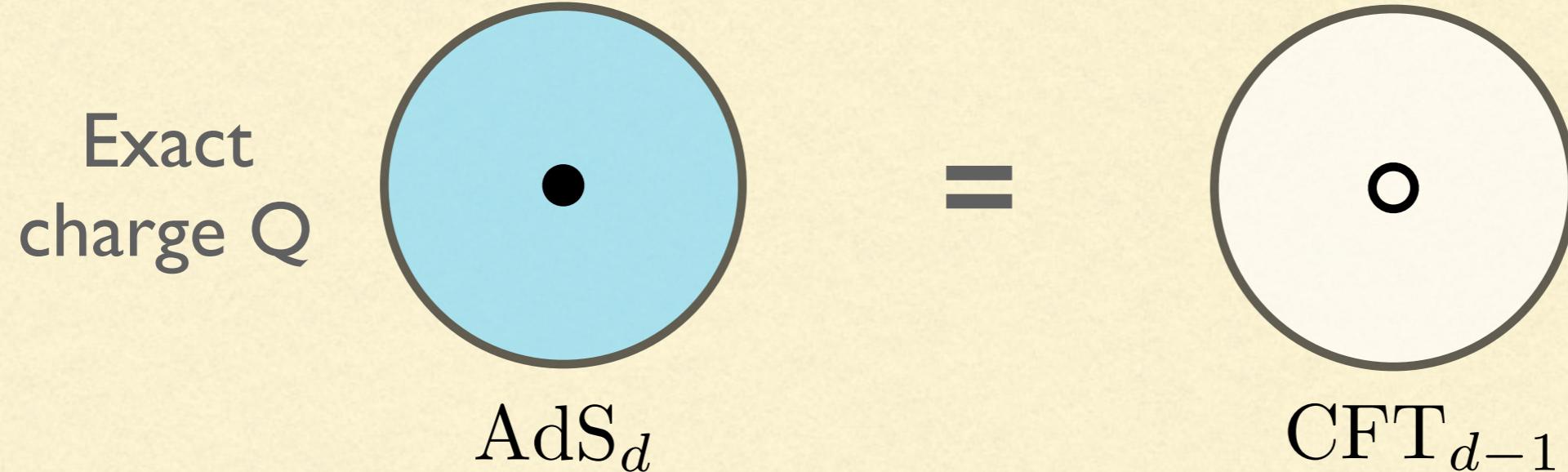
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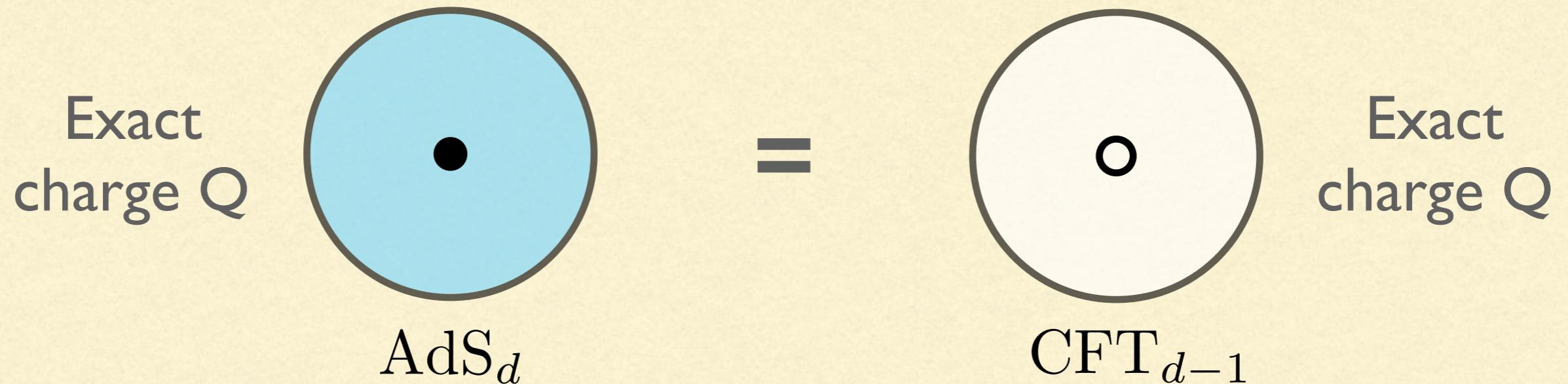
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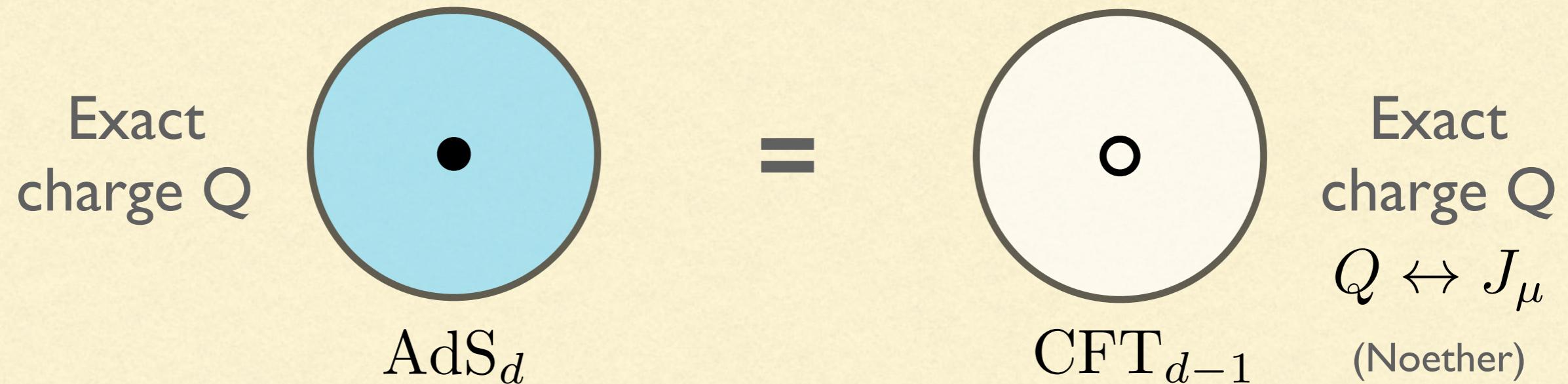
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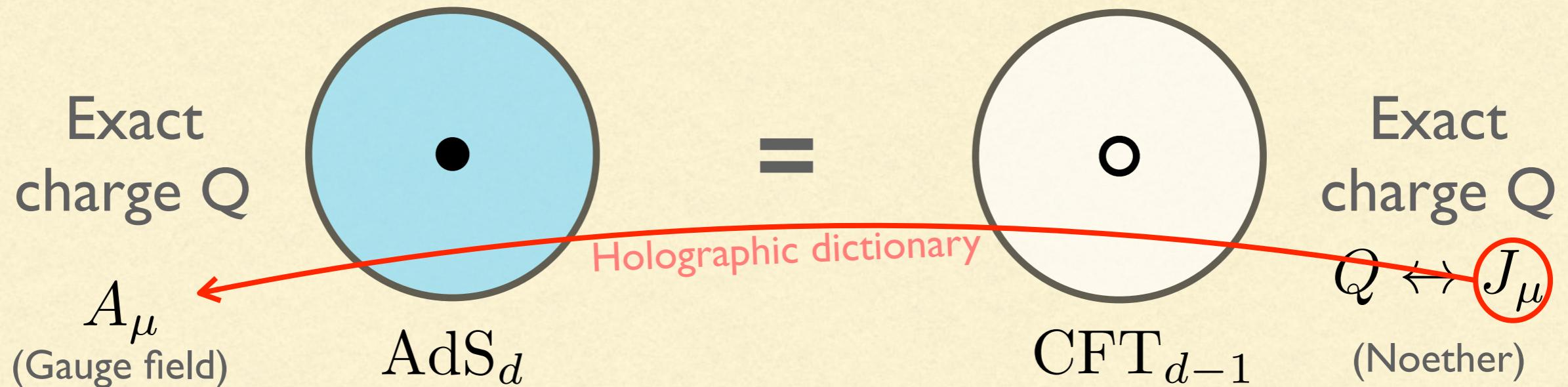
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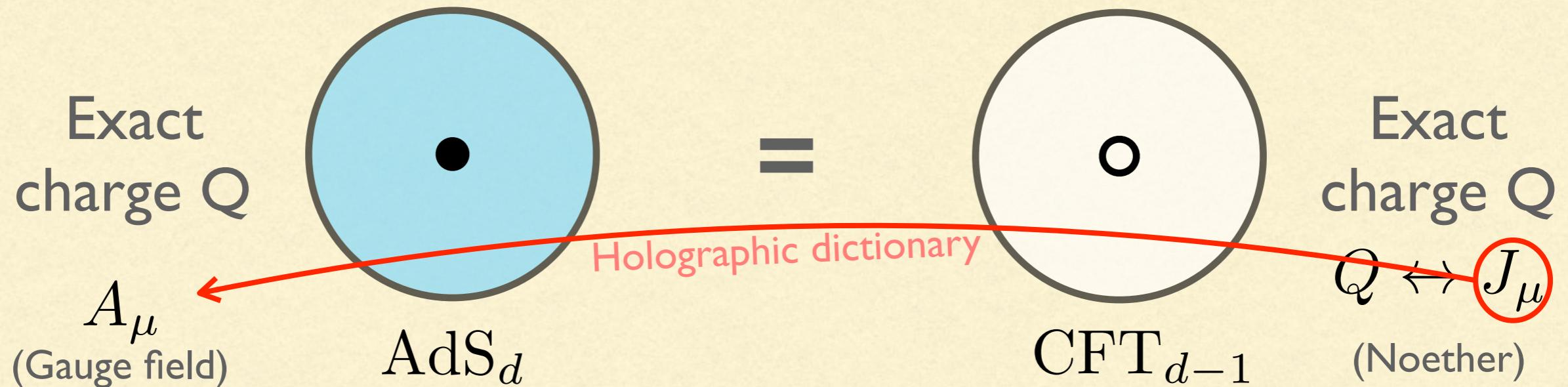
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One caveat: Noether's theorem is not a theorem in QFT

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and this allows us to connect to the heuristic arguments and **recent calculations** in Euclidean QG, which **do not** assume String Theory.

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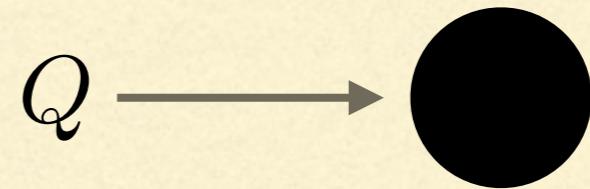
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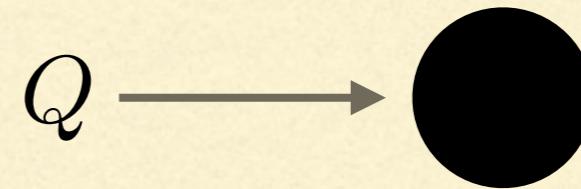


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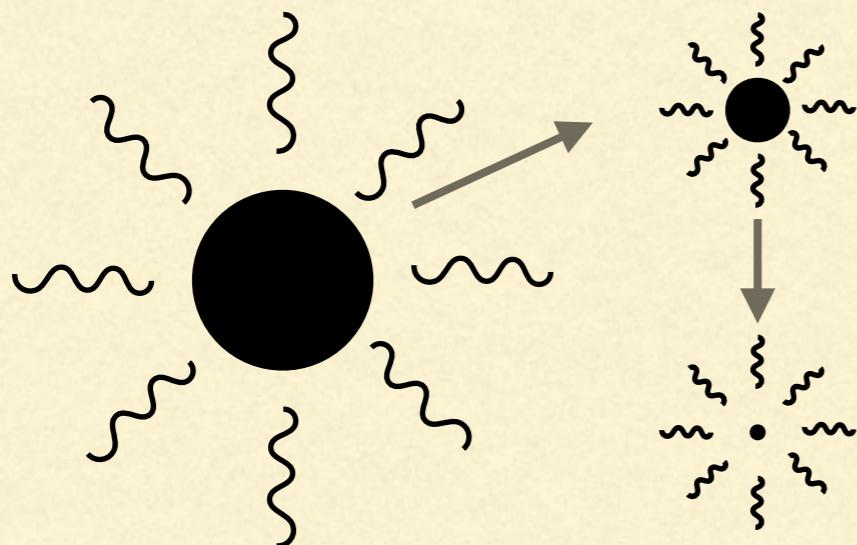
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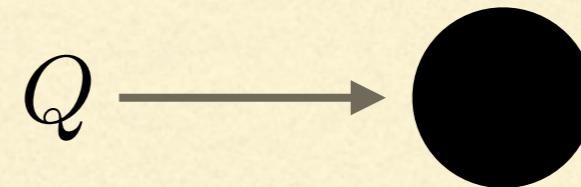


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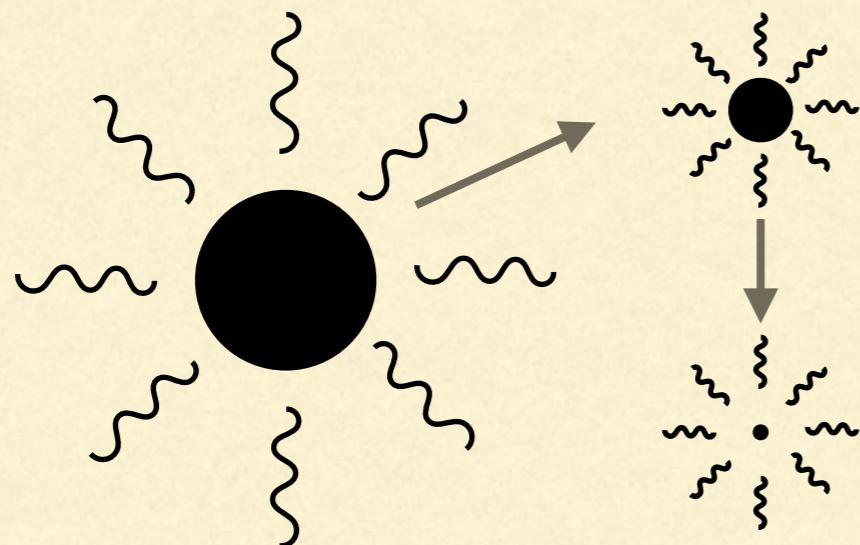
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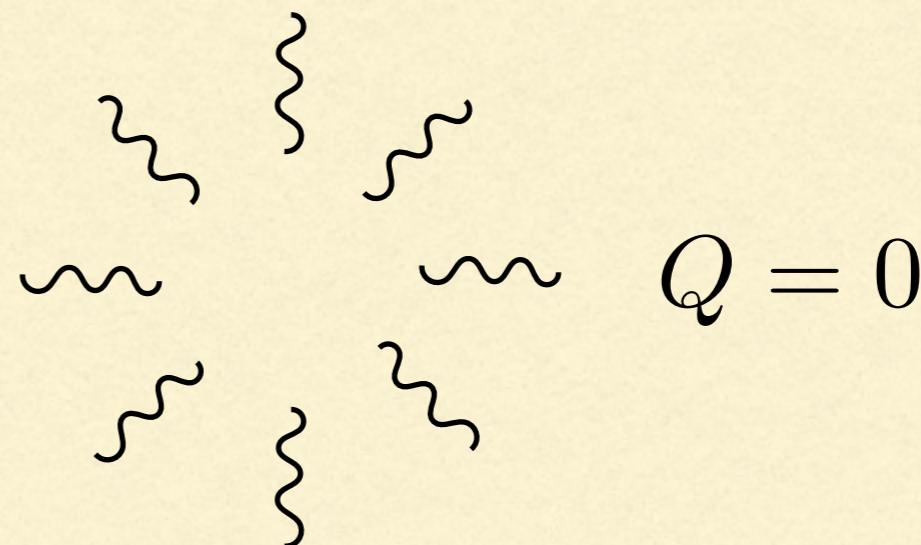
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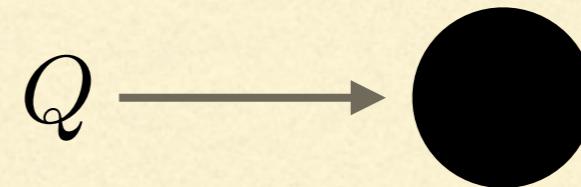


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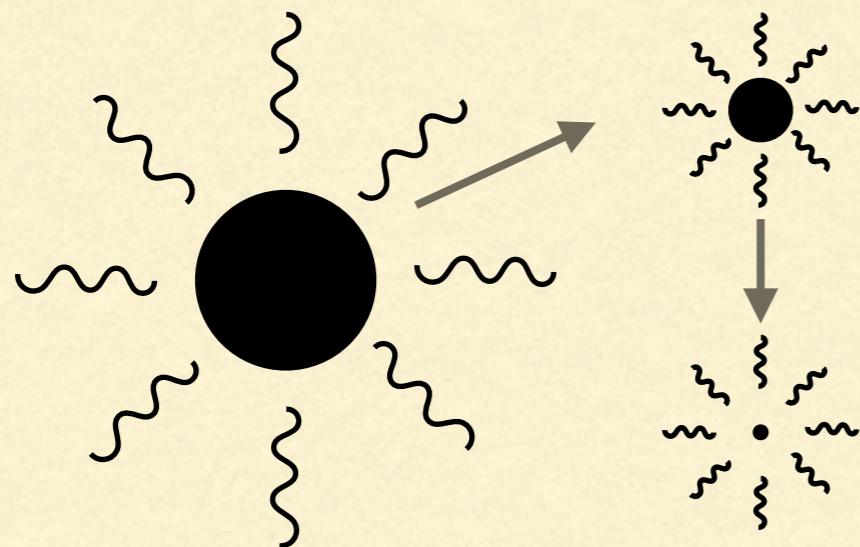
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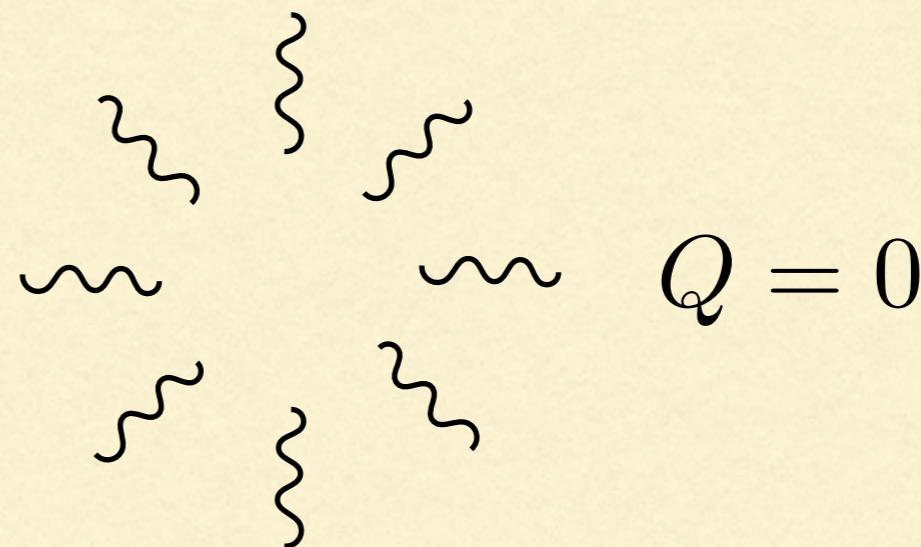
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Many caveats, but since a few years back, we have a more solid version of this, based on Gravitational Path Integral techniques.

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Also, has led to a precise formula to compute entanglement entropies in CFT via AdS/CFT (Ryu-Takayanagi), which passed many checks

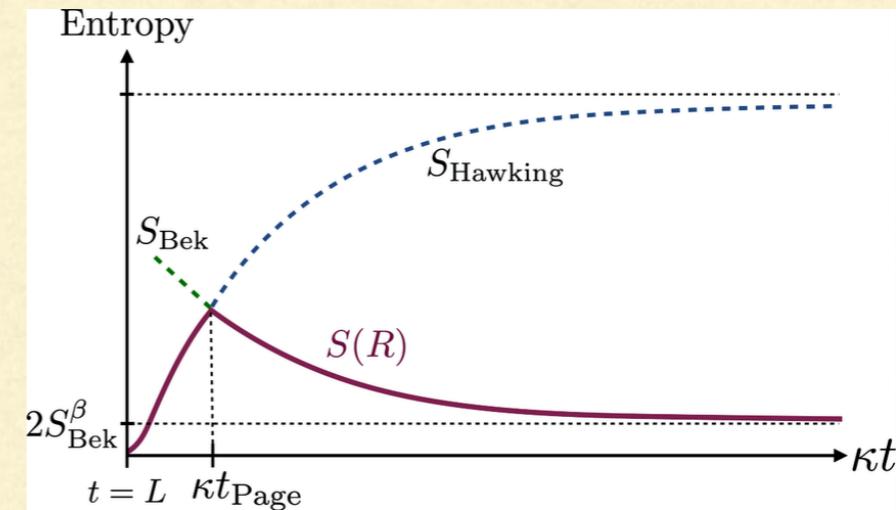
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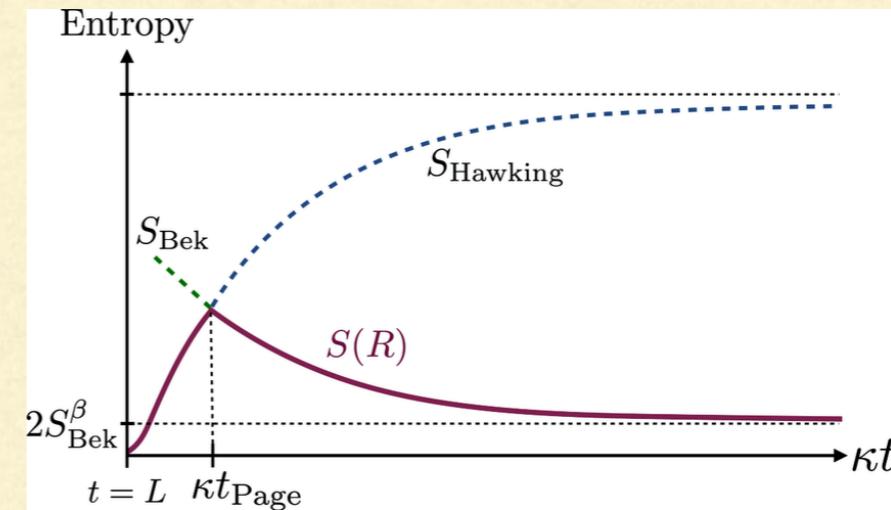


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For instance, including wormholes produces a unitary **Page curve** for black holes (expected from unitary BH evaporation)

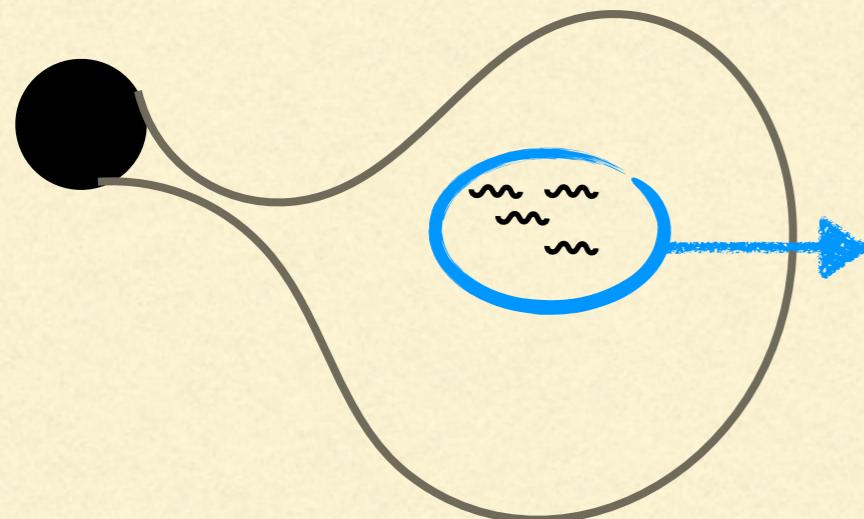
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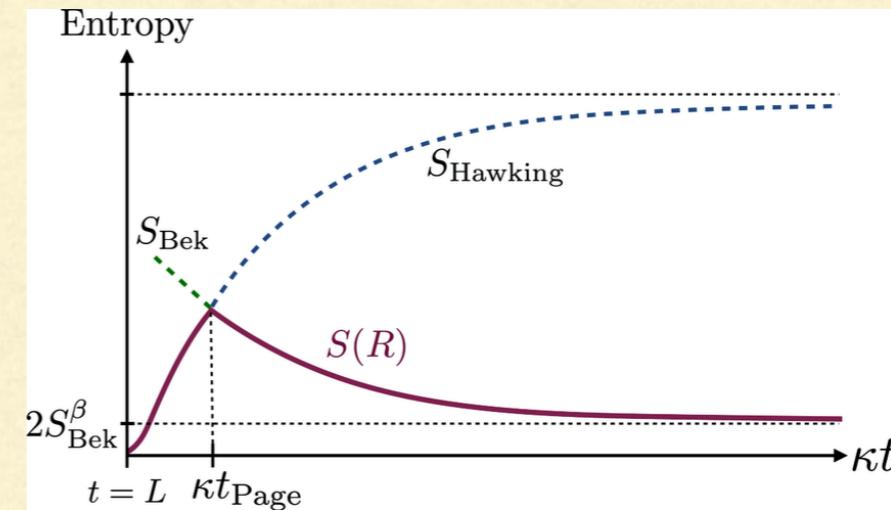
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[Valasubramanian-Magan-Sasieta '22, ...]

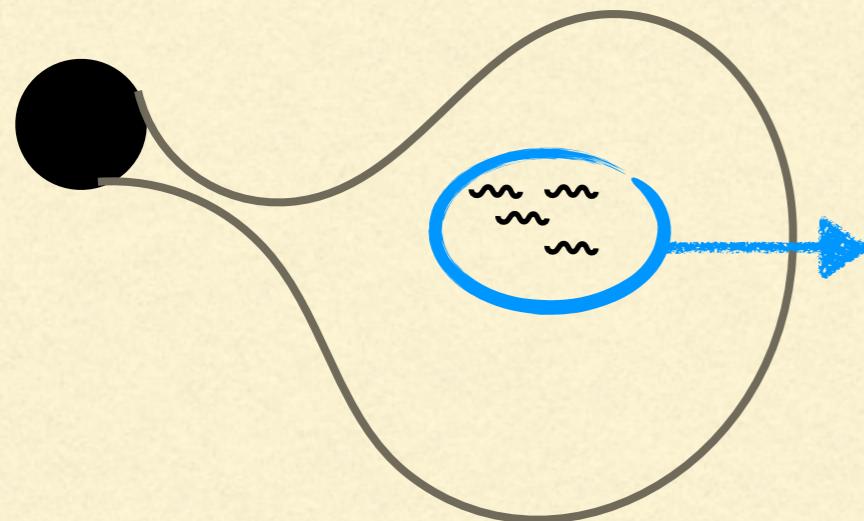
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And give non-degenerate EFT for extremal BH's [Turiaci '23]

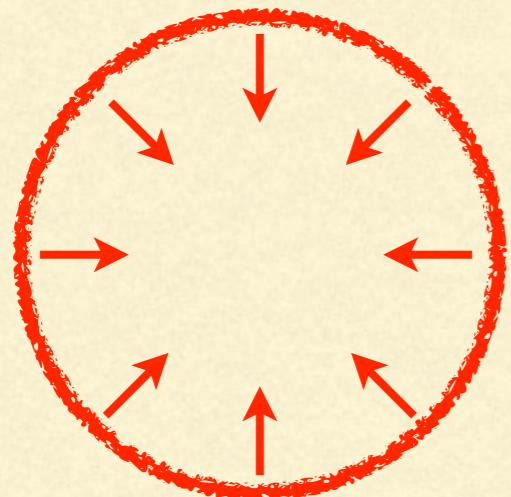
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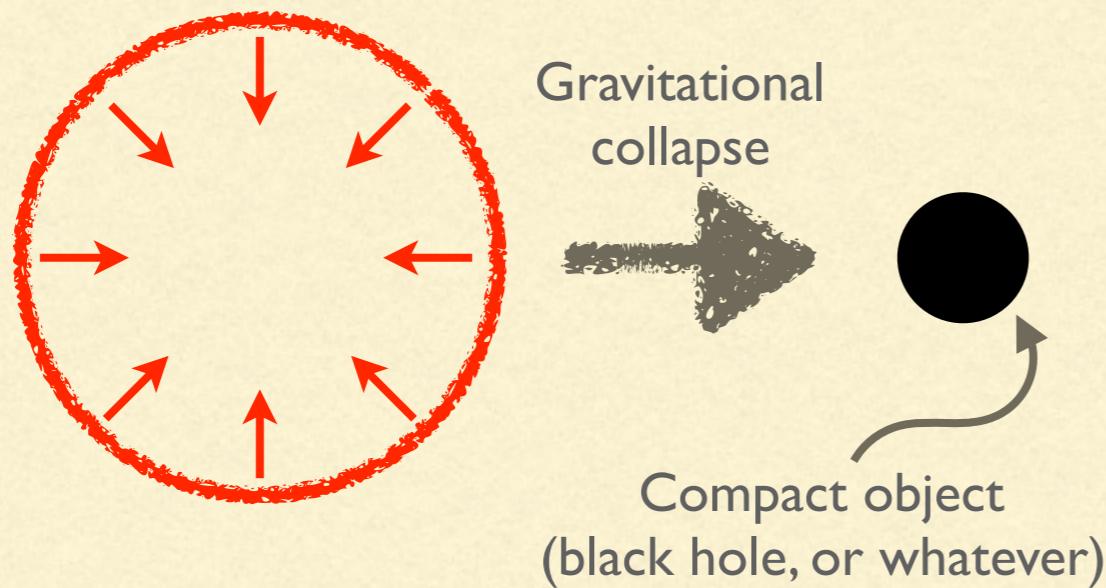


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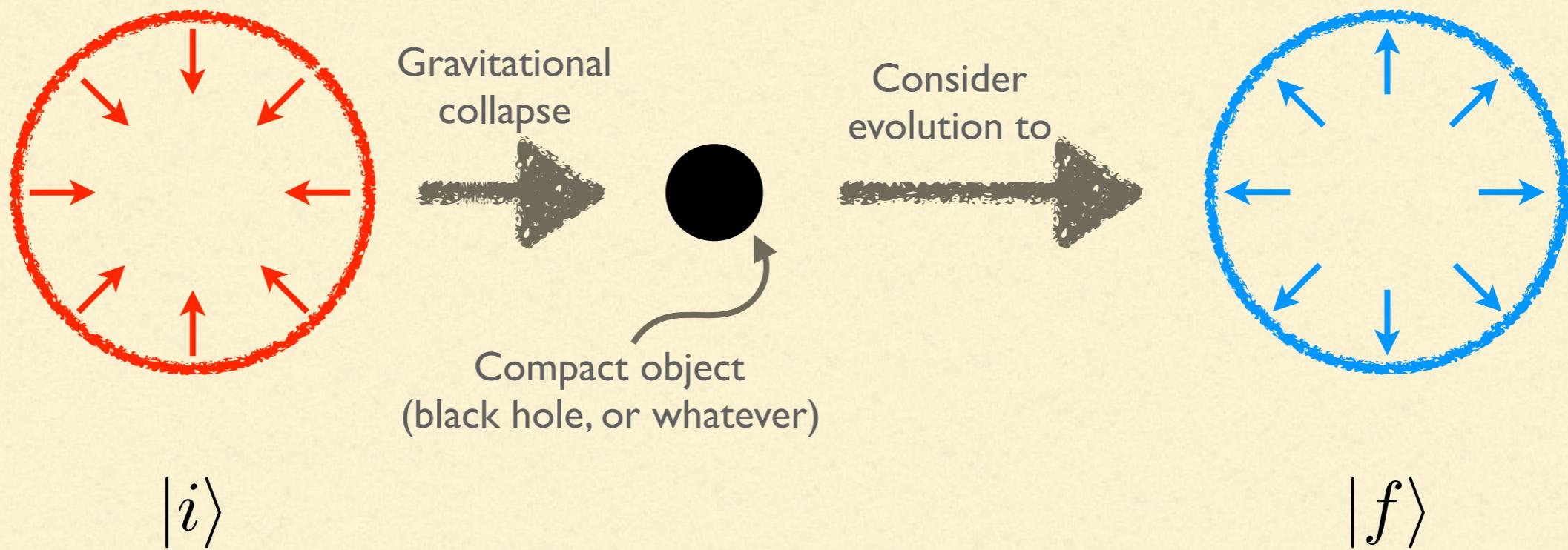


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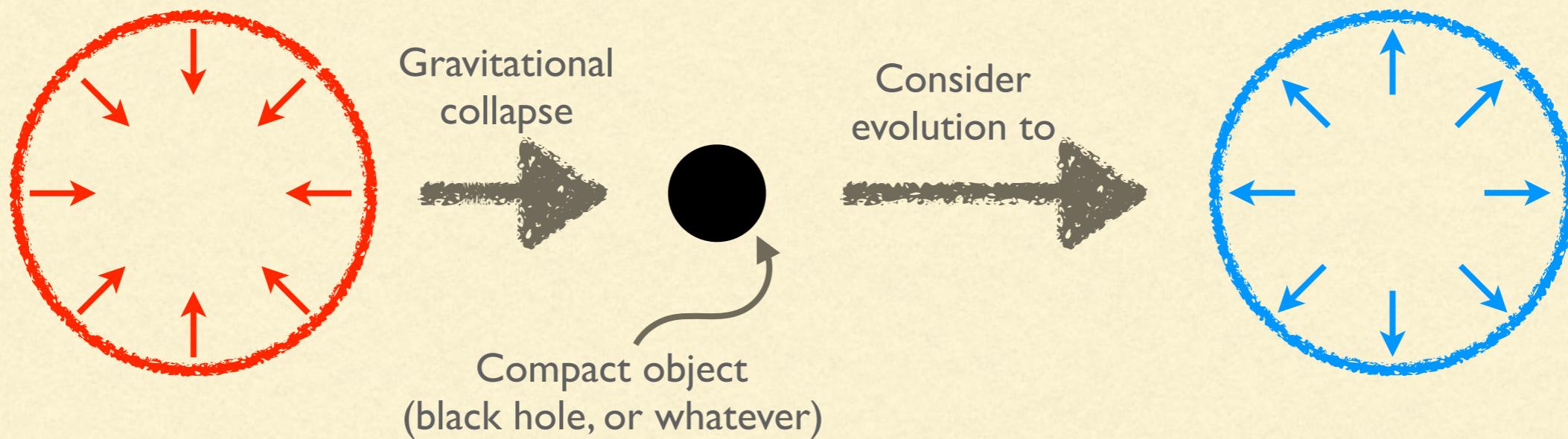
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Wanna compute

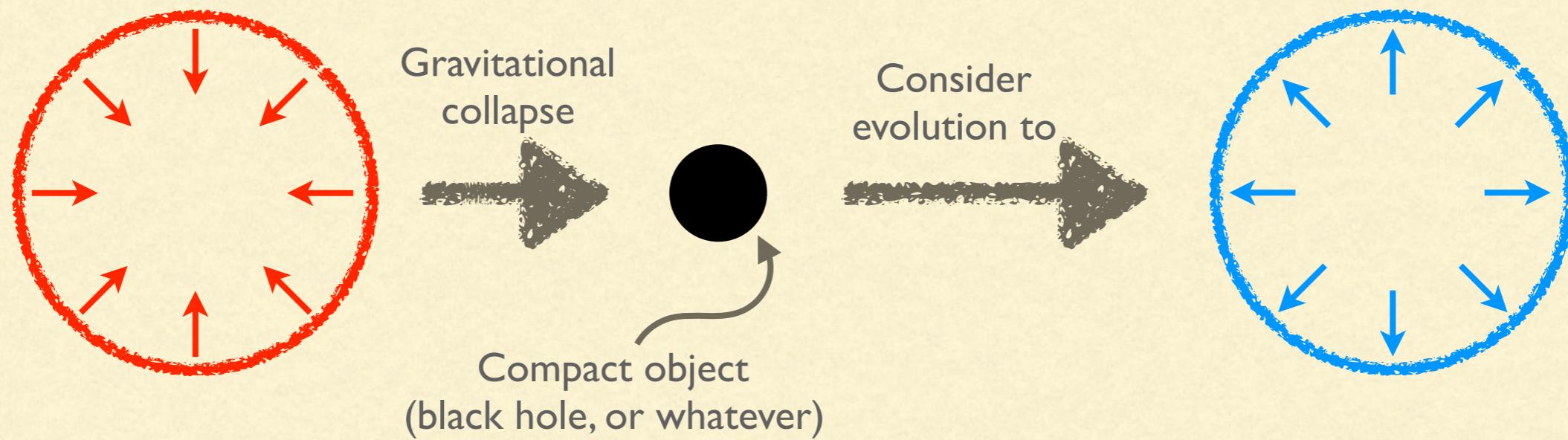
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[Bah-Chen-Maldacena '22]

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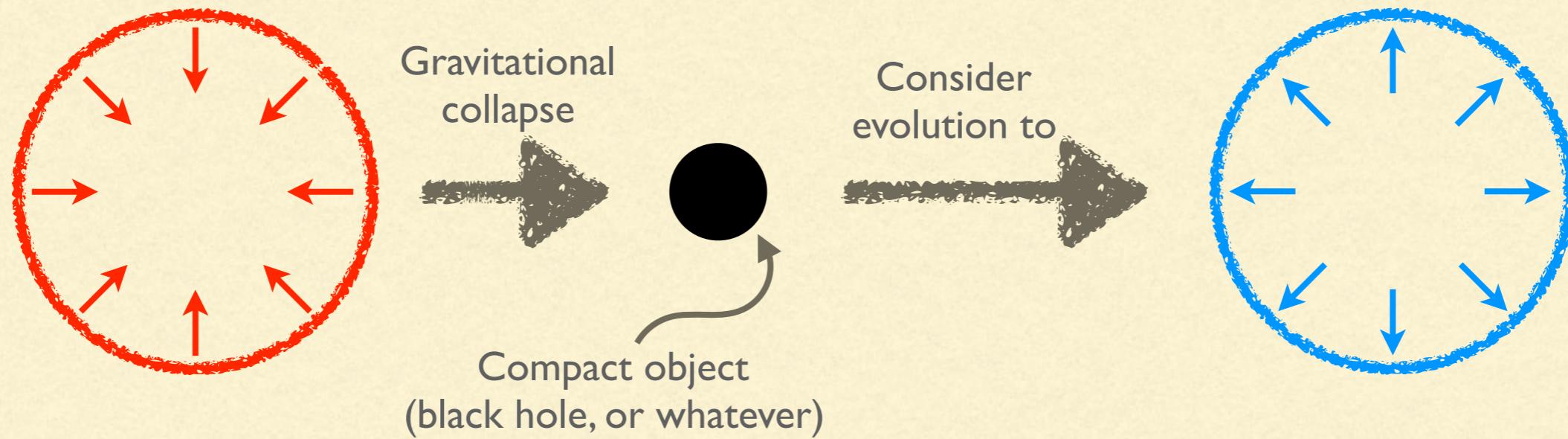
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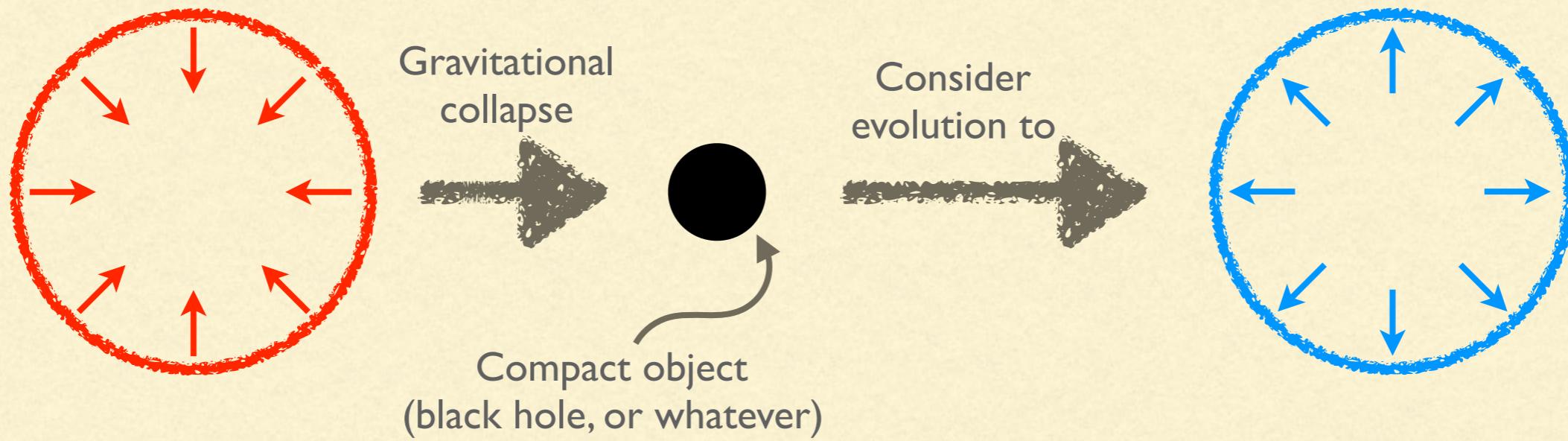
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Thus, no GS comes from trustworthy **Euclidean gravity** rules

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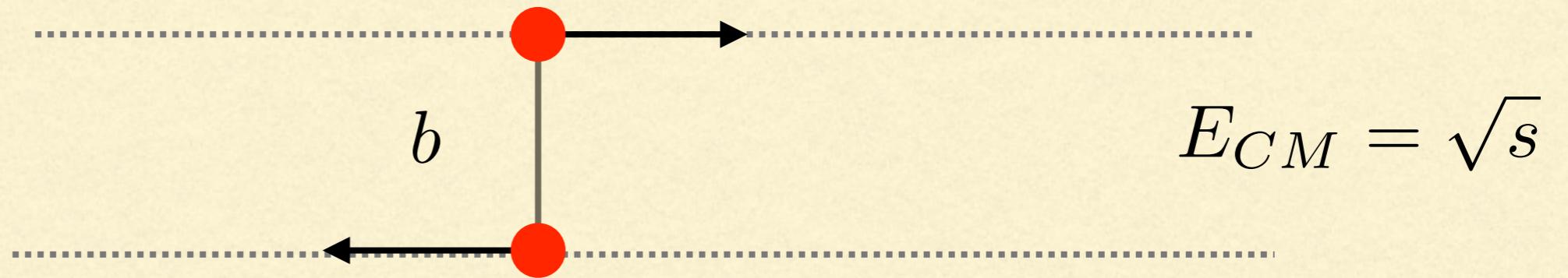


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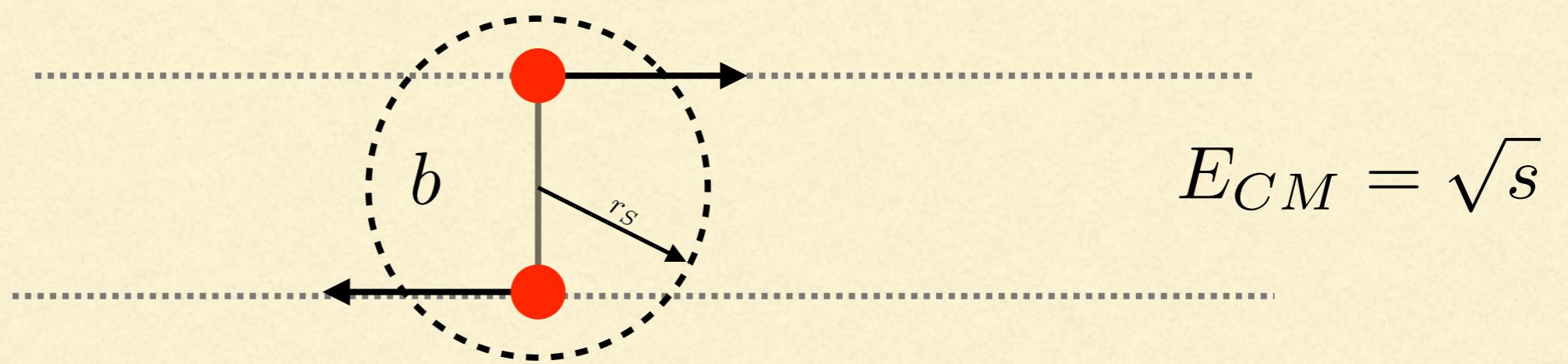
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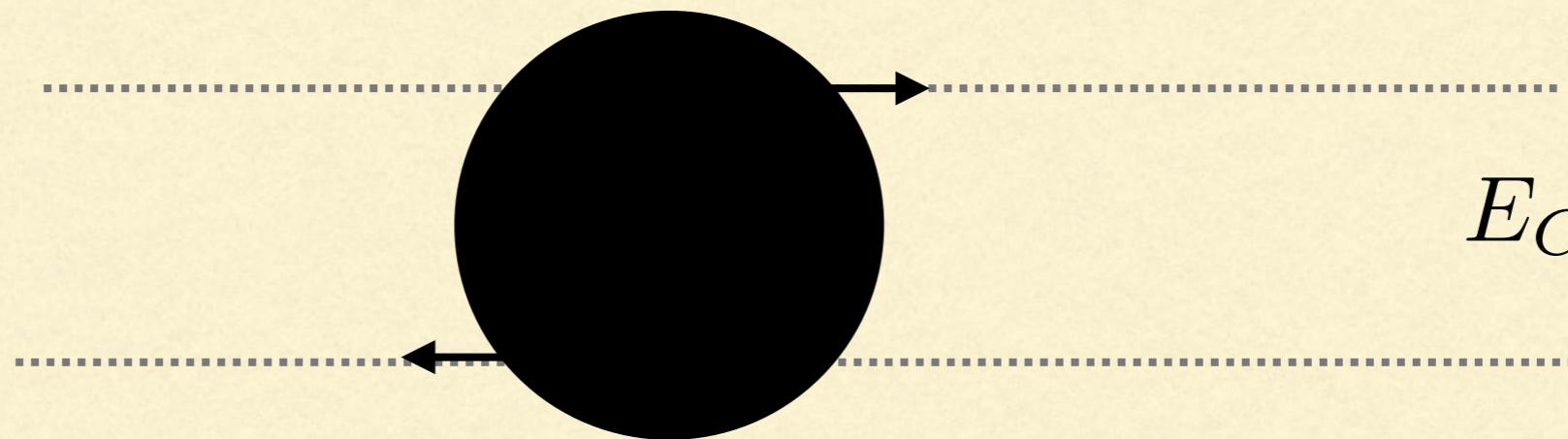
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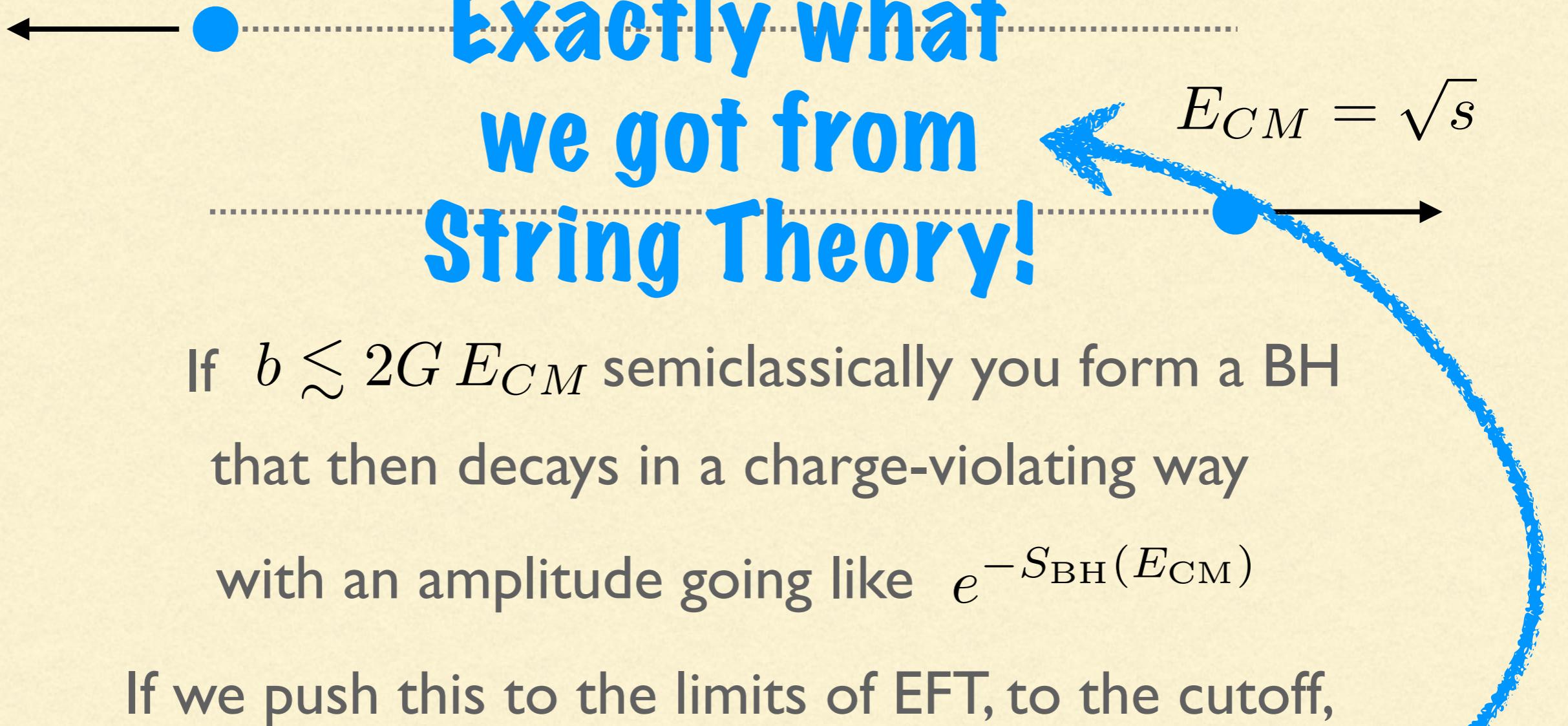
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Exactly what
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String Theory!



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String theory vacua in $d>3$ have these two properties.

(So no wonder that we found no global symmetries!)

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Asymptotic Safety: Can attack questions of EFT+gravity but recent papers saw no evidence of GS violation

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If not: Is this a breaking of GR at low energies? (since horizon curvature remains small) Can it be used to make predictions?

WOULD LOVE TO CHAT MORE!

- Strong evidence for no exact global symmetries in String Theory and holography

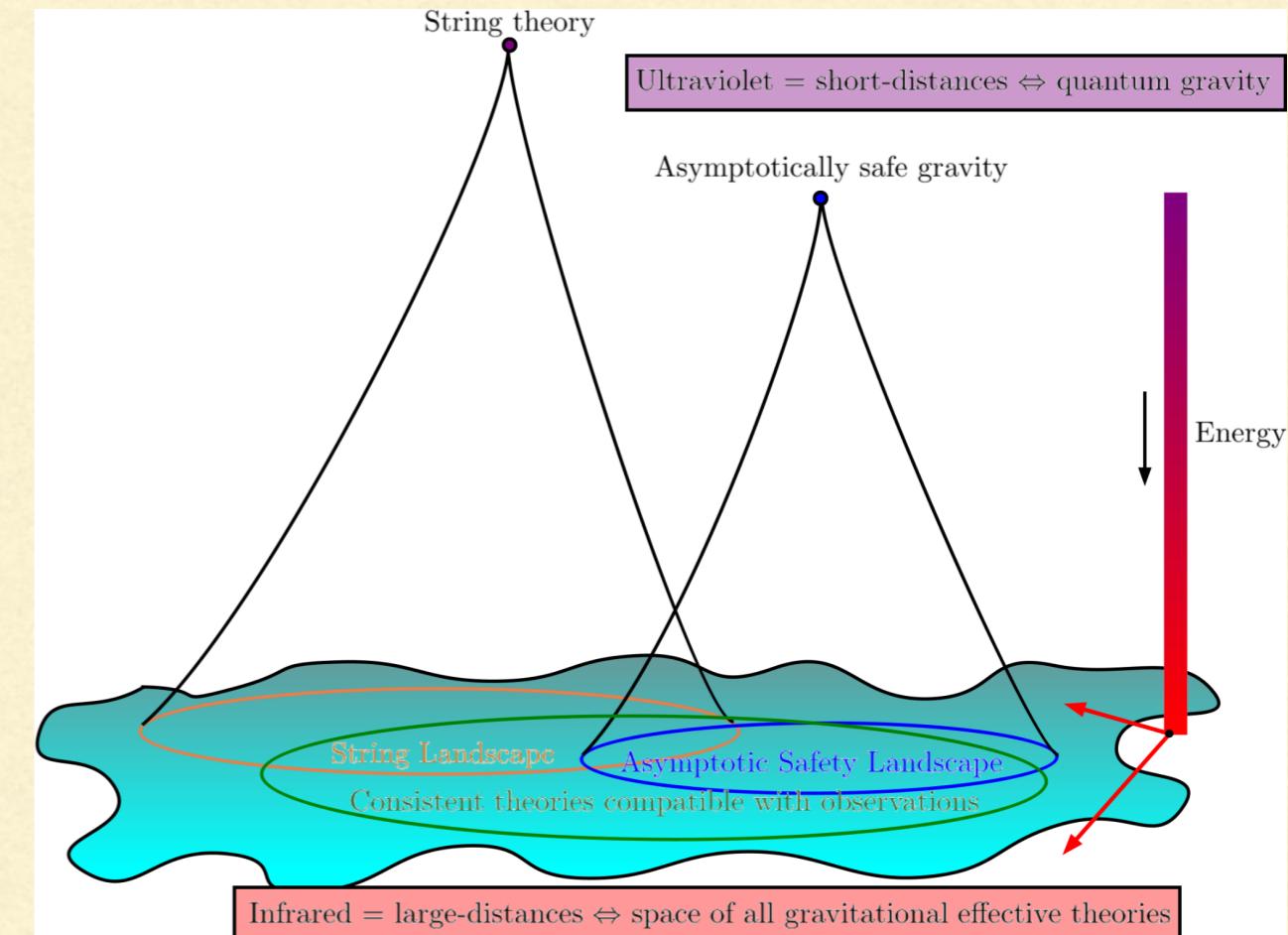
- Breaking seems controlled by entropy of smallest BH in the theory

- General heuristics supported by GPI calculations

- Key assumptions: There are BH and we can form them dynamically

Are these true in other QG approaches, like GS?

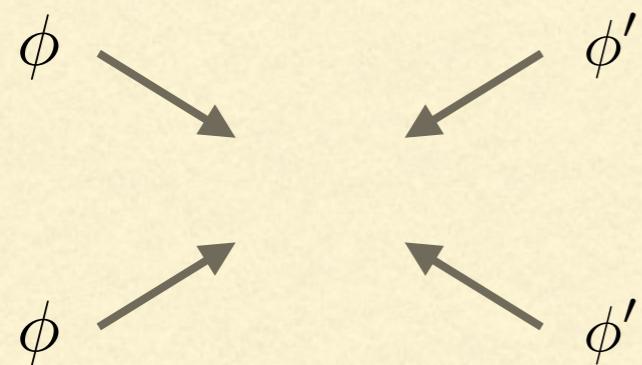
Are we missing some other important aspect of the problem?



Dankeschön!

Approach #1: Put a **lower bound** on symmetry-violating amplitudes

[Bah-Chen-Maldacena '22]

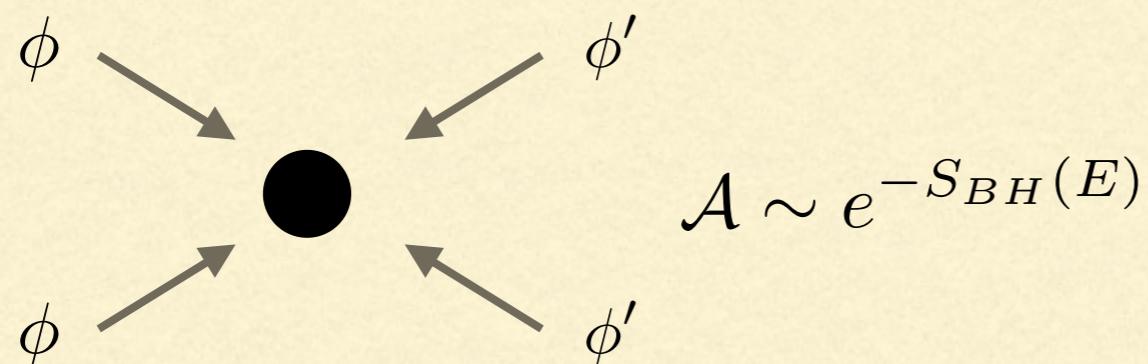


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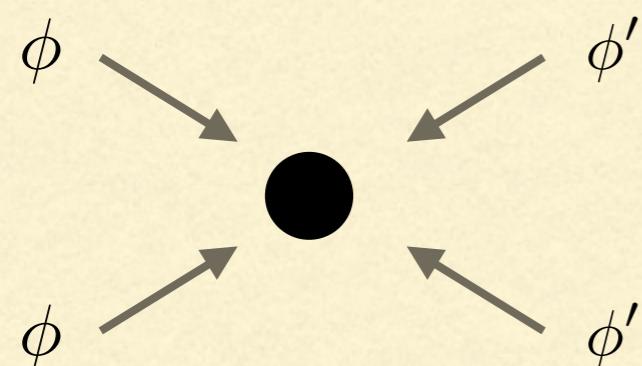


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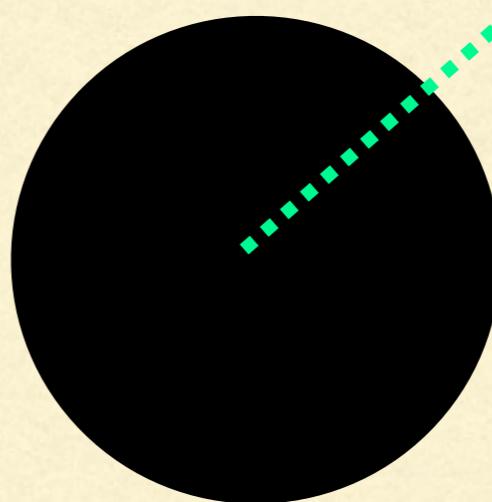


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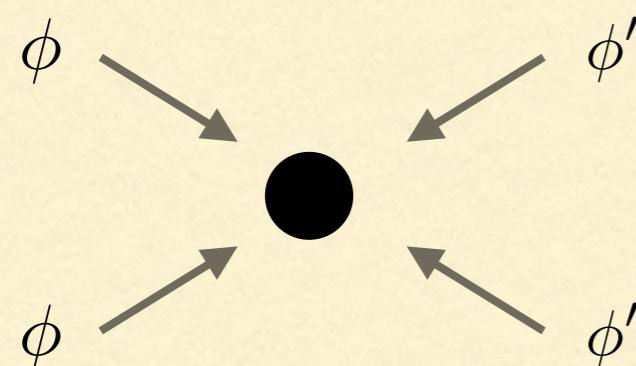


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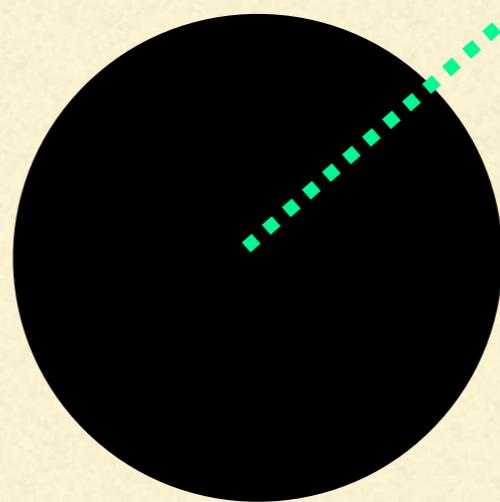


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Matches what we find “experimentally” in string theory examples!

Approach #2: Apply to **generalized** symmetries!

These are symmetries under which the charged objects are not particles, but **strings, membranes...**

Thank you!
