

Title: What is Space?

Date: Aug 02, 2006 10:45 AM

URL: <http://pirsa.org/06080005>

Abstract:

What is space?

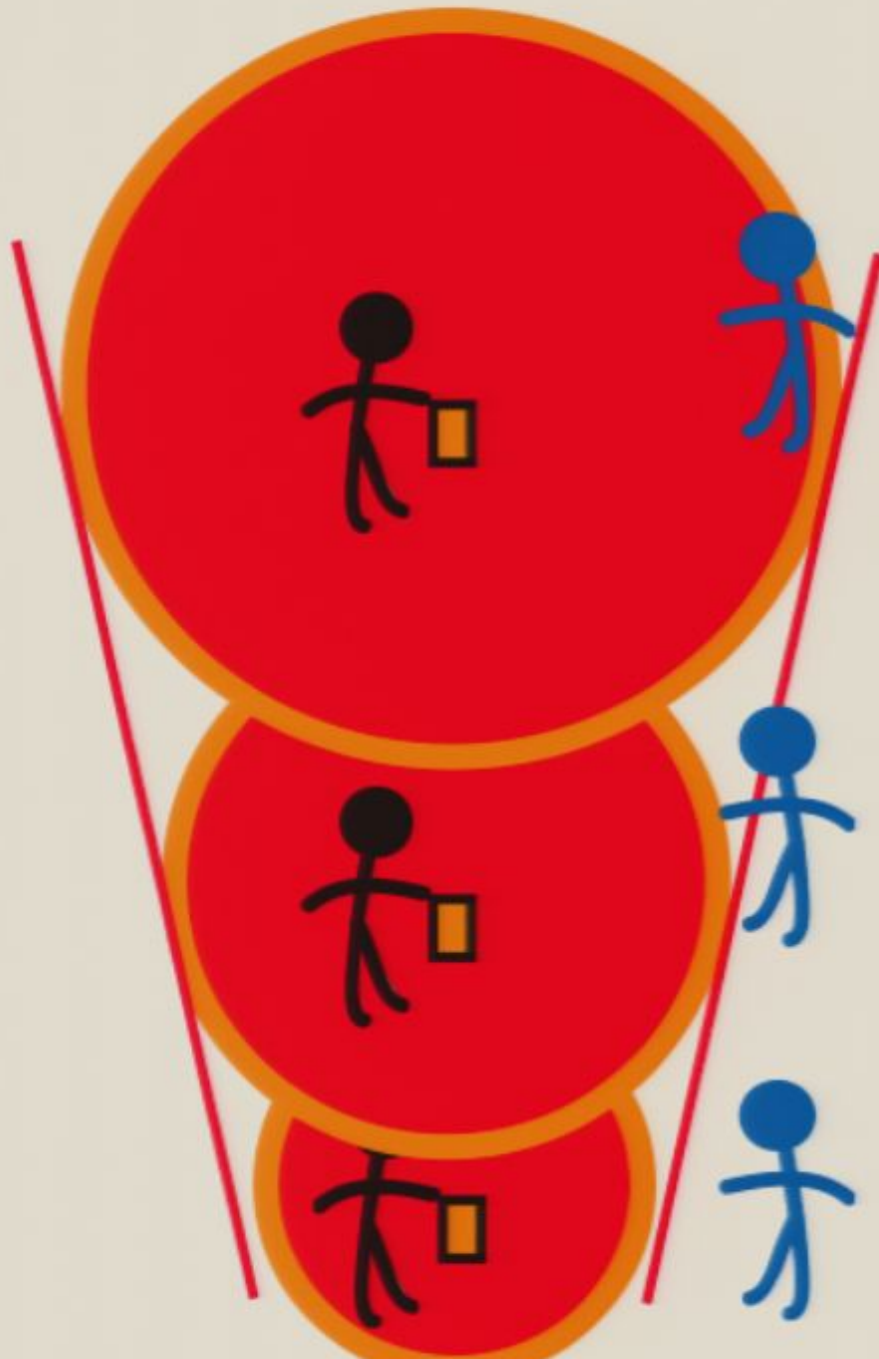


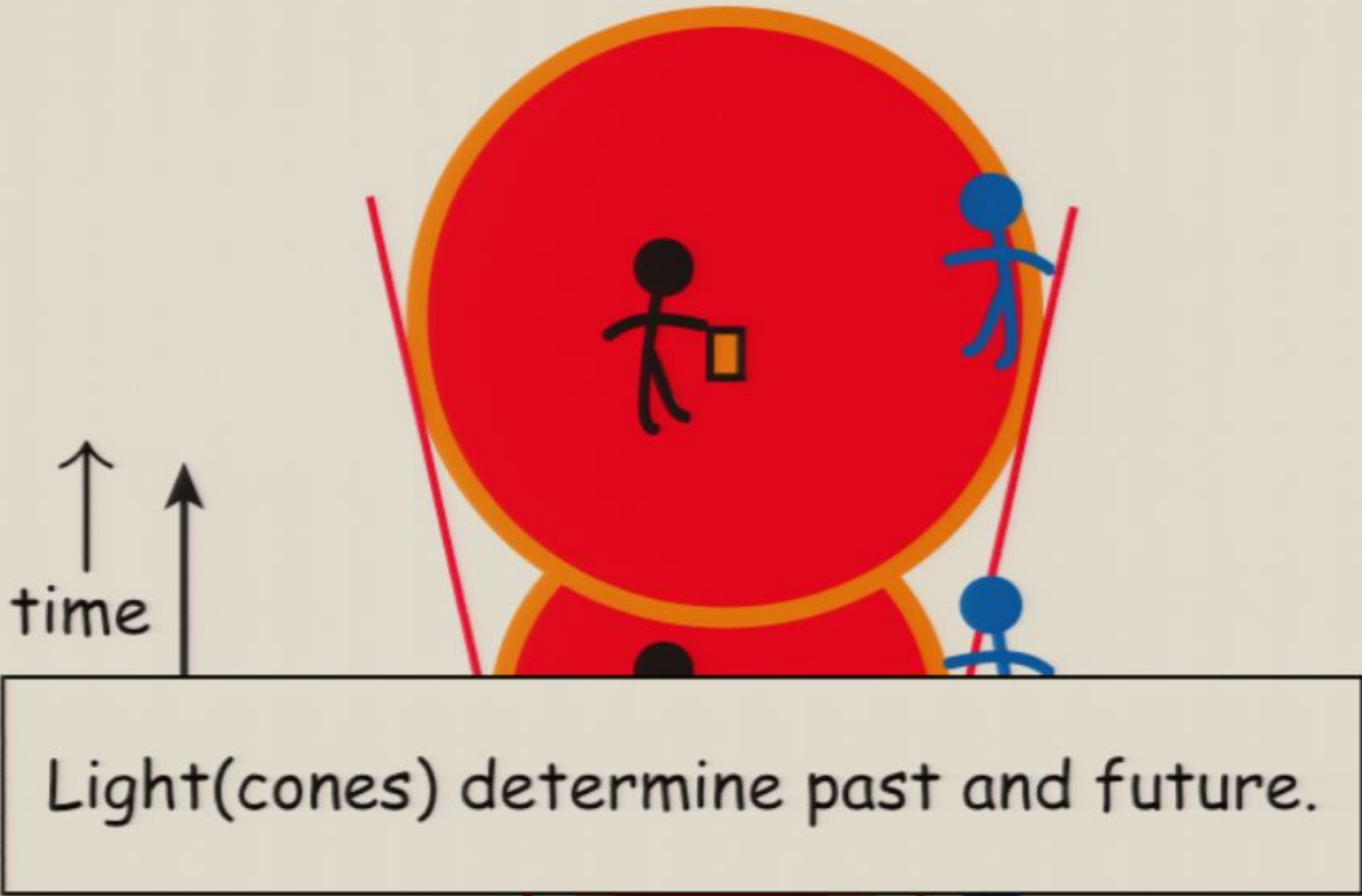


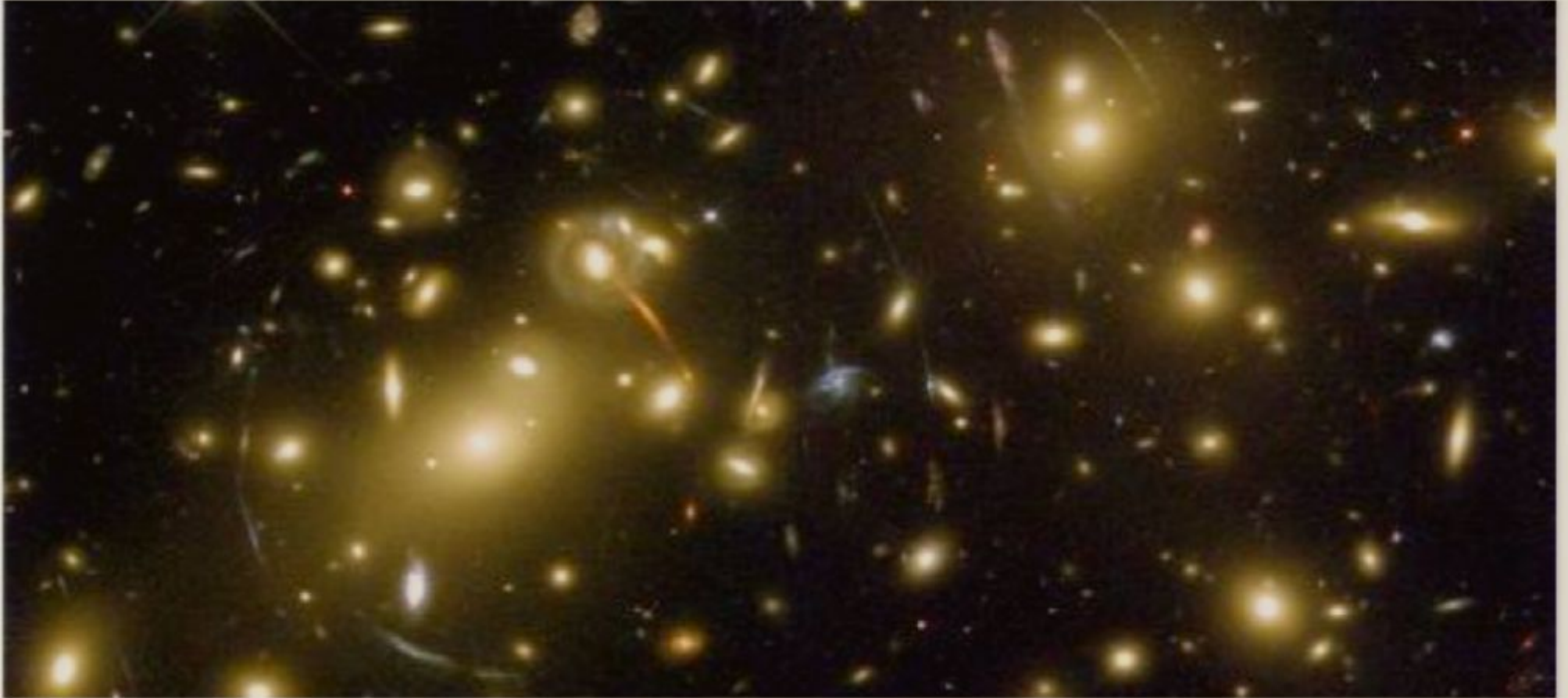
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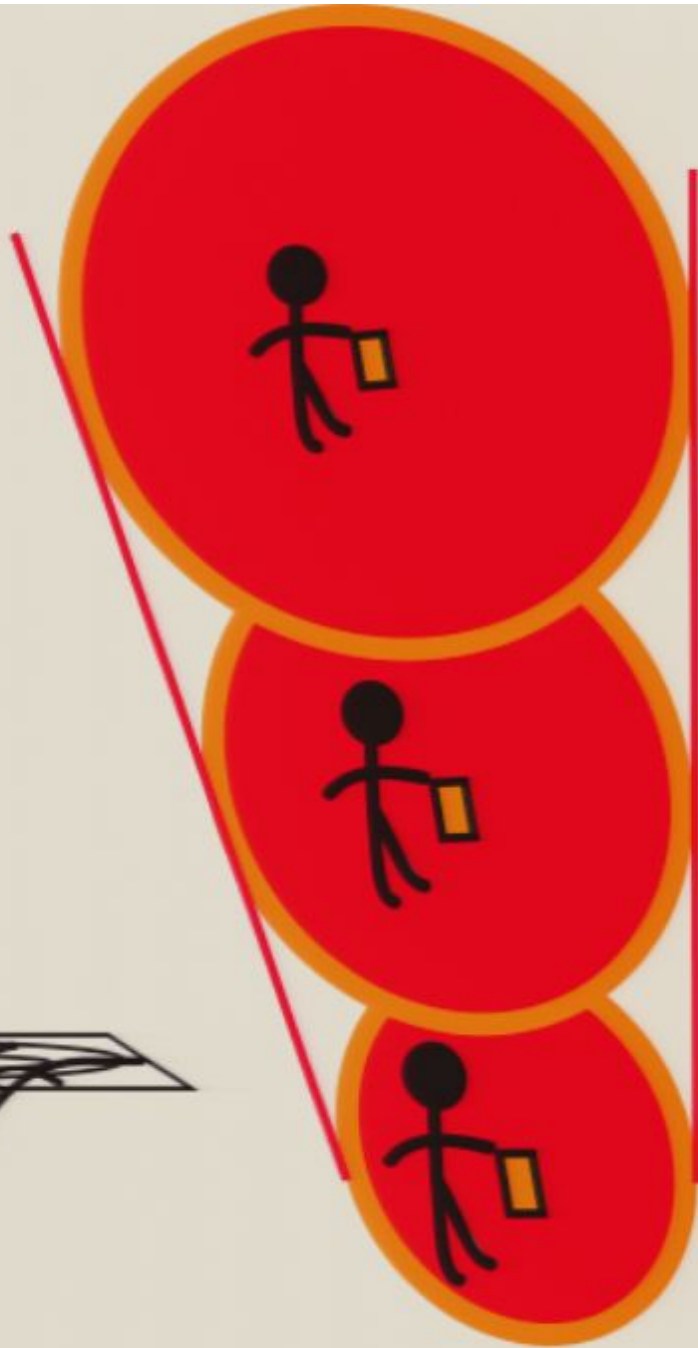






Galaxy Cluster Abell 1689.
Hubble Space Telescope - Advanced Camera for Surveys (NASA)

Gravity bends light.





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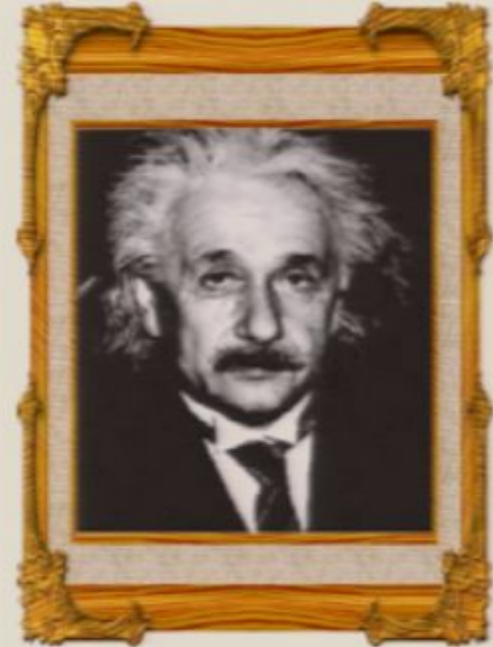






Gravity \longleftrightarrow past and future

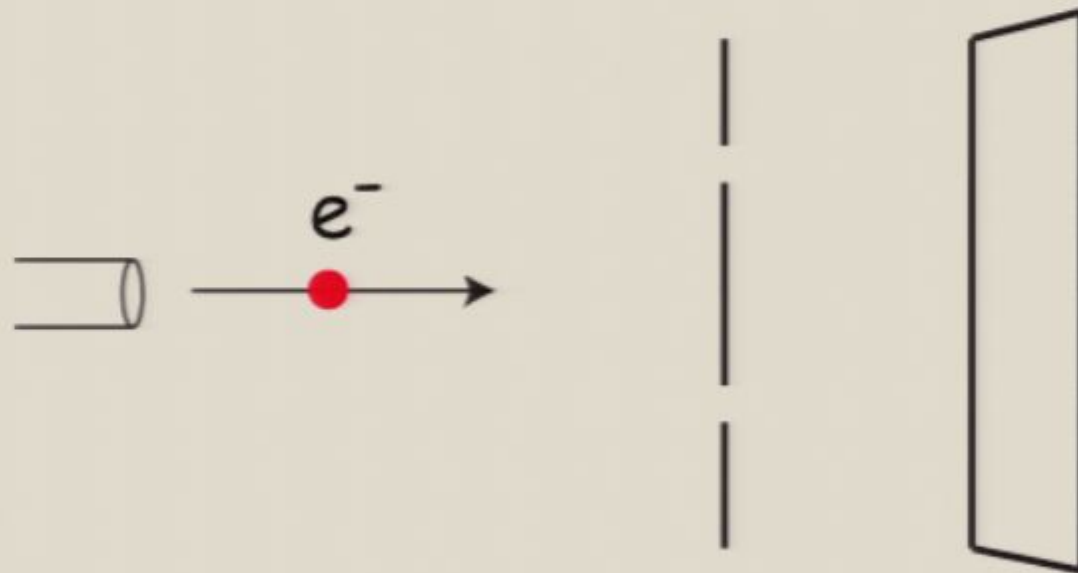
What Einstein understood about space and time

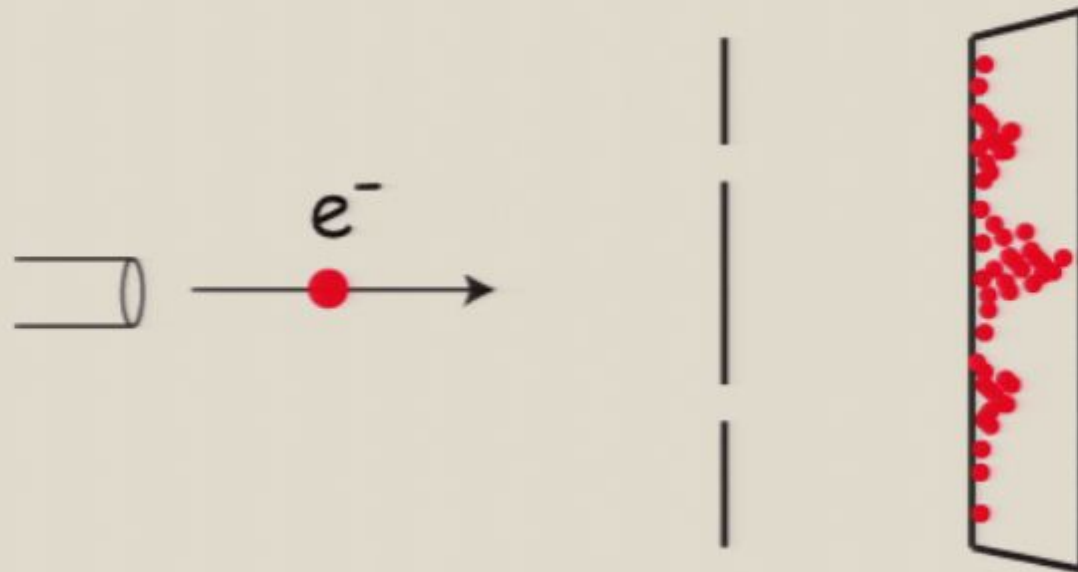


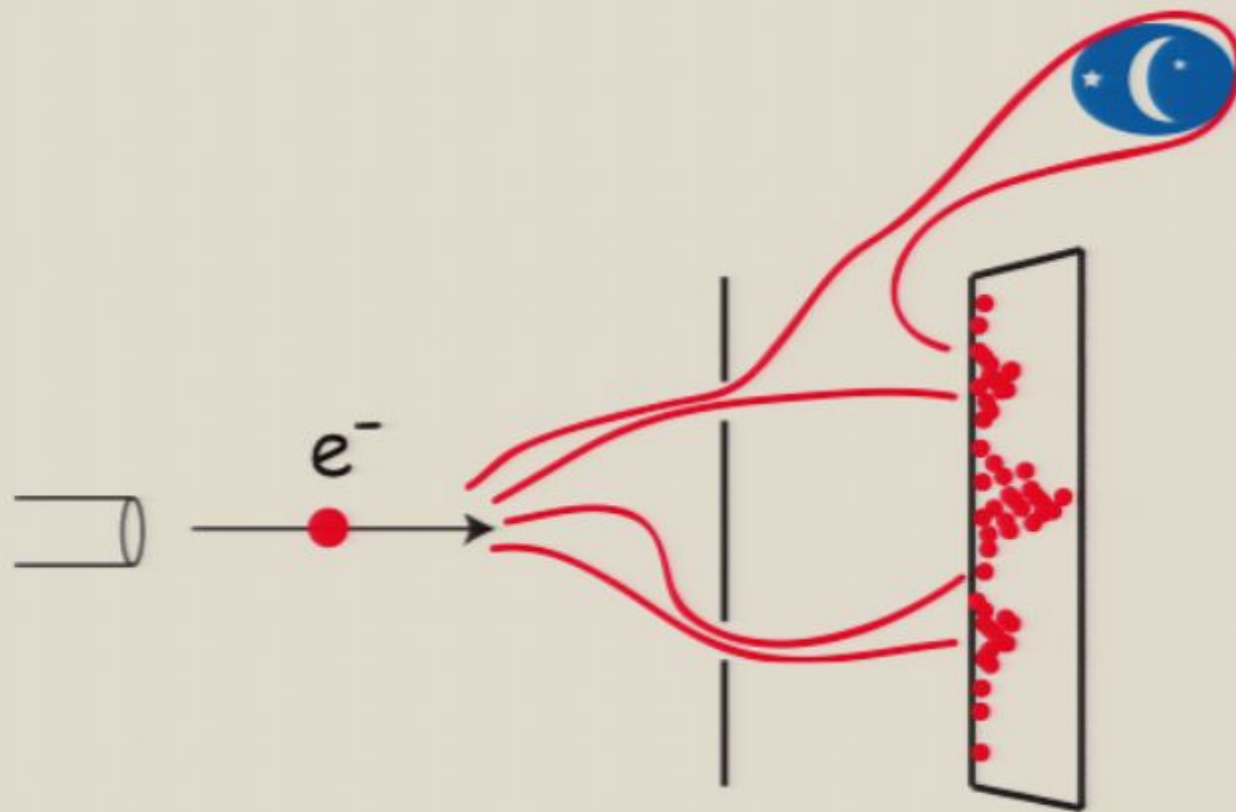
Only events are physical. Coordinates we may use to describe them have no inherent physical meaning.

Therefore, coordinate distances are not physical.
In General Relativity, the spacetime metric is **dynamical**.

**Matter curves spacetime and
spacetime tells matter where to go.**



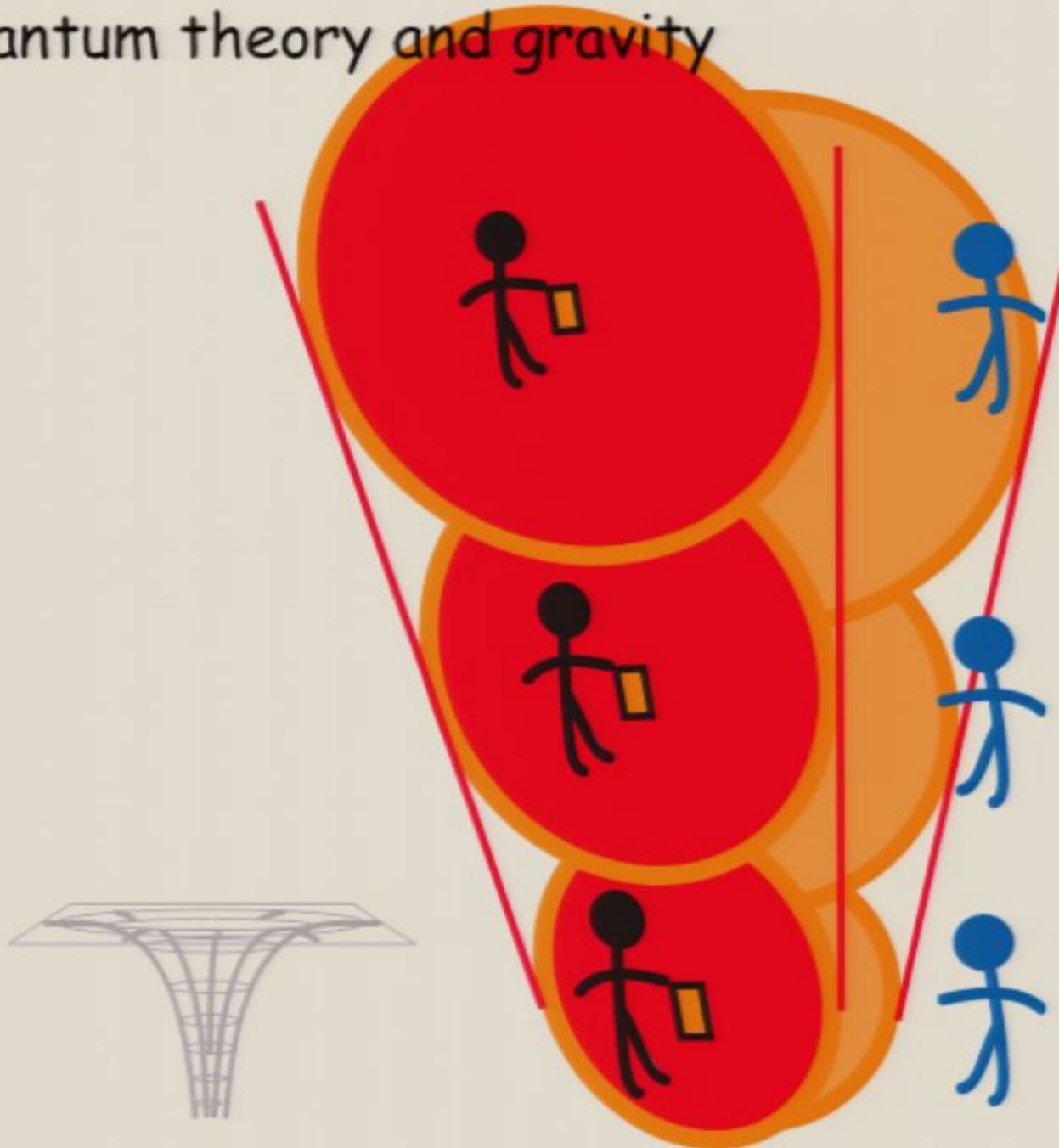




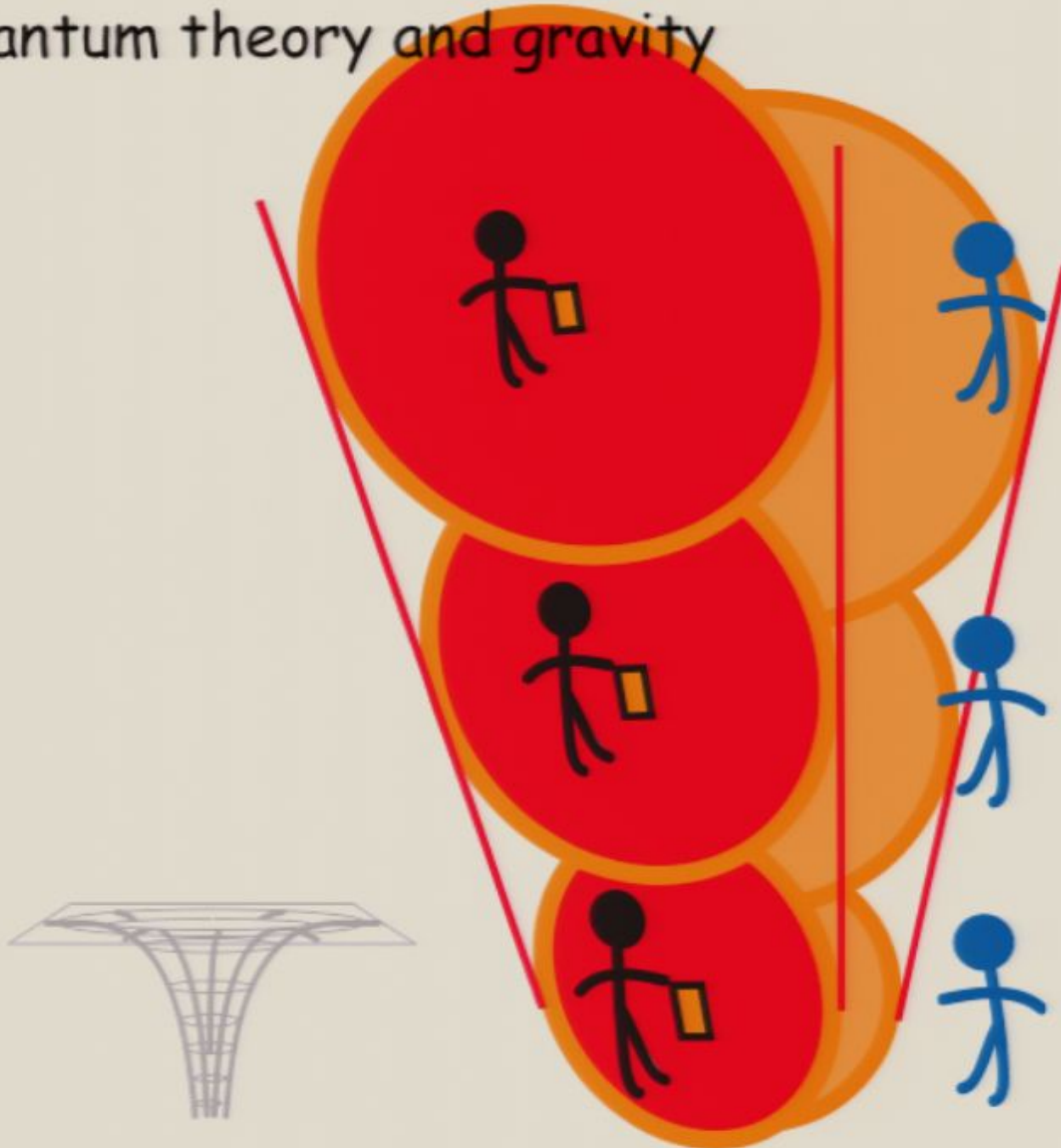
Quantum theory and gravity

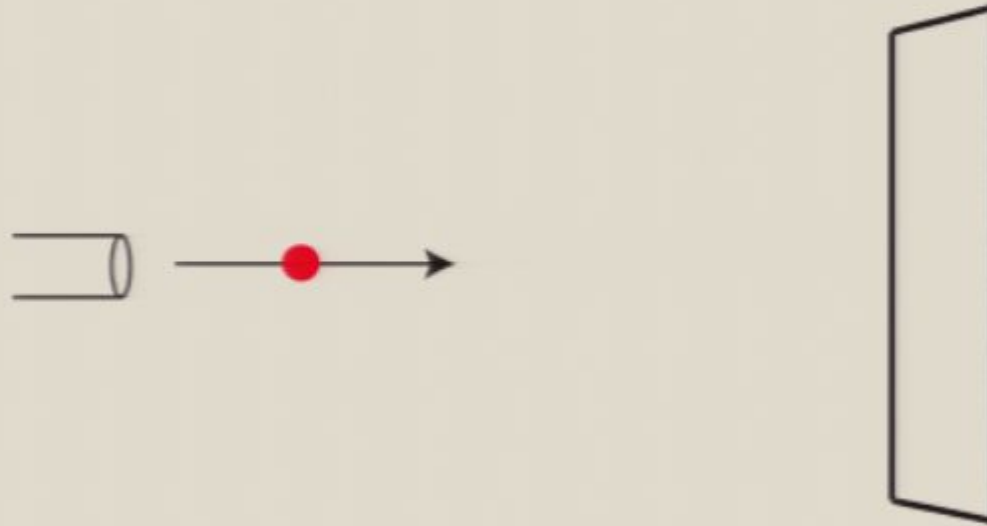


Quantum theory and gravity



Quantum theory and gravity



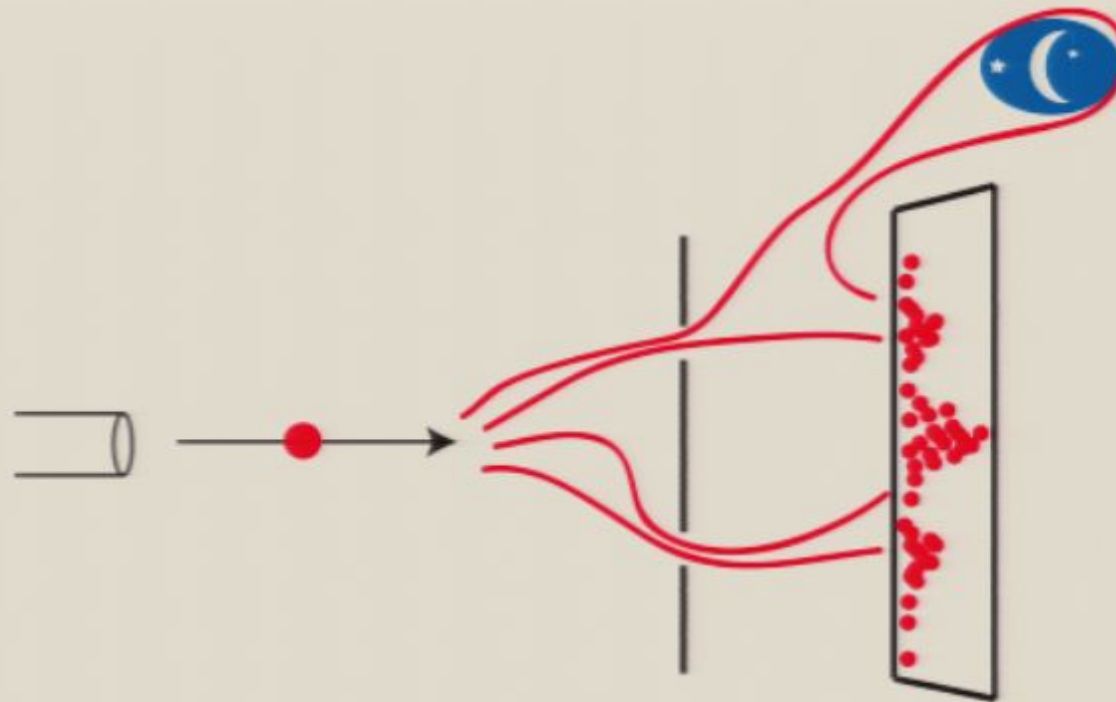


What is the path of a particle?

GR: The shortest one

QT: All possible paths simultaneously.

Does an interference experiment result in a **quantum superposition of spacetimes?**

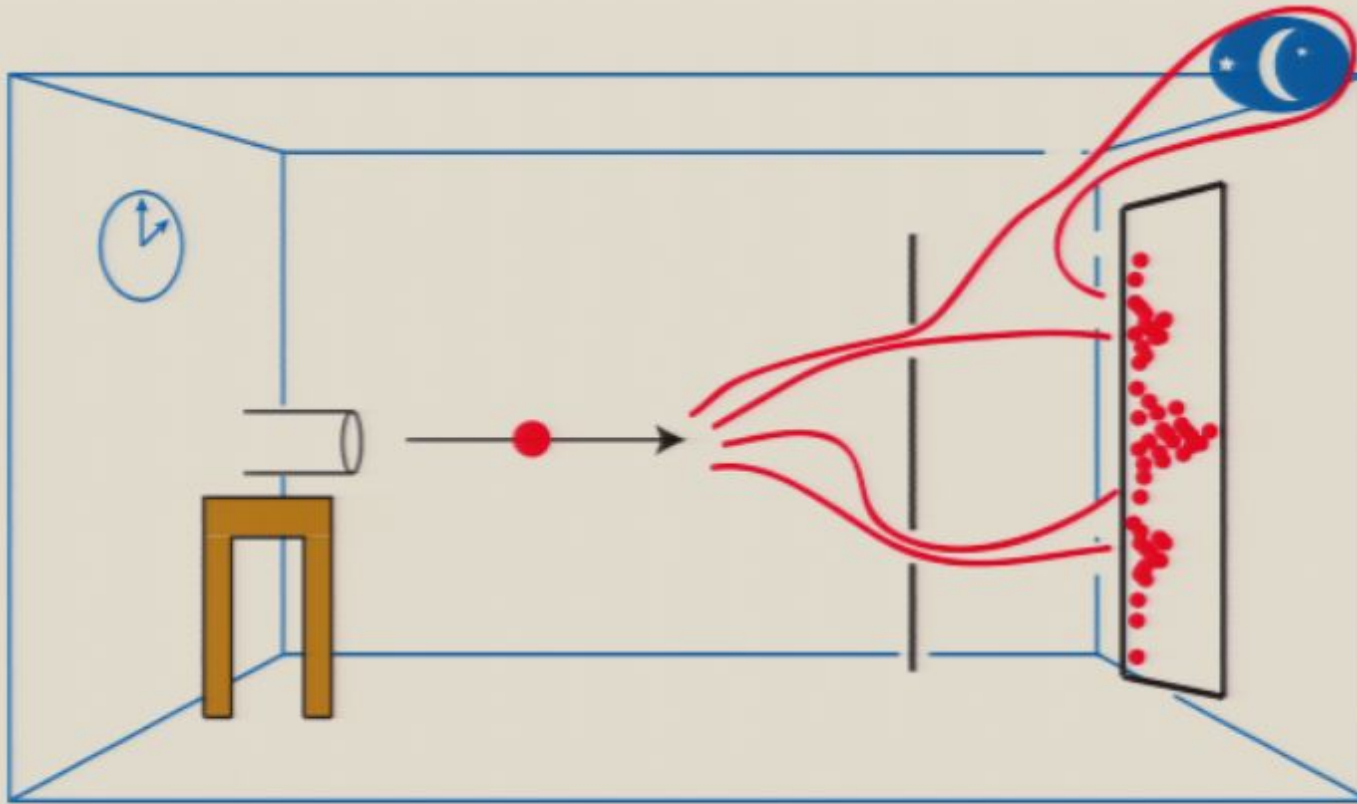


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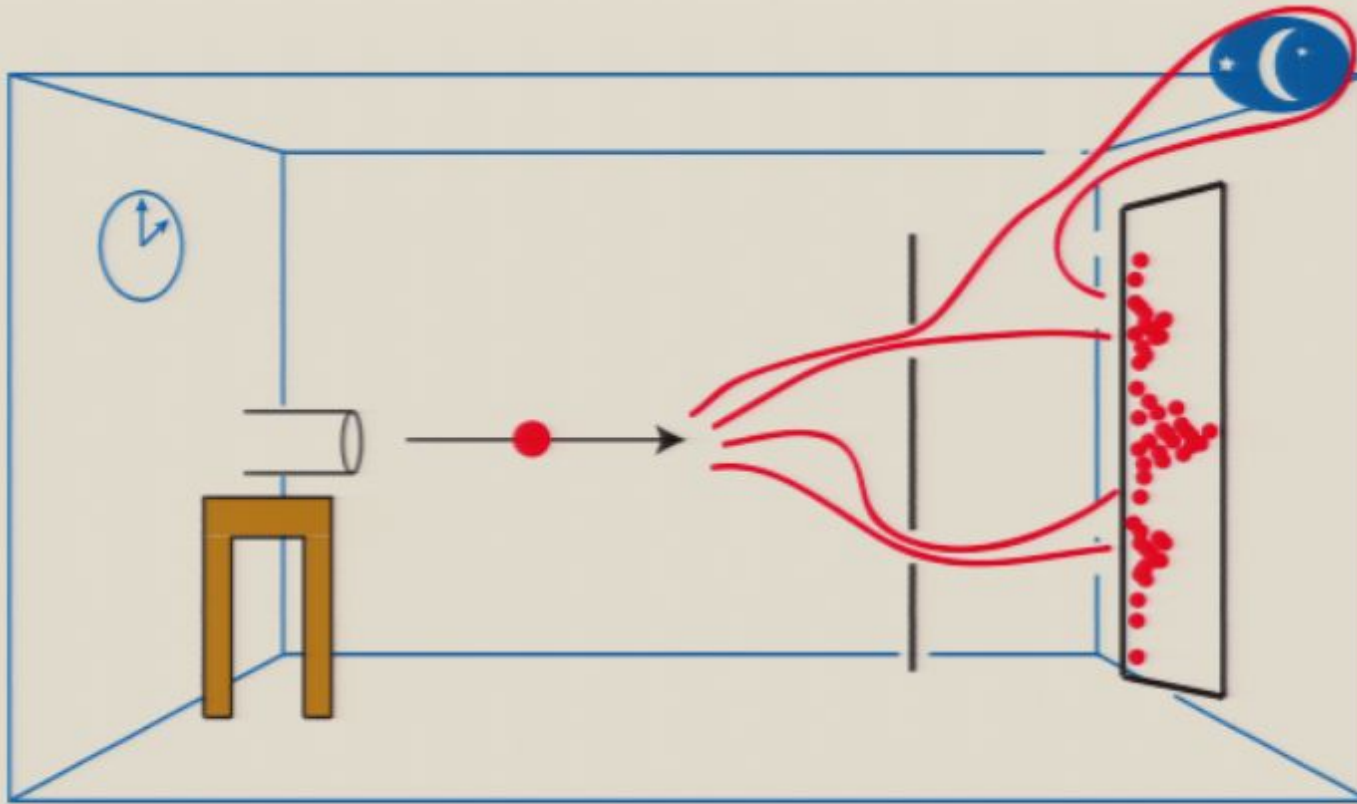


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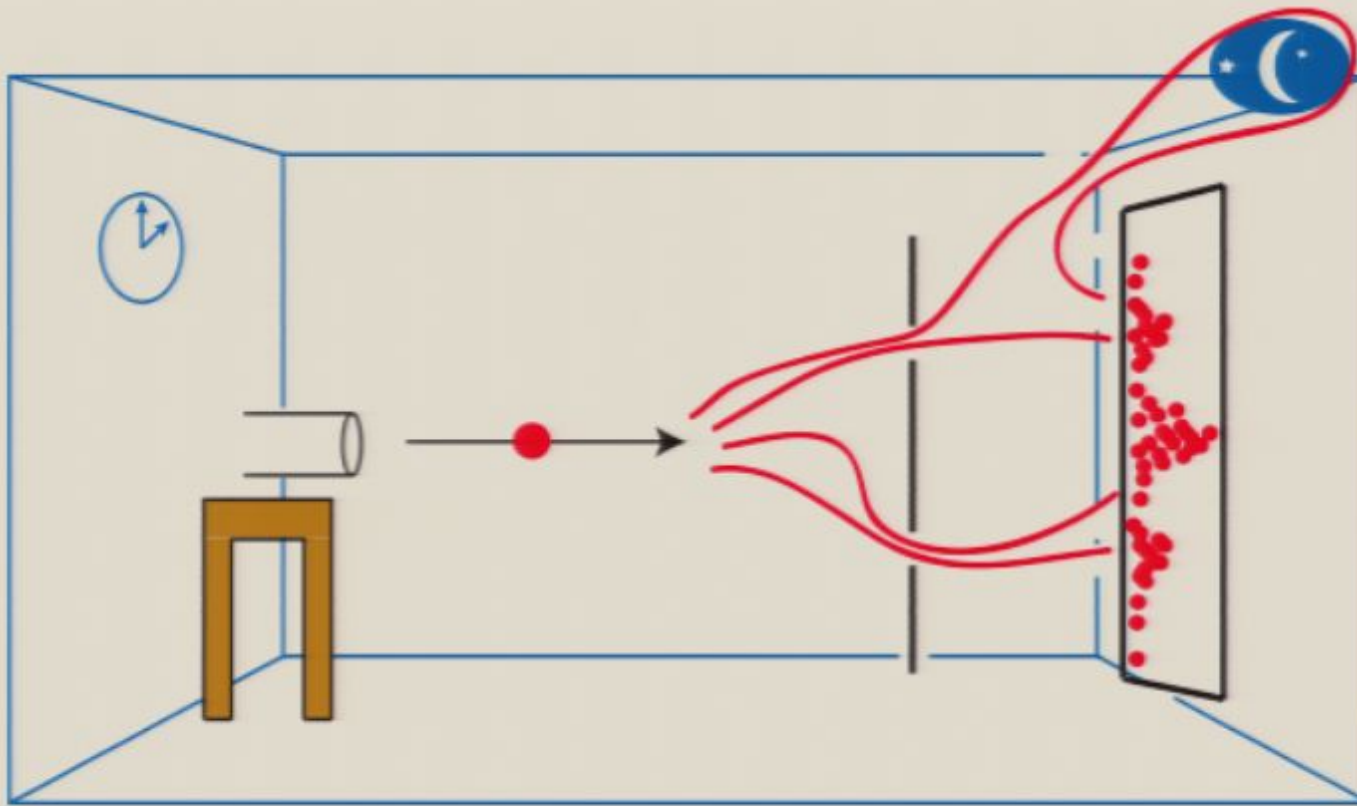
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General relativity/quantum theory are incomplete.



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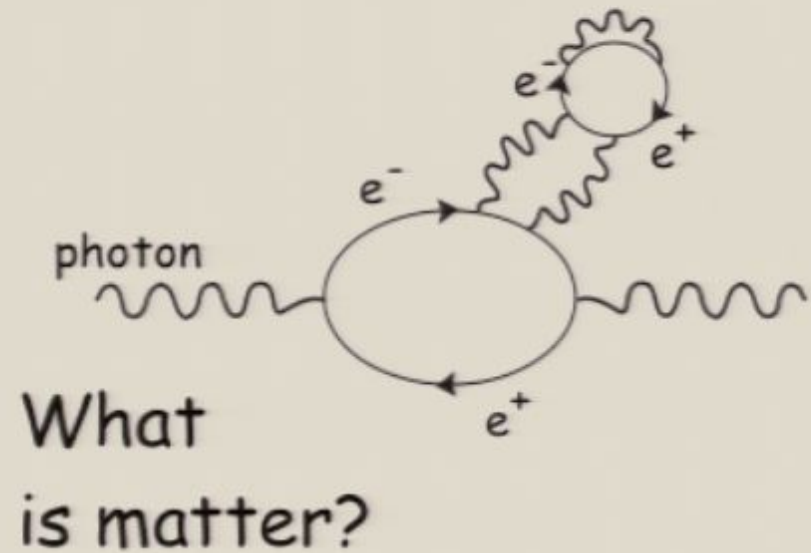
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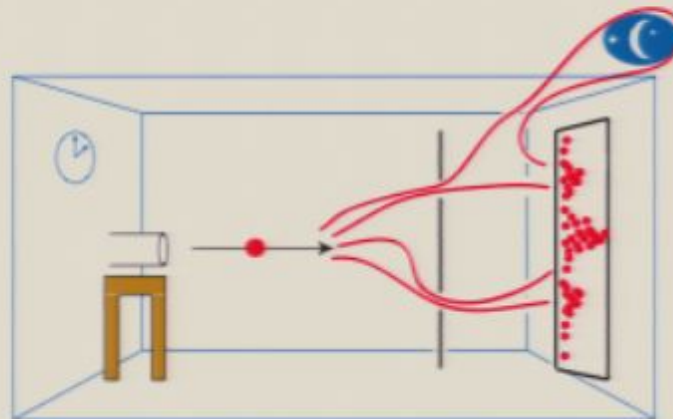
General relativity/quantum theory are incomplete.

Quantum Theory and General Relativity have limitations!

What happens inside a black hole?
What was the Big Bang?



How should we understand quantum theory?

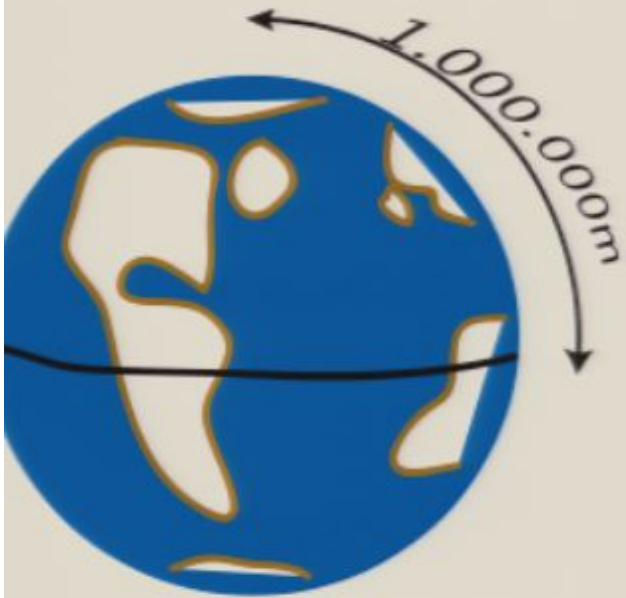


We need a

QUANTUM THEORY
OF GRAVITY

When does that happen?

At the Planck scale: $l_{\text{Pl}} = \sqrt{\frac{G\hbar}{c^3}} = 10^{-35} \text{ m}$

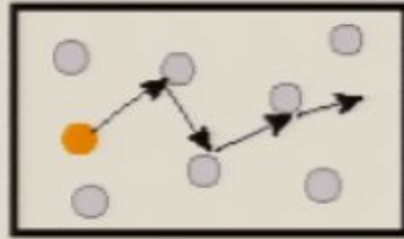


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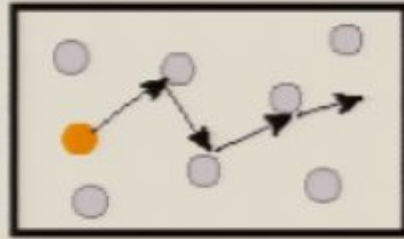
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x 100.000.000.000.000.000.000

Let's try: What is space **made of**?

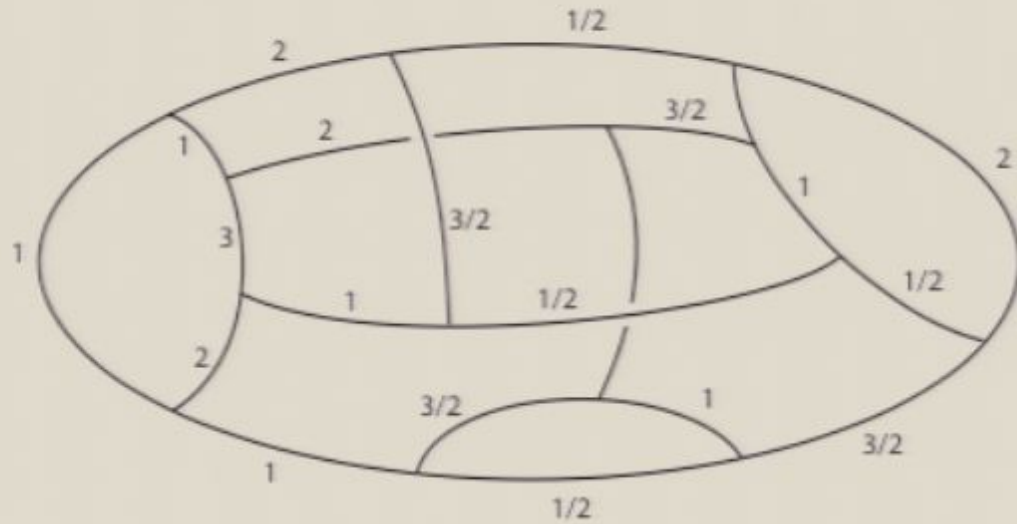
atoms of matter:



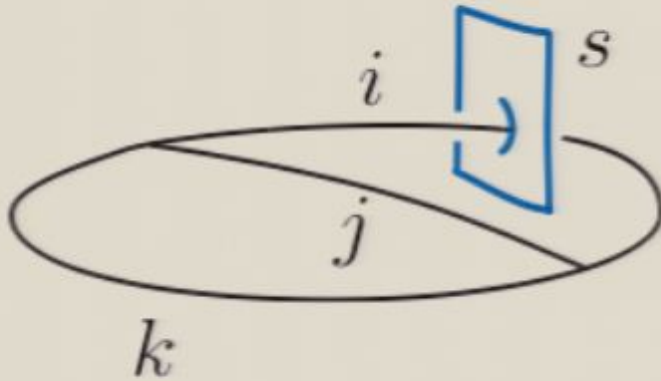
atoms of matter:



atoms of space:
spin networks

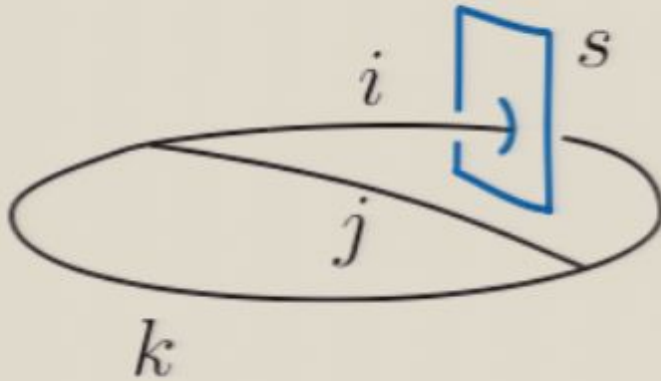


Area:



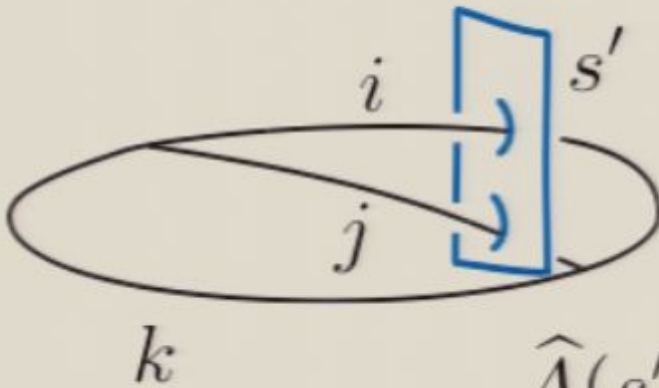
$$\hat{A}(s) = l_{\text{Pl}}^2 \sqrt{i(i+1)}$$

Area:



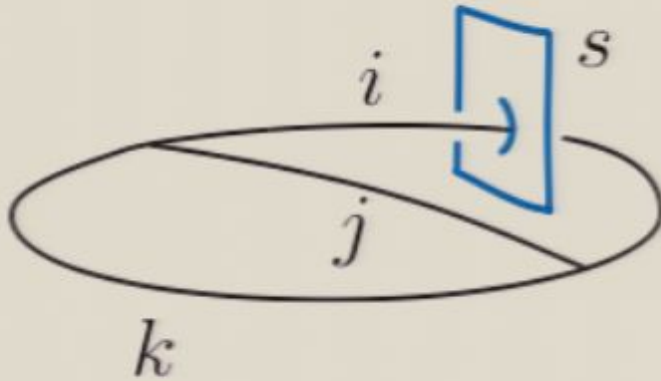
$$\hat{A}(s) = l_{\text{Pl}}^2 \sqrt{i(i+1)}$$

Discreteness:



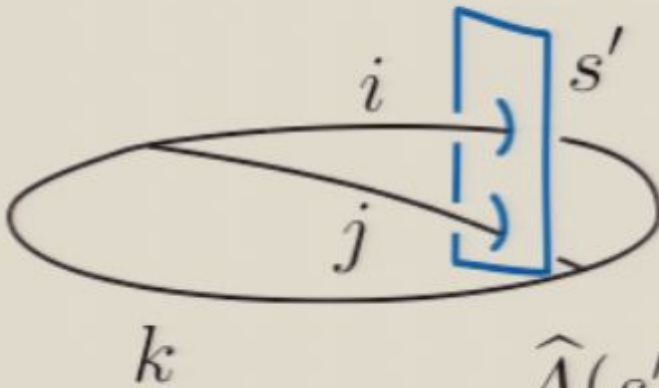
$$\hat{A}(s') = l_{\text{Pl}}^2 \left(\sqrt{i(i+1)} + \sqrt{j(j+1)} \right)$$

Area:



$$\hat{A}(s) = l_{\text{Pl}}^2 \sqrt{i(i+1)}$$

Discreteness:



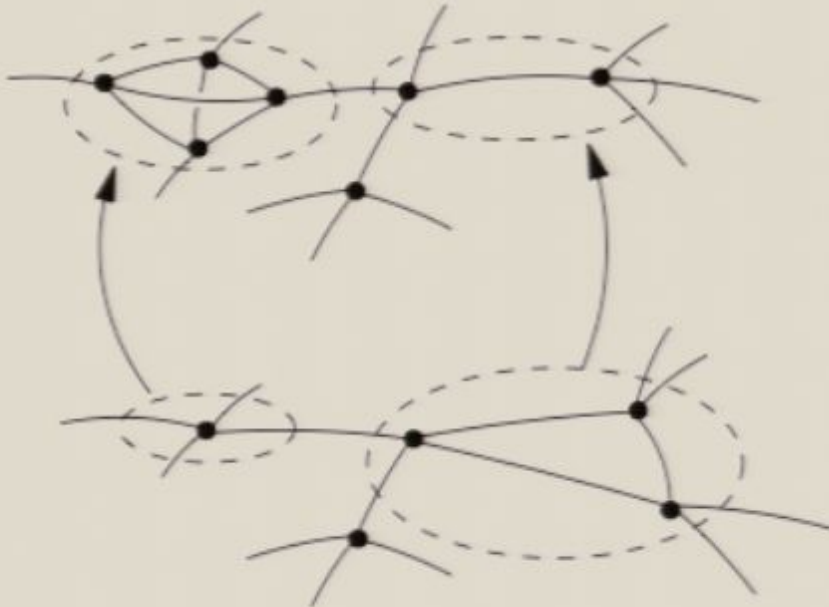
$$\hat{A}(s') = l_{\text{Pl}}^2 \left(\sqrt{i(i+1)} + \sqrt{j(j+1)} \right)$$

(Similarly for volume)

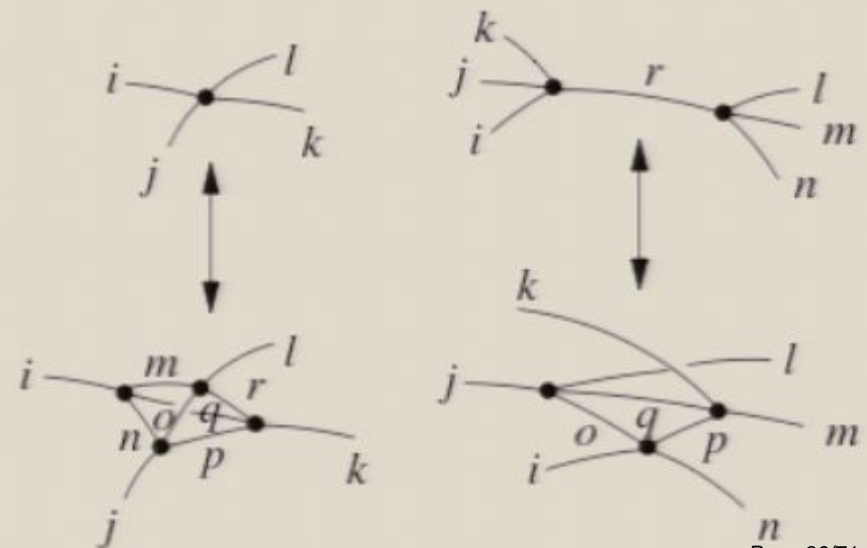
"Atoms of space"



Local evolution of spin network graphs is by **local moves**:

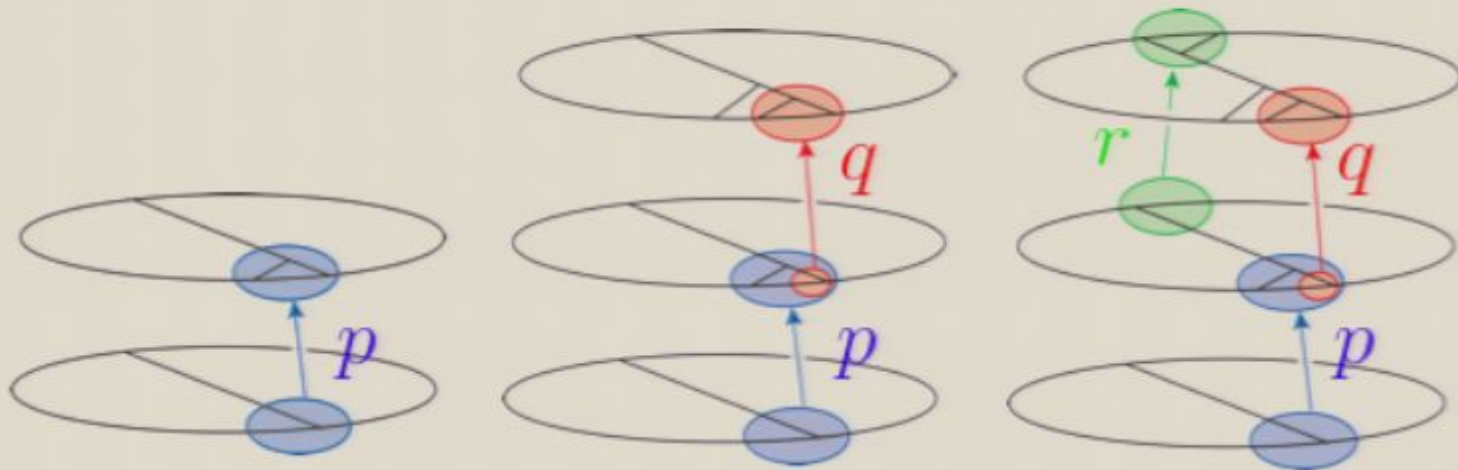


There is a small number of generating moves.



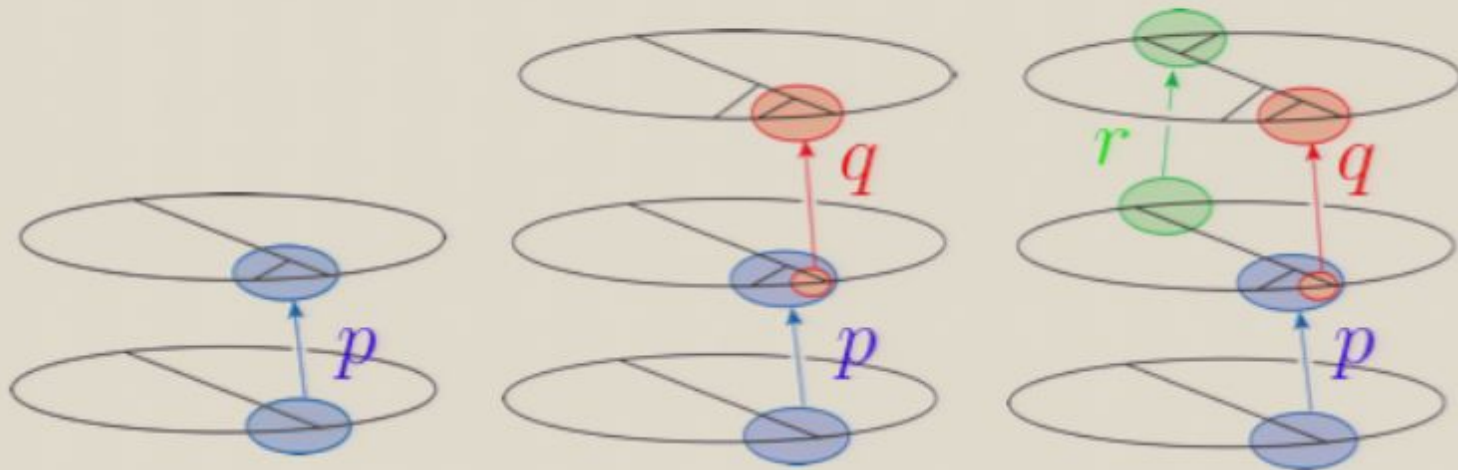
"Atoms of spacetime":

causal evolution of spin networks
generates a "spacetime network", or **Spin Foam**.



"Atoms of spacetime":

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$$Z_{\text{in} \rightarrow \text{out}} = \sum_{\text{histories}} \sum_{\text{labels}} \mathbf{A}(\text{vertices})$$

Different choices of labels and amplitudes give different models.
Several models have been constructed and studied.

Which one, if any, is correct?

Think of these as **MODELS**
for the microscopic structure
of spacetime.

Precisely what does it mean
to be a **MODEL**?

This is a magnet:



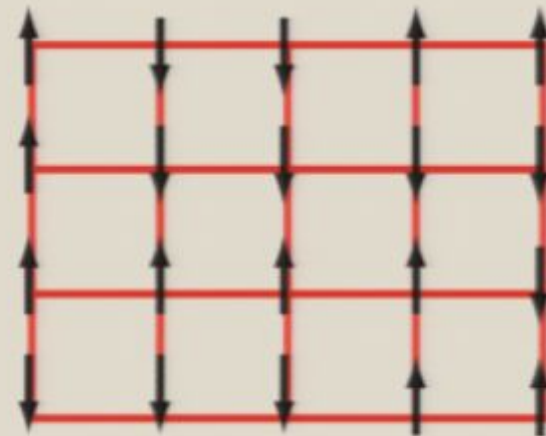
A magnet is made of atoms:



And this is a MODEL for a magnet:



magnetized



not magnetized

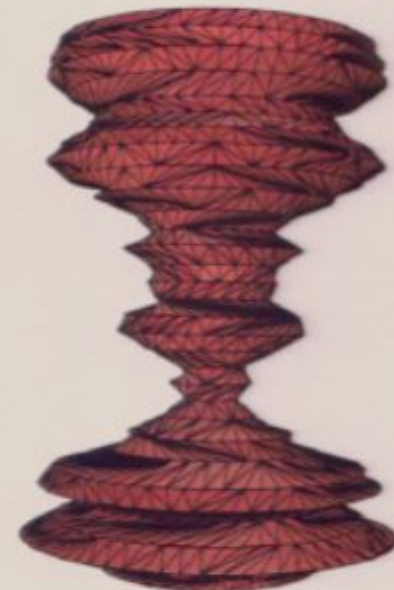
This is spacetime:

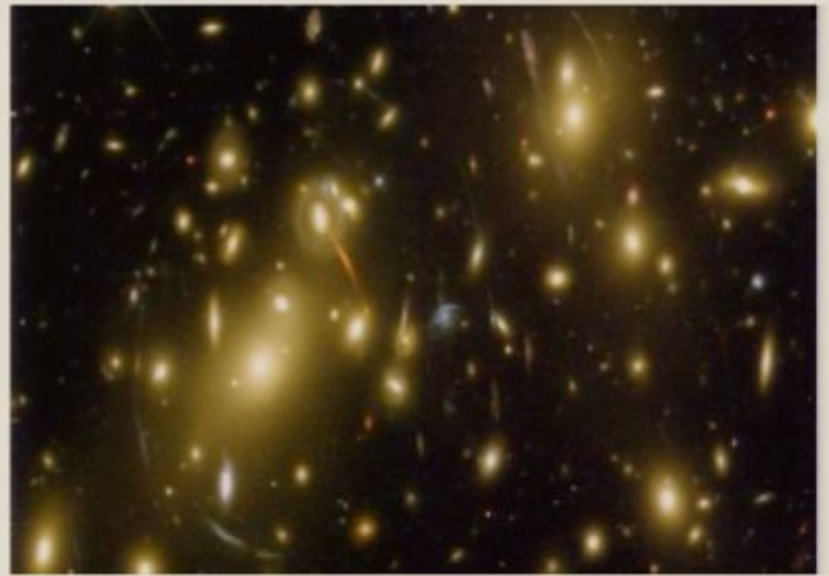
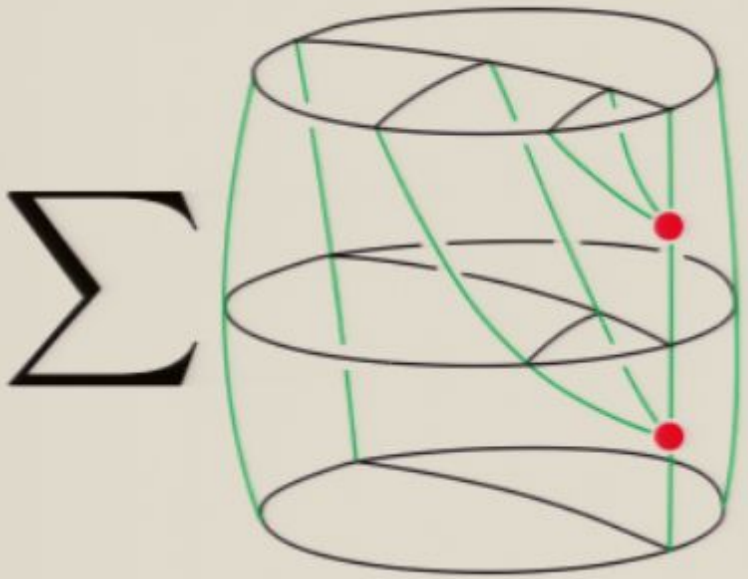


And this is a MODEL for quantum spacetime:

$$A_{L(in) \rightarrow L(out)} = \sum_{t=0}^{\infty} A(L(in), L(out), t)$$

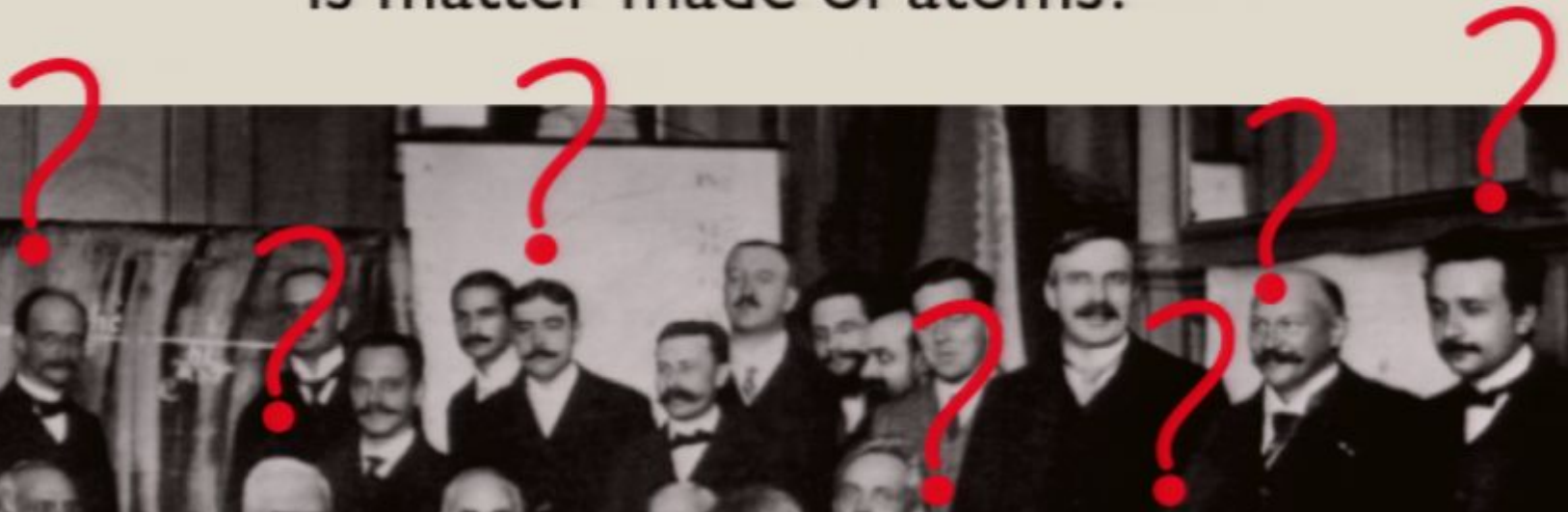
$$A(L(in), L(out), 1) = \frac{g^2 L_1 L_2}{(1 - L_1)(1 - gL_1 - gL_2)}$$





Roll Back to 1900...

is matter made of atoms?



“Every Tom, Dick and Harry, felt himself called upon to devise his own special combination of atoms and vortices and fancied in having done so that he had pried out the ultimate secrets of the Creator.”

L. Boltzmann, 1899.

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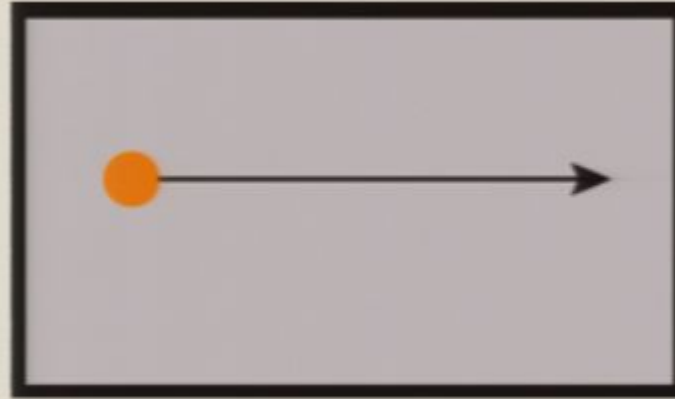
“**Any** hypothesis on the microstructure of matter was opposed on the grounds that

- (a) such a structure is inherently unobservable;
- (b) phenomenological theories are quite adequate for the legitimate purposes of science.”

S. Brush, “The Kind of Motion we call Heat”

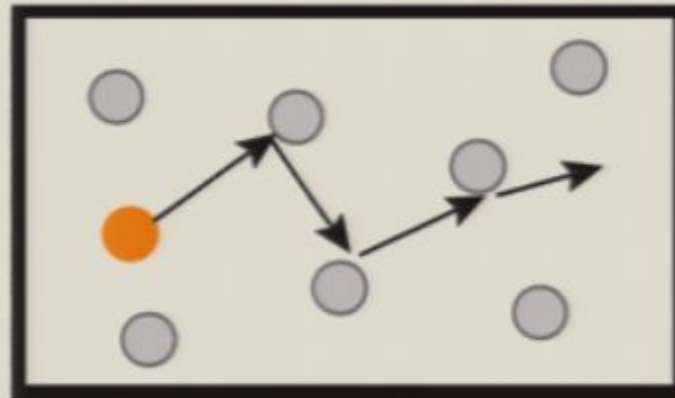
None of this convinced anyone. What worked was Einstein's theory of Brownian motion:

If matter is continuous...



distance proportional to time

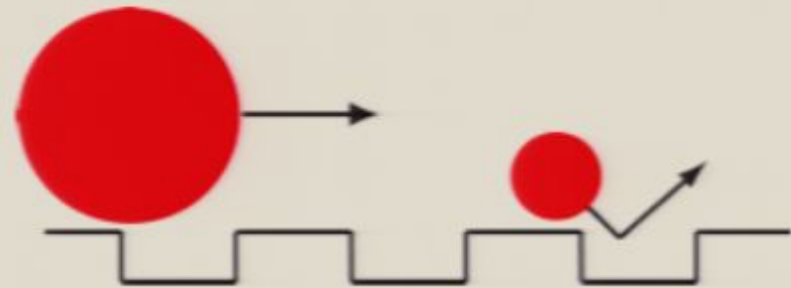
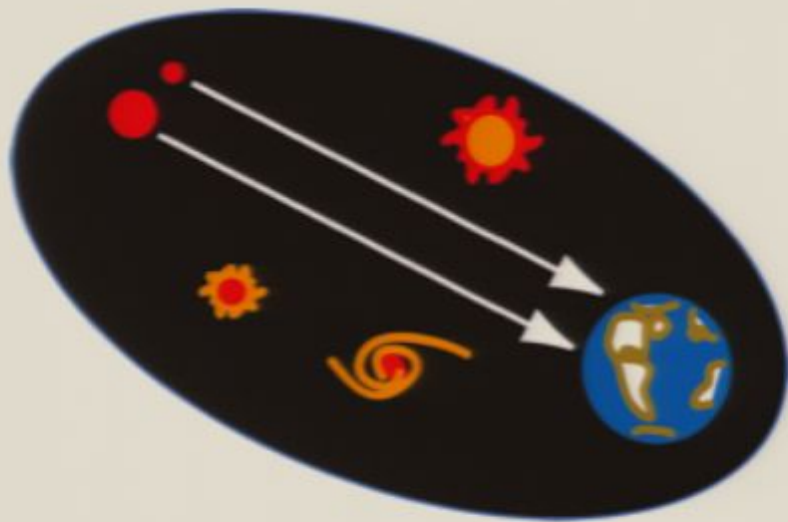
If matter is made of atoms...



distance proportional to the square root of time

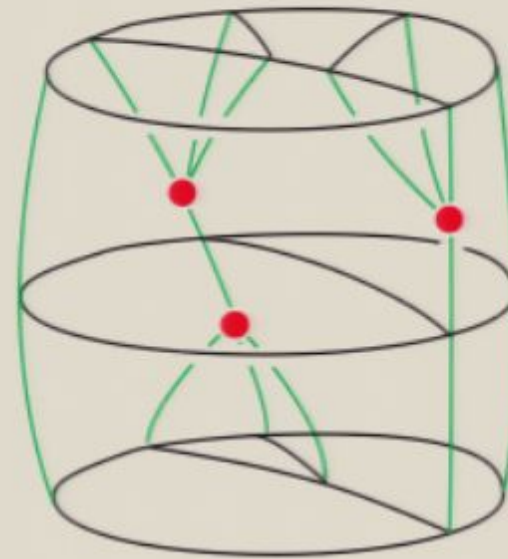
Similarly, models of quantum spacetime should be just that: models.

This means that experiments are crucial!



Some of the Problems

How do the
networks grow?



single basis state for quantum space:



quantum space means superposition of all
basis states...



quantum space means superposition of all
basis states...

- Superposition of graphs... confusing

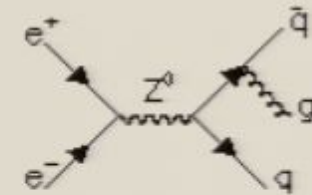
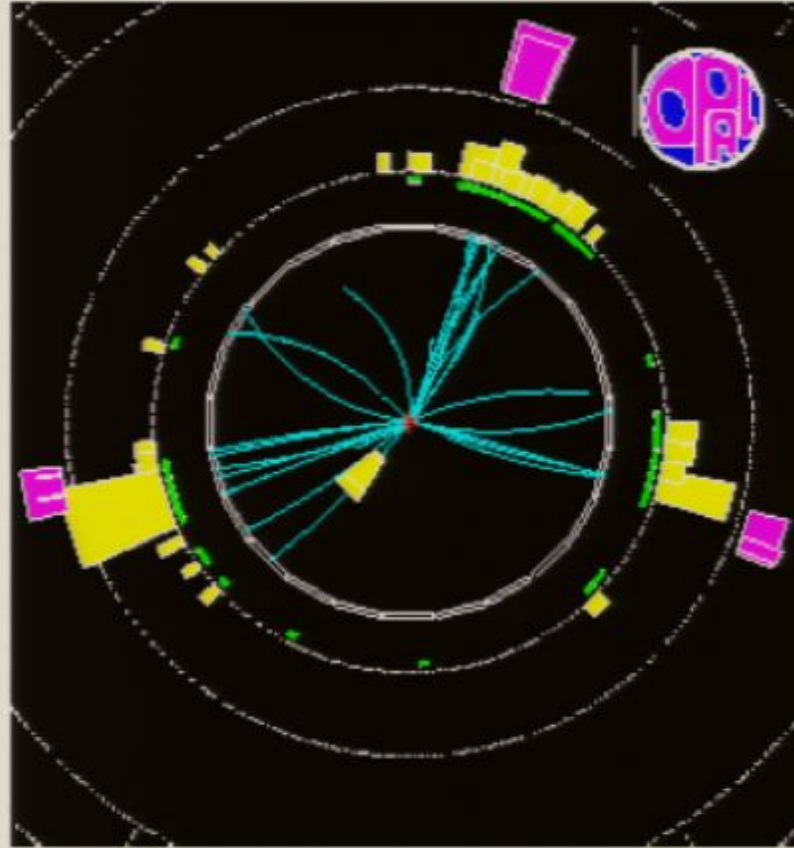
quantum space means superposition of all
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- One graph... which one?

quantum space means superposition of all basis states...

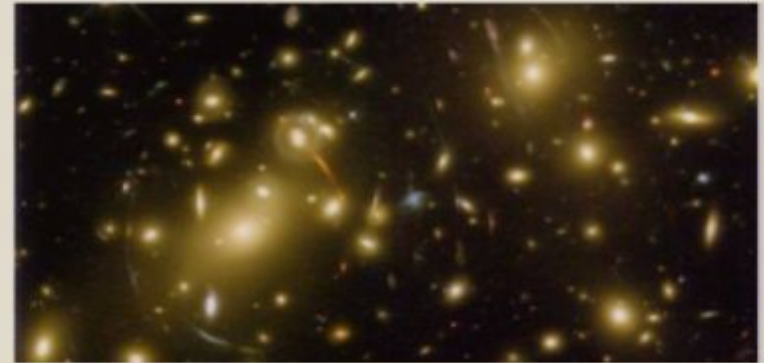
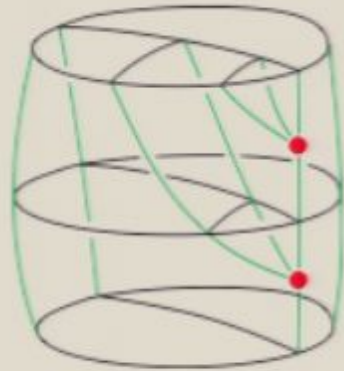
- Superposition of graphs... confusing
- One graph... which one?
- One graph and it doesn't matter which one... why doesn't it matter?

The real meaning of spacetime is that it is a set of ordered physical events.



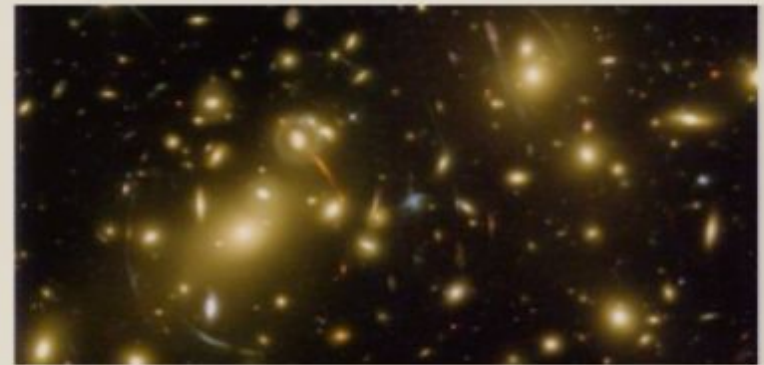
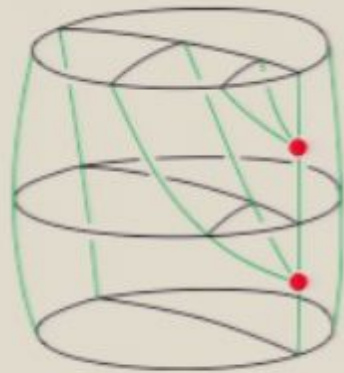
The event is a coincidence of what persists (thingy).
Why do thingies exist?

Which aspects of the network are important?
What makes space stable?



x 100.000.000.000.000.000.000.000.000.000.000.000.000.000.000

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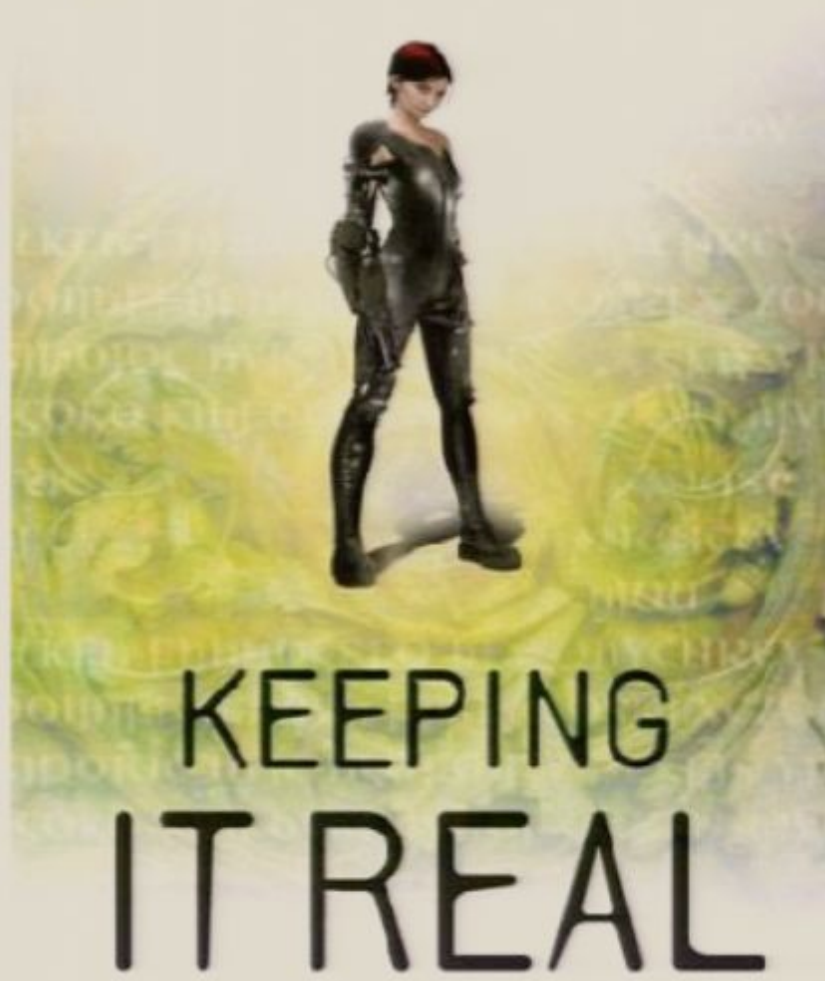


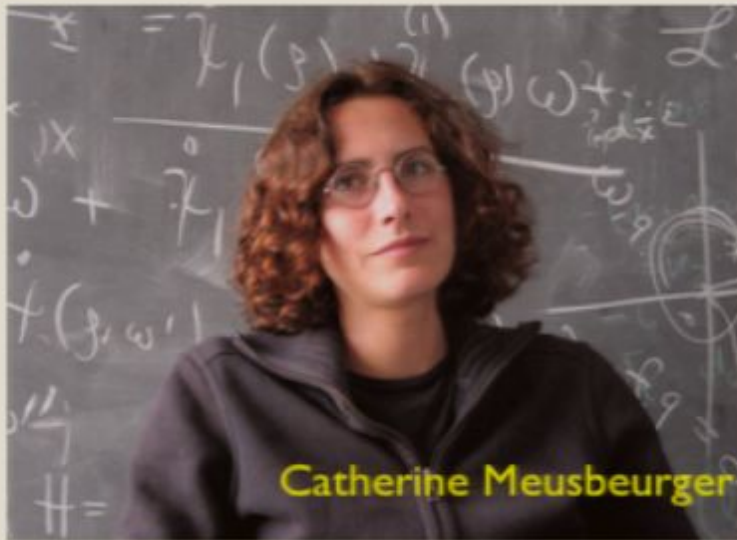
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... Space as **emergence of order**.
Order can give persisting identity.

Does space exist?

QUANTUM GRAVITY BOOK ONE





Catherine Meusbeurger



Rowan Thomson



Sabine Hossenfelder



Bianca Dittrich



Eleonora Dell'Aquila

Yujun Chen









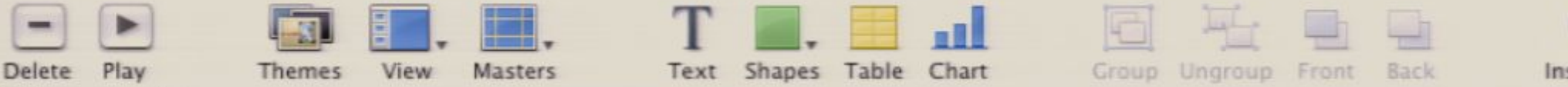












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