Title: Quantum Gravity/Quantum Foundations

Speakers: Francesca Vidotto

Collection: Scicomm Collider

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QUANTUM GRAVITY

& Quantum Foundations

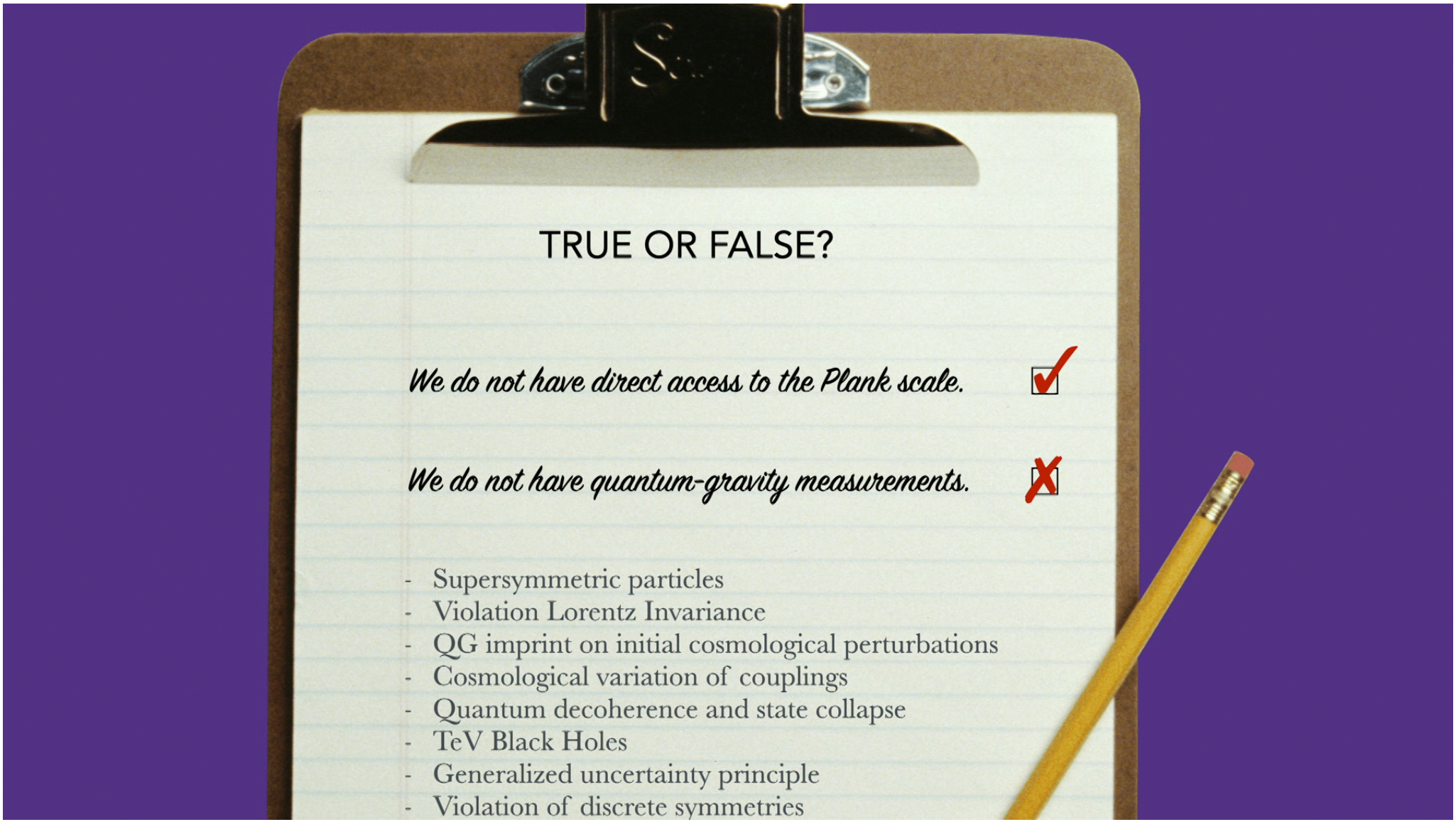
Francesca Vidotto

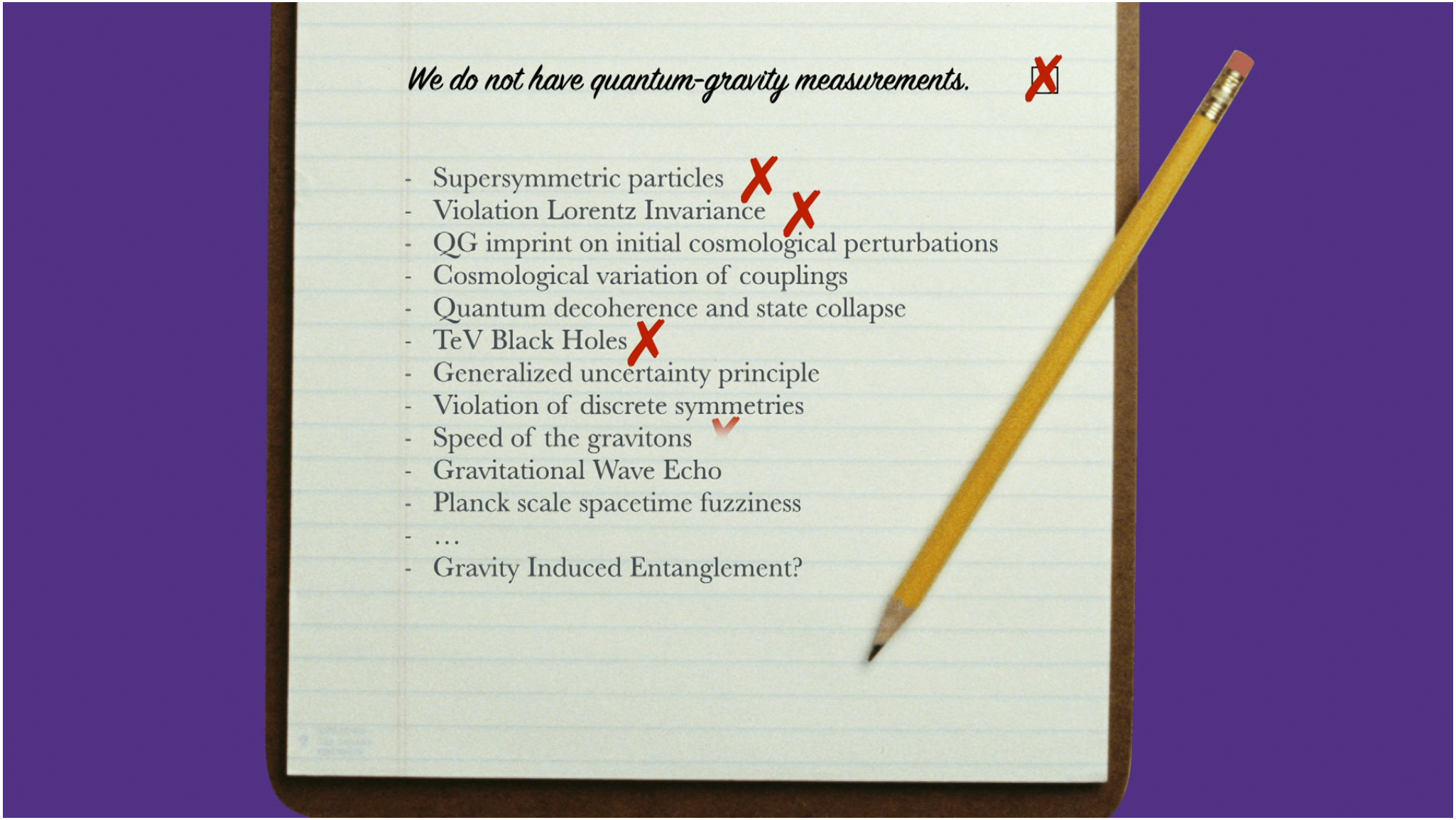
@FrancesVidotto

Rotman Institute of Philosophy

Canada Research Chairs

Western


TRUE OR FALSE?
We do not have direct access to the Plank scale.
We do not have quantum-gravity measurements.
- Supersymmetric particles
- Violation Lorentz Invariance
- QG imprint on initial cosmological perturbations
- Cosmological variation of couplings
- Quantum decoherence and state collapse
- TeV Black Holes
- Generalized uncertainty principle
- Violation of discrete symmetries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- Generalized uncertainty principle
- Violation of discrete symmetries
- Speed of the gravitons
- Gravitational Wave Echo
- Planck scale spacetime fuzziness
- …
- Gravity Induced Entanglement?

QUANTUM

- *Discreteness* $\hbar$
- *Superposition*

QUANTUM

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QUANTUM

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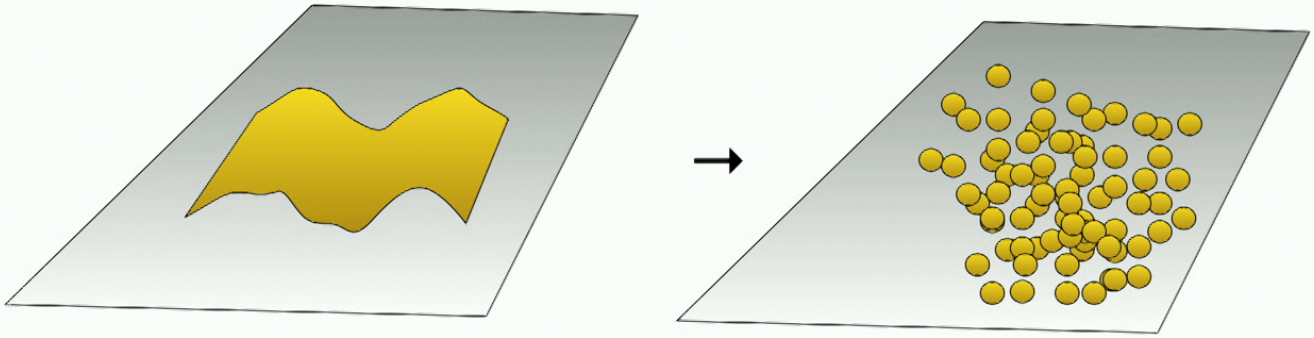
QUANTUM

- *Discreteness* $\hbar$
- *Superposition*

$(\mathcal{H}, \mathcal{A}, \mathcal{W})$

STATES OF THE THEORY
PHYSICAL QUANTITIES
DYNAMICS / PROBABILITIES

EXAMPLE: QUANTUM ELECRODYNAMICS



The quanta of a field are particles (Dirac).
DISCRETENESS of the spectrum of the energy of each mode

$(\mathcal{F}, \mathcal{A}, W)$

- STATES $\mathcal{F} \ni |p_1 ... p_n\rangle$
- OBSERVABLES $\mathcal{A} \ni a(k), a^\dagger(k)$
- DYNAMICS $W \rightarrow Feynman\ rules$

QUANTUM GRAVITY

- *Discreteness* $G\hbar$
- *Superposition*

$(\mathcal{H}, \mathcal{A}, \mathcal{W})$

STATES OF THE THEORY
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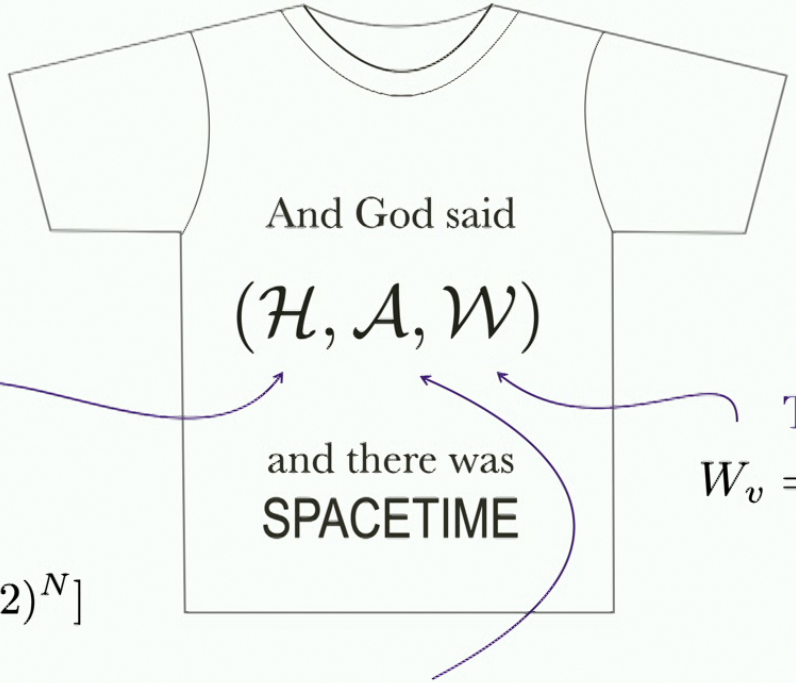
LOOP QUANTUM GRAVITY IN A T-SHIRT



STATES OF THE THEORY

Hilbert Space:

$$\mathcal{H}_\Gamma = L_2[SU(2)^L/SU(2)^N]$$

DYNAMICS / PROBABILITIES

Transition Amplitude:

$$W_v = (P_{SL(2,\mathbb{C})} \circ Y_\gamma\ \psi_v)(\mathbf{1})$$

PHYSICAL QUANTITIES

Operator Algebra:

$$\left[L^i_a, L^j_b\right] = i\delta_{ab}\ell^2\epsilon^{ij}_k L^k_a$$

Covariant Loop Quantum Gravity, with C. Rovelli

WHERE IS SPACE?

1. "*Space*" **in the most weak sense:** the relation determined by the continuity of things

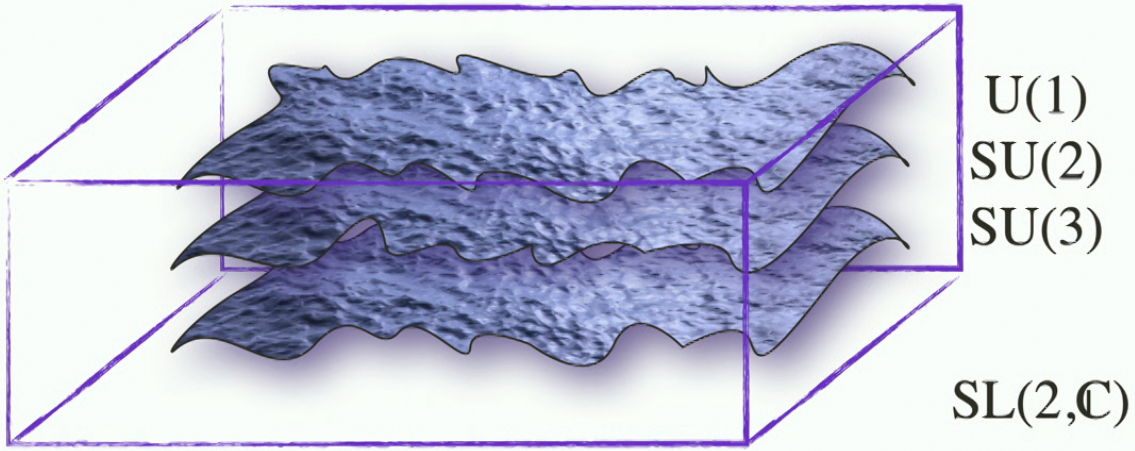
2. "*Space*" **in the sense of geometry:** quantity that we can measure with rods

3. "*Space*" **in the sense of a continuous Riemaniann space:** not in the theory

4. "*Space*" **in the sense of the container within which things happen:** not in the theory

EINSTEIN 1915

- General Relativity: spacetime is the gravitational field
- background independence / general covariance



FIELDS ⟷ GAUGE SYMMETRIES

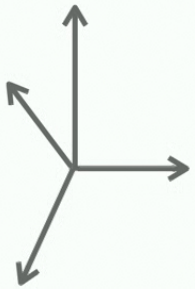
Gravity as an interacting gauge field

GRAVITATIONAL FIELD

- VECTOR FIELD: for each point, associate a vector

- TENSOR: for each point, associate n-plet of vectors (references frame)

Minkowski theorem (1897)



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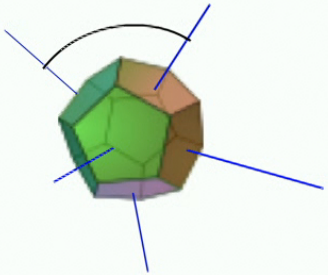

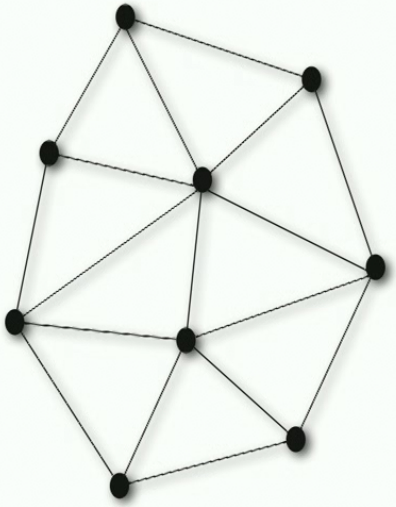

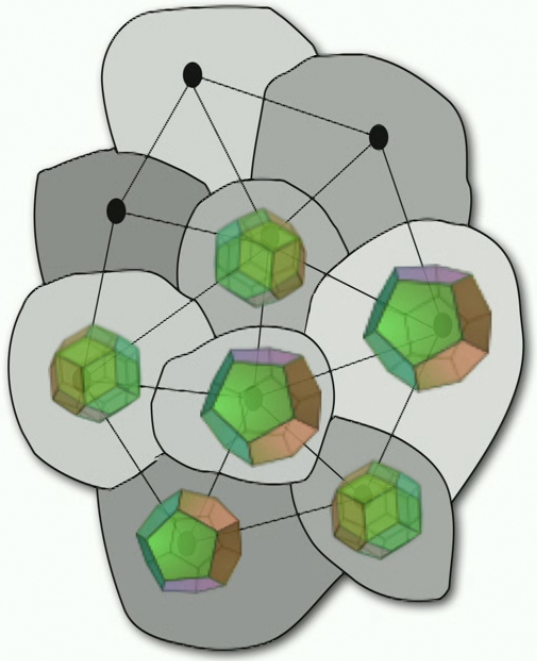

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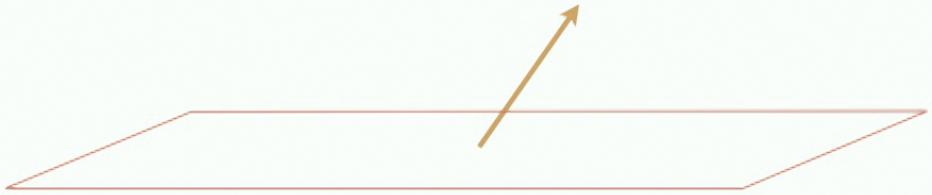

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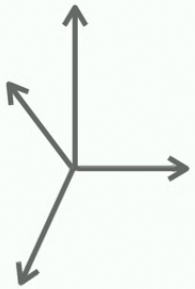

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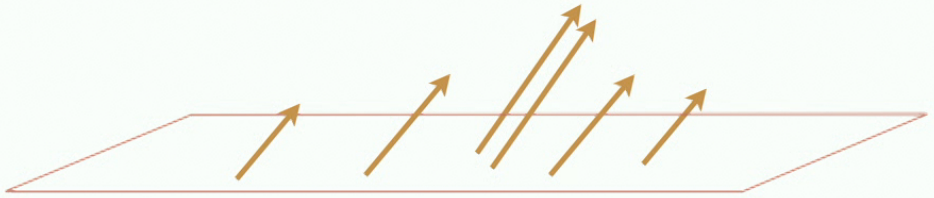

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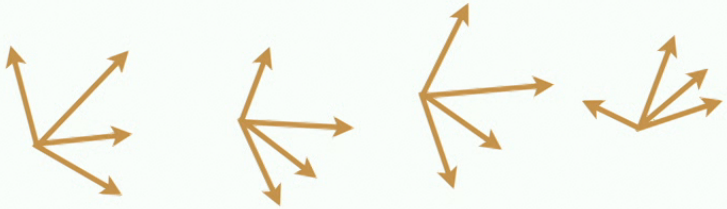

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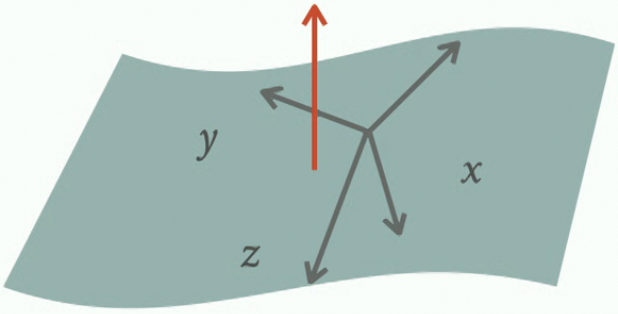
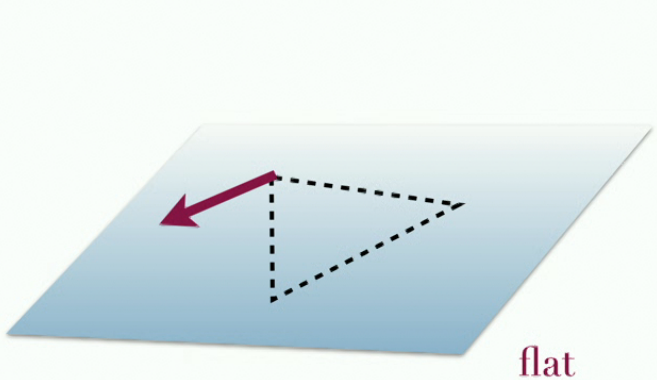


QUANTUM GRAVITY GOAL

- A concrete realization of a quantum theory of the gravitational field
- That is well defined without uncontrollable infinities
- Whose classical limit is General Relativity
- In 4 Lorentzian dimensions
- With the standard matter couplings

MEASURING GRAVITY



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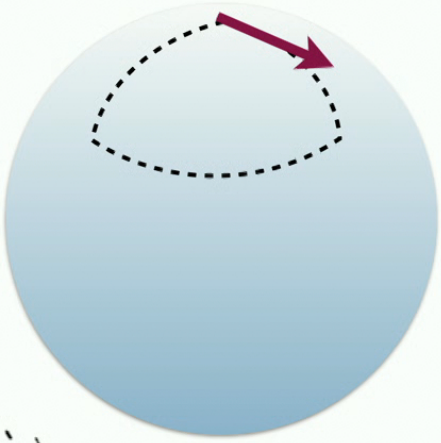

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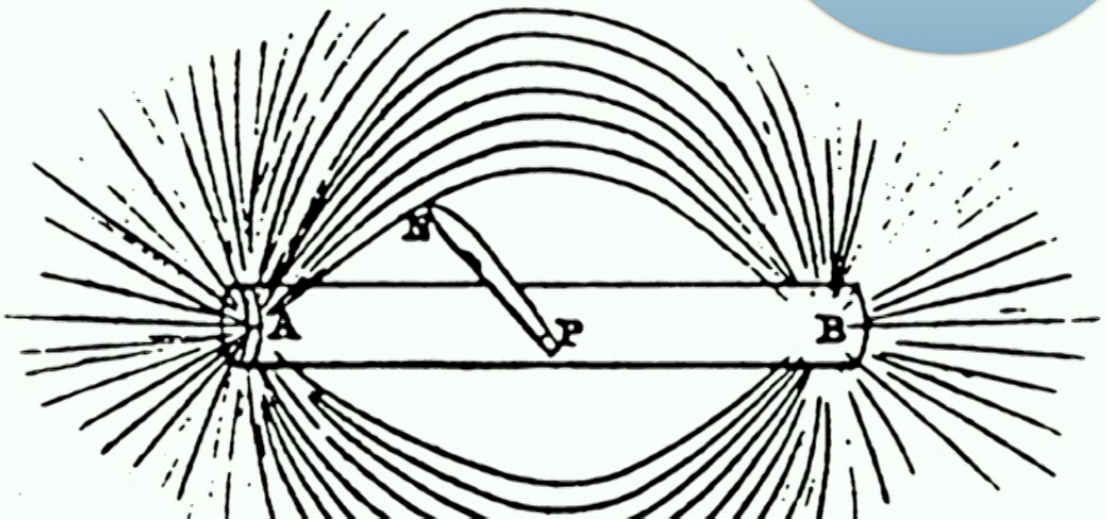

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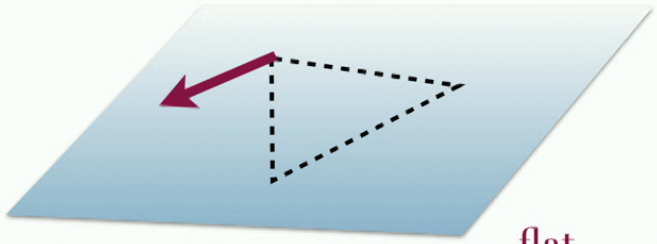

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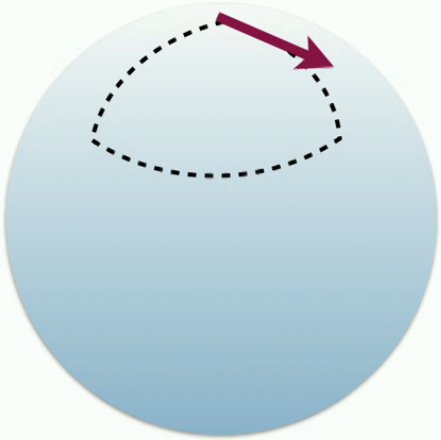

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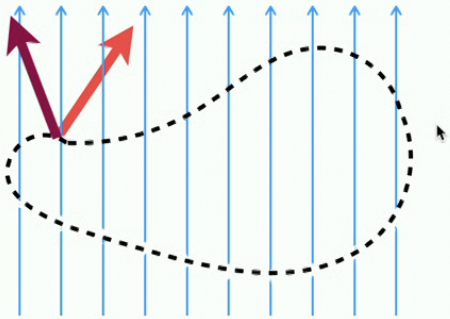

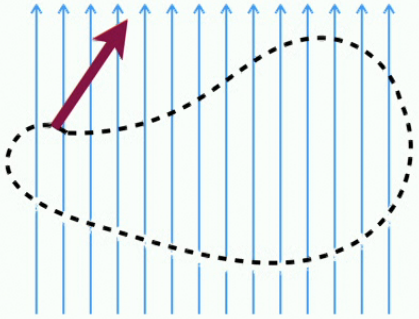

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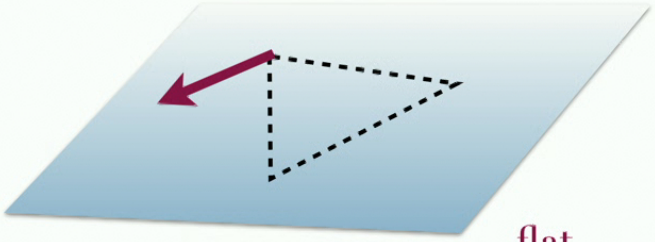

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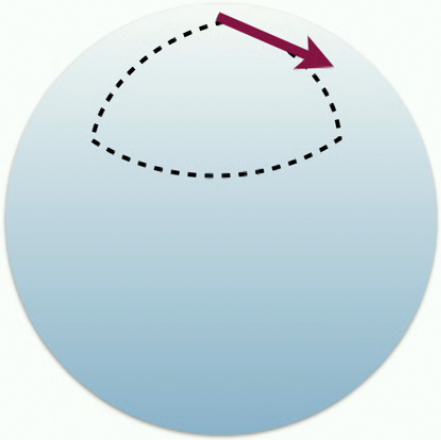

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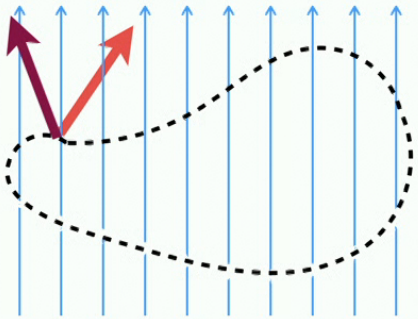

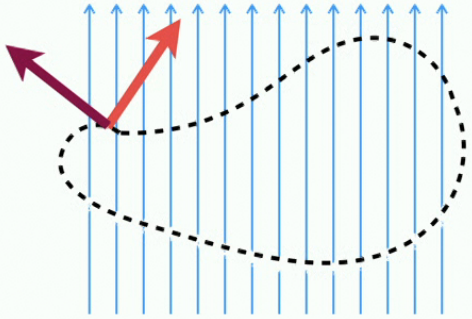

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- UV and IR finite (with Λ)
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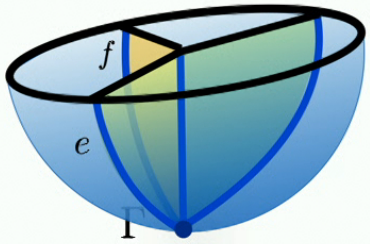
www.cpt.univ-mrs.fr/~rovelli/IntroductionLQG.pdf



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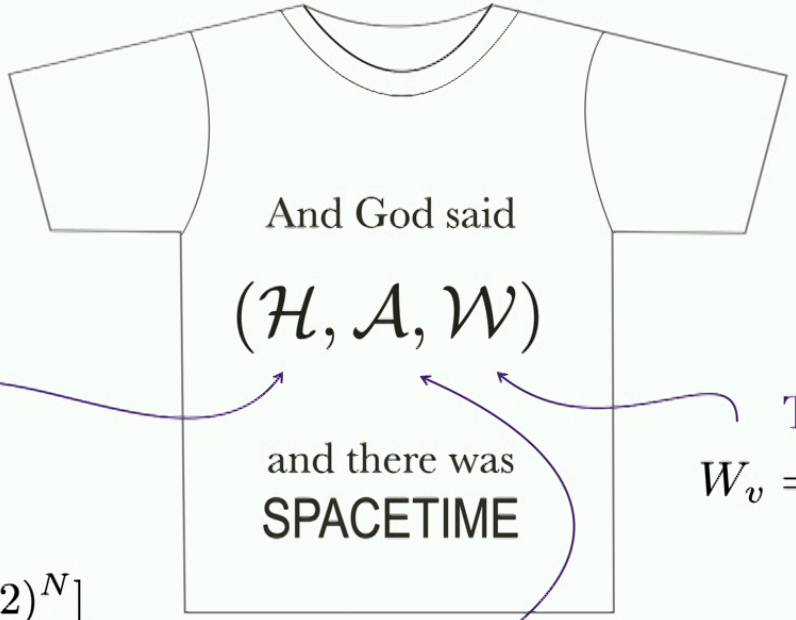

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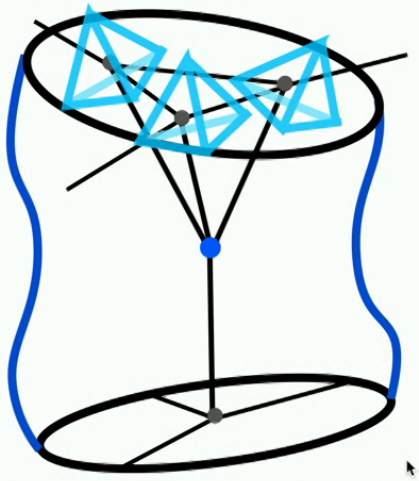

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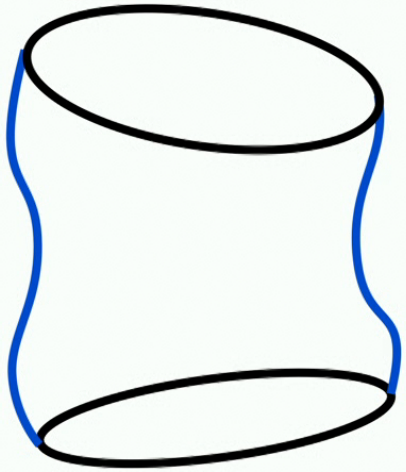

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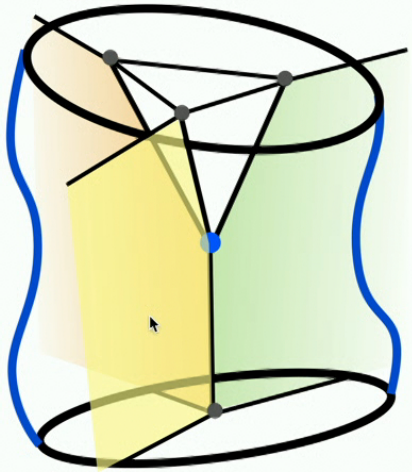

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QUANTUM GRAVITY

at low energy

QUANTUM REFERENCE FRAMES

- Physical Laws arre invariant with respect to change of reference frame
- Reference frames are defined by material clocks and rods
- Clock and Rods have a quantum nature
- They can be in superposition: indefinite causal structure

QUANTUM SYSTEMS

- Systems superposed up to ~ 20 g

Quantum superposition of molecules beyond 25 kDa

Yaakov Y. Fein, Philipp Geyer, Patrick Zwick, Filip Kiałka, Sebastian Pedalino, Marcel Mayor, Stefan Gerlich & Markus Arndt ✉

Nature Physics **15**, 1242–1245 (2019) | Cite this article

- Systems superposed as far as ~ 0.5 m

Quantum superposition at the half-metre scale

T. Kovachy, P. Asenbaum, C. Overstreet, C. A. Donnelly, S. M. Dickerson, A. Sugarbaker, J. M. Hogan & M. A. Kasevich ✉

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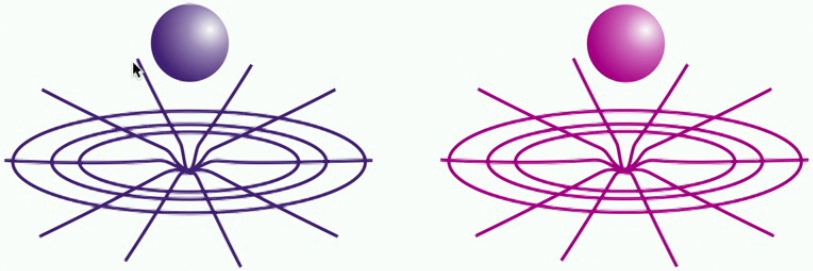
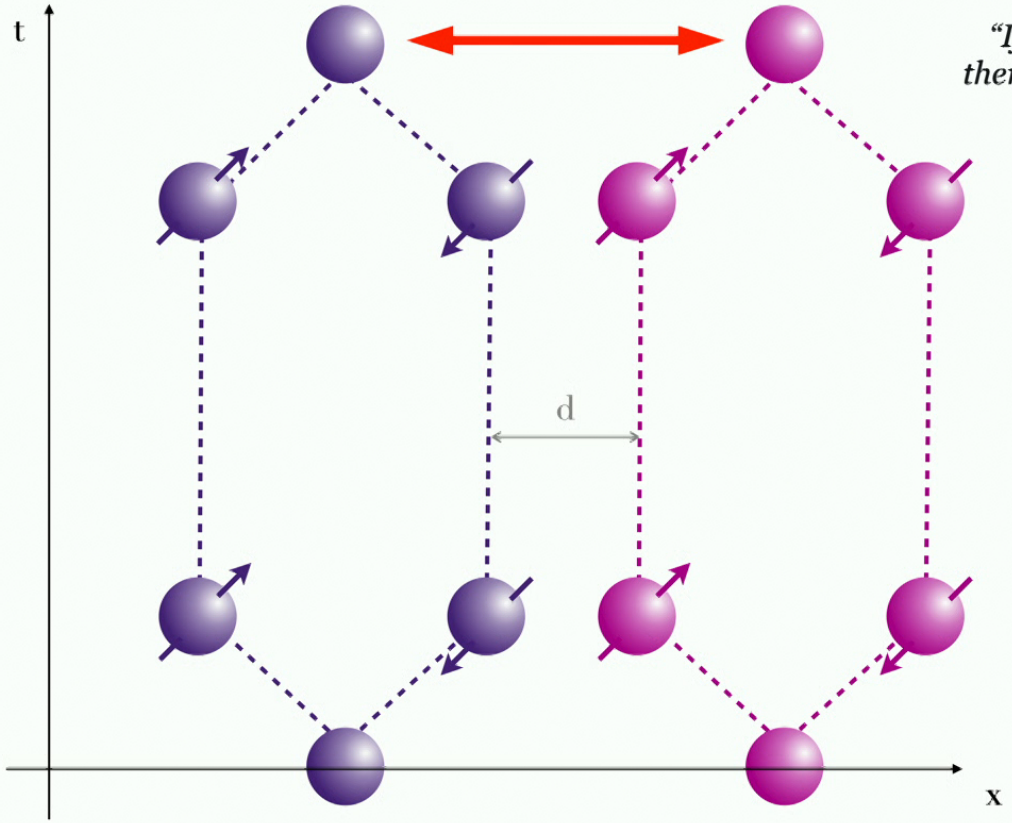


GRAVITY INDUCED ENTANGLEMENT

Bose, Mazumdar, Morley, Ulbricht, Toroš, Paternostro, Geraci, Barker, Kim, Milburn, PRL 2017
Marletto, Vedral, PRL 2017



"If you believe in quantum mechanics up to any level then you have to believe in gravitational quantization in order to describe this experiment."

R. Feynman, Chapel Hill Conference (1957)

Theorem: Only non-classical interactions can give rise to an entangled state!

QUANTUM GRAVITY

at high energy

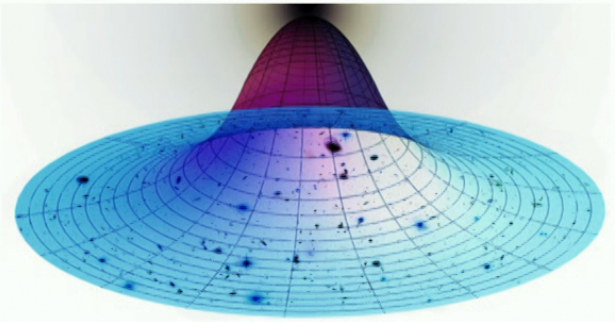
BLACK HOLES

- WHITE HOLES

  Singularity is removed

  Quantum Tunnelling

  No information paradox



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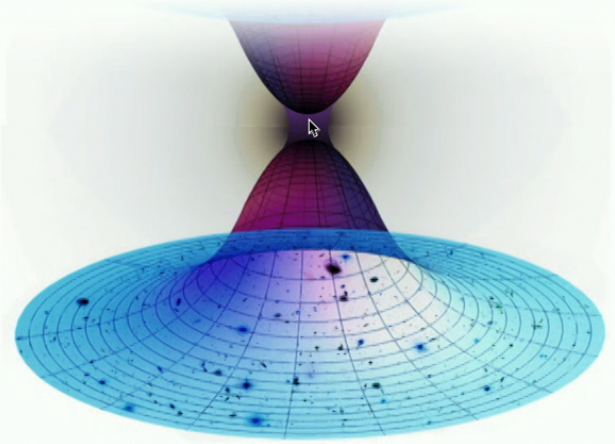

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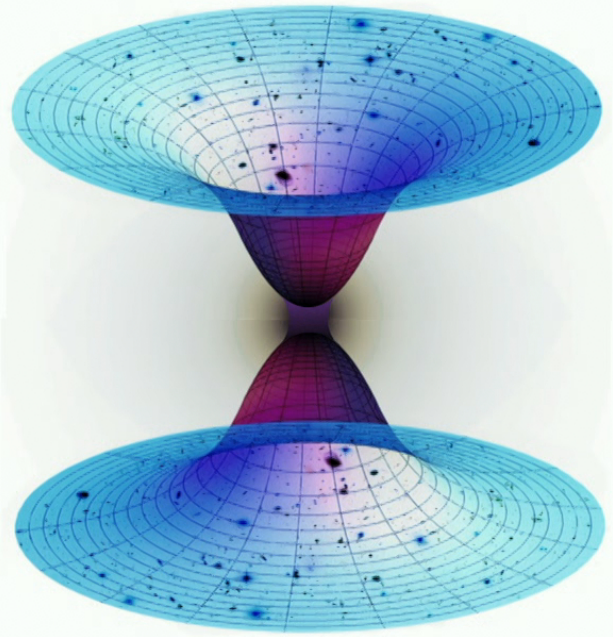


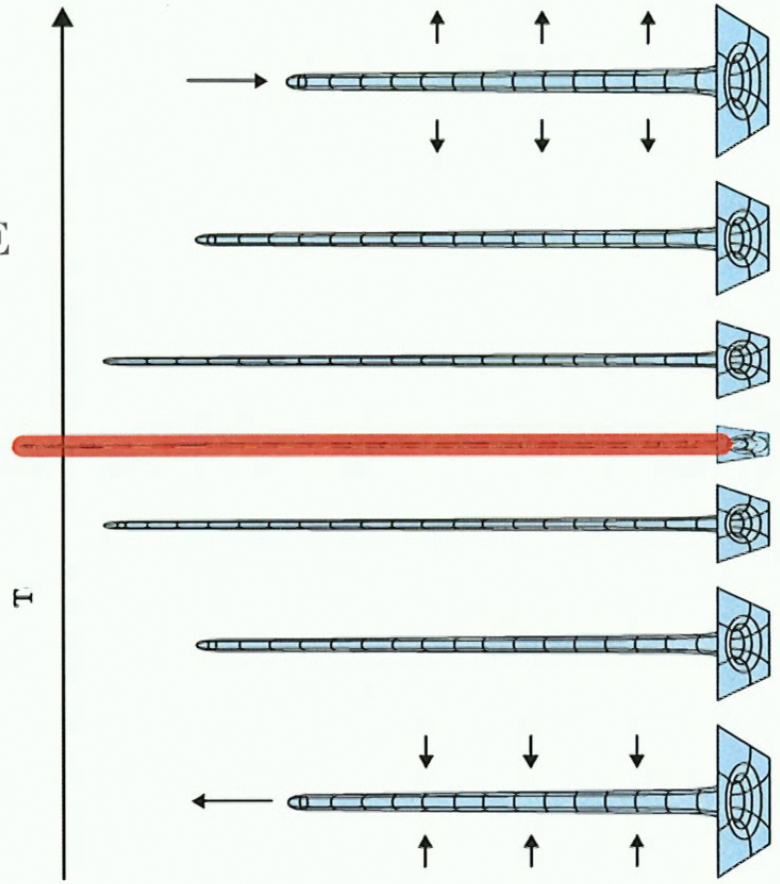
BLACK HOLES

- REMNANTS

  Minimal Area + Large internal volume = STABLE

  They can be produced before the Big Bang

  Viable Dark Matter Candidate

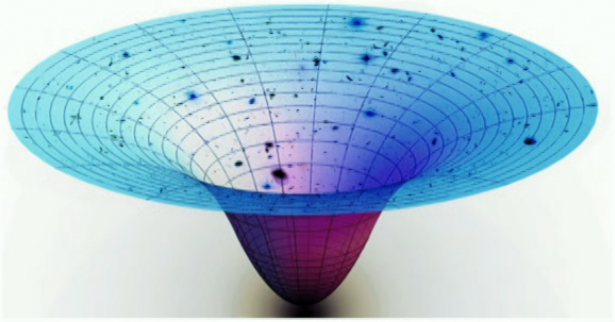


COSMOLOGY

- **BOUNCING UNIVERSE**

  Singularity is removed

  Signature in the CMB



- **PRIMORDIAL QUANTUM FLUCTUATION**

  Spinfoam wavefunction of the universe

  Initial state of the quantum geometry

  (at the bounce)

COSMOLOGY

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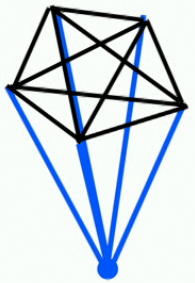
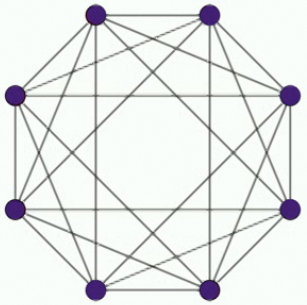
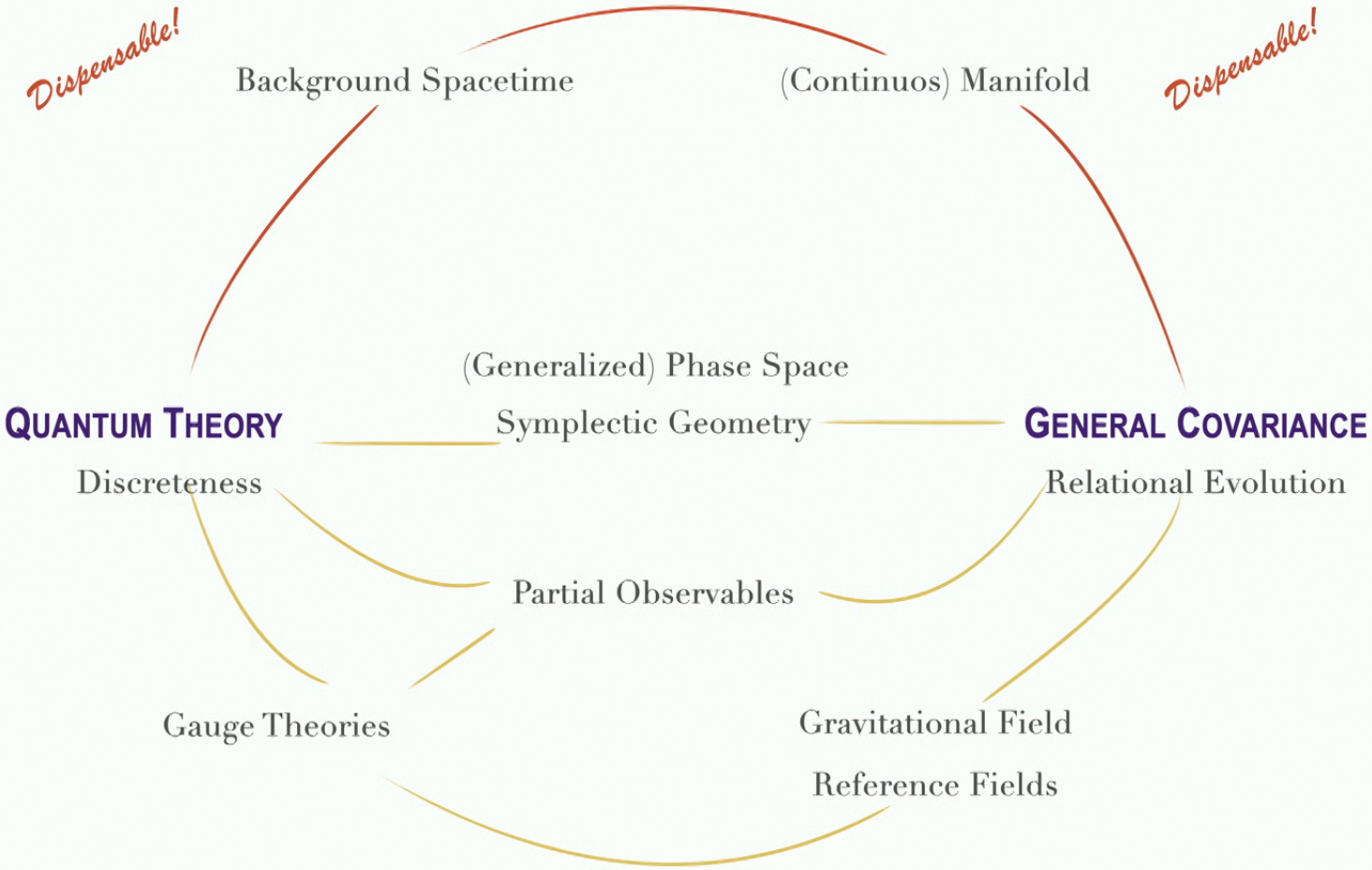
  Initial state of the quantum geometry

  (at the bounce)



- Correlations and entanglement entropy?

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Background Spacetime
(Continuos) Manifold
Dispensable!
(Generalized) Phase Space
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Symplectic Geometry
GENERAL COVARIANCE
Discreteness
Relational Evolution
Partial Observables
Gauge Theories
Gravitational Field
Reference Fields

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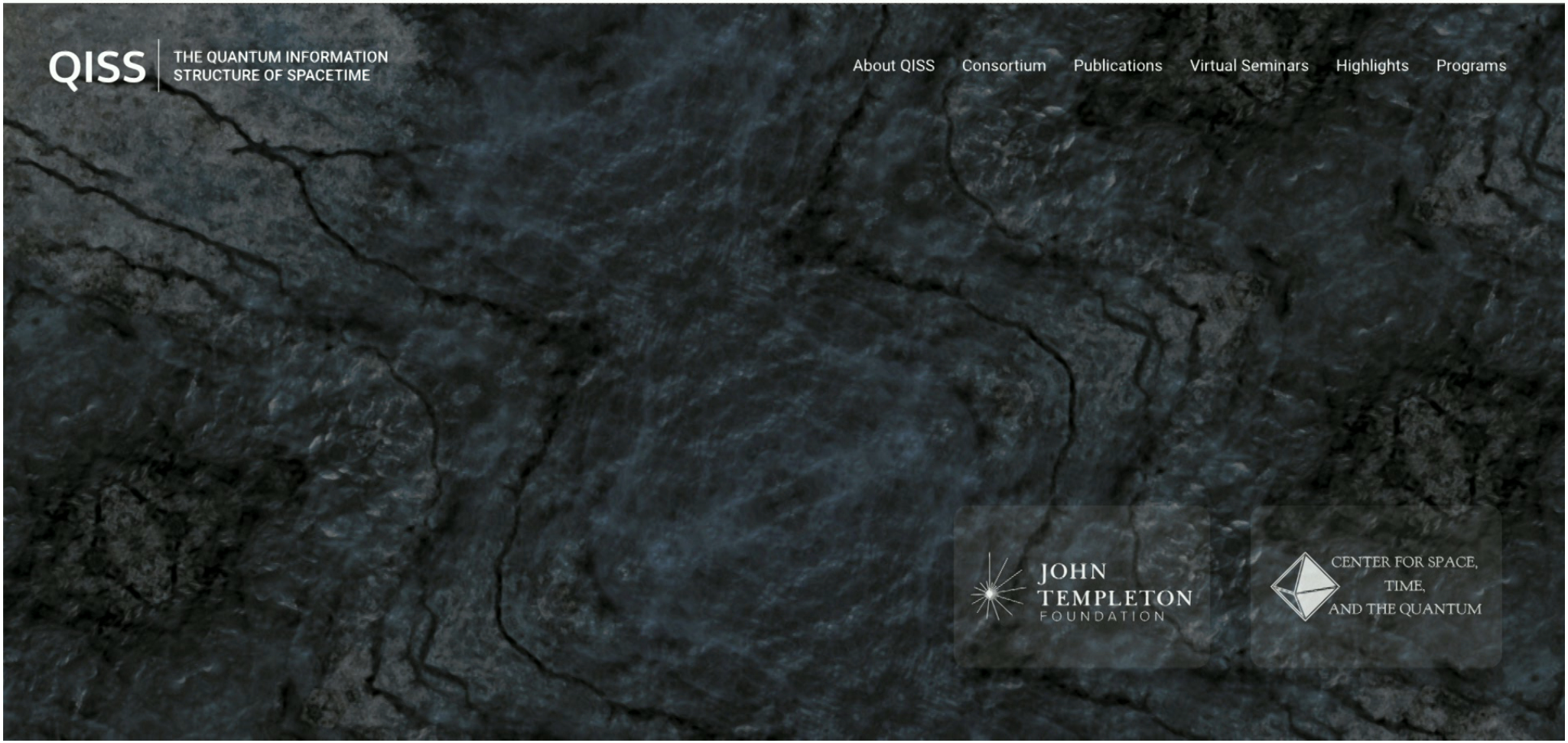
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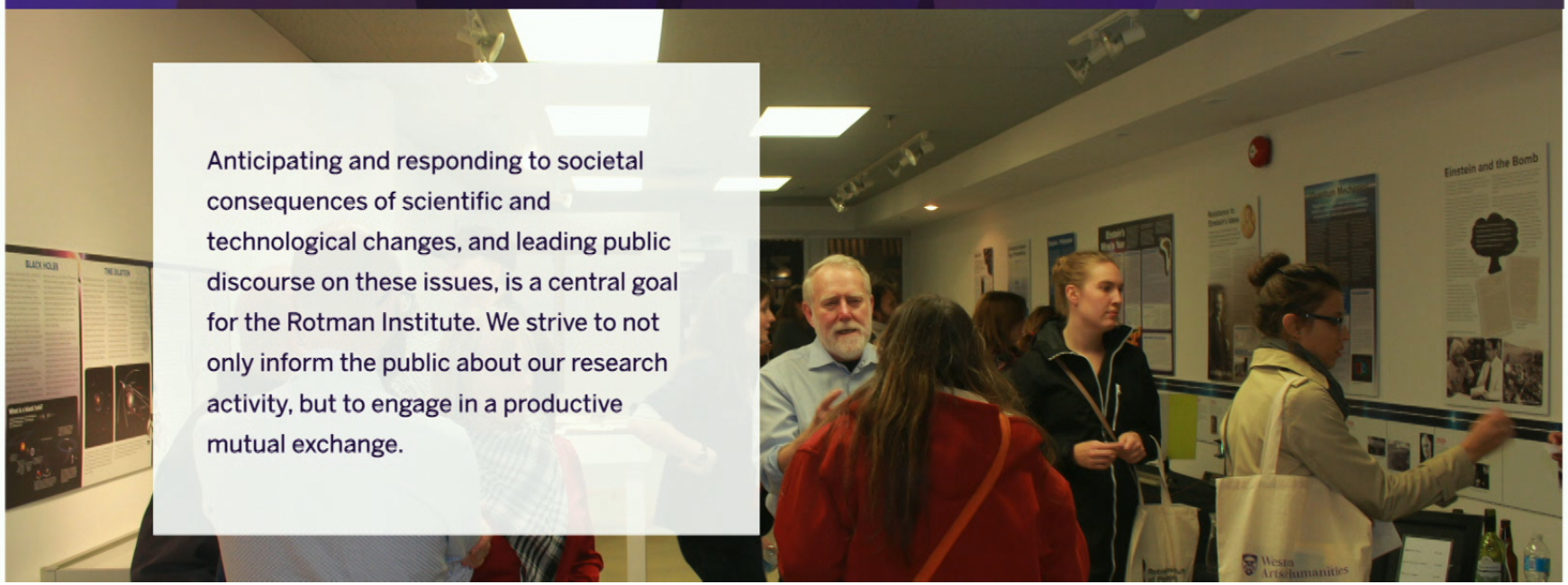

Anticipating and responding to societal consequences of scientific and technological changes, and leading public discourse on these issues, is a central goal for the Rotman Institute. We strive to not only inform the public about our research activity, but to engage in a productive mutual exchange.

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at high energy