

Title: Keynote Presentation - Introduction to quantum gravity

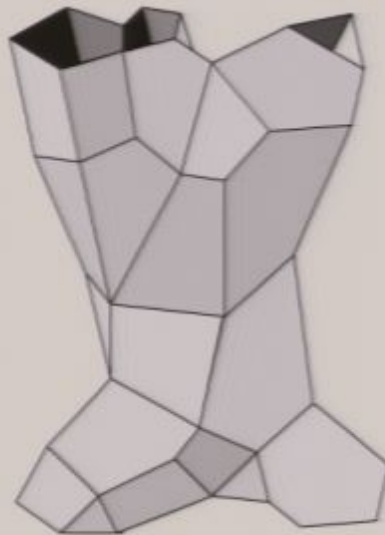
Date: Jul 13, 2006 01:00 PM

URL: <http://pirsa.org/06070027>

Abstract:

Quantum Gravity

The quest to quantise Einstein's theory
of General Relativity



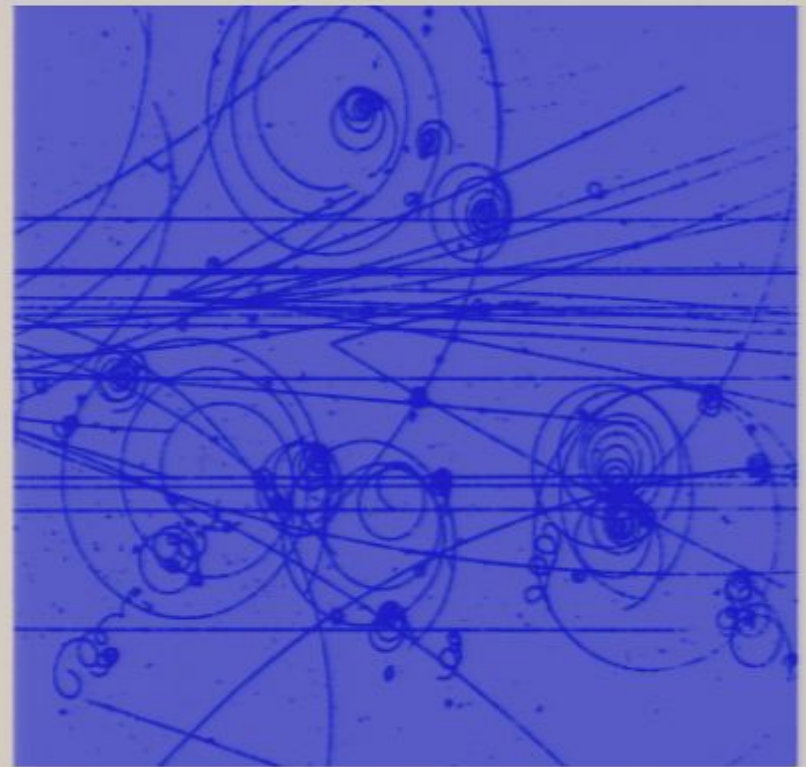
Simone Speziale

Perimeter Institute, 13-07-2006

Physics of the 20th century: the incomplete revolution



General Relativity



Quantum Theory

Physics of the 20th century: the incomplete revolution



General relativity

Quantum theory

Physics of the 20th century: the incomplete revolution



General relativity



Quantum theory

~

$$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$$

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Physics of the 20th century: the incomplete revolution



General relativity



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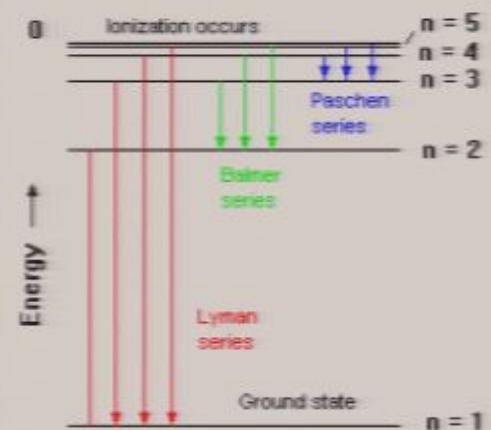
General relativity

Quantum theory

Physics of the 20th century: the incomplete revolution



General relativity

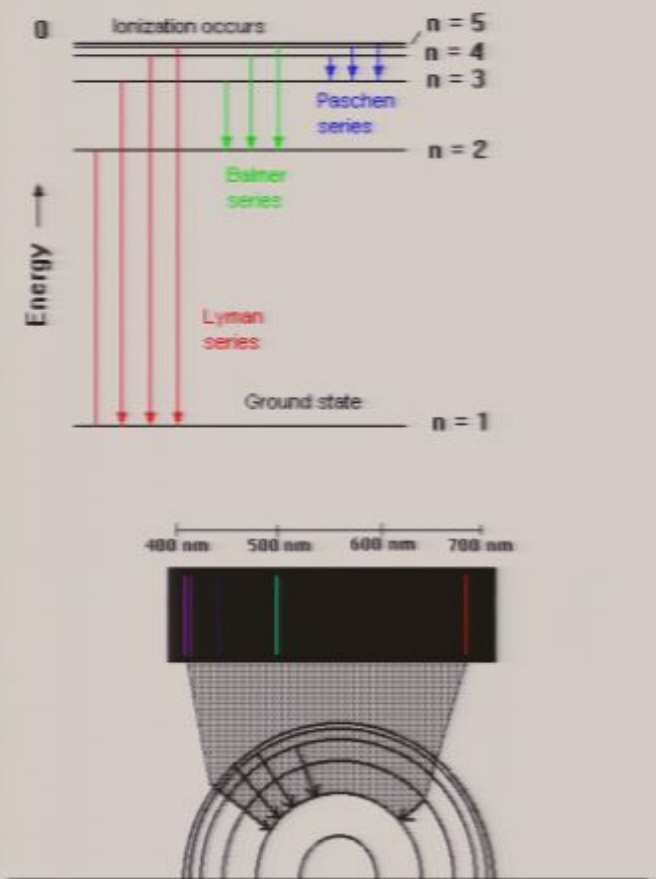


Quantum theory

Physics of the 20th century: the incomplete revolution



General relativity

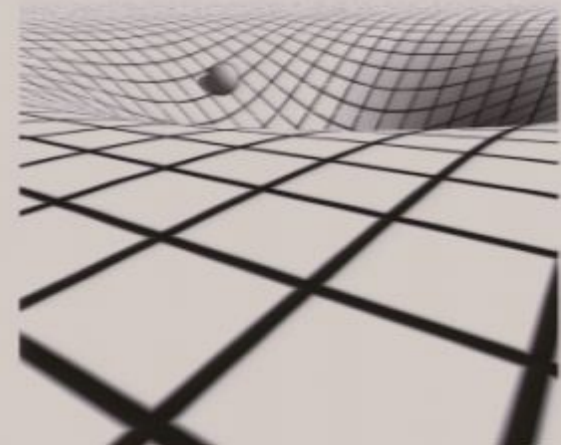


Quantum theory

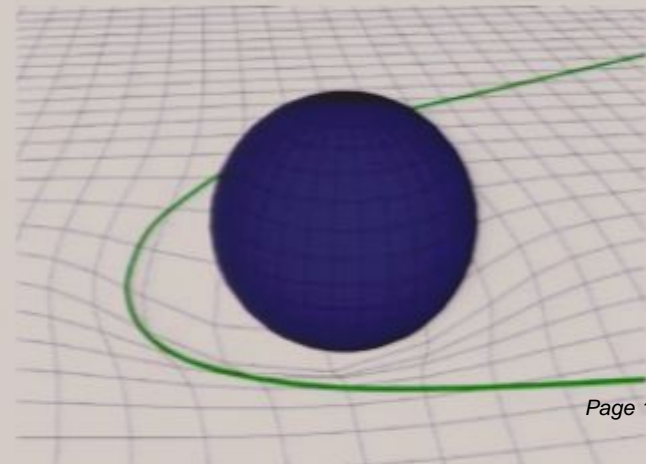
General Relativity

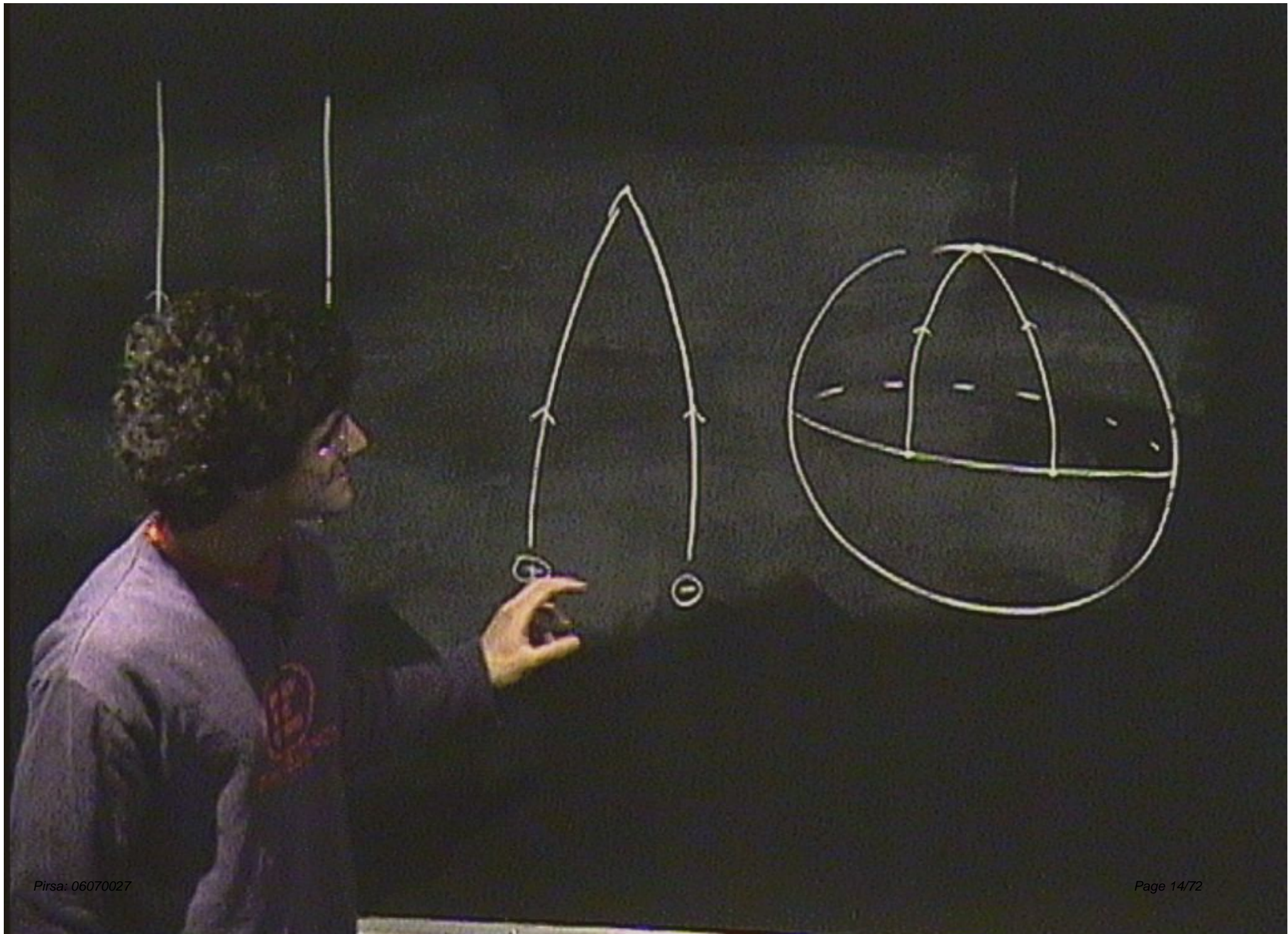
Equivalence principle: The laws of nature are the same for all observers, inertial or not

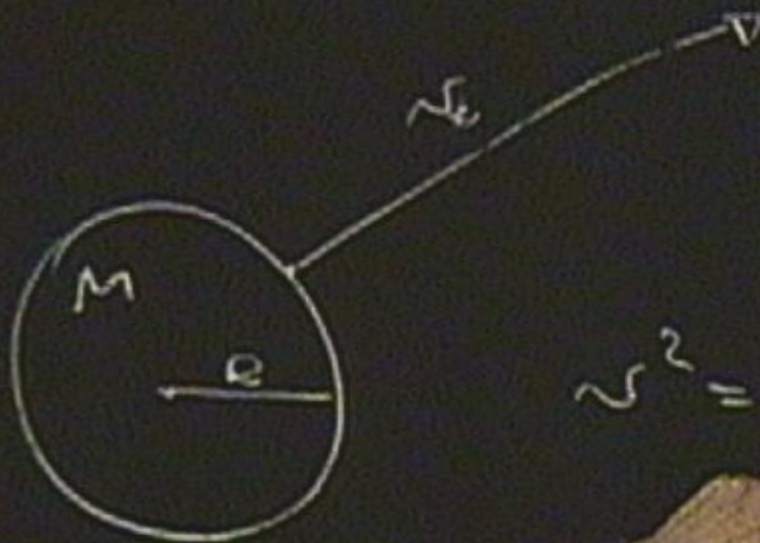
The force of gravity is the manifestation of the curvature of spacetime



Matter moves along geodesics







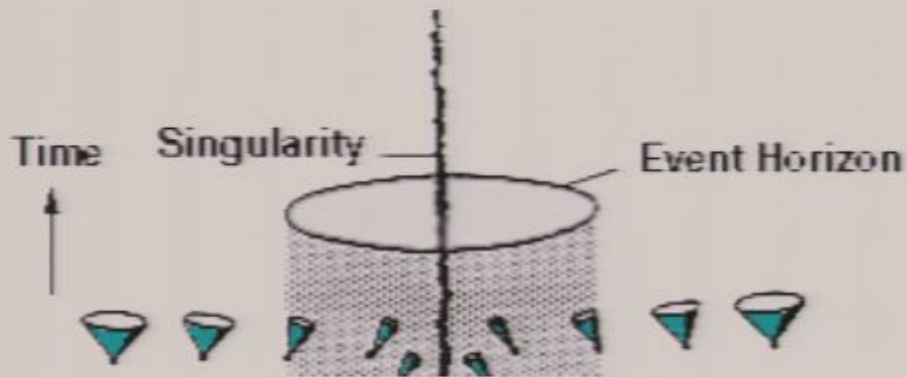
$$v^2 = \frac{2MG}{r}$$

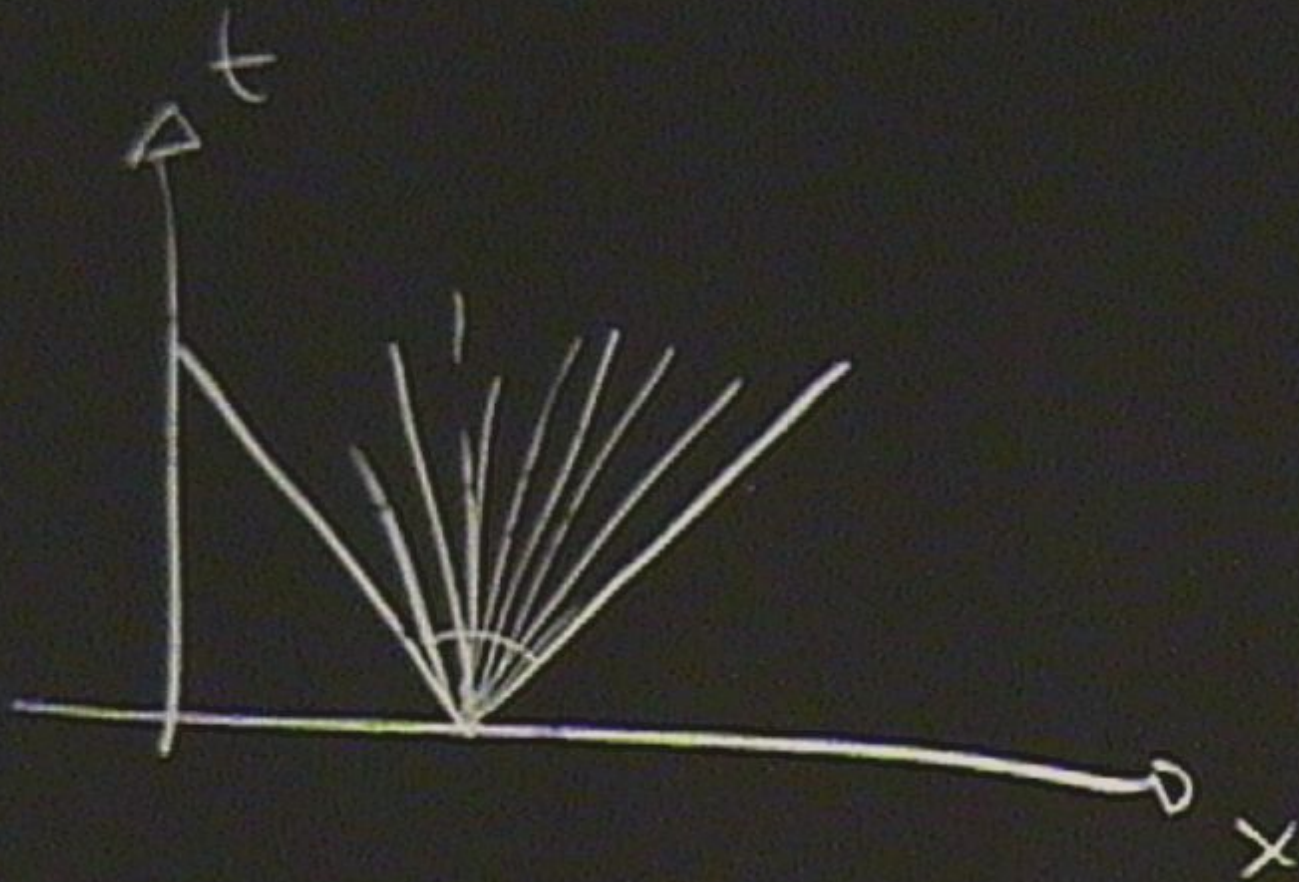


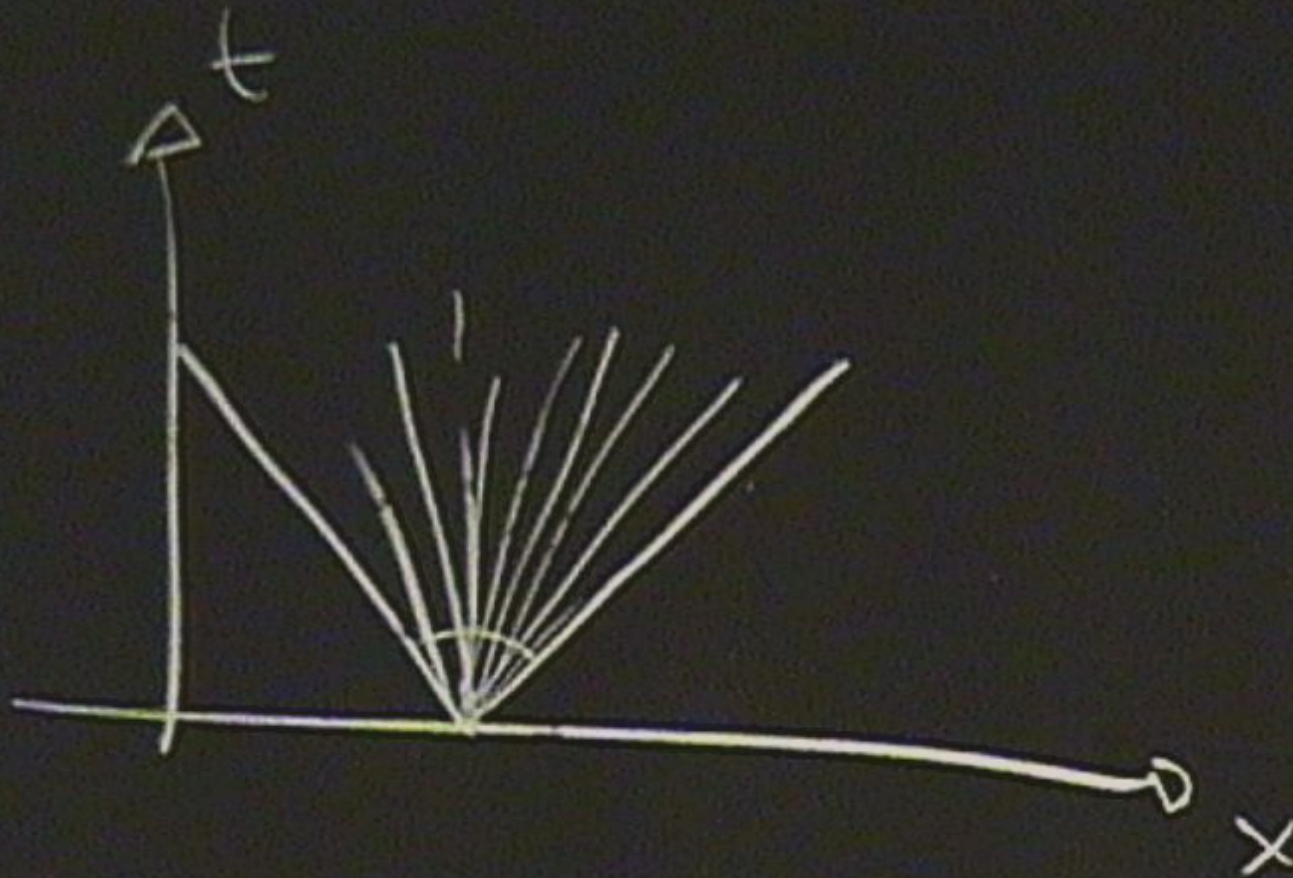
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General Relativity: the black hole

(Laplace 1795!!)

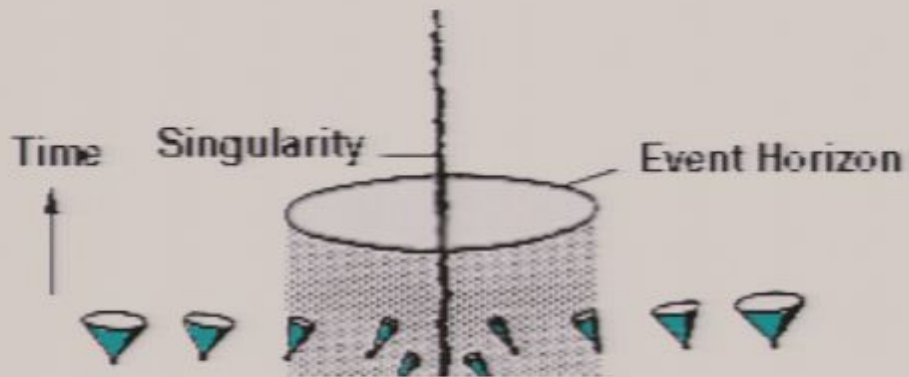






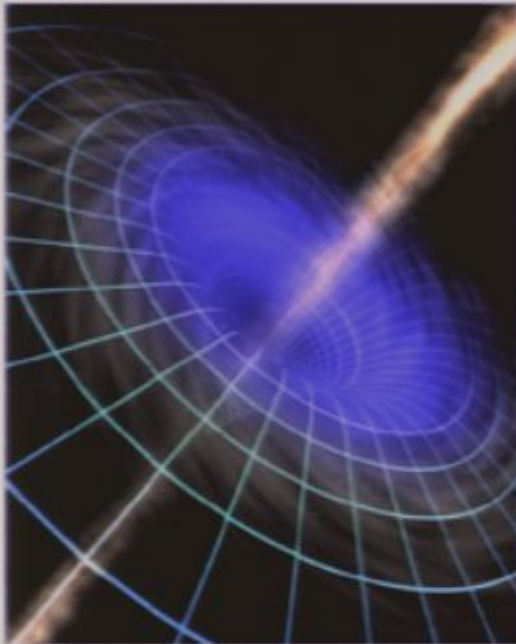
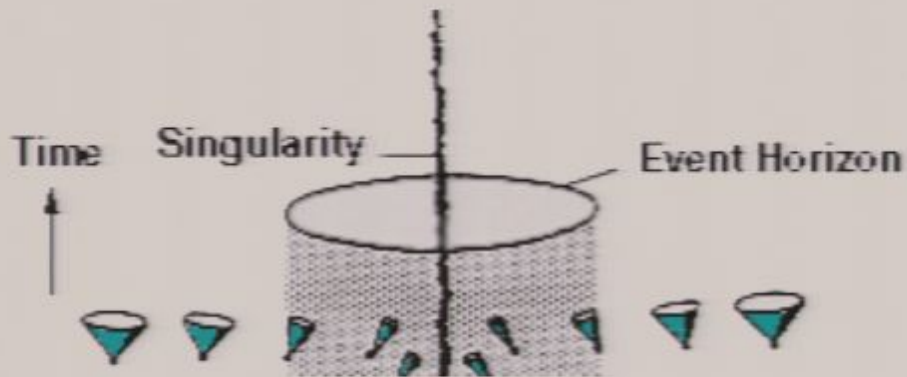
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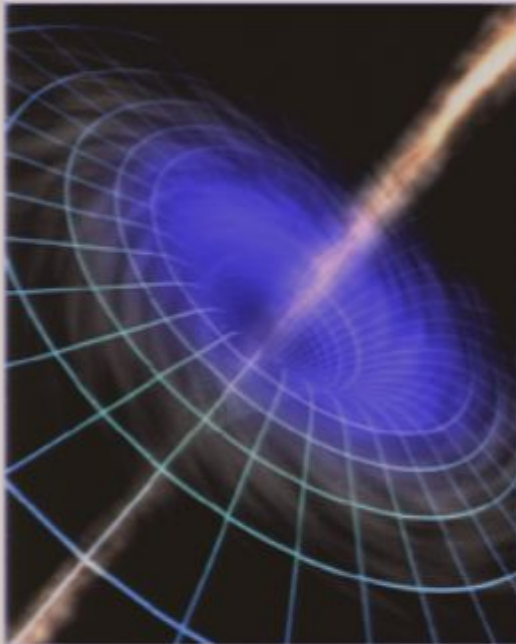
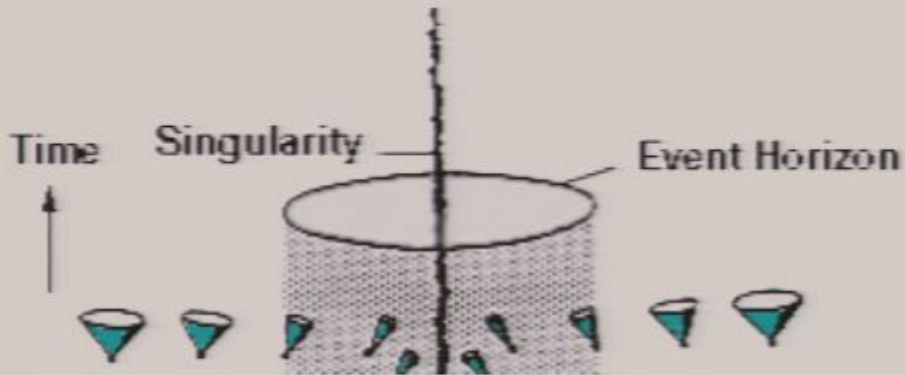
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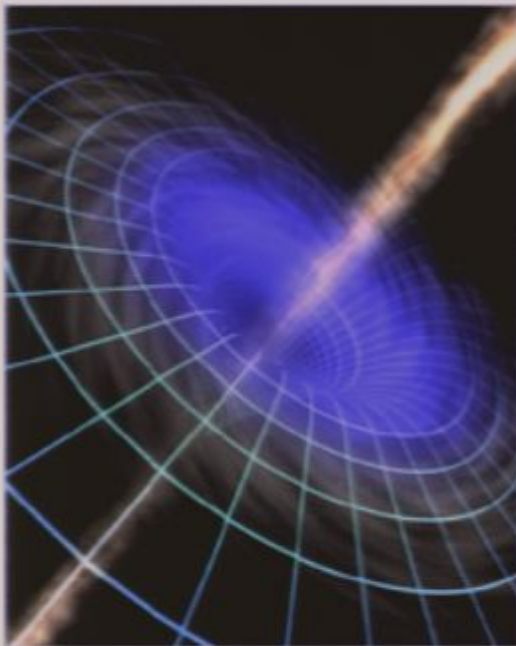
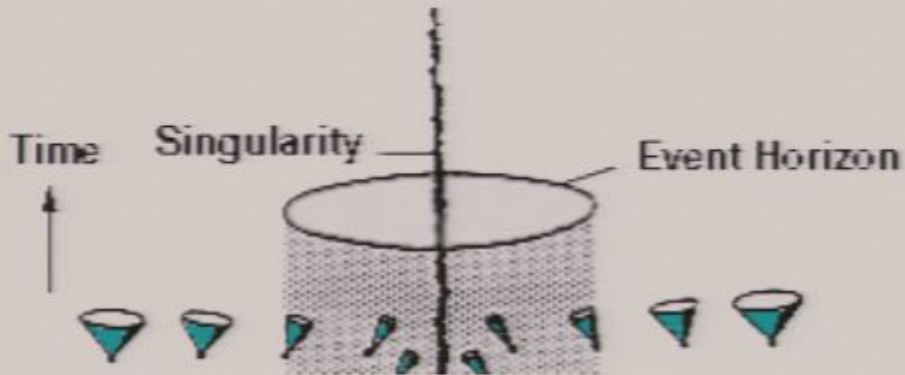
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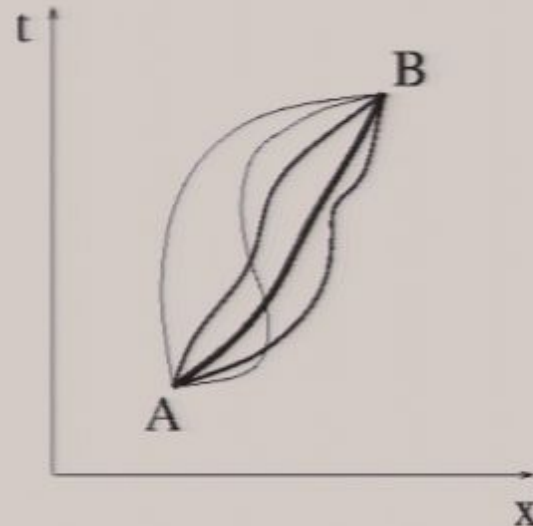
Quantum Theory

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

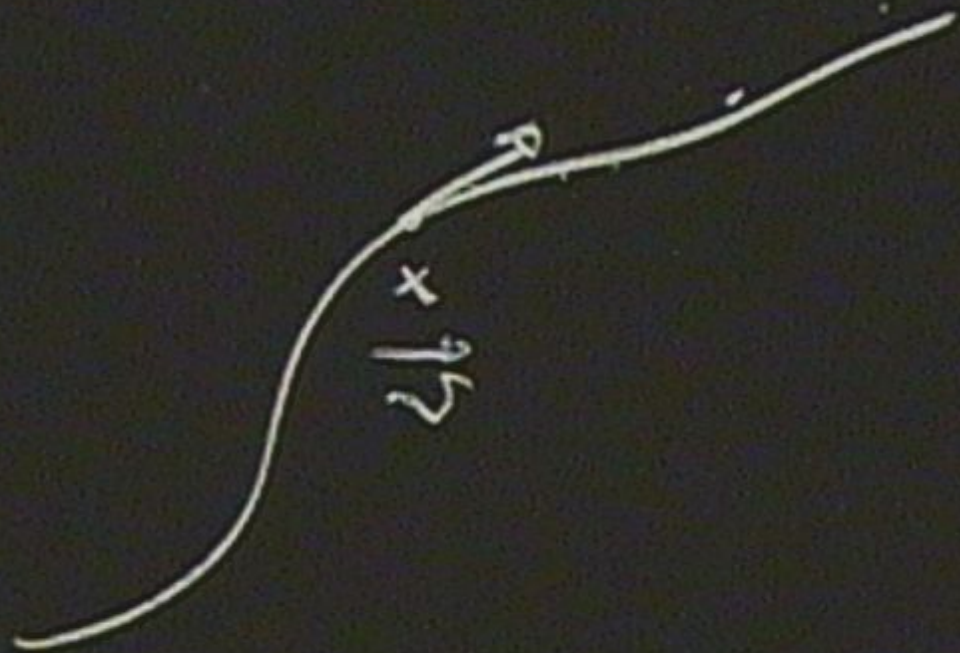


x and p are called incompatible observables

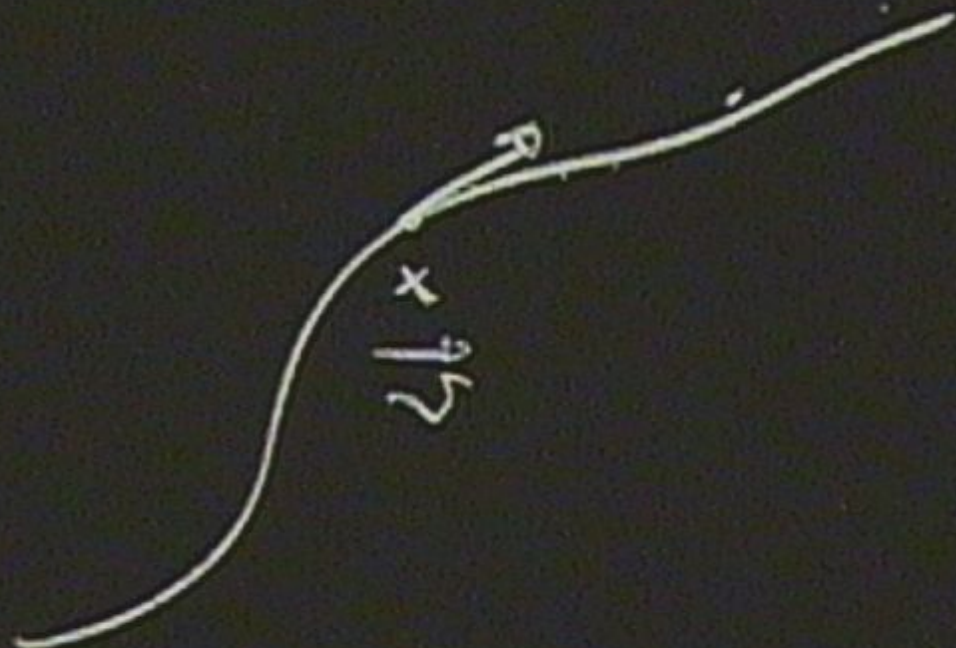
V-1-02

x 15

V-1-2
C2



V-1-2



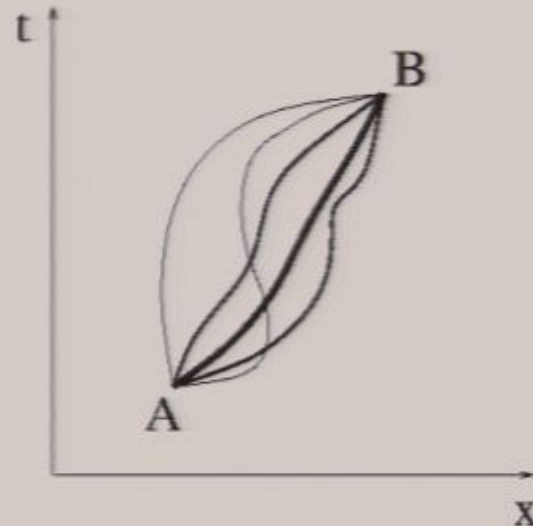
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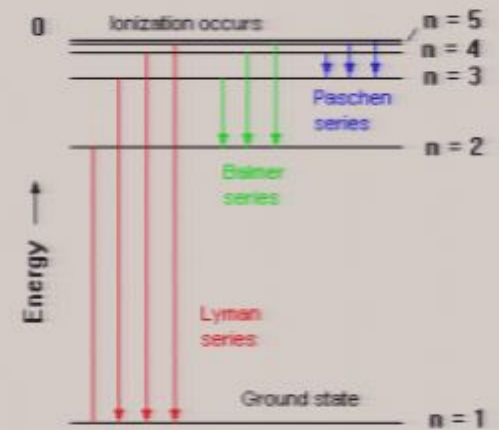
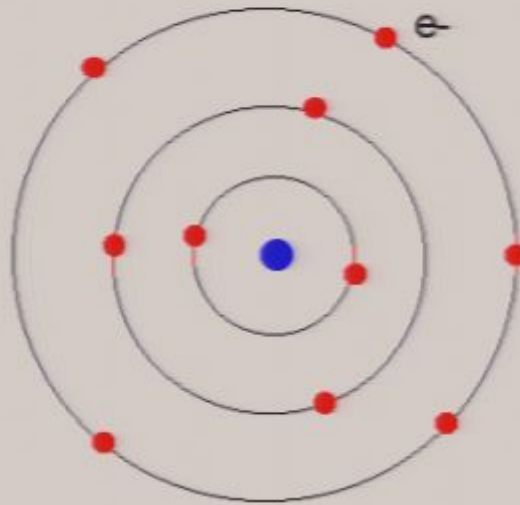
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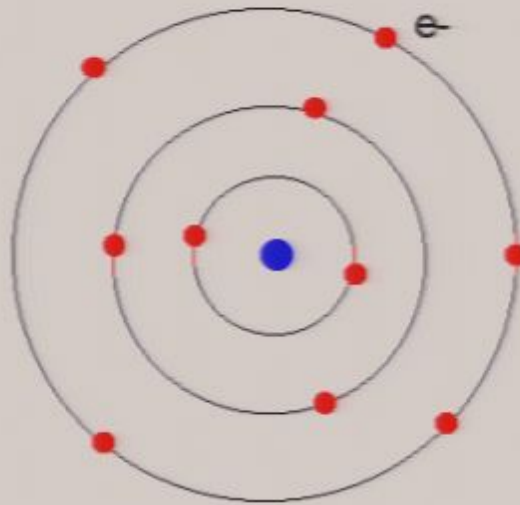
Discreteness and Quanta

Atomic structures

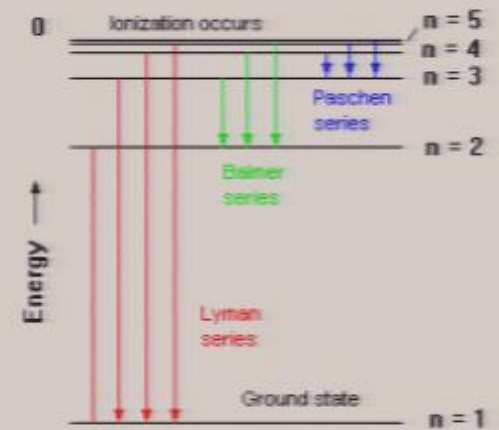


Discreteness and Quanta

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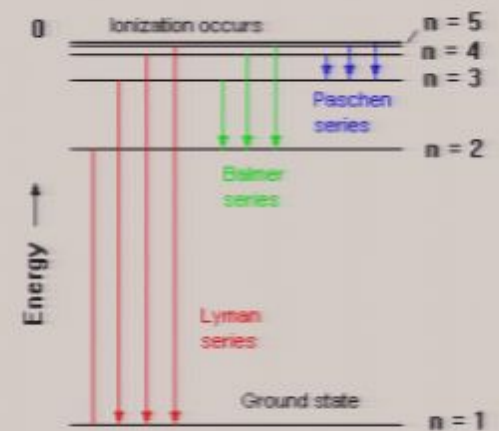
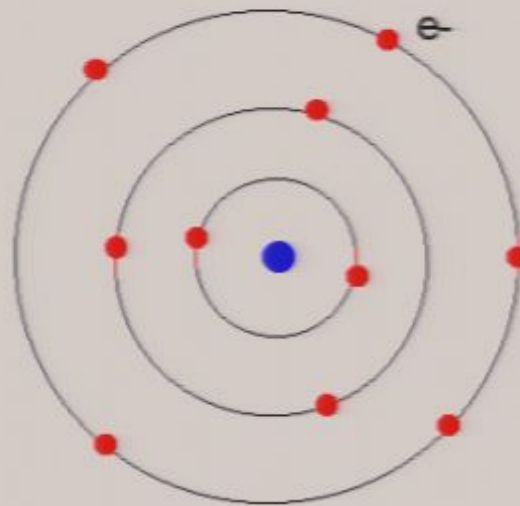


Spin of the electron



Discreteness and Quanta

Atomic structures



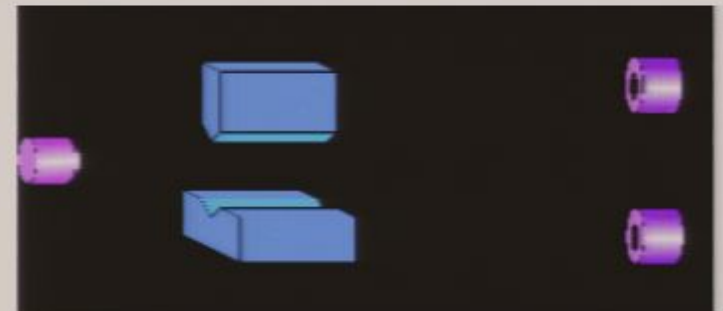
Spin of the electron



$$m_s = 1/2$$



$$m_s = -1/2$$



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

What are the quanta of gravity?



“grains of space”

Quanta of space



What are the quanta of gravity?



“grains of space”



smooth space

Quanta of space



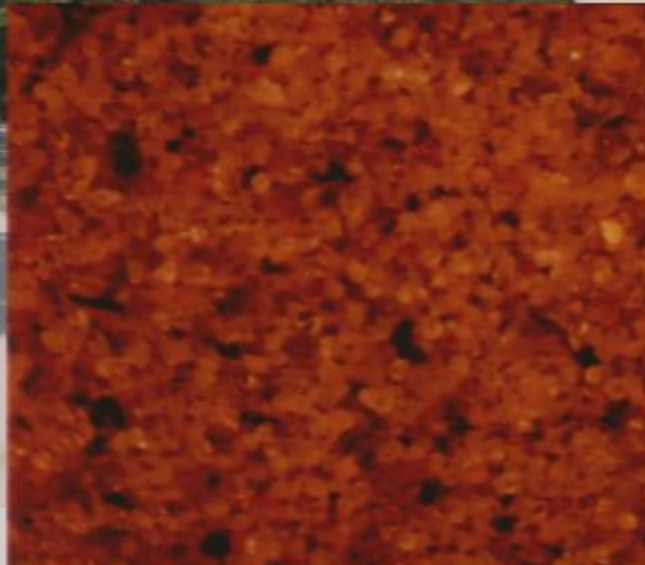
What are the quanta of gravity?



"grains of space"



smooth space



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

What do we know about the quanta of space?

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

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We are lost in the dark!

Purely theoretical quest

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Purely theoretical quest

Seventy years, still no consistent theory making testable predictions

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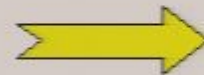
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Purely theoretical quest

Seventy years, still no consistent theory making testable predictions

Particle physics approach



String Theory

What do we know about the quanta of space?

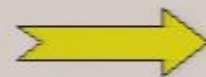
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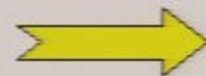
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Particle physics approach



String Theory

General relativistic approach



Loop Quantum Gravity

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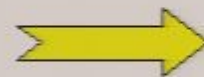
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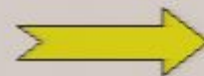
Seventy years, still no consistent theory making testable predictions

Particle physics approach



String Theory

General relativistic approach



Loop Quantum Gravity

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



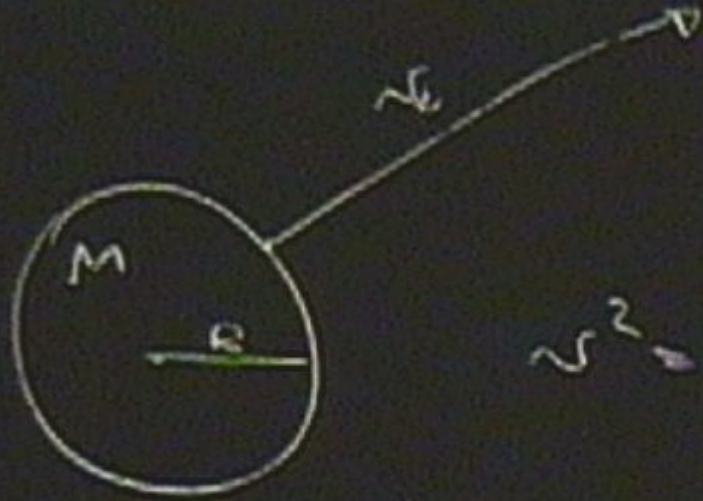
Very powerful: gives a unified picture of matter and interactions

- extra dimensions

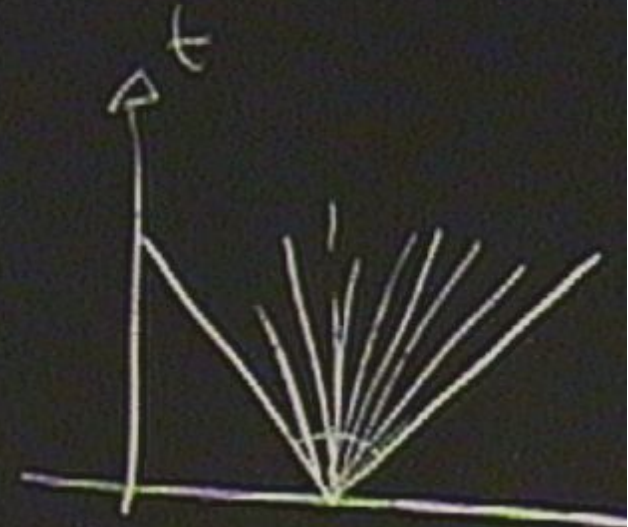
- SUSY particles

In spite of all efforts, no testable predictions

Pirsa: 06070027

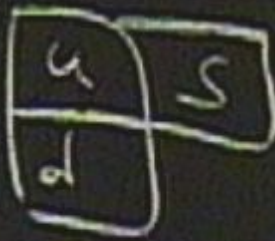


$$v^2 = \frac{2MG}{R}$$



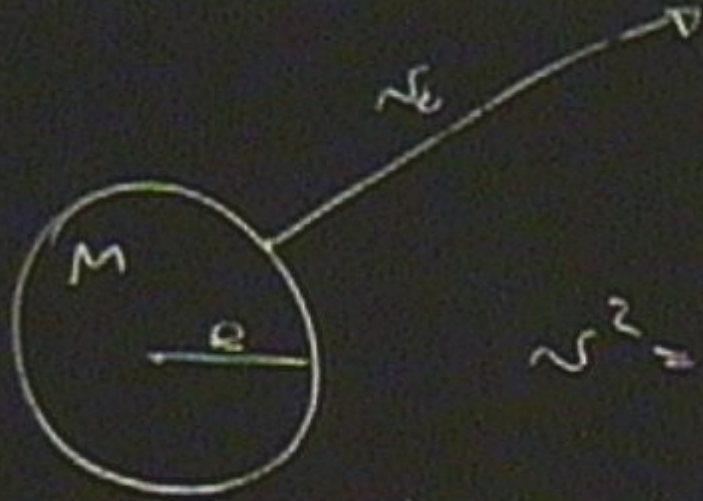
p. und

v. p.p.

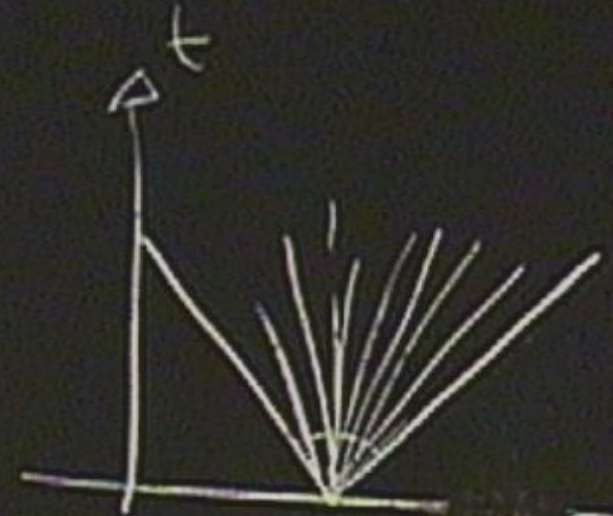


u
d

u
d

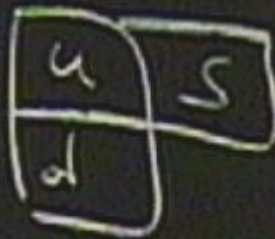


$$v_e^2 = \frac{2MG}{R}$$



p. and

n. and

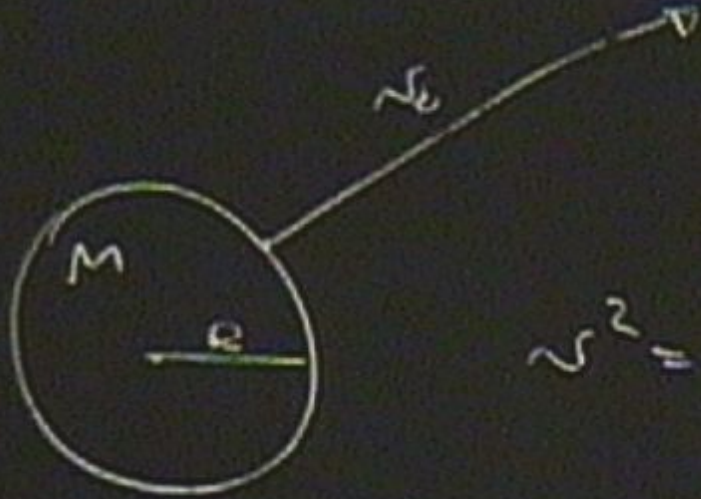


u
d

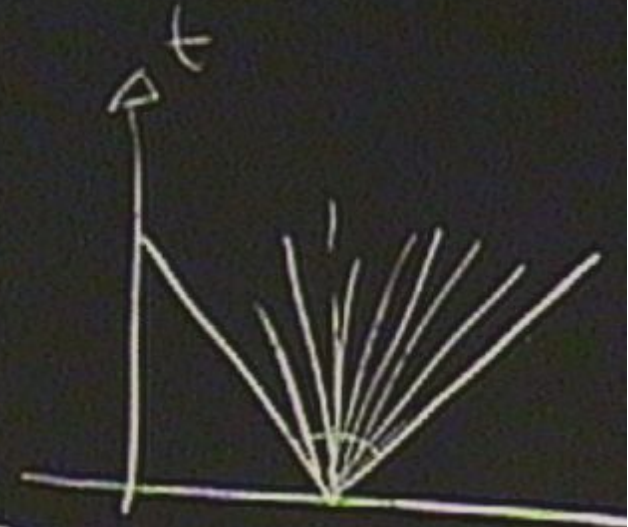
u
d

$SU(3)$

$SU(4)$



$$v^2 = \frac{2MG}{R}$$



$p \cdot$
 $u \cdot d$
 $n \cdot$

u	s	
d		

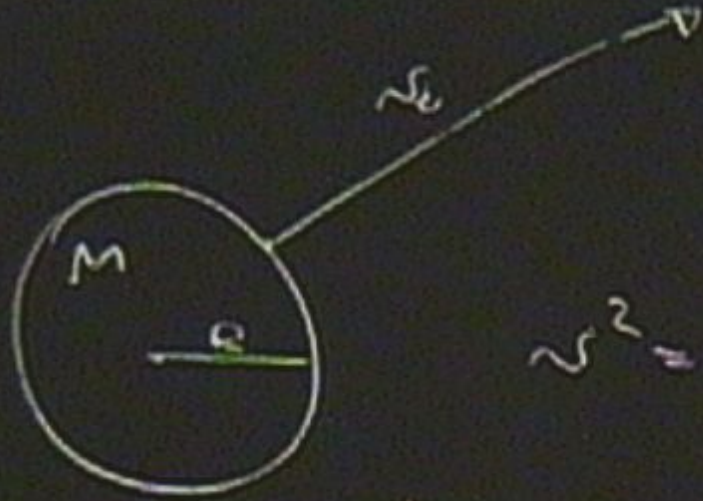


$\begin{smallmatrix} \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \end{smallmatrix}$

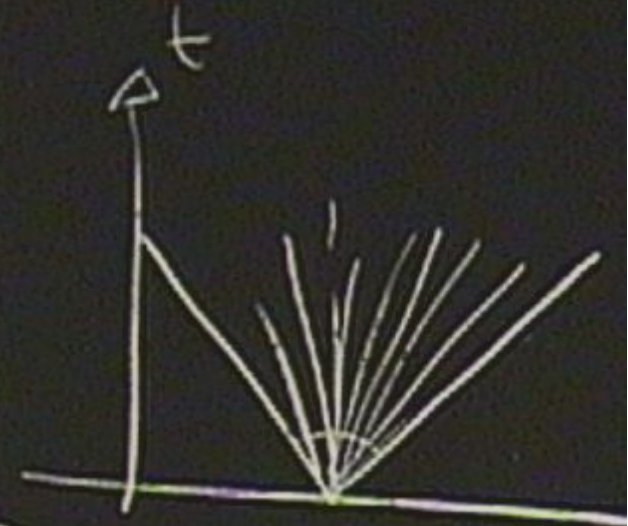
$SU(3)$

$\begin{smallmatrix} \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \end{smallmatrix}$

$SU(4)$



$$v^2 = \frac{2MG}{R}$$



P.

U.

u d
p p h

u	S	
d		



u d
p p h

u d
p p h

$SU(2)$

$SU(4)$



Very powerful: gives a unified picture of matter and interactions

- extra dimensions

- SUSY particles

Unseen: they must be very heavy

Pirsa: 06070027

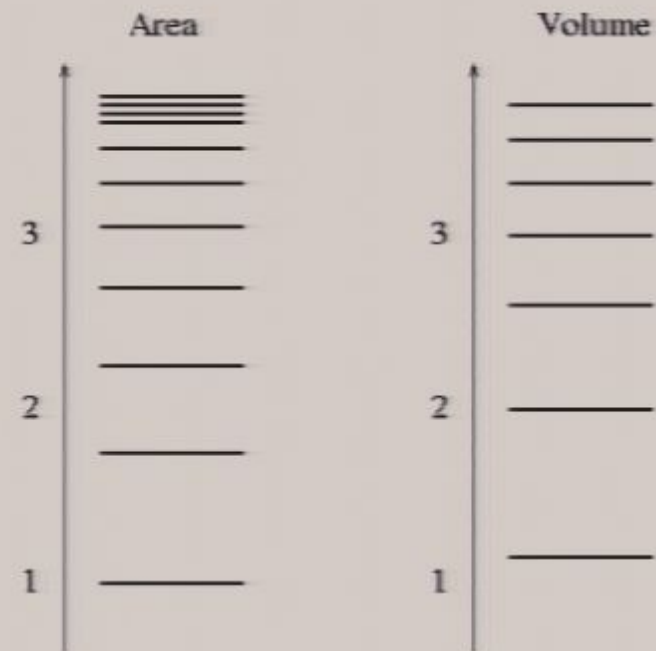
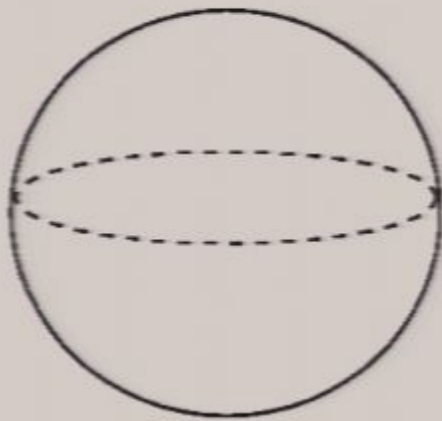
It does not address directly the question of quantum spacetime

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Loop Quantum Gravity

A candidate theory to a quantum description of spacetime.

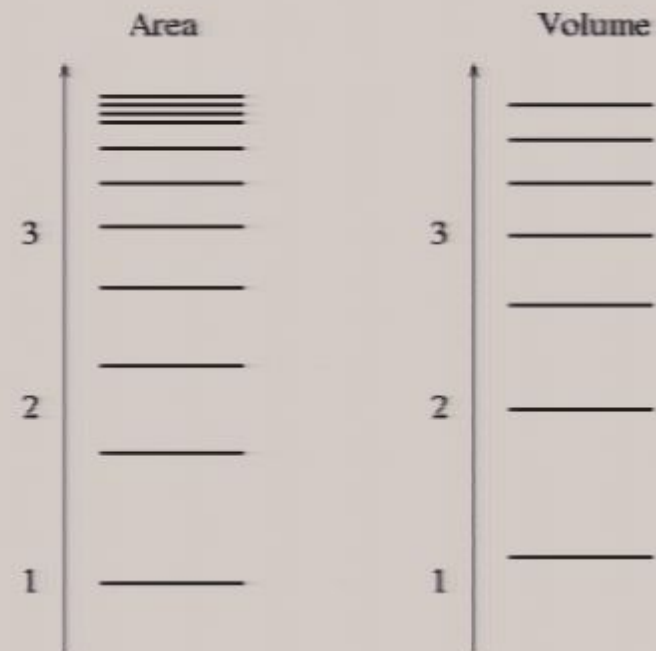
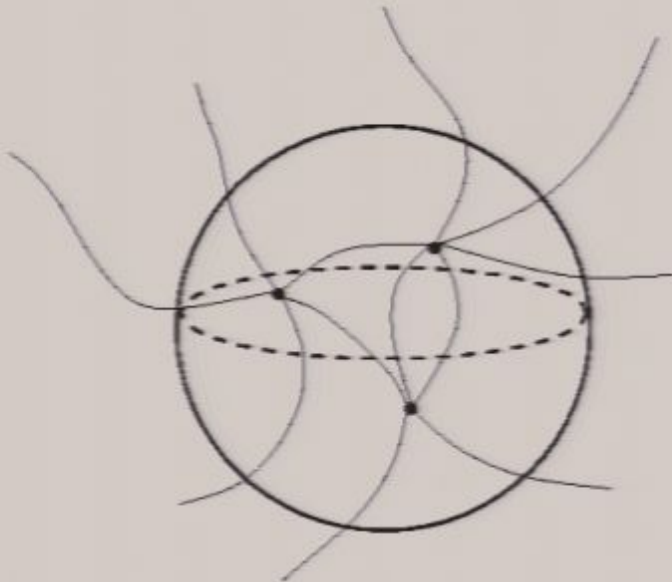
It describes quanta of spacetime and their dynamics



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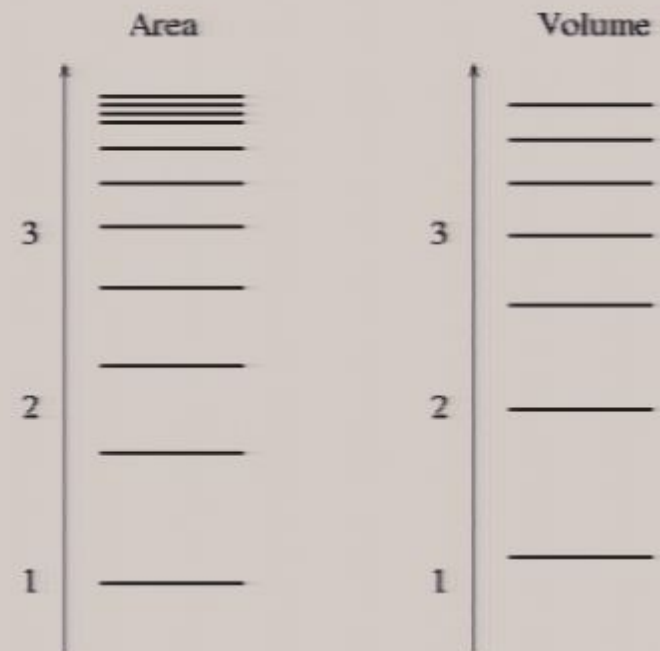
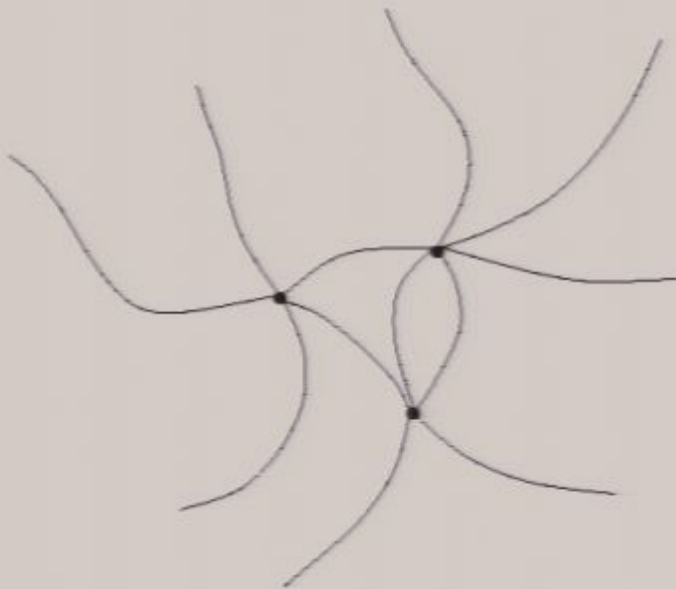
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Loop Quantum Gravity

A candidate theory to a quantum description of spacetime.

It describes quanta of spacetime and their dynamics



h

$$E = 2\pi h\nu$$

c

$$F = G \frac{Mm}{r^2}$$

G

$$F_c = \frac{k q_1 q_2}{r^2}$$

h

$$E = 2\pi h \nu$$

c

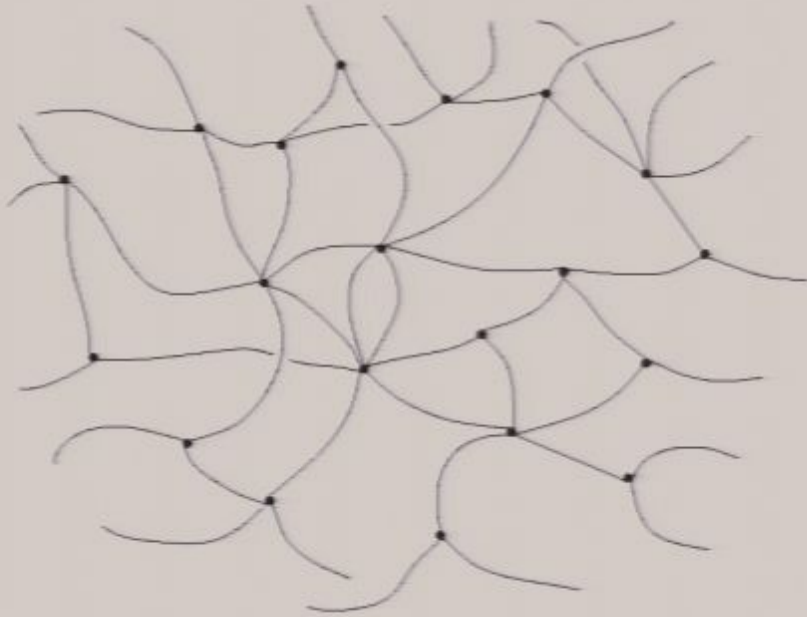
$$F = G \frac{Mm}{r^2}$$

G

$$F_c = \frac{k q_1 q_2}{r^2}$$

$$\frac{e_p}{c^3} = \sqrt{\frac{hG}{c^3}}$$

Spin Networks



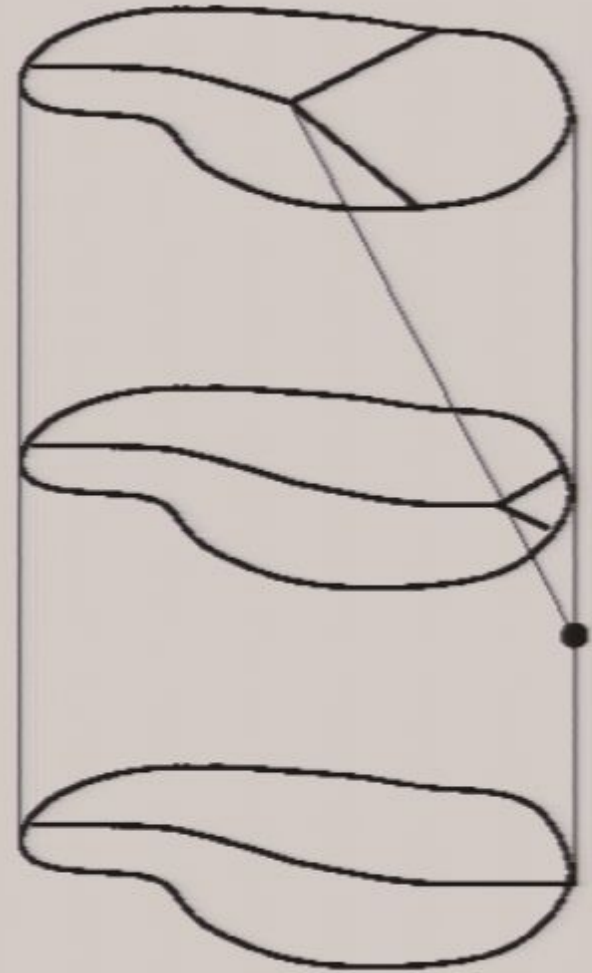
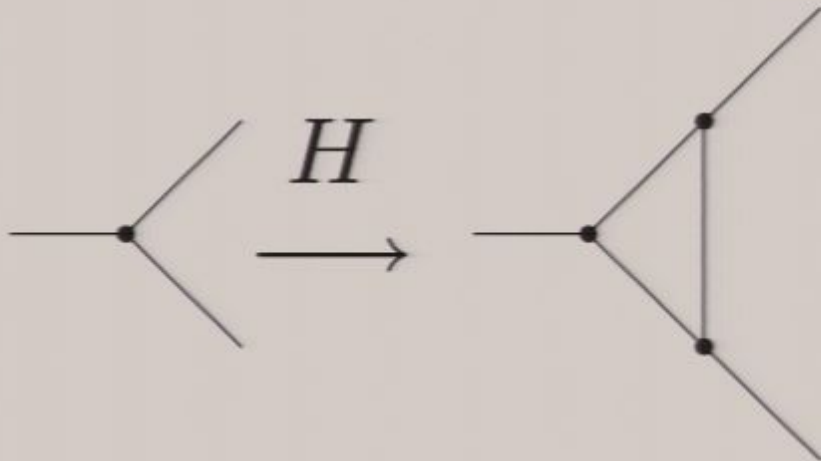
A graph: a set of nodes
linked to each other

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

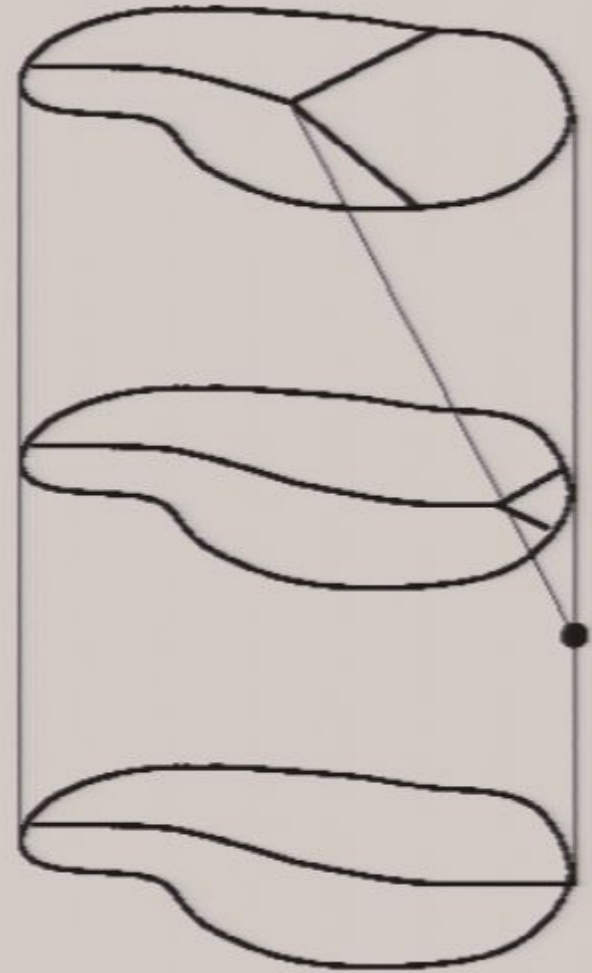
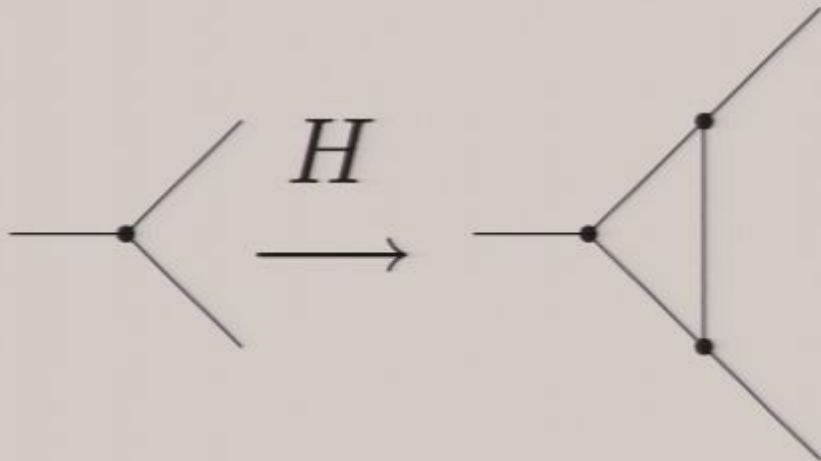
LQG dynamics: spinfoams

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



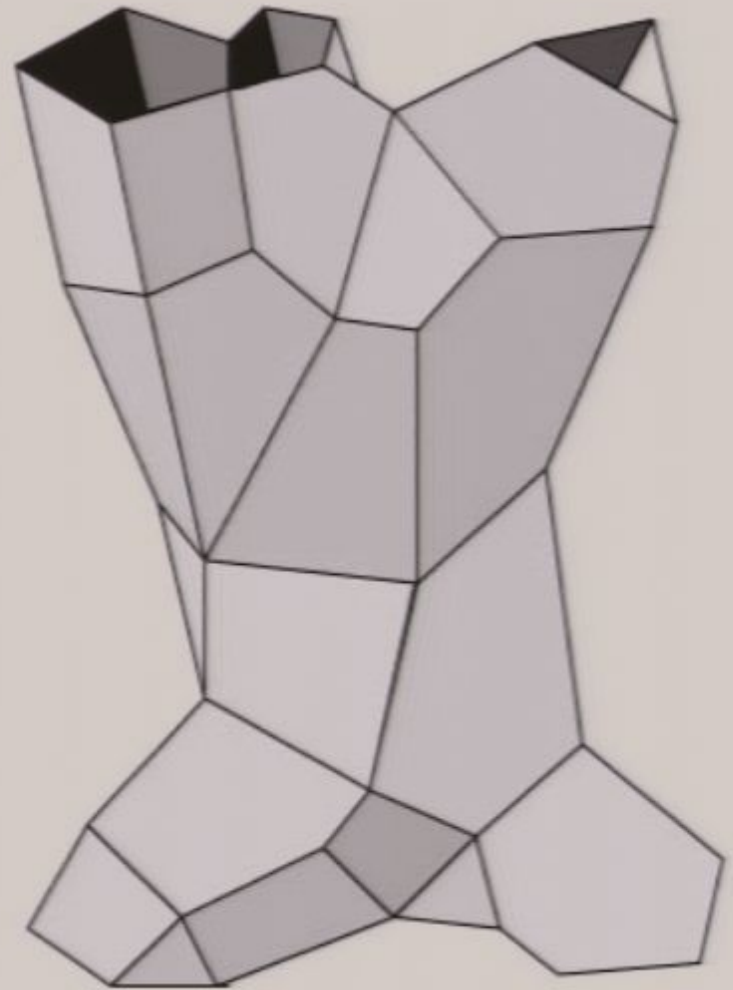
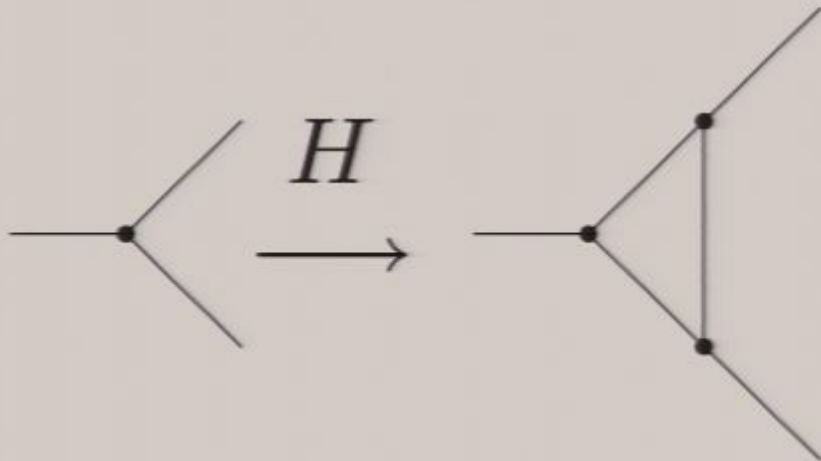
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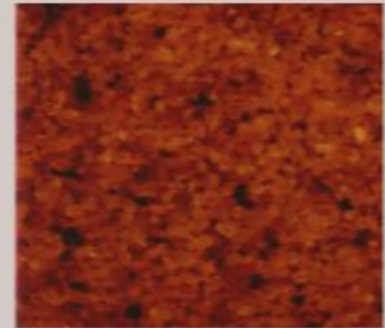
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Physics of LQG

Discreteness
of spacetime

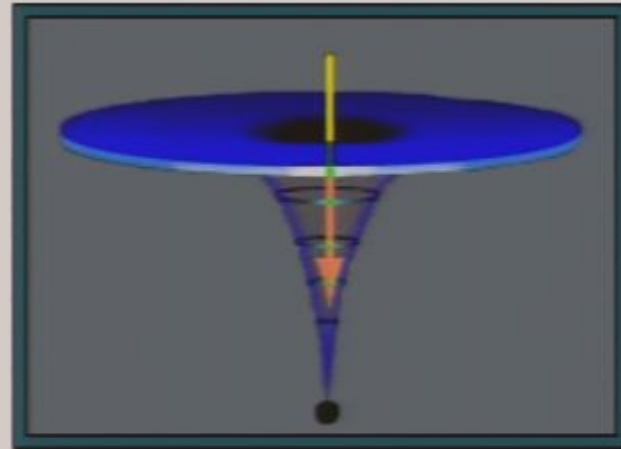


Risolution of
singularities

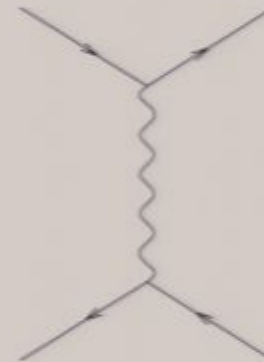
New description of
the propagation of
matter

Resolution of singularities

Spacetime singularities



Particle interaction singularities





$$\frac{2\pi R \sin \theta}{\lambda}$$



$$2\pi + 4\pi$$

$$\Delta \times \Delta p \geq \frac{h}{2}$$



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

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

Example: GZK threshold

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

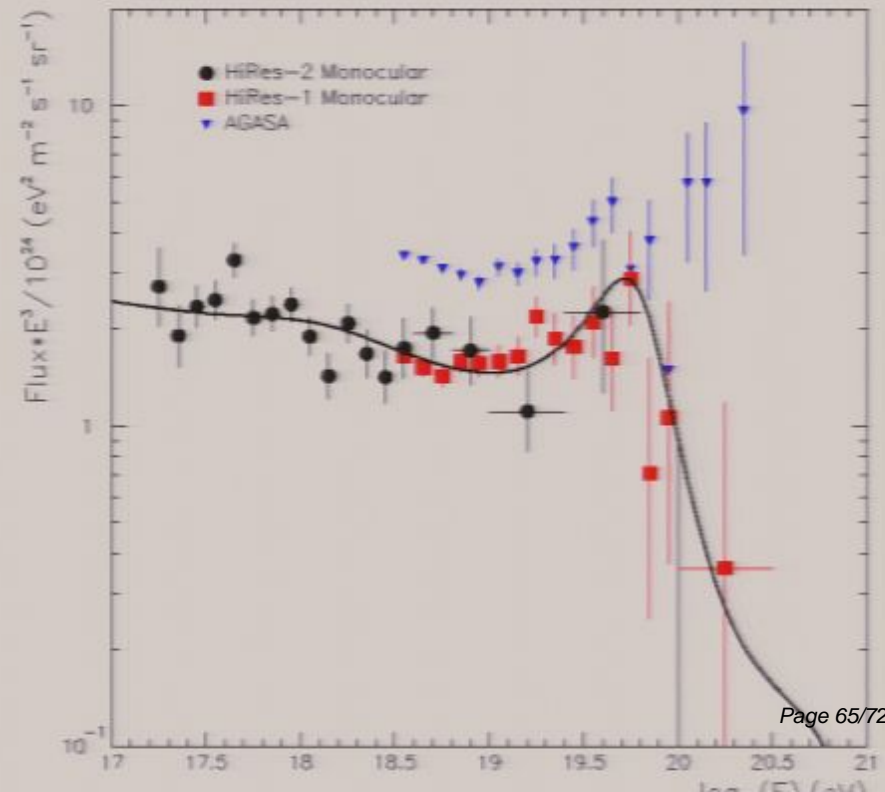
Phenomenology

Deformations of the Lorentz symmetry

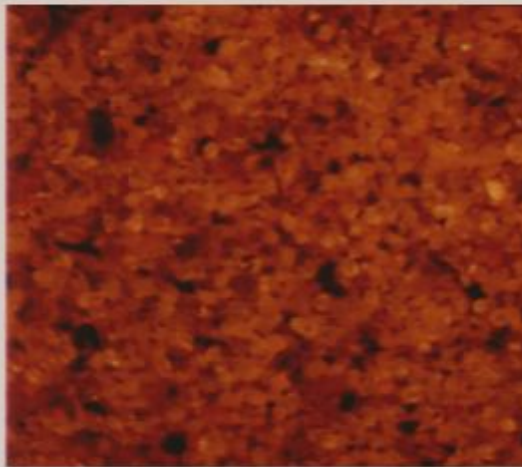
$$E^2 = m^2 + \vec{p}^2 + \alpha l_P E^3 + \beta l_P^2 E^4 + \dots$$

Example: GZK threshold

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



Discrete structure of spacetime?



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

Physics is about experimental facts

Physics is about experimental facts

such as...



Italy won the World Cup!

Physics is about experimental facts

such as...

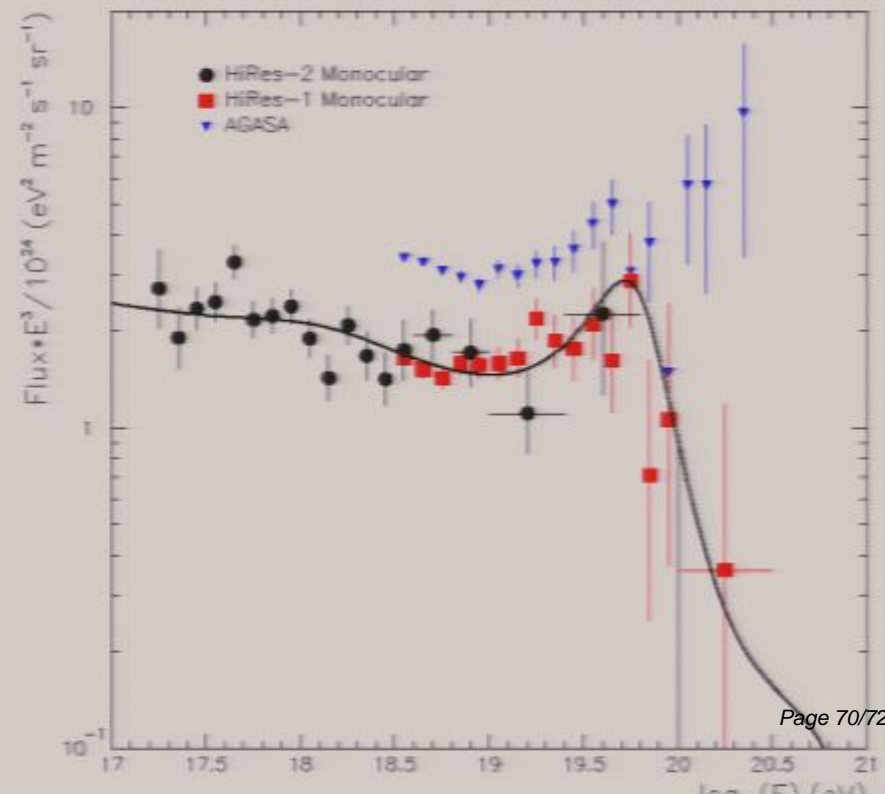
Phenomenology

Deformations of the Lorentz symmetry

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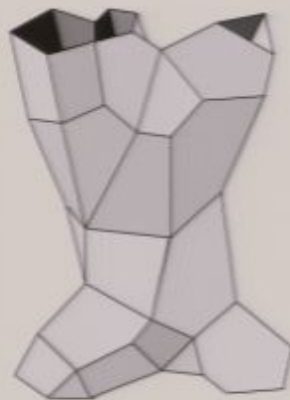
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Quantum Gravity

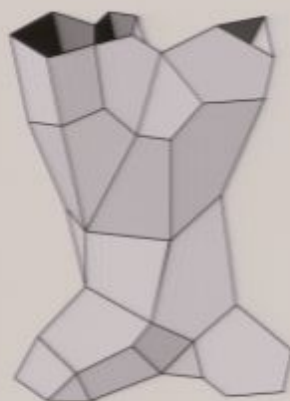
The quest to quantise Einstein's theory
of General Relativity



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Quantum Gravity

The quest to quantise Einstein's theory
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Impostazioni