Title: Physics of the 20th Century: The Incomplete Revolution - ISSYP Keynote Session

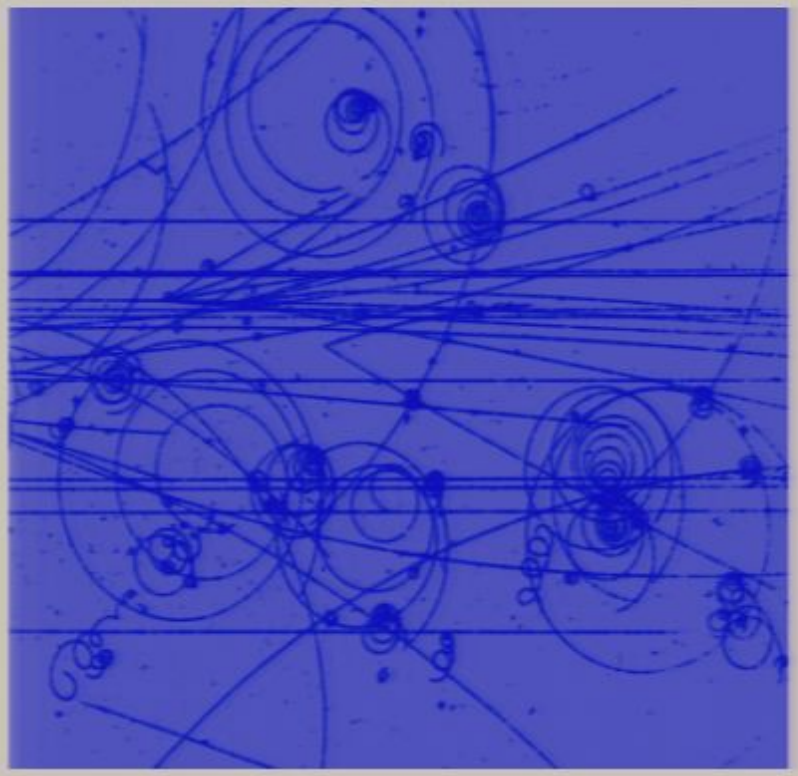
Date: Aug 07, 2007 09:00 AM

URL: http://pirsa.org/07080060

Abstract: In the first part of the talk, a brief introduction to general relativity and quantum theory is given. Their independent successes are discussed, as well as the desire and difficulty in merging them, to obtain a unique language to describe the universe.
Then I focus on Loop quantum gravity, a particular approach towards this objective, in which a discrete microscopic structure of spacetime is envisaged.

Physics of the 20th century: the incomplete revolution

General Relativity



Quantum Theory

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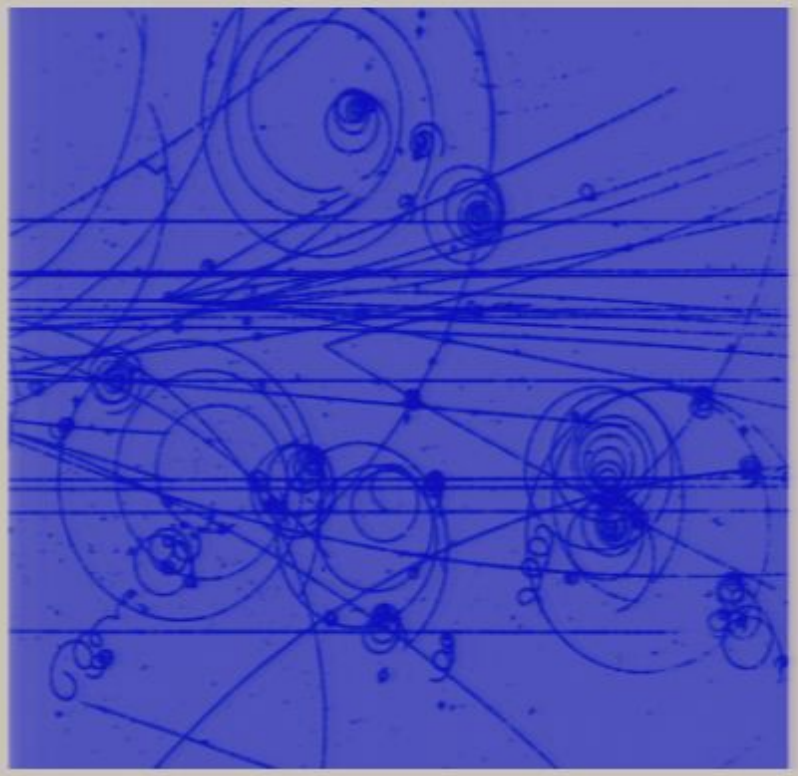

Quantum Theory

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General relativity

Quantum theory

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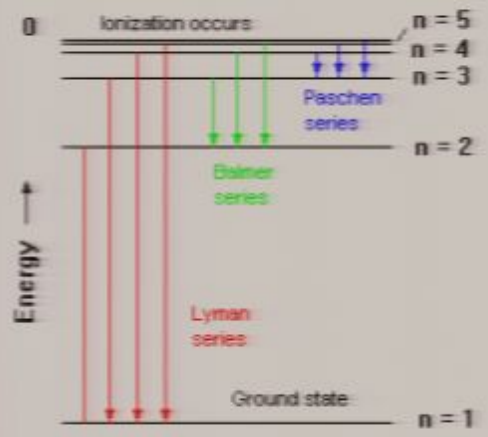

General relativity

Quantum theory

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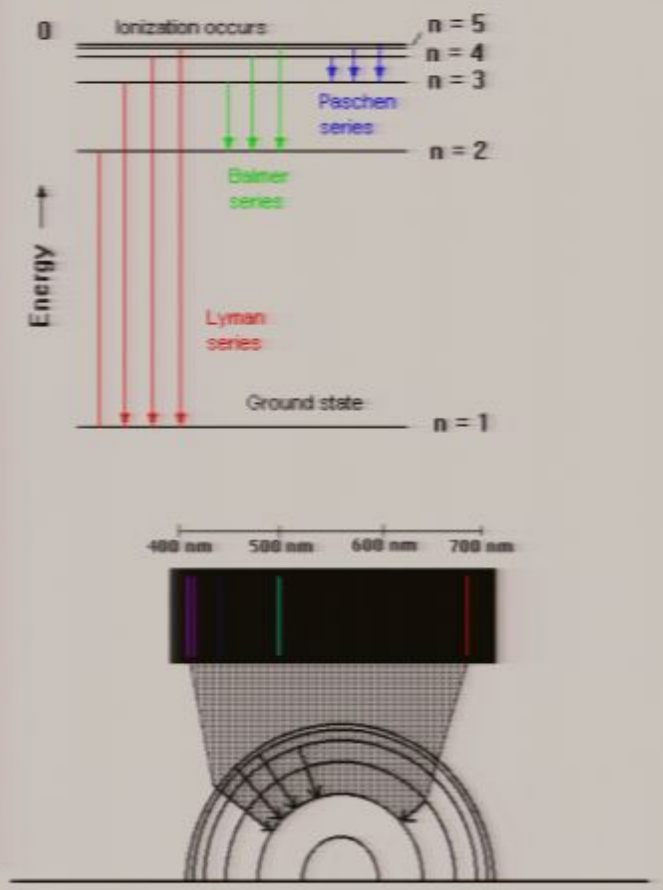


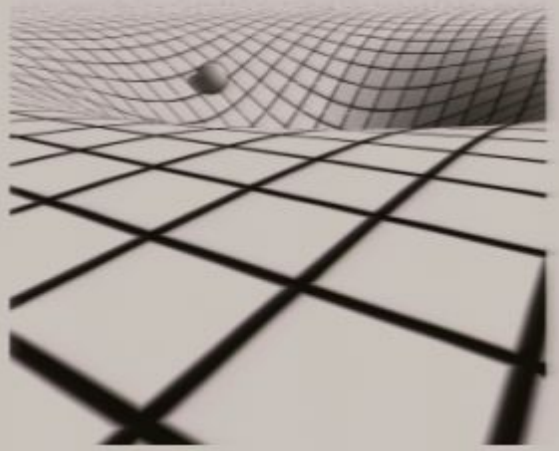
General relativity

Quantum theory

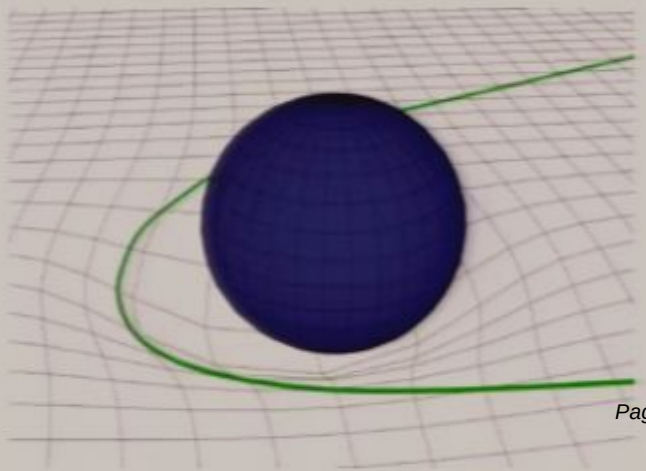
General Relativity

Equivalence principle: The laws of nature are the same for all observers, inertial or not

The force of gravity is the manifestation of the curvature of spacetime



Matter moves along geodesics



Einstein's equations

General Relativity: the black hole

(Laplace 1795!!)

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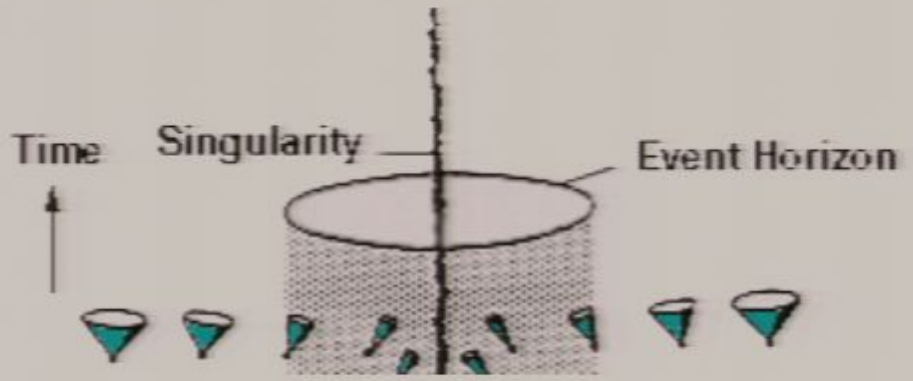

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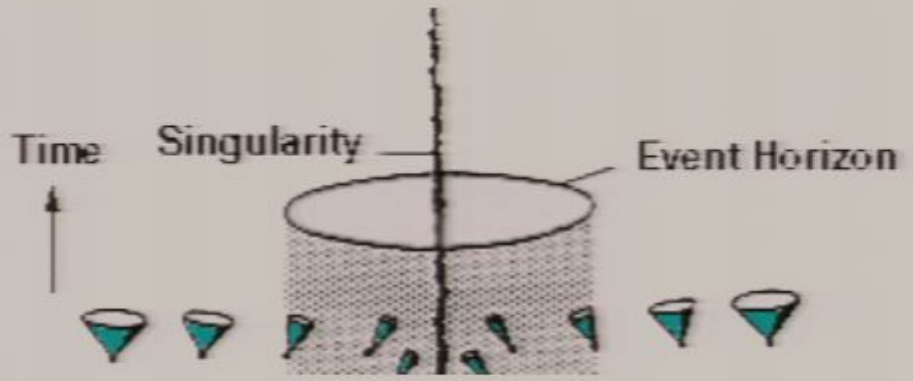

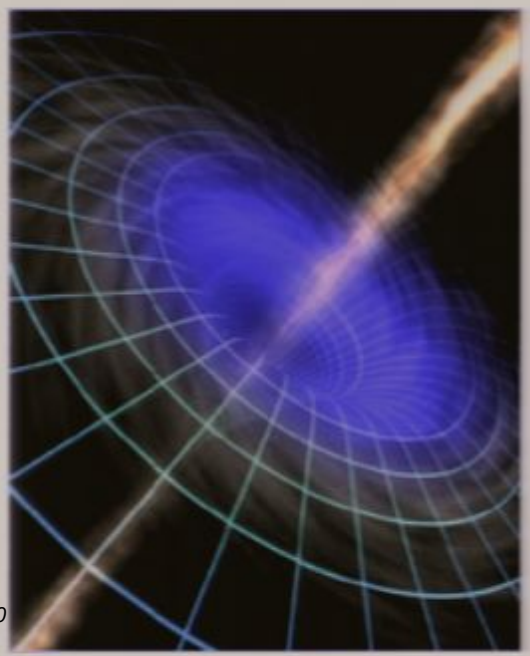

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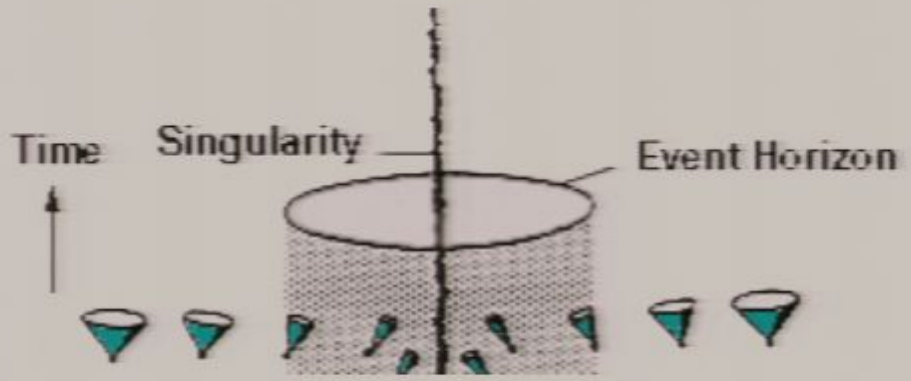

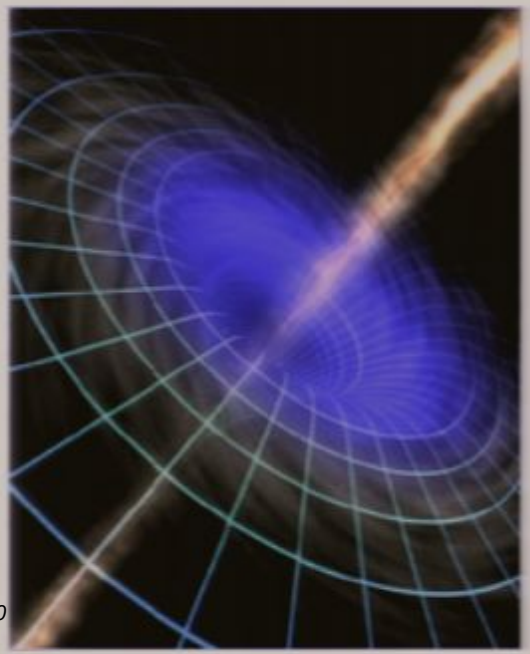

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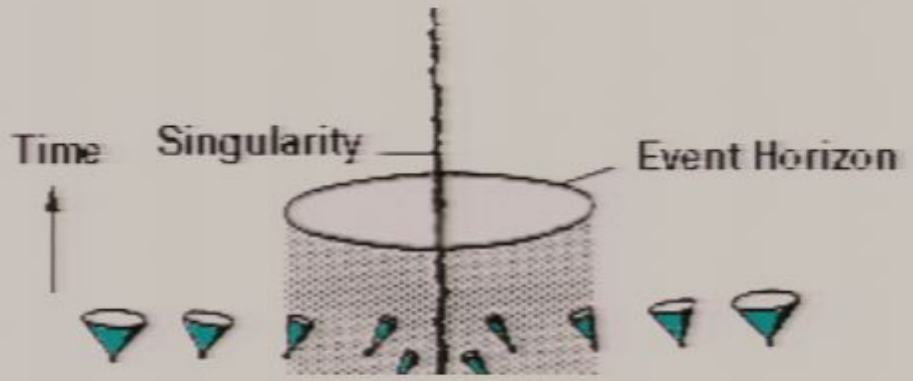
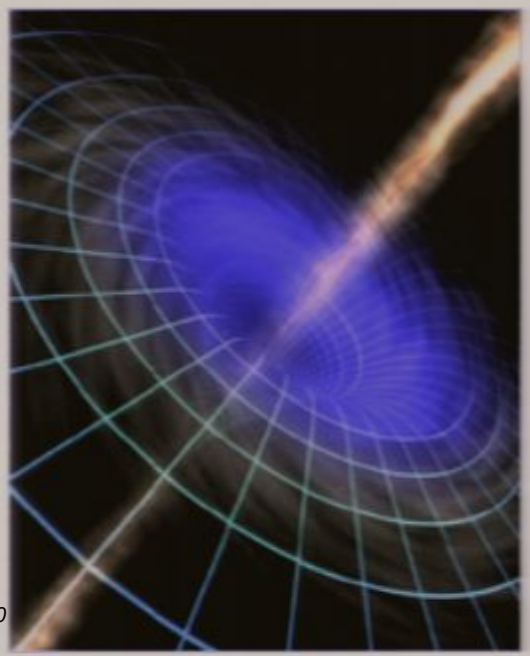


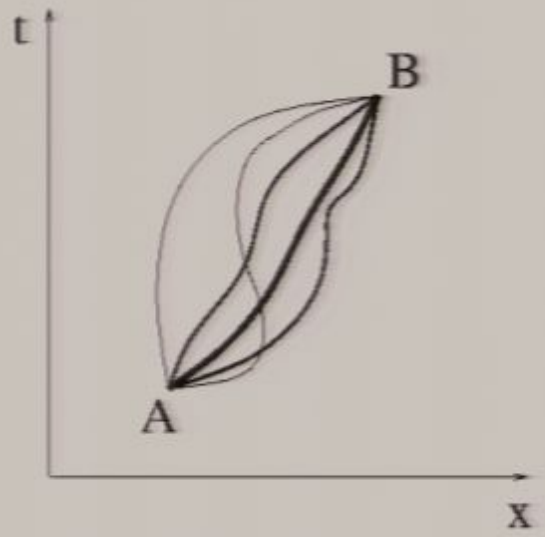


Quantum Theory

Heisenberg uncertainty principle: exact position and momentum of a particle can not be known simultaneously

$$\Delta x \, \Delta p \geq \frac{\hbar}{2}$$

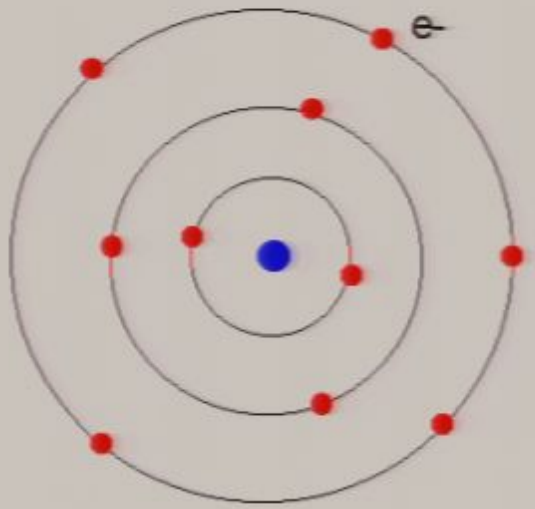
fuzzy trajectories

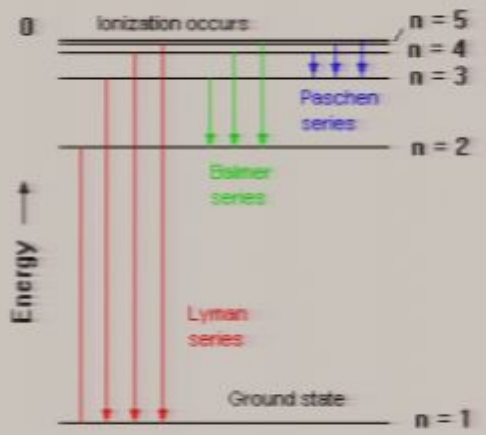


x and p are called incompatible observables

Discreteness and Quanta

Atomic structures





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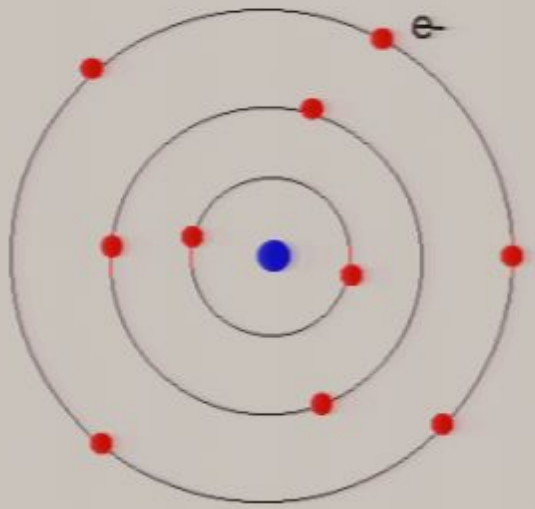

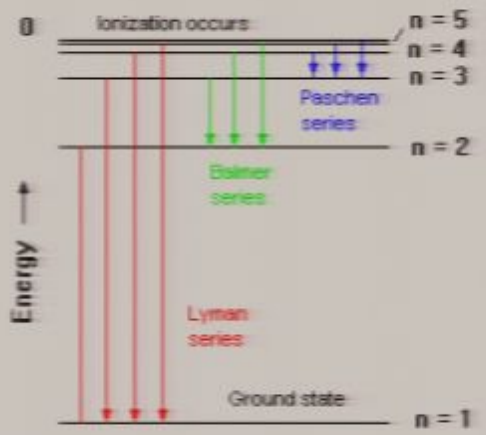

Spin of the electron

Discreteness and Quanta

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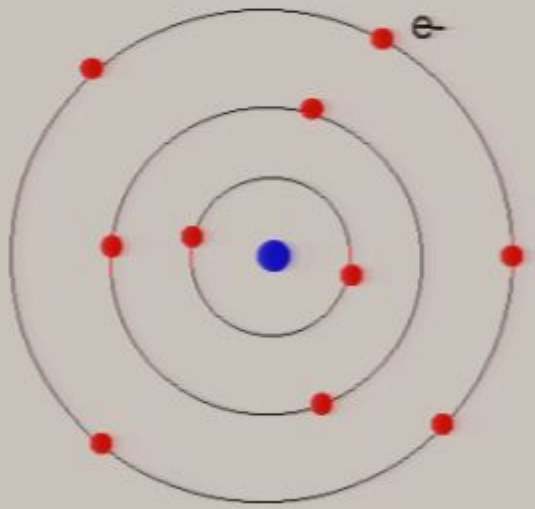

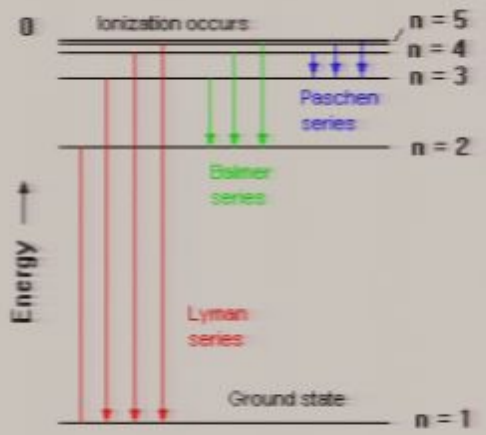

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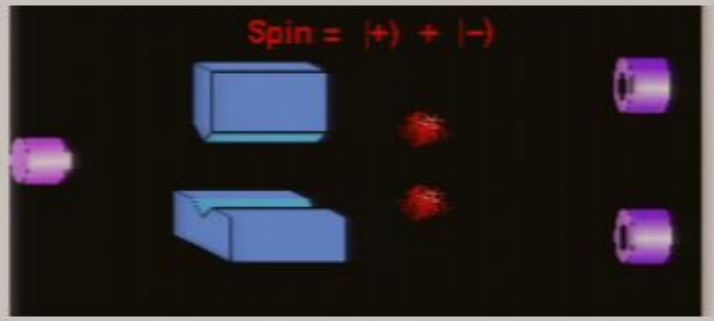

Quantising General Relativity

Lesson from General Relativity: spacetime is dynamic

Lesson from Quantum Theory: dynamical quantities are quantised

quantum spacetime ?

Quanta of space

What are the quanta of gravity?

Quanta of space

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"grains of space"

Quanta of space

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↓

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↓

smooth space

Quanta of space

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smooth space

$\Updownarrow \quad \ell_P \sim 10^{-33}\text{cm}$

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No direct experiment No indirect hints from experiments (so far)

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...but there are also other ideas around! especially in the absence of experiments, one should try to be as open–minded as possible

A (brief) look at the Dark Side:

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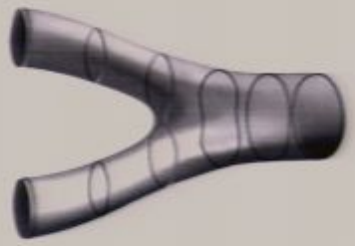

String theory

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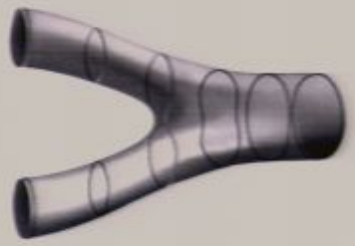

String theory

Very tempting: it follows a path which has been elegant and successfull until 1974

Very powerful: gives a unified picture of matter and interactions

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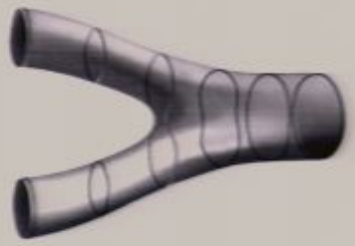

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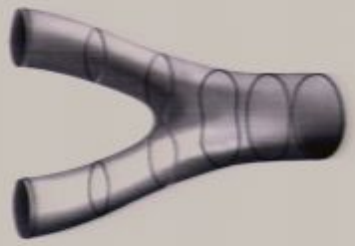

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It does not address directly the question of quantum spacetime

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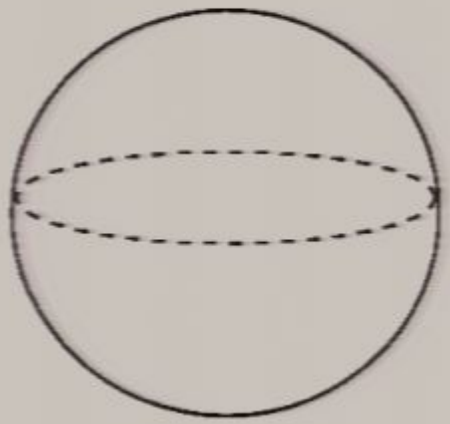
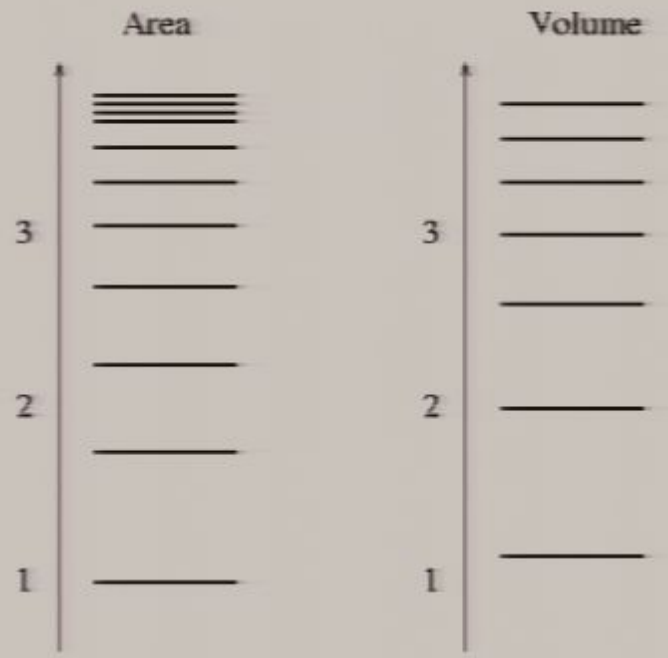
Loop Quantum Gravity

A candidate theory to a quantum description of spacetime.

It describes quanta of spacetime and their dynamics





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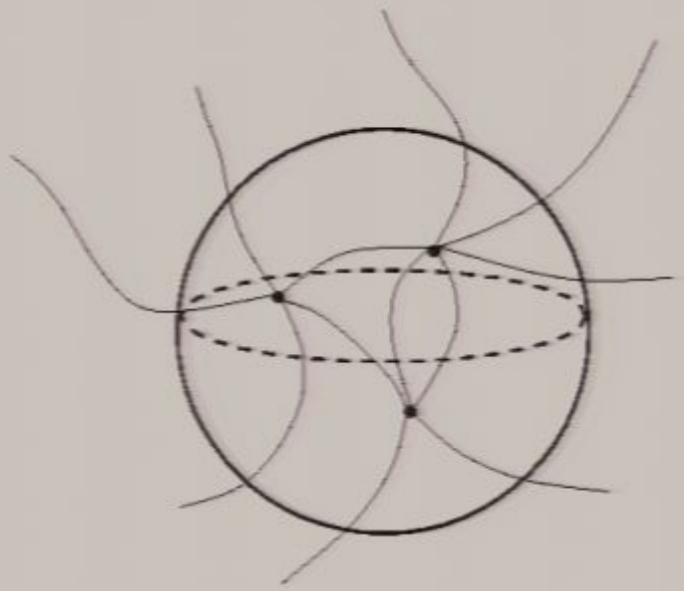

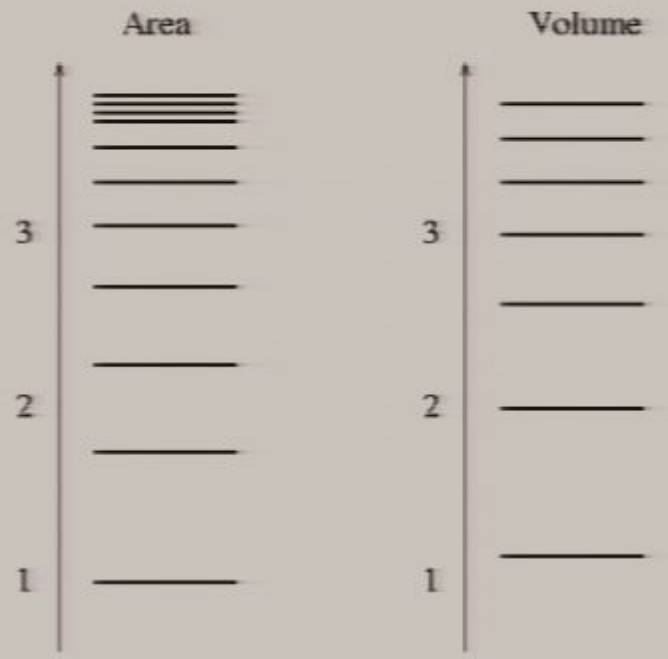

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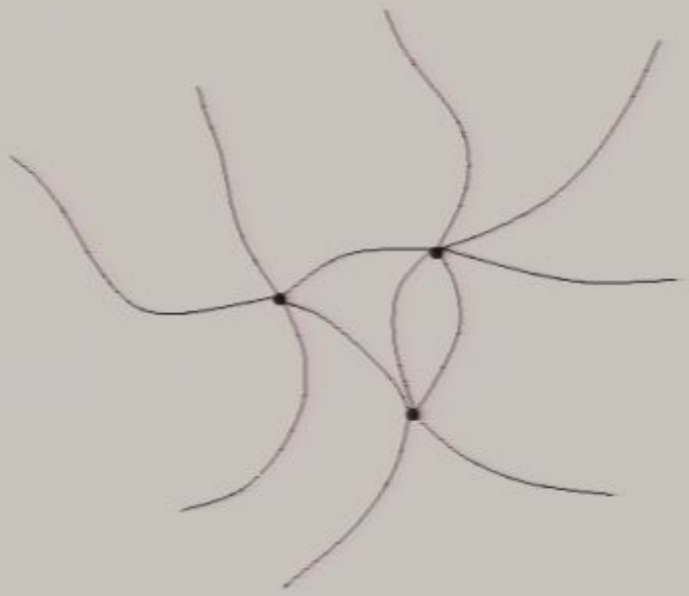
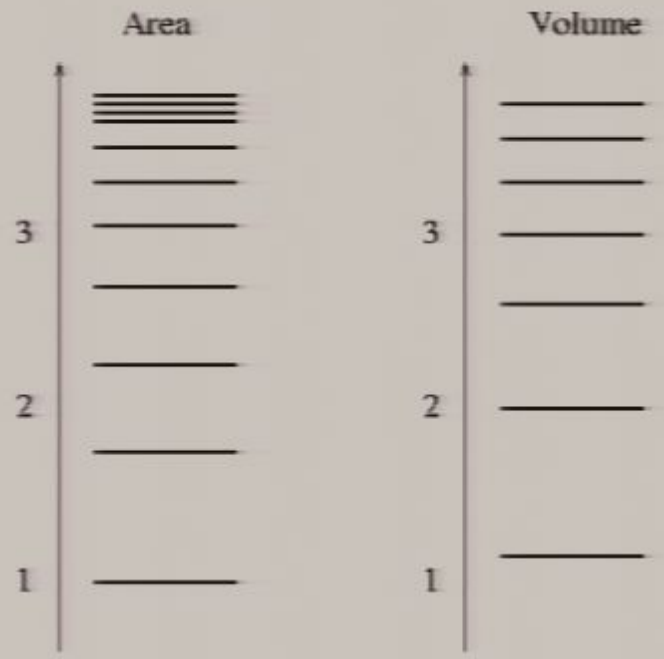
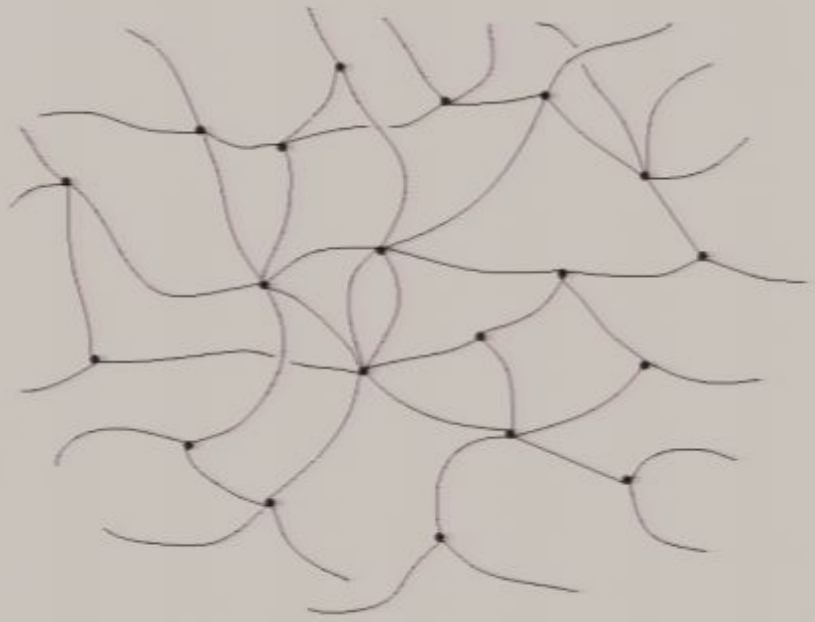




Spin Networks



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Each graph is defined solely by the way the nodes are linked together: there is no background structure over which the graph lives

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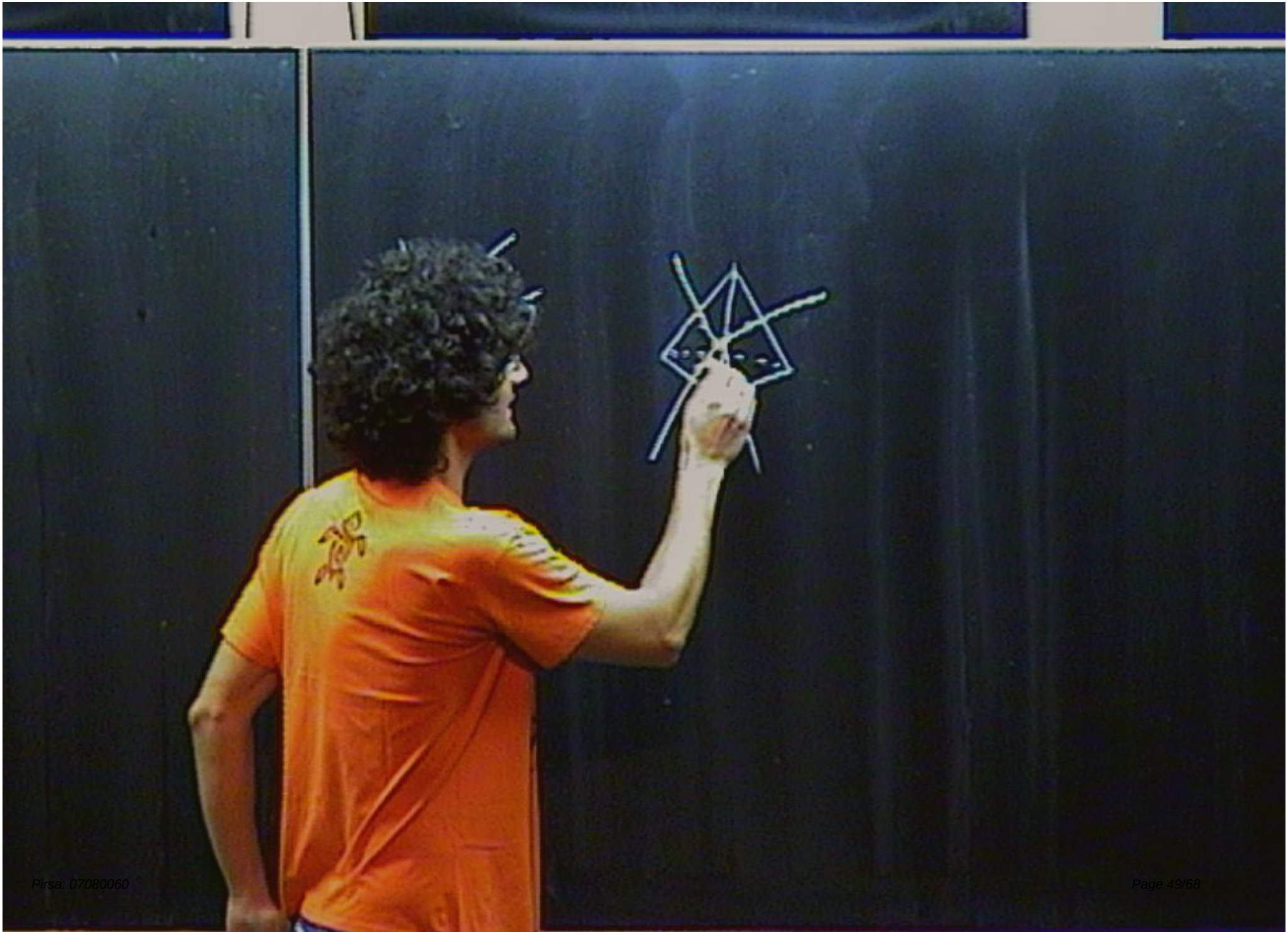
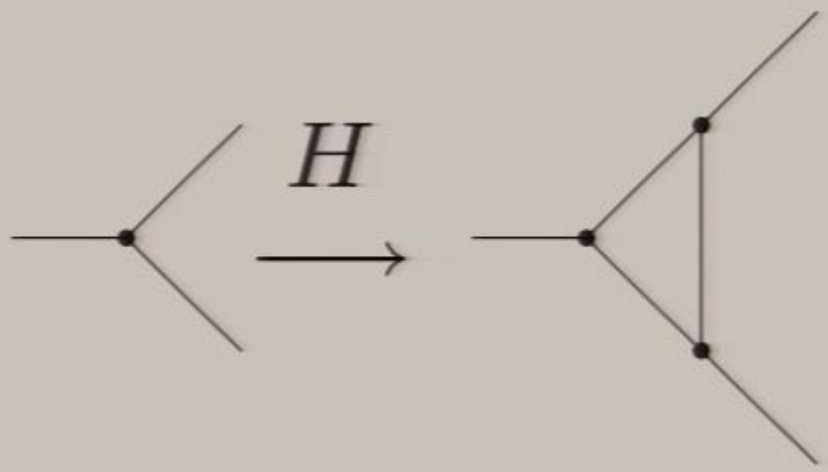
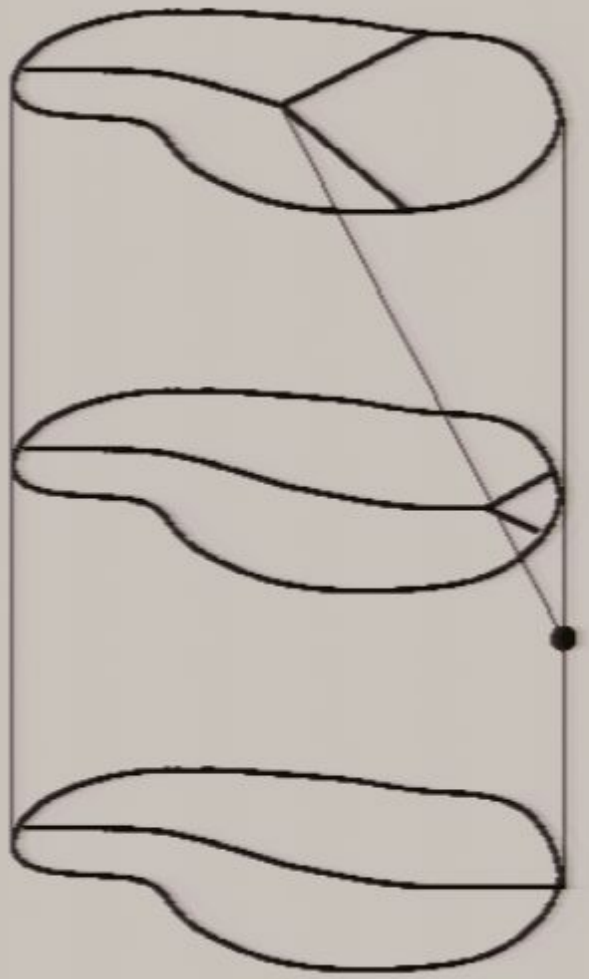


LQG dynamics: spinfoams

The Hamiltonian operator
acts on the nodes
of the spin network:





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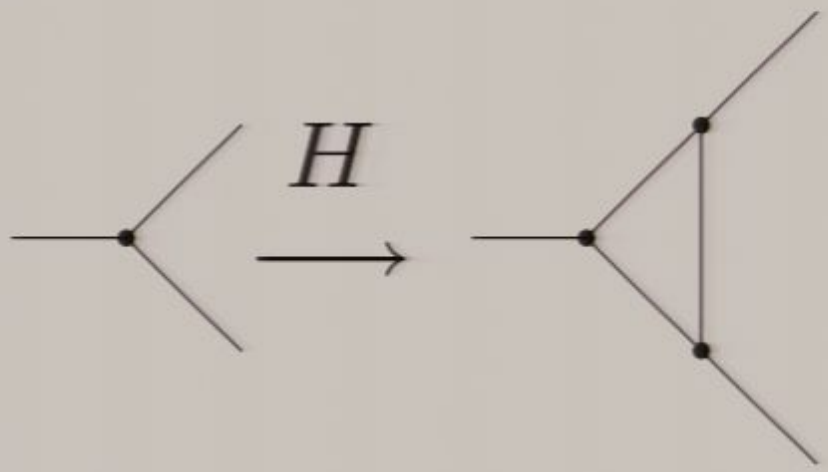
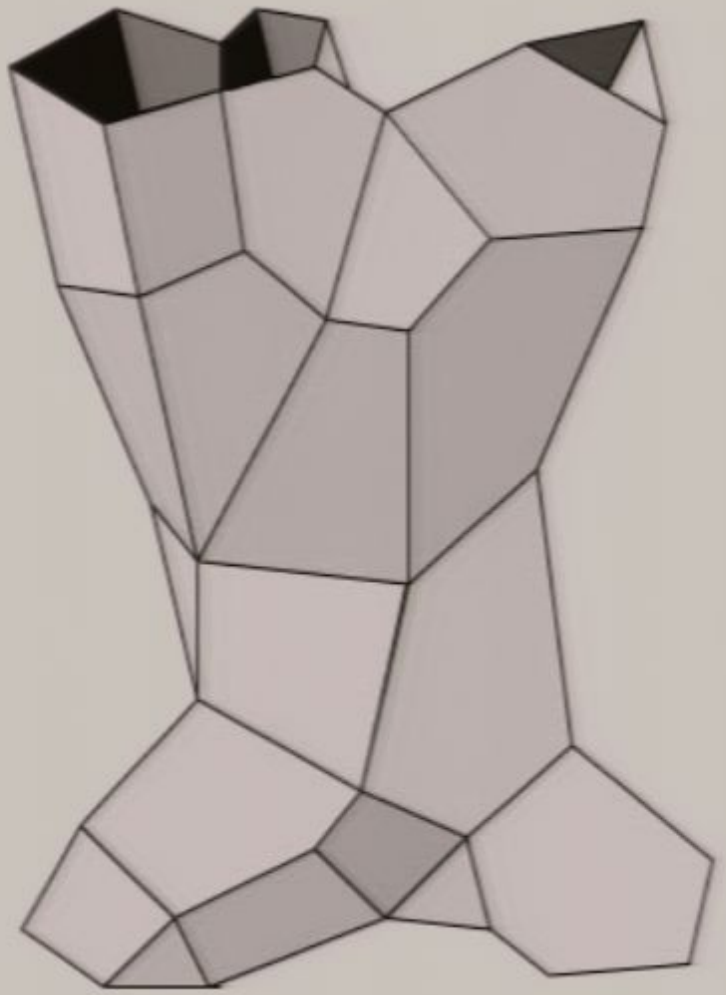
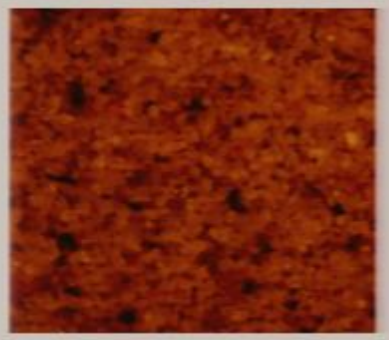




Physics of LQG

Discreteness of spacetime

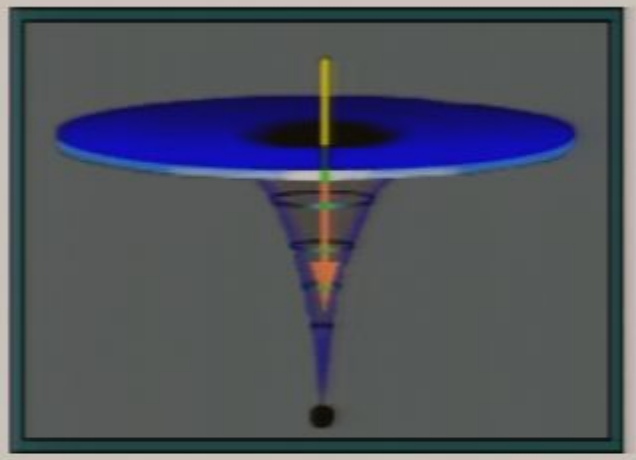


Risolution of singularities

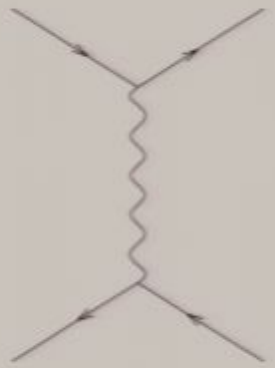
New description of the propagation of matter

Resolution of singularities

Spacetime singularities



Particle interaction singularities



New propagation of matter

High energy probes are sensible to fine structure of spacetime

$$\lambda = \frac{2\pi\hbar c}{E}$$

Phenomenology

Deformations of the Lorentz symmetry

$$E^2 = m^2 + \vec{p}^2$$

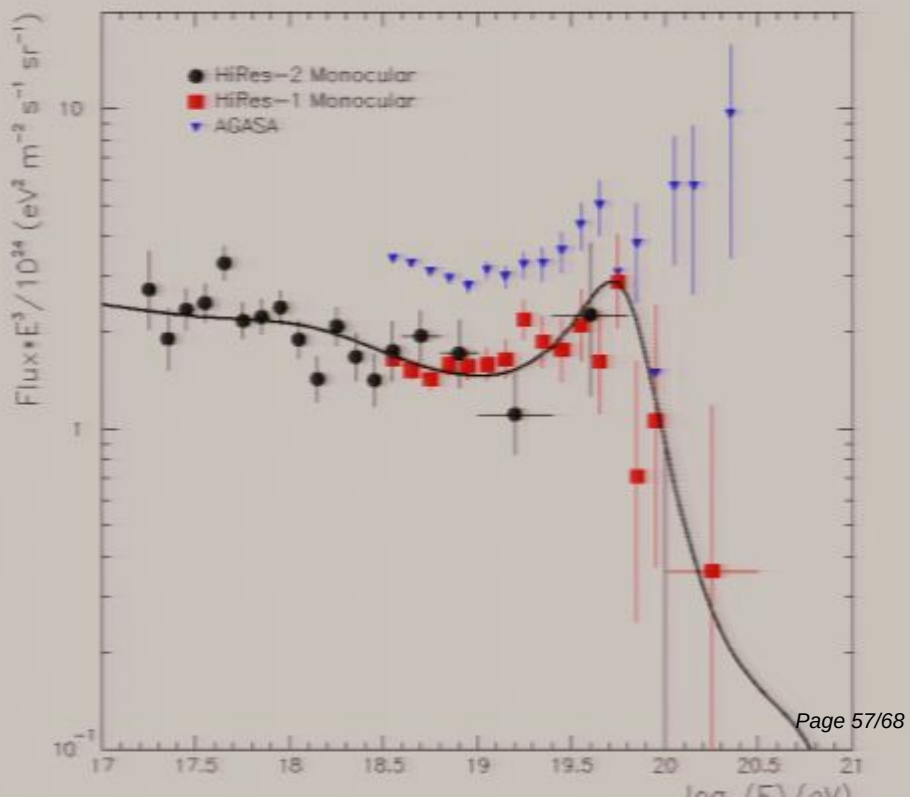
Phenomenology

Deformations of the Lorentz symmetry

$$E^2 = m^2 + \vec{p}^2 \qquad + \alpha \ell_P E^3 + \beta \ell_P^2 E^4 + \dots$$

Example: GZK threshold

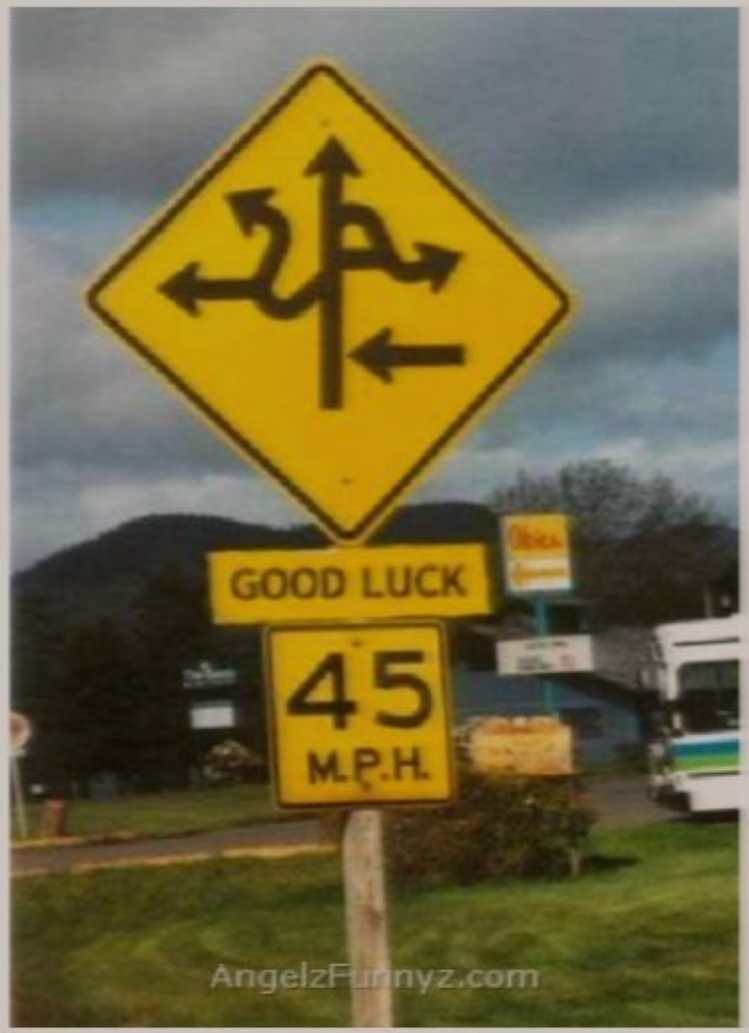
$$p + \gamma_{CMB} \mapsto \begin{cases} p + e^+ + e^- \\ p + \pi_0 \end{cases}$$



Discrete structure of spacetime?

We don't know if this picture is correct until we have experimental confirmation of predictions of the theory

The path is right in front of us!



Microsoft PowerPoint - [EinsteinFest06]

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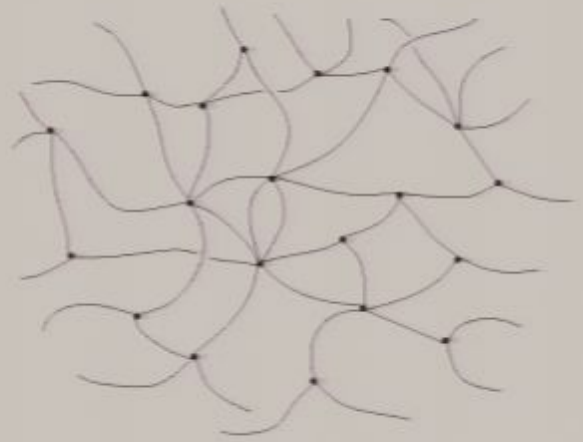
The path is right in front of us!

Forme

Struttura Struttura predefinita

Spin Networks



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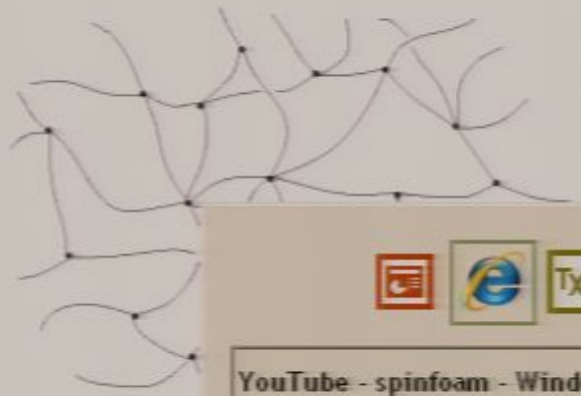

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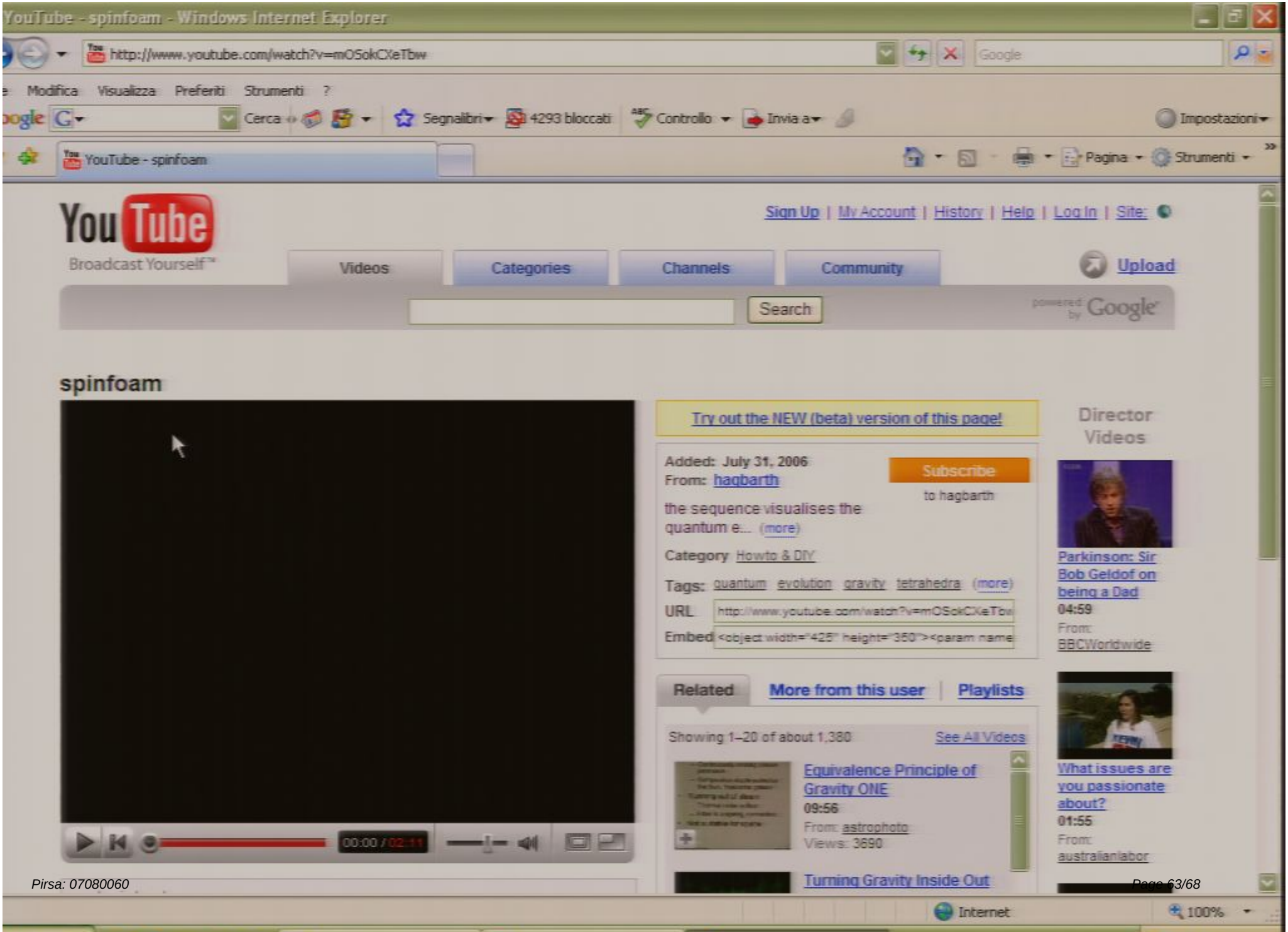
YouTube - spinfoam - Windows Internet Expl...

Each graph is defined solely by the way the nodes are linked together: there is no background structure over which the graph lives

Particularly suitable to implement the idea of relationalism of physics pushed by General Relativity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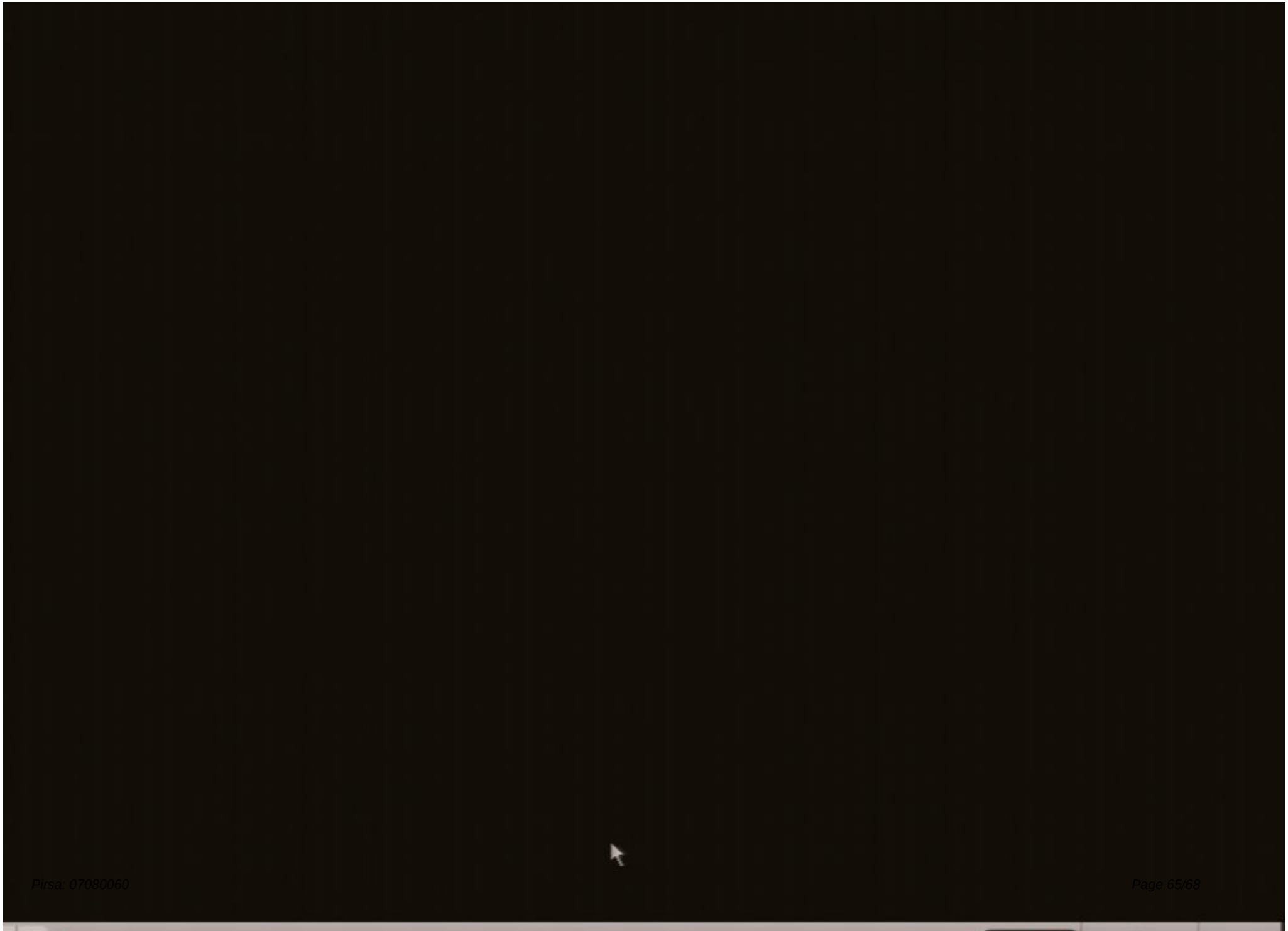

Quantum Spin Dynamics in Loop Quantum Gravity

The following sequence visualises the quantum evolution of geometry in Loop Quantum Gravity. The colours of the faces of the tetrahedra indicate where and how much area exists at a given moment of time. The movie illustrates how these excitations of geometry change as dictated by the Quantum Einstein Equations.

Technically, the faces form a complex dual to the graph of a spin network state and the colour shows the amount of spin (area) with which the edges of the graph are charged.