THE ATOMS OF SPACE-TIME
GRAVITATION
NEWTON’S GRAVITATION

\[ F = - G \frac{M_1 M_2}{R^2} \]
NEWTON’S GRAVITATION

\[ F = - G \frac{M_1 M_2}{R^2} = M_1 a \quad \implies \quad a = - G \frac{M_2}{R^2} \]

Acceleration is independent of mass of the object!!
Einstein’s Gravitation

• In the presence of gravitating bodies, space-time becomes curved.

• Bodies move along `straight’ lines in such a curved space-time

Gravity and geometry of space-time are one and the same thing.
Einstein’s Gravitation

- Matter tells space-time how to curve.
- Space-time tells matter how to move.

The matter that causes curving also moves along geodesics.
Enter Quantum Mechanics!
Quantum particles in curved space-time move like this!

They obey the superposition principle. Gravity does not.
This leads to a problem!

Because Quantum Mechanics Needs Time!

however...

Space-time is produced by things which move like this

But...
• Things which move like this

• are made of things which move like this
Suppose the world only had things which behave like this:

What kind of a space-time will such things produce?

CERTAINLY NOT THE KIND THAT QUANTUM MECHANICS NEEDS!
We have to be able to describe
Quantum Mechanics
Without using Space-Time

Doing so leads to a quantum theory of gravity
We no longer make a distinction between Matter and Space-Time
Atoms of Space-Time-Matter
Atoms of Space-Time-Matter

- An STM atom is a fundamental description of an elementary particle, which produces and carries its own space-time geometry.

- Fundamentally, the universe is described by a mathematical space of enormously many STM atoms.

- Coarse graining this space gives rise to a quantum mechanics without space-time.

- Further coarse-graining gives rise to the universe we live in.
What did the referee say?


“This paper is a continuation of earlier papers by the same author, with the aim to proposing an alternative quantum theory of gravity that is also able to provide a solution to the measurement problem. The idea is to start from a non-commutative classical spacetime and to end up with "atoms of space-time" that give rise to quantum general relativity in the thermodynamic limit.

Although this proposal is speculative and not yet presented in a complete form, it is in my opinion interesting enough to warrant publication.”

- Zeitschrift fur Naturforschung A
Definition of an STM Atom

• It is the non-commutative generalisation of the action

\[ S = \frac{1}{L_p^2} \int d^4x \sqrt{-\Phi} \, R(\tilde{\Gamma}) + \frac{1}{L_1^2} \int \sqrt{-\gamma} \, d^2\chi + \frac{1}{L_2^2} \int \psi_{\mu\nu} \, d\sigma^{\mu\nu} \]

• This action describes a gravity-torsion theory based on an asymmetric metric and metric induced induced torsion, sourced by a classical string.

In Non-Commutative Geometry:

\[ S_{NCG} = \frac{1}{L_{pl}^2} \int_{\text{geom}} d\hat{s}^2 + \frac{1}{L^2} \int_{\text{matter}} d\hat{s}^2 \]
What is non-commutative geometry?

EUCLIDEAN GEOMETRY

NON-EUCLIDEAN GEOMETRY

NON-COMMUTATIVE GEOMETRY

[Space-time coordinates do not commute]
THE NON-COMMUTATIVE GEOMETRY IT PRODUCES

= 

An STM Atom

Non-commutative Spaces Evolve with Time!!!!
Understanding non-commutative gravity

Identify the Position and Momentum Variables
The set of q and p

Make them non-commutative

Non-commutative Gravity
= An STM atom
Classical Gravity Theory

QUANTIZE

Quantum Gravity ?
Classical Gravity Theory

DO NOT QUANTIZE
Classical Gravity Theory

Non-commutativize

Classical Non-Commutative Gravity

= An STM Atom
The evolution of an STM atom is non-linear, and non-unitary, but geodesic.

The entanglement of STM atoms

\[ |1a\rangle |2a\rangle + |1b\rangle |2b\rangle \]

Space-time Emerges from Entanglement
THE FOUR LEVELS OF
GRAVITATIONAL DYNAMICS
At the most basic level, the Universe is described by a mathematical space [a Hilbert space] populated by STM atoms.

The STM atoms interact via entanglement. There is no classical space-time.

There are only two fundamental constants: square of Planck length, and the speed of light.
THE FOUR LEVELS OF GRAVITY

III. Level THREE: CLASSICAL GRAVITATIONAL DYNAMICS

\[ ds^2 = g_{\mu\nu} dx^\mu dx^\nu \]

Torsion Gravity
Asymmetric Metric: \( \Phi_{\mu\nu} = g_{\mu\nu} + \psi_{\mu\nu} \)

II. Level TWO: QFT ON CLASSICAL CURVED SPACE-TIME

\[ ds^2 = g_{\mu\nu} dx^\mu dx^\nu \]

Space-time with Torsion
Asymmetric Metric: \( \Phi_{\mu\nu} = g_{\mu\nu} + \psi_{\mu\nu} \)

I. LEVEL ONE: QUANTUM GRAVITY

THERMODYNAMICS OF ATOMS

Quantum Gravity
Asymmetric Operator Metric

0. Level ZERO: NON-COMMUTATIVE TORSION GRAVITY

ATOMS OF SPACE-TIME-MATTER

Non-commutative Geometry
Asymmetric Metric
LEVEL I

• IF WE ARE NOT EXAMINING DYNAMICS ON THE PLANCK SCALE, WE DO A STATISTICAL MECHANICS OF THE ATOMS.

• THIS IS EXACTLY HOW WE EXTRACT THERMODYNAMICS FROM THE UNDERLYING ATOMS IN A BOX OF GAS ATOMS.

• THE STATISTICAL THERMODYNAMICS OF STM ATOMS YIELDS QUANTUM THEORY WITHOUT CLASSICAL TIME, AT THERMODYNAMIC EQUILIBRIUM.

• PLANCK’S CONSTANT AND NEWTON’S GRAVITATIONAL CONSTANT EMERGE.

• QUANTUM GRAVITY IS AN EMERGENT PHENOMENON.

• STILL NO CLASSICAL SPACE-TIME.
THE FOUR LEVELS OF GRAVITY

I. LEVEL ONE : QUANTUM GRAVITY

- Atoms of Space-Time-Matter
- Non-commutative Geometry
- Asymmetric Metric

II. LEVEL TWO : QFT ON CLASSICAL CURVED SPACE-TIME

- QFT
- Torsion Gravity
- Asymmetric Metric: $\Phi_{\mu\nu} = g_{\mu\nu} + \psi_{\mu\nu}$

III. LEVEL THREE : CLASSICAL GRAVITATIONAL DYNAMICS

- Classical Gravitational Dynamics
- Asymmetric Metric: $\Phi_{\mu\nu} = g_{\mu\nu} + \psi_{\mu\nu}$

IV. LEVEL FOUR : NON-COMMUTATIVE TORSION GRAVITY

- Torsion Gravity
- Asymmetric Metric: $\Phi_{\mu\nu} = g_{\mu\nu} + \psi_{\mu\nu}$

$ds^2 = g_{\mu\nu} dx^\mu dx^\nu$
FROM LEVEL I TO LEVEL III

• STATISTICAL FLUCTUATIONS ABOUT EQUILIBRIUM BECOME IMPORTANT FOR HIGHLY ENTANGLED SYSTEMS.

• THE FERMIONIC (MATTER) PART OF STM ATOMS UNDERGOES SPONTANEOUS LOCALISATION, THUS SEPARATING MATTER FROM SPACE-TIME.

• CLASSICAL GENERAL RELATIVITY EMERGES FROM THE LEVEL 0. NONCOMMUTATIVE GRAVITY.
THE FOUR LEVELS OF GRAVITY

I. Level Zero: Non-commutative Torsion Gravity

II. Level Two: QFT on Classical Curved Space-Time

III. Level Three: Classical Gravitational Dynamics

Torsion Gravity
Asymmetric Metric: \( \Phi_{\mu\nu} = g_{\mu\nu} + \psi_{\mu\nu} \)

Space-time with Torsion
Asymmetric Metric: \( \Phi_{\mu\nu} = g_{\mu\nu} + \psi_{\mu\nu} \)

Quantum Gravity
Asymmetric Operator Metric

Non-commutative Geometry
Asymmetric Metric

Atoms of Space-Time-Matter

Atoms of Space-Time-Matter

Thermodynamics of Atoms

CST

STM Fluid

QFT

SL

CM
• The mechanism of spontaneous localisation (collapse of the wave function)

- Explains the absence of macroscopic superpositions

- Explains the emergence of space-time
Sometimes, simple questions have deep answers
Question:

Why do all objects fall with the same acceleration in a gravitational field?

Answer:

Because gravity is the curvature of space-time.
Question:

Why do we never see a table in two places at the same time?

Answer:

Because gravity is the curvature of NON-COMMUTATIVE space-time.
THANK YOU!