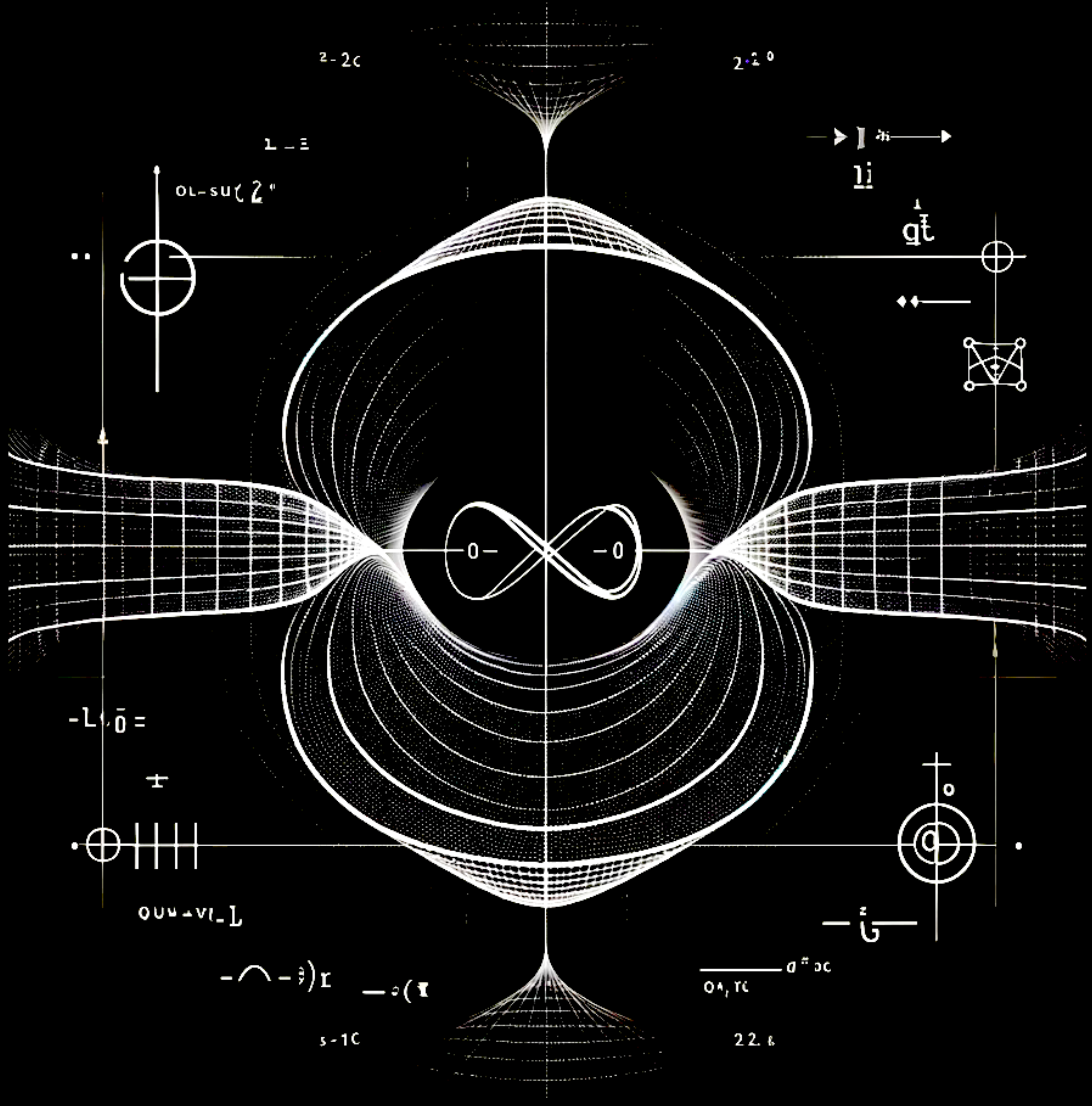

Gravity, you weirdo!

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Incidence of and risk factors for nodding off at scientific sessions

Kenneth Rockwood, David B. Hogan, Christopher J. Patterson, and for The Nodding at Presentations (NAP) Investigators

See the reply "The study of NOELs" in volume 172 on page 1540.

Abstract

Go to:

We conducted a surreptitious, prospective, cohort study to explore how often physicians nod off during scientific meetings and to examine risk factors for nodding off. After counting the number of heads falling forward during 2 days of lectures, we calculated the incidence density curves for nodding-off episodes per lecture (NOELs) and assessed risk factors using logistic regression analysis. In this article we report our eye-opening results and suggest ways speakers can try to avoid losing their audience.

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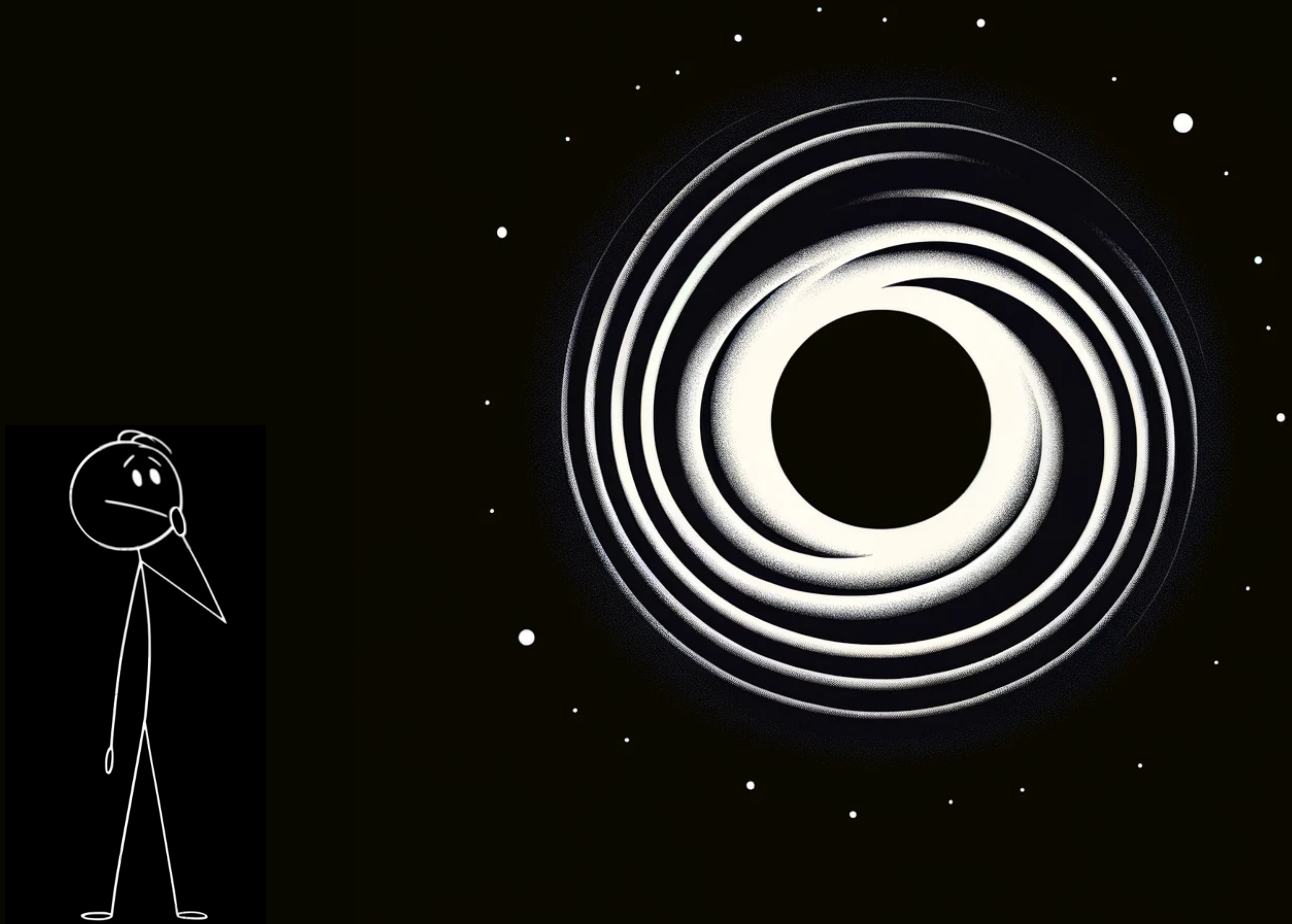
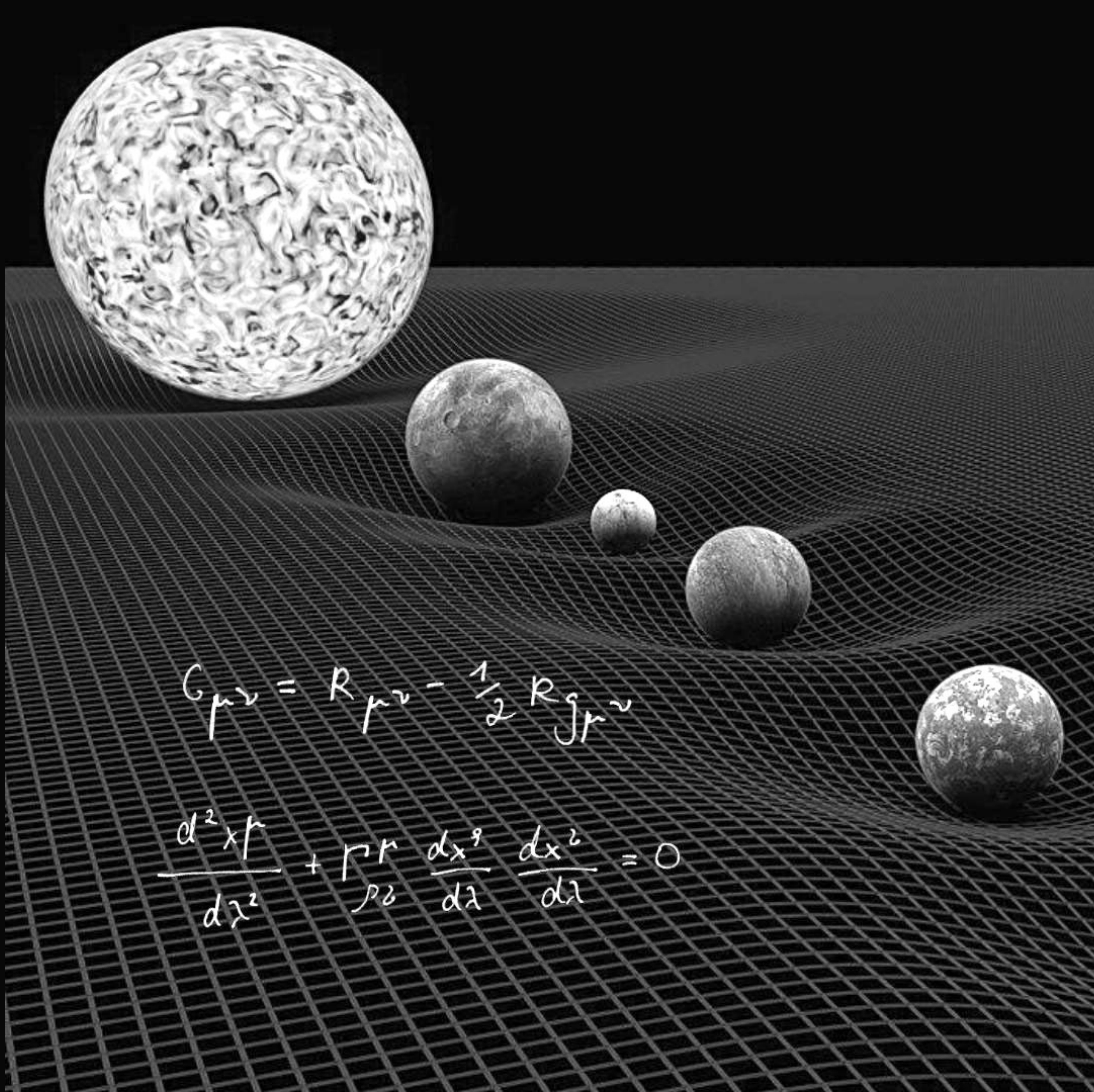


What have we learned so far?

- Universality I
- Operational Measurement Limitation
- No local observables in QG I
- Holography
- Universality II
- Quantum-gravitational subsystems:
  no local observables in QG II

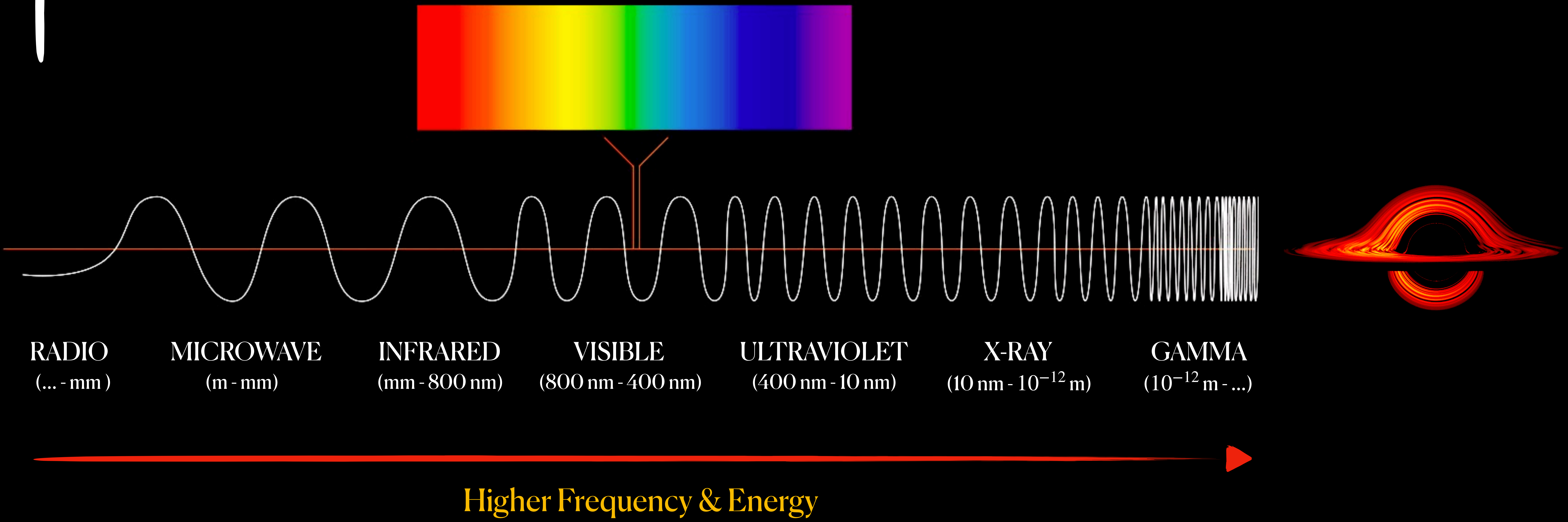


Universality I

Universal scope and universal strength.

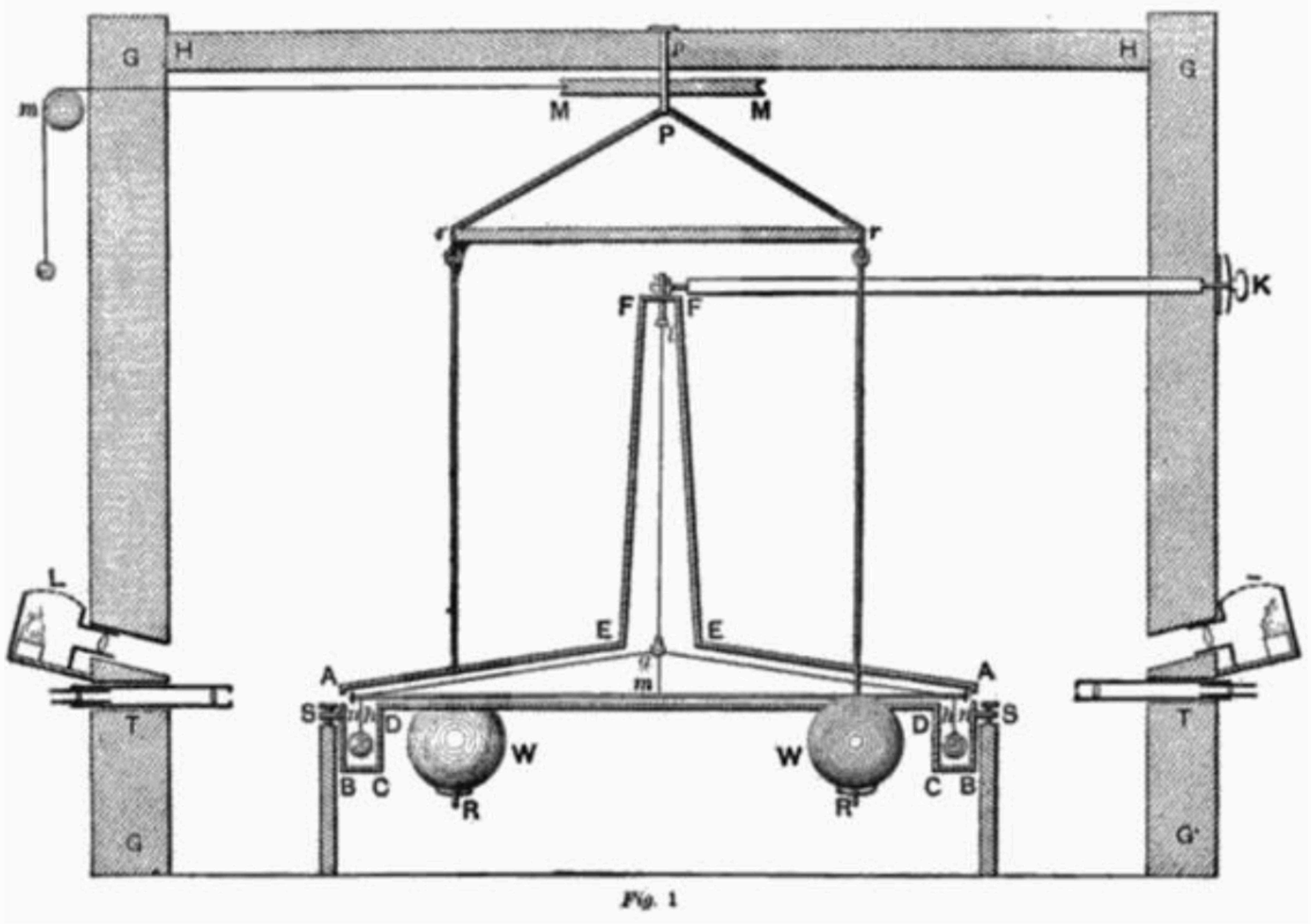
"The fact of a universal attraction might remind us of the situation in molecular physics; we know that all molecules attract one another by a force which at long distance goes like $1/r^6$. This we understand in terms of dipole moments which are induced by fluctuations in the charge distributions of molecules... Well, one possibility is that gravitation may be some attraction due to similar fluctuations in something, we do not know just what, perhaps having to do with charge."

Operational Measurement Limitation



Normal Kids Interlude I

- **First infinity:** quantum mechanics is a probabilistic theory, so unless infinite experiments intrinsic error in accuracy of order $1/\sqrt{n}$.
- **Second infinity:** we need an apparatus of infinite size to record with an arbitrary precision the value of any physical quantity; it should have an infinite dimensional Hilbert space. Otherwise, intrinsic error of order e^{-n}, where $\dim \mathscr{H}_{\text{app}} = n$.

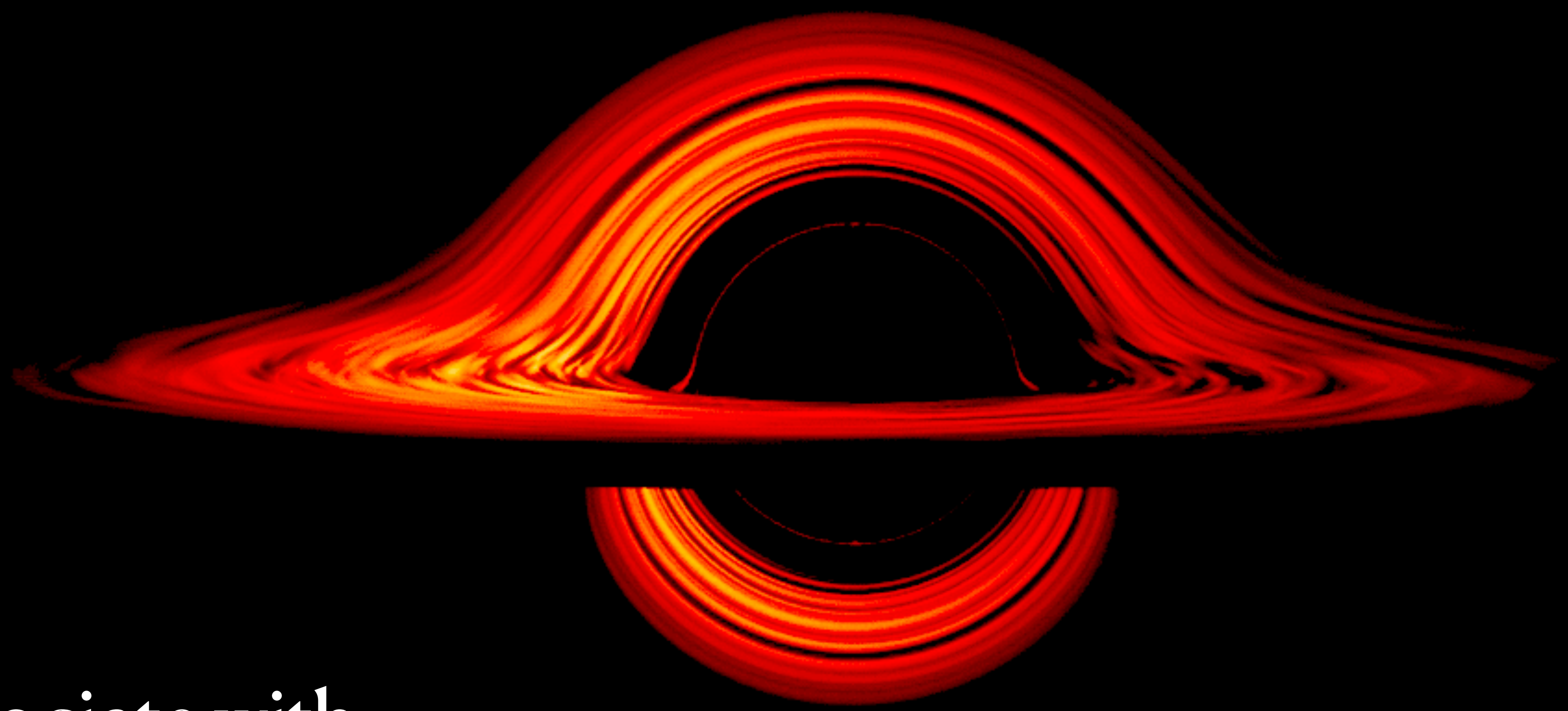


[*Conversations on Quantum Gravity,* Jácome Armas: Nima Arkani-Hamed]

No local observables in Quantum Gravity I

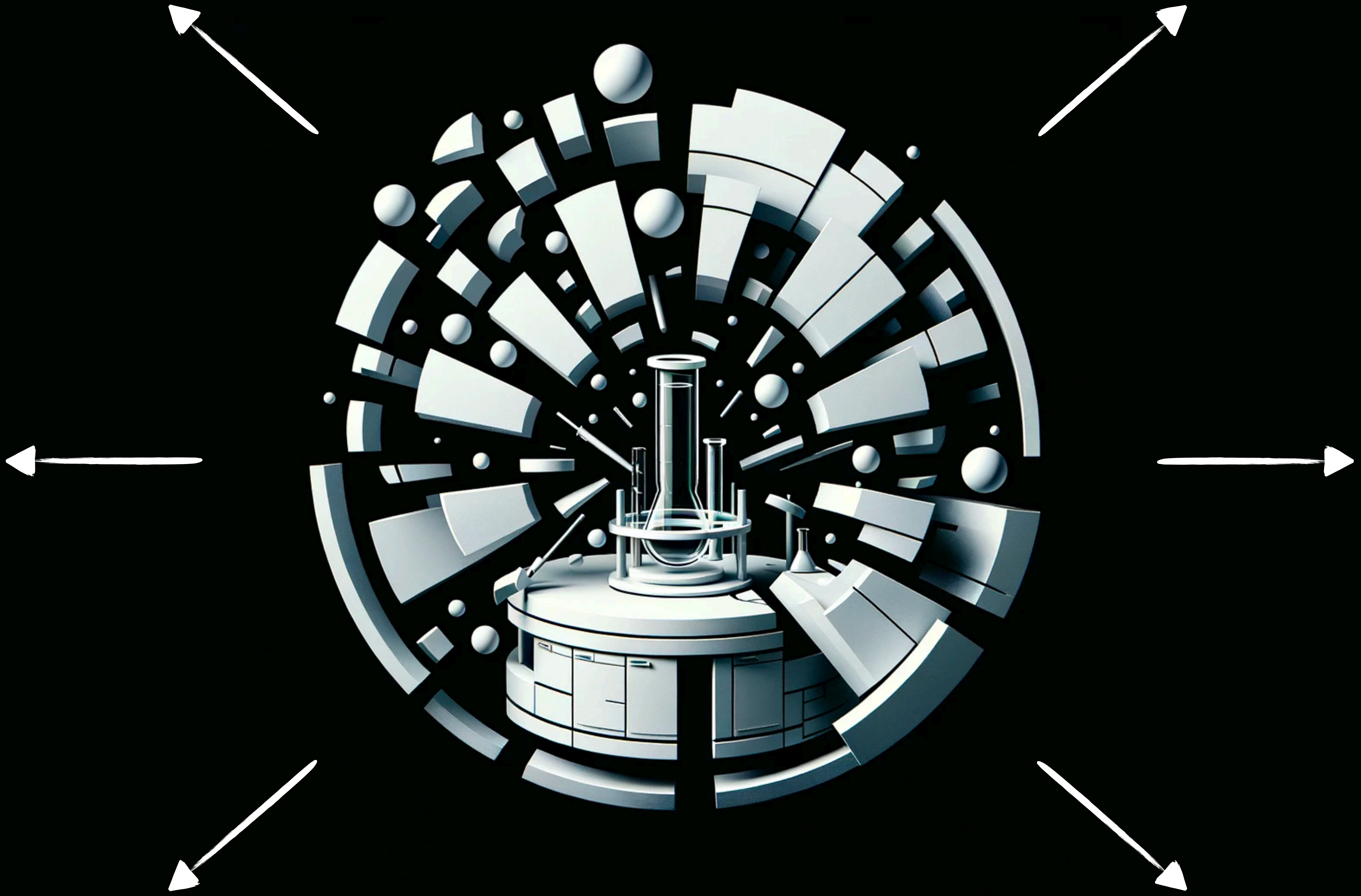
Turn gravity back on. Try to make your apparatus larger and larger, and at some point...

Thus, limitation on the amount of degrees of freedom locally available to perform the experiment, and that's given by the black hole entropy. Thus, the error actually scales as $e^{-A/G}$.



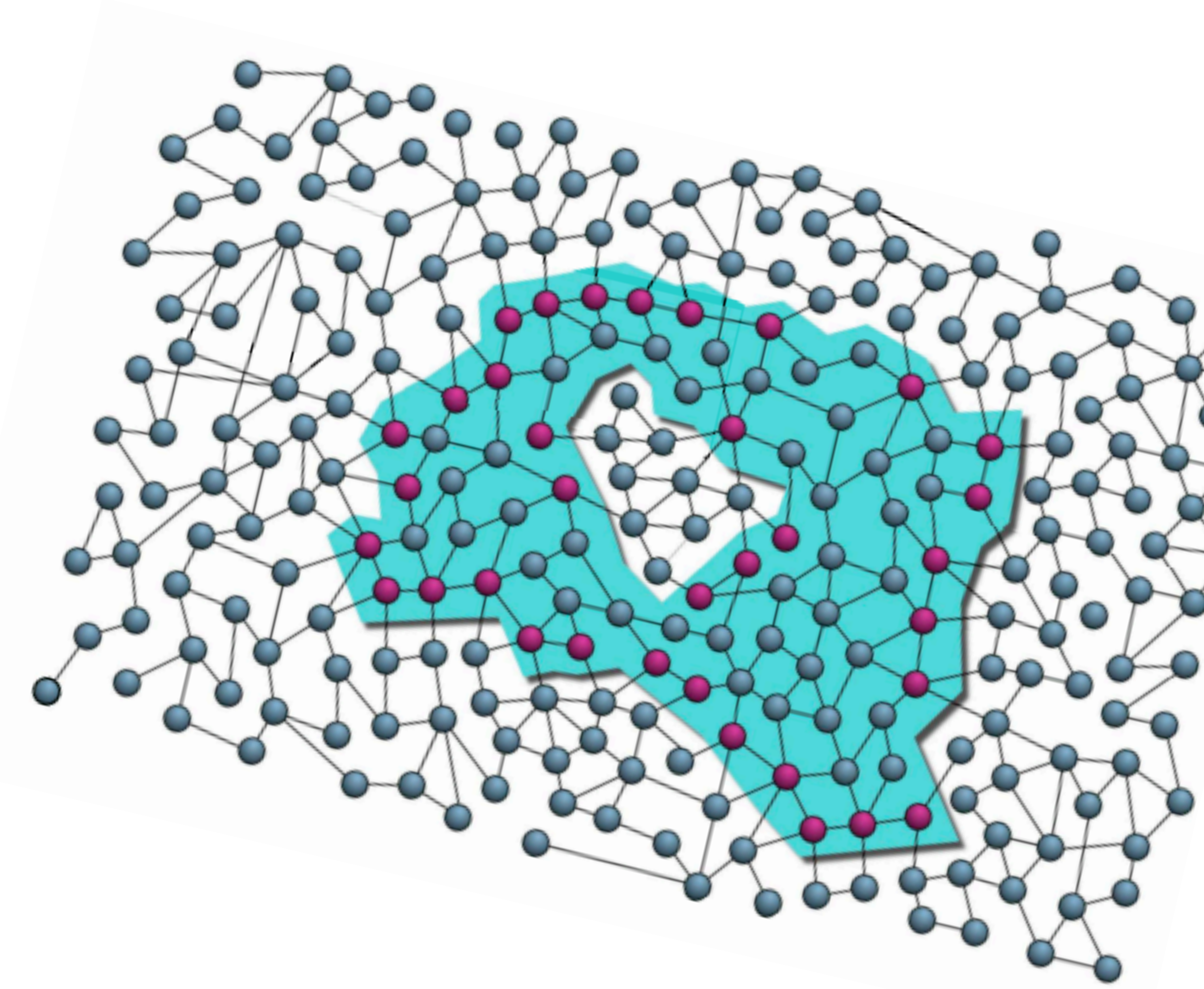
Therefore, there is no precise observable one can associate with any measurement performed in a finite-size room. **Unless....**

[*Conversations on Quantum Gravity,* Jácome Armas: Nima Arkani-Hamed]



Normal Kids Interlude II

The von Neumann entropy of quantum fields associated with a compact region of space is infinite. Such behavior is universal and independent of the state because all the states look like the vacuum at short distances. The physical picture is that there are an infinite number of degrees of freedom in the region that are entangled with infinitely many outside.



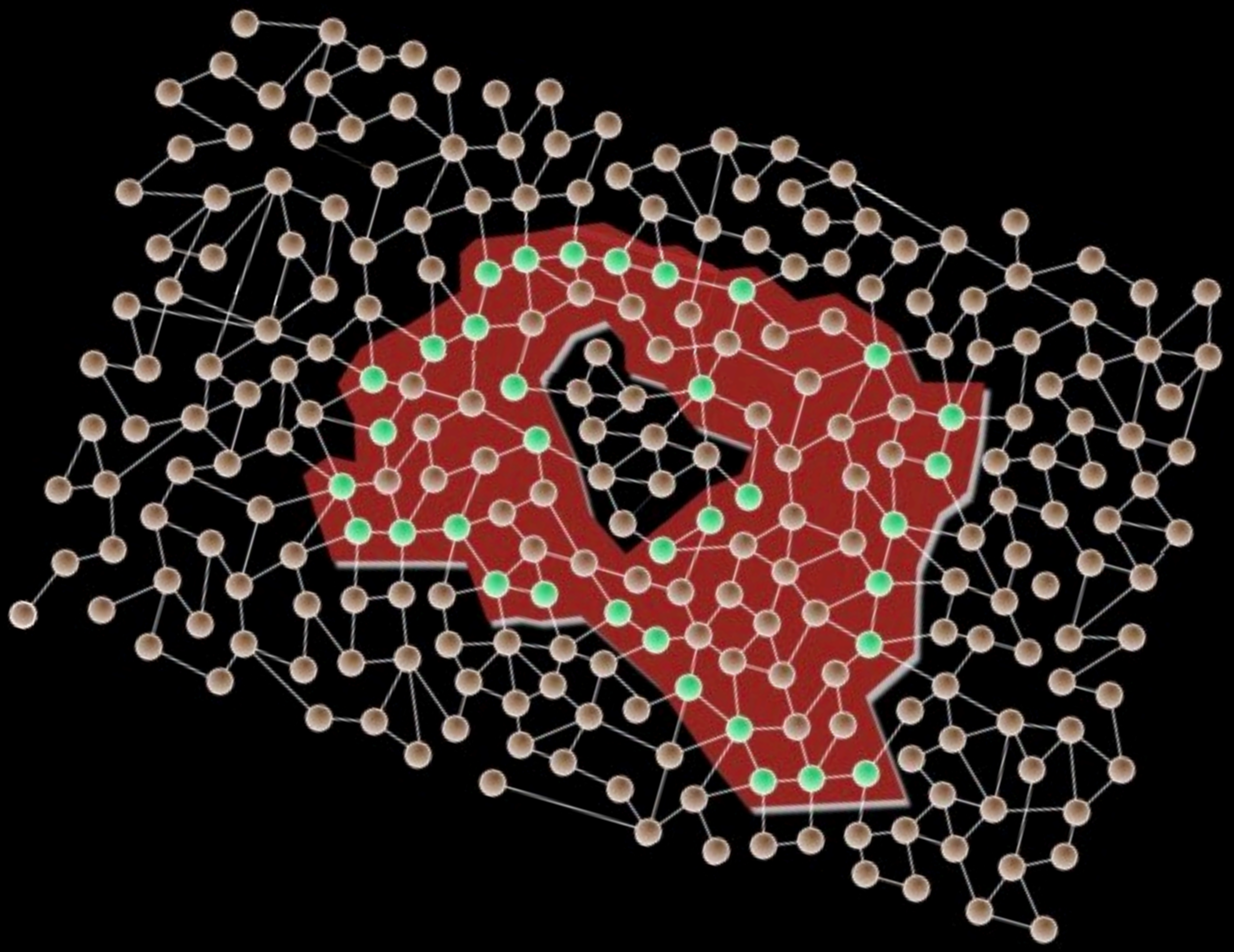
Srednicki showed that to be the case for the ground state, and derived the area scaling as the finite part of the entropy. This starkly contrasts the 'classical entropy' of systems like an ideal gas, where entropy is an extensive property scaling with the volume.

[Srednicki, '93]
[Witten, '18]

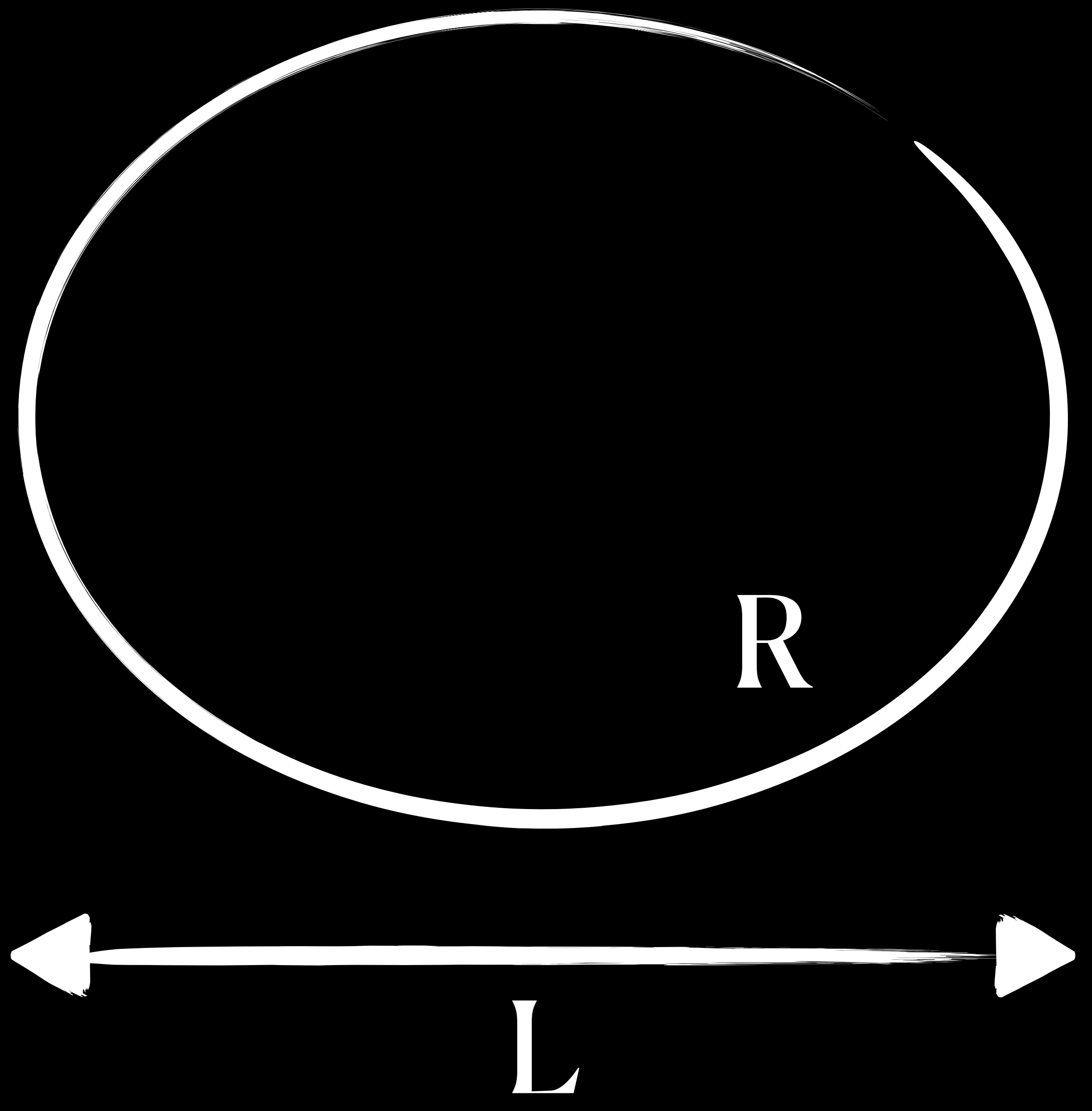
Holographic Principle

The entropy on any light sheet of a surface will not exceed the area of :

$$S[L(B)] \leq \frac{k_B c^3}{\hbar} \frac{A(B)}{4G}$$



[Bousso, '02]



Bekenstein Bound ('81)

$$S_R \leq \frac{\pi k L E}{\hbar c}$$

$$\dim \mathscr{H}_R = \exp(S) < \infty$$

↓

Gravity cannot be a QFT.

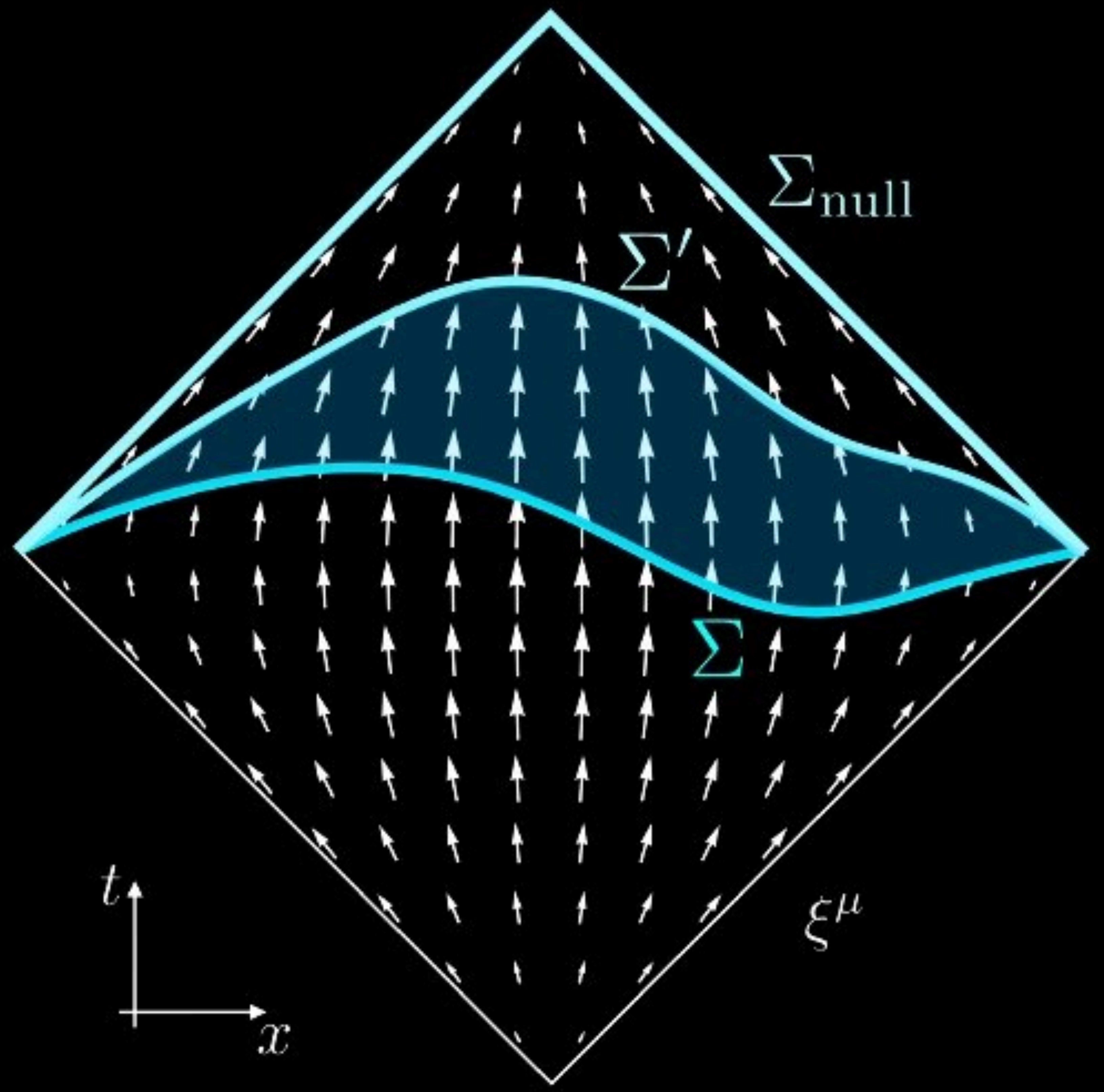
[Bao, Carroll, Singh '17]

[Jacobson, '15]

Universality II

$\delta S \sim \eta \, \delta A$

$|\Psi\rangle$



[Donelly&Giddings, '16]
[Fewster, '16]

Interlude: What's a normal kid?

	Notion of Separability	Notion of Subsystem
QM	$\mathscr{A}_{\mathscr{U}} \simeq \mathscr{B}(\mathscr{H}_{\mathscr{U}})$	$\mathscr{H}_{\mathscr{U}}$ of states localized in $\mathscr{U}$
QFT	**Einstein Separability** $[\mathscr{A}_{\mathscr{U}}, \mathscr{A}_{\mathscr{U}'}] = 0$	measurements and state preparations can be carried out independently
	Split Property	

[Donelly&Giddings, '16]
[Fewster, '16]

QED coupled with scalar field

$$\mathscr{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2\alpha}(\partial_\mu A^\mu)^2 - |(\partial_\mu - iqA_\mu)\phi|^2 - \frac{1}{2}m^2|\phi|^2$$

$$\begin{cases} A_\mu(x) \to A_\mu(x) + \partial_\mu \Lambda(x) \\ \phi(x) \to e^{-iq\Lambda(x)}\phi(x) \end{cases}$$

$[\phi(x), \phi(y)] = 0,$ for x and y spacelike, but not gauge invariant.

Dressed Operator

$$\mathscr{D}(x,y) = \phi(x)\exp\left\{ \mathrm{i}q\int_{z_x}^{z_y} \mathrm{d}zA_z \right\}\phi^*(y)$$

[Donelly&Giddings, '16]

And then...

$$\mathscr{L} = \frac{2}{\kappa^2}R - \frac{1}{2}\left(g^{\mu\nu}\nabla_\mu\phi\nabla_\nu\phi + m^2\phi^2\right)$$

$$\begin{cases} \delta h_{\mu\nu} = -2\partial_{(\mu}\xi_{\nu)} + \mathcal{O}(\kappa) \\ \delta\phi = -\kappa\xi^\mu\partial_\mu\phi + \mathcal{O}(\kappa^2) \end{cases}$$

$[\phi(x), \phi(y)] = 0$, for x and y spacelike, but not gauge invariant.

Gauge-Inv. Dressed Operator

$$\Phi(x) = e^{\mathrm{i}V^\mu(x)P_\mu}\phi(x)e^{-\mathrm{i}V^\mu(x)P_\mu}, \quad \text{e.g.: } V_\mu(x) = \frac{\kappa}{2}\int_x^\infty d\tilde{x}^\nu\left[h_{\mu\nu}(\tilde{x}) + 2\int_{\tilde{x}}^\infty d\tilde{\tilde{x}}^\lambda\partial_{[\mu}h_{\nu]\lambda}(\tilde{\tilde{x}})\right]$$

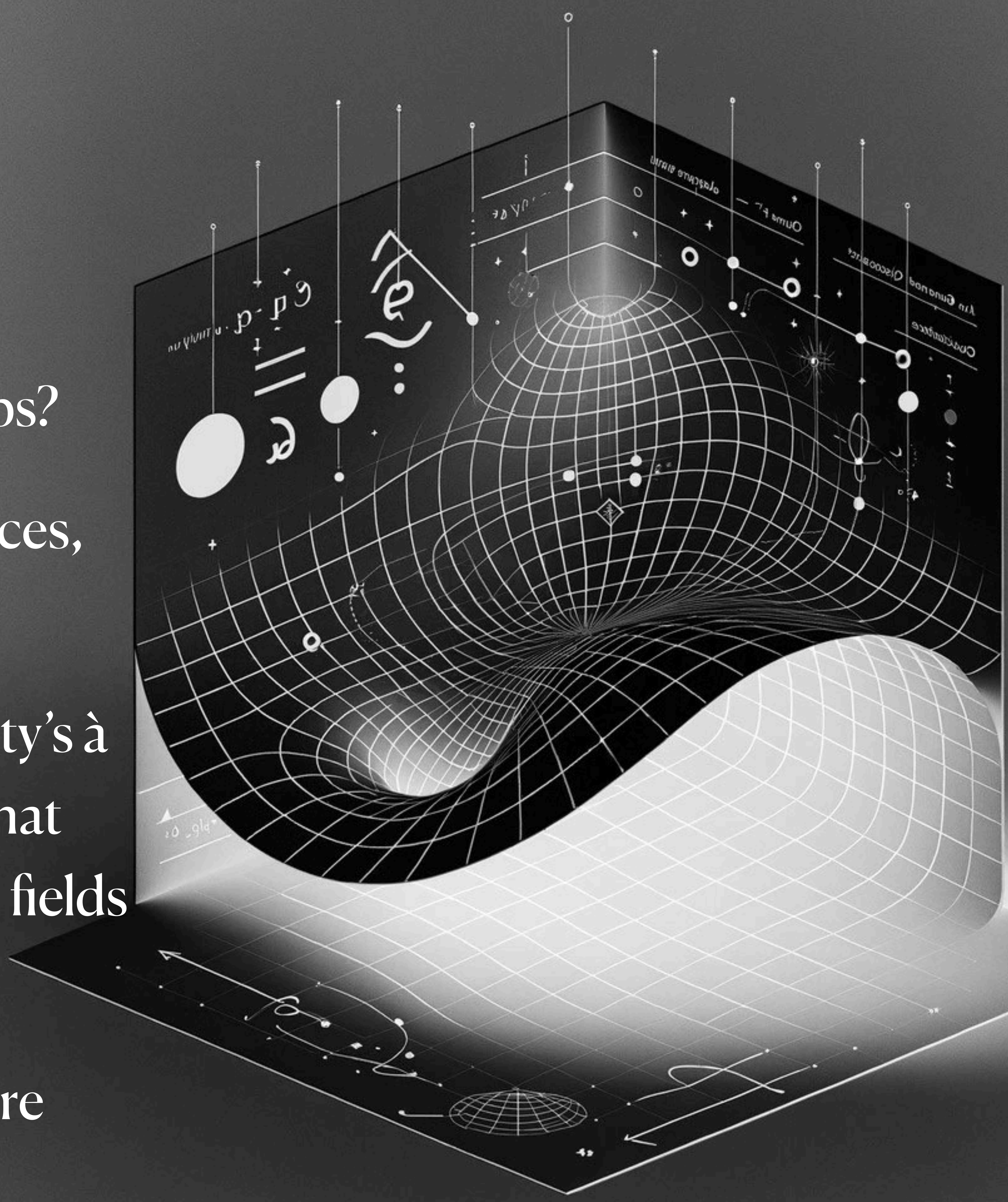
The algebraic approach is obstructed in gravity because $\Phi(x)$ does not commute with itself at all spacelike separations.

The reason is that the gravitational strings of any two operators $\Phi(x)$ and $\Phi(y)$ can intersect no matter how far apart these points are. We cannot screen the gravitational field of a particle as there is no notion of a negatively "charged" particle (or any Poincaré charge for that matter), preventing us from defining localized observables.

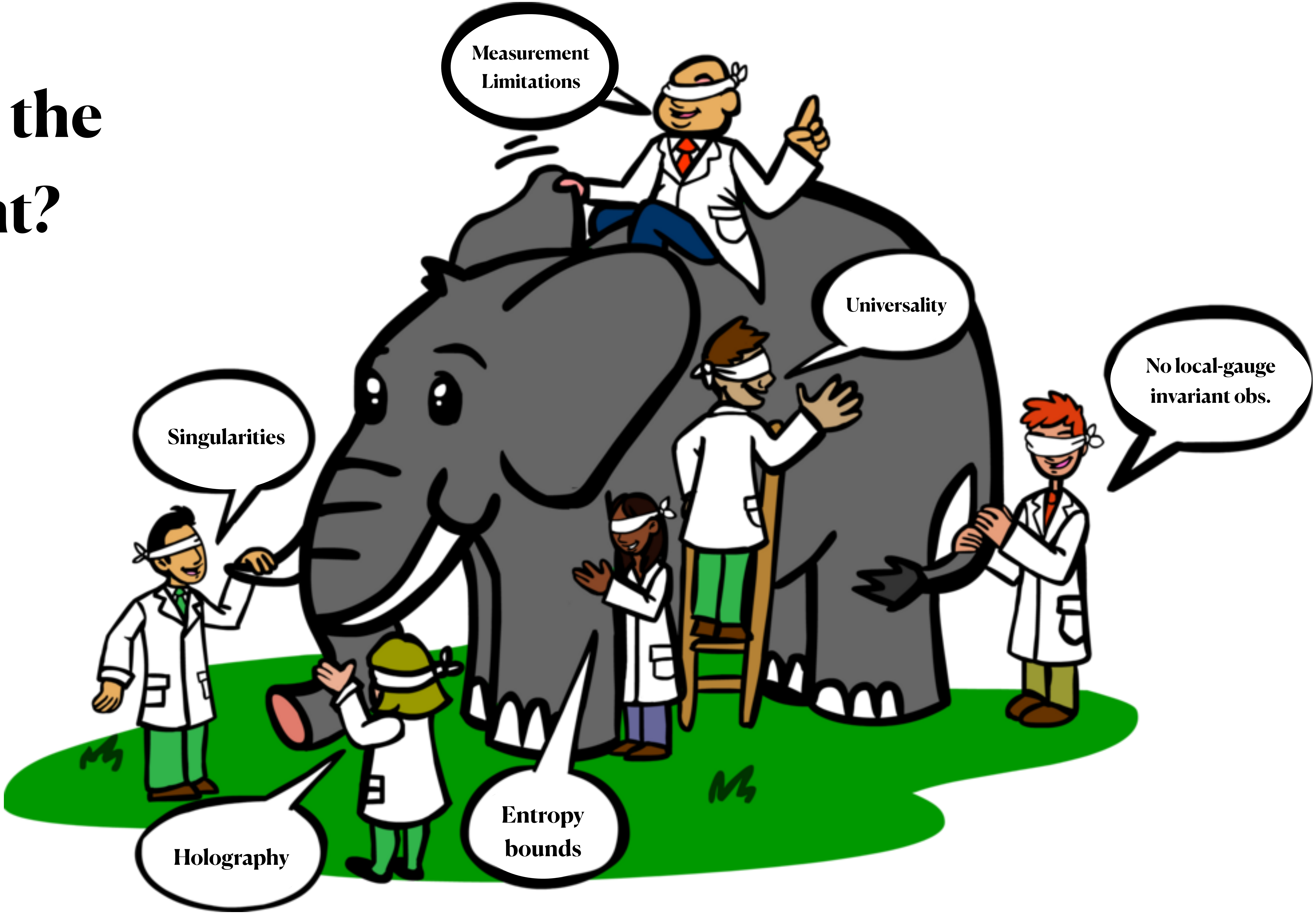
We only used the gauge symmetries to make such an argument, thus remains valid for any diff-invariant theory at the linear level.

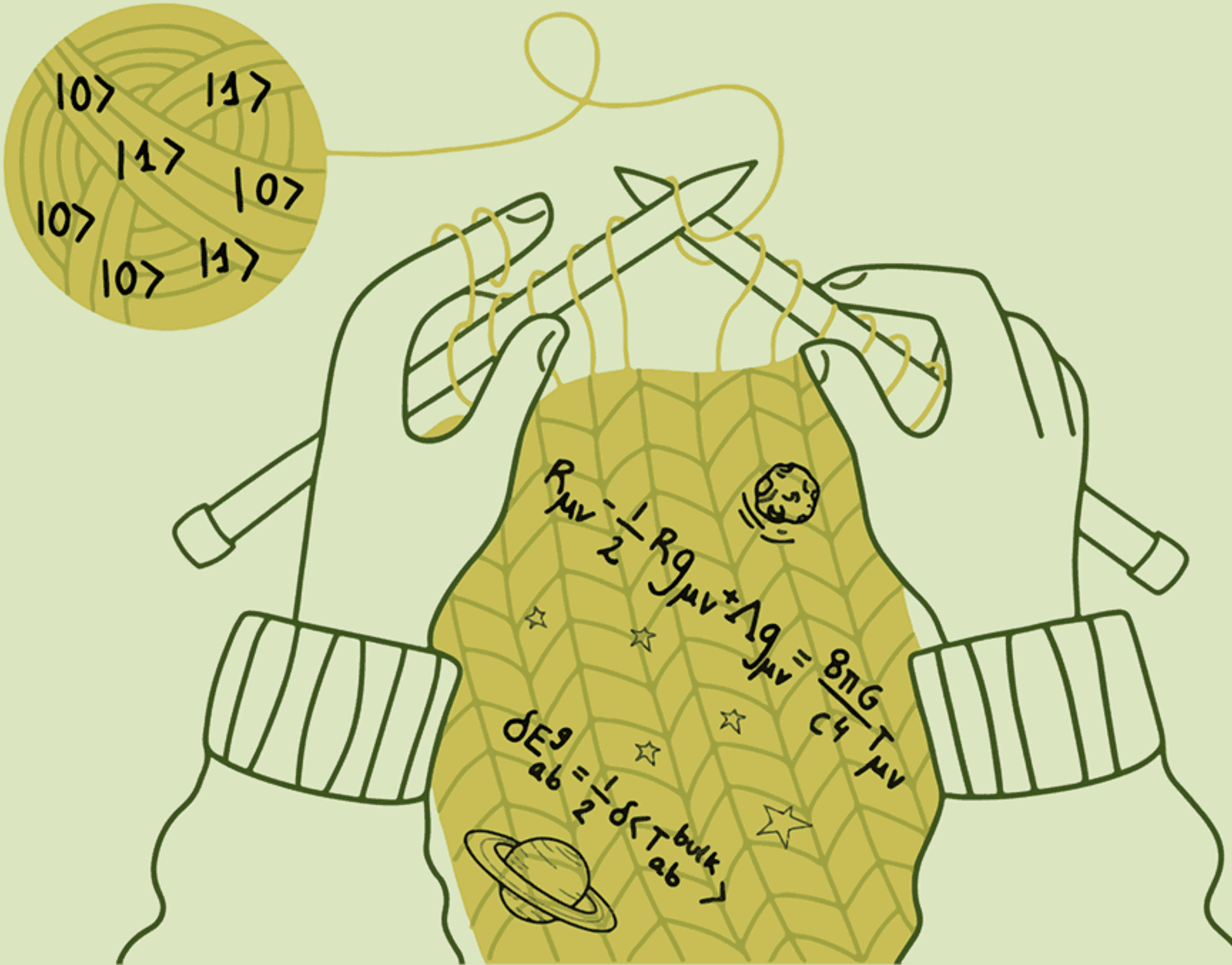
Now what?

- Updated directions to RQI?
- What are the implications to descriptions of GIE exps?
- If local regions of spacetime have a finite-dim. H-spaces, no issues with defining local quantum subsystems
- Feynman's universality appears on the IR, while gravity's à la Jacobson in the UV. Is that connected to the fact that area-entropy scaling laws appear in the IR for matter fields while in the UV for gravity?
- Are all these things hinting towards a strong departure from our classical gravity intuition?



What is the elephant?

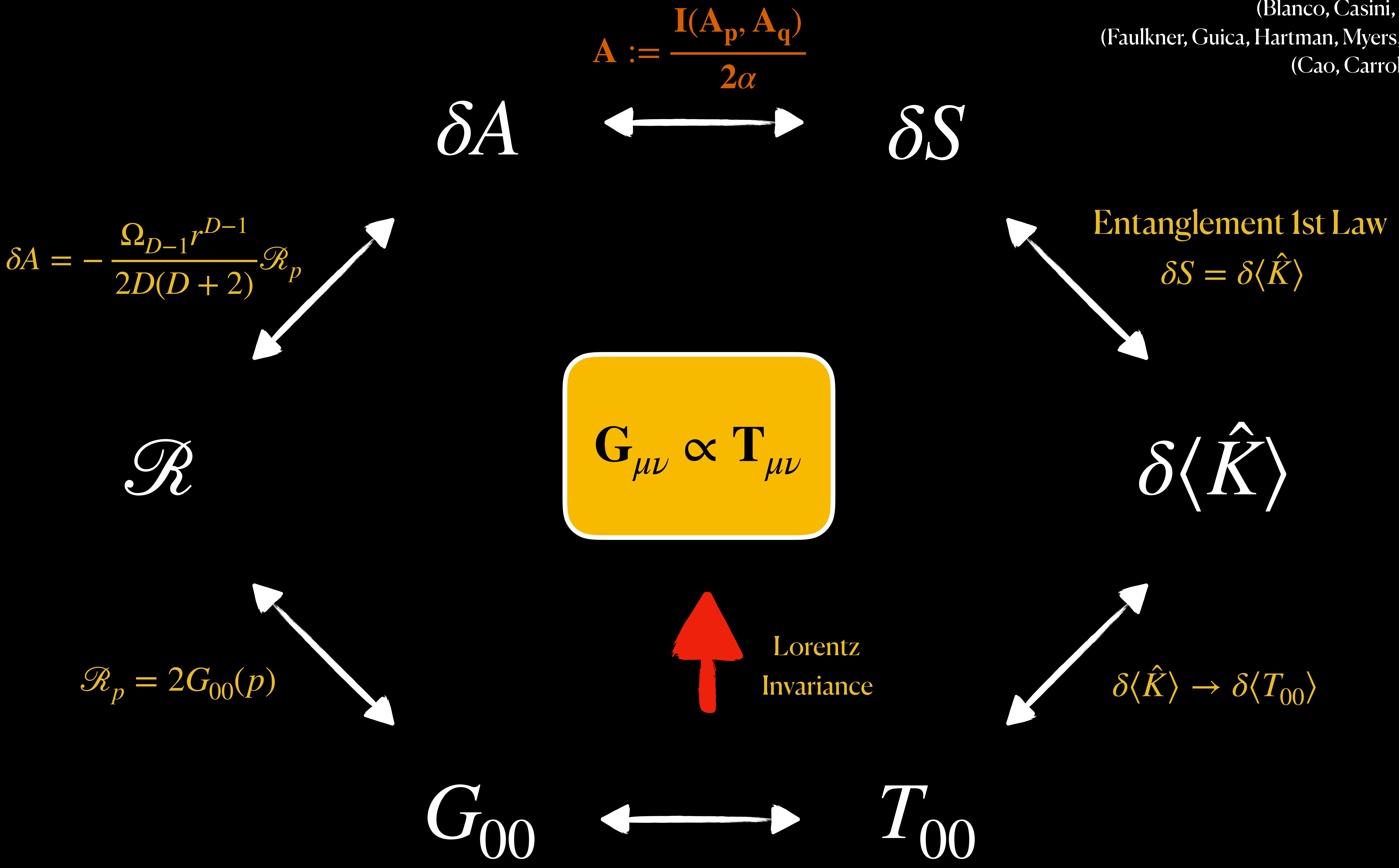


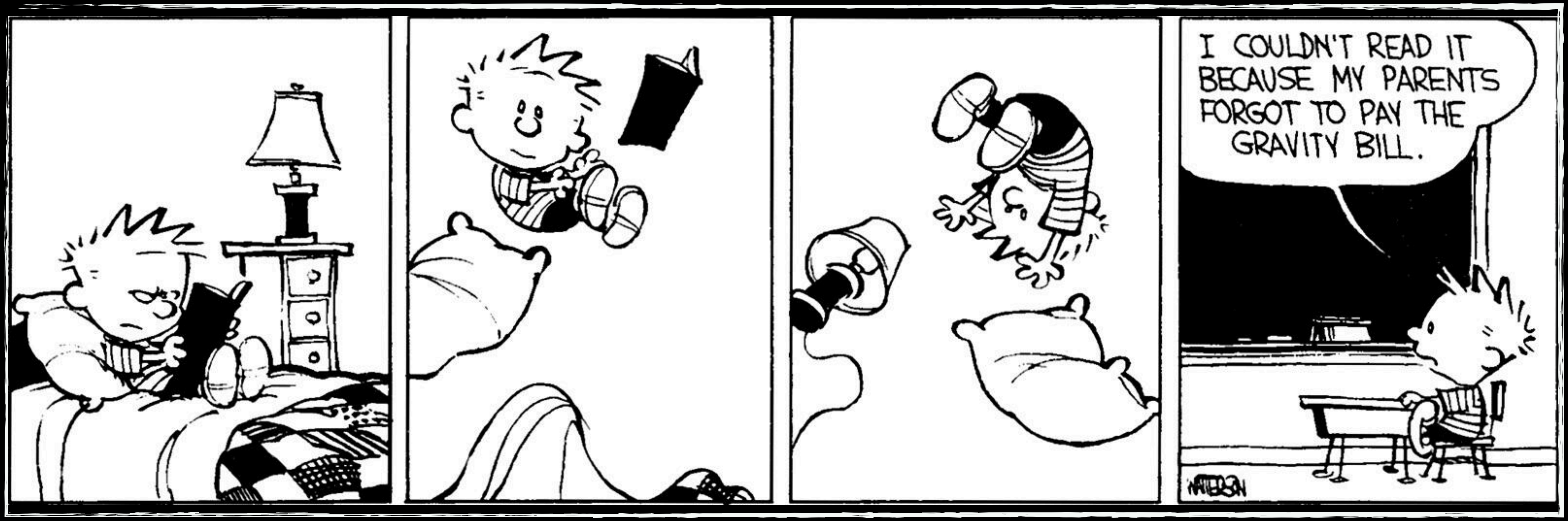


Spacetime Emergence

[Clara Aldegunde]

(Jacobson, '15)
(Blanco, Casini, Hung, Myers, '13)
(Faulkner, Guica, Hartman, Myers, Raamsdonk, '13)
(Cao, Carroll, Michalakis, '16)




I COULDN'T READ IT BECAUSE MY PARENTS FORGOT TO PAY THE GRAVITY BILL.
WATTERSON

Thank you!