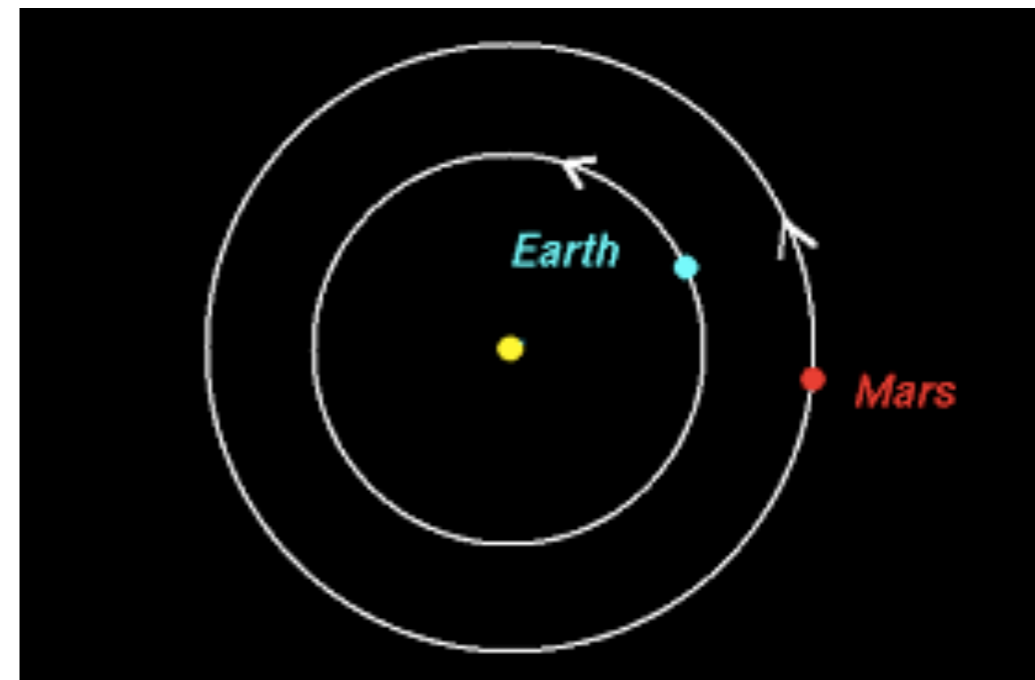# THE ATOMS OF SPACE-TIME
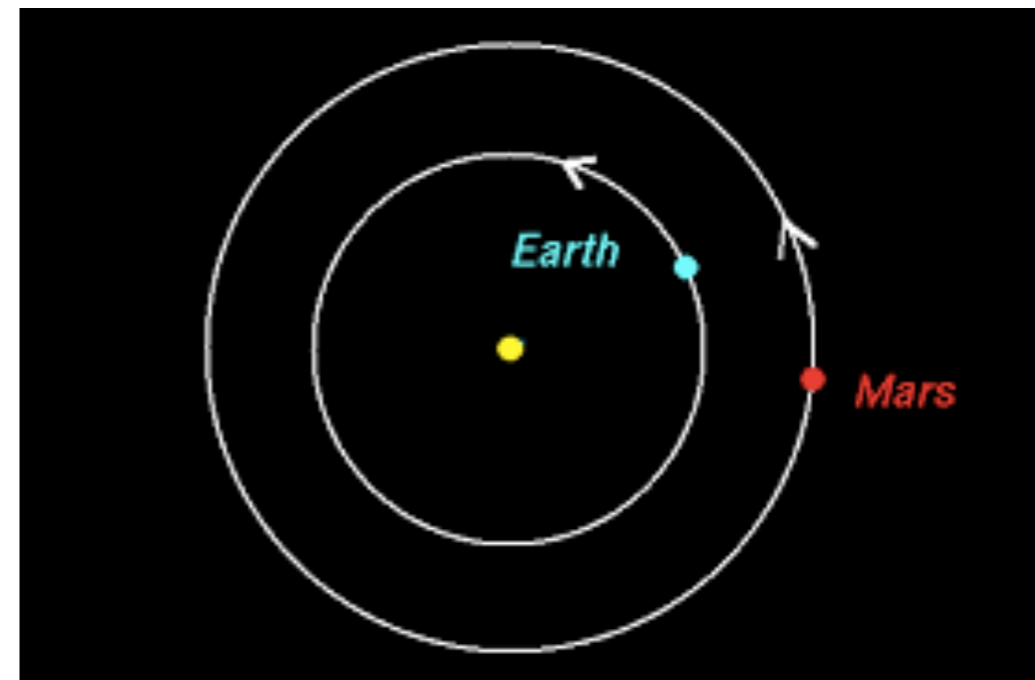
GRAVITATION

NEWTON'S GRAVITATION

$$F = -G\frac{M_1 M_2}{R^2}$$

NEWTON'S GRAVITATION

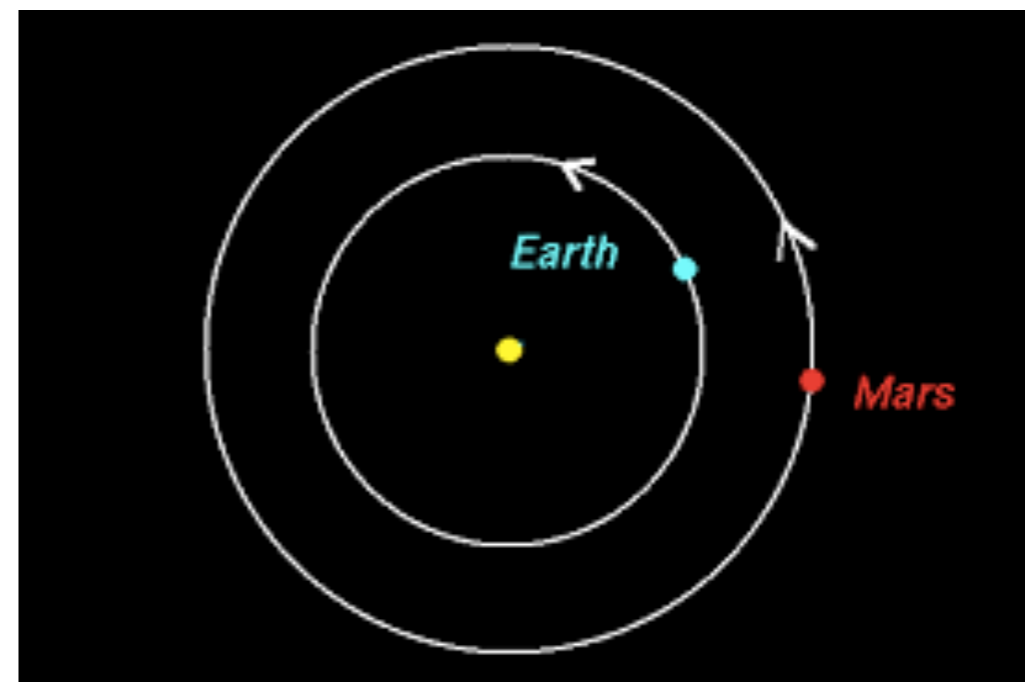

$$F = -G\frac{M_1 M_2}{R^2} = M_1 a \implies a = -G\frac{M_2}{R^2}$$

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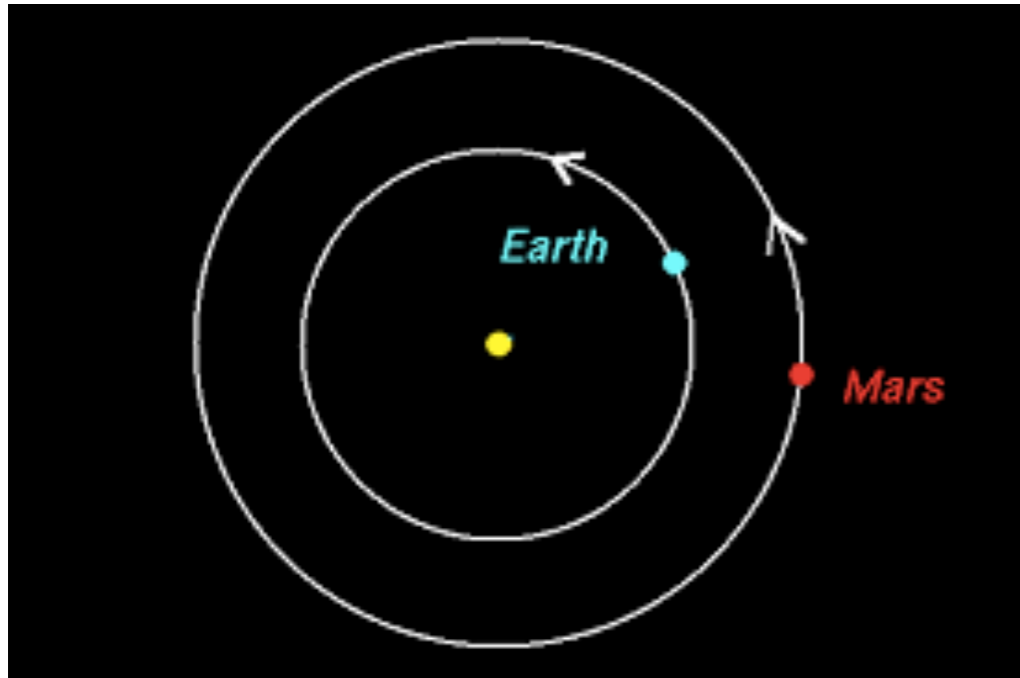
Einstein's Gravitation

- **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!
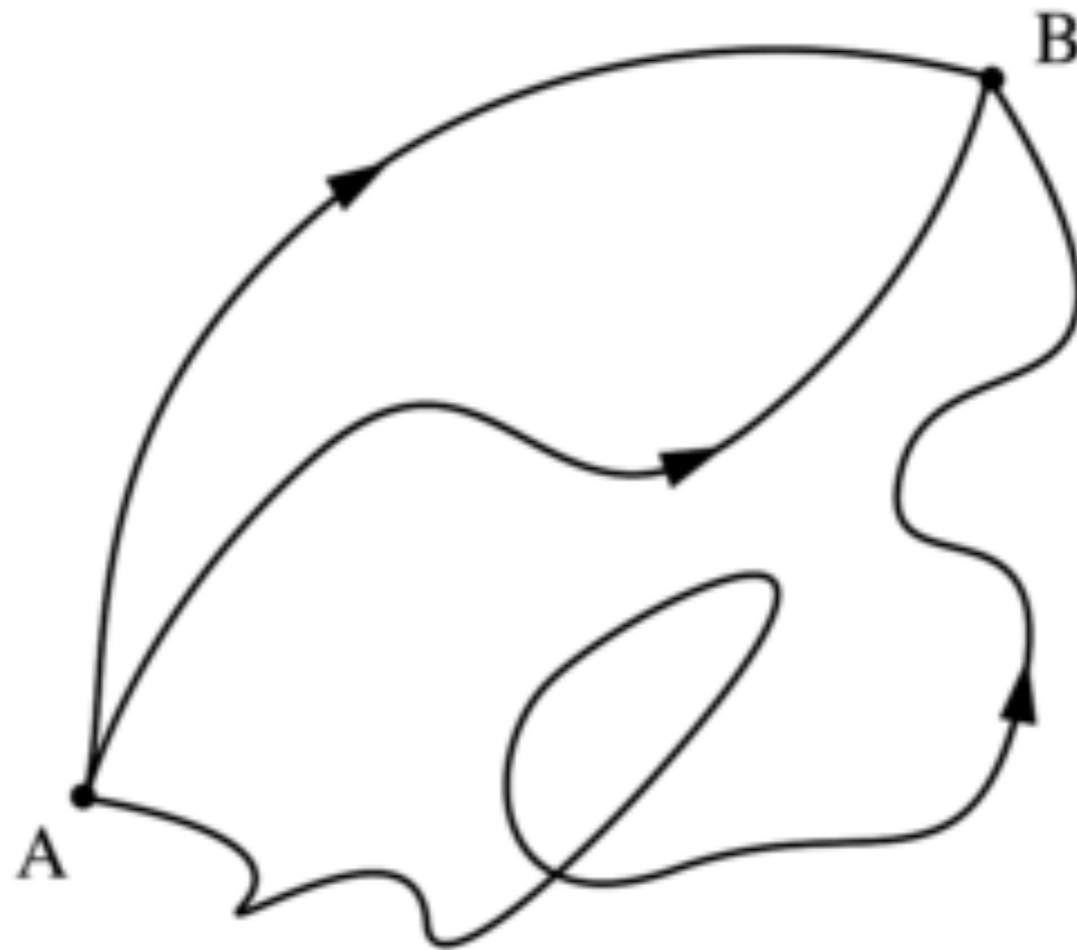
They obey the superposition principle. Gravity does not.

This leads to a problem!

Because Quantum Mechanics Needs Time!

however...

Space-time is produced by things which move like this
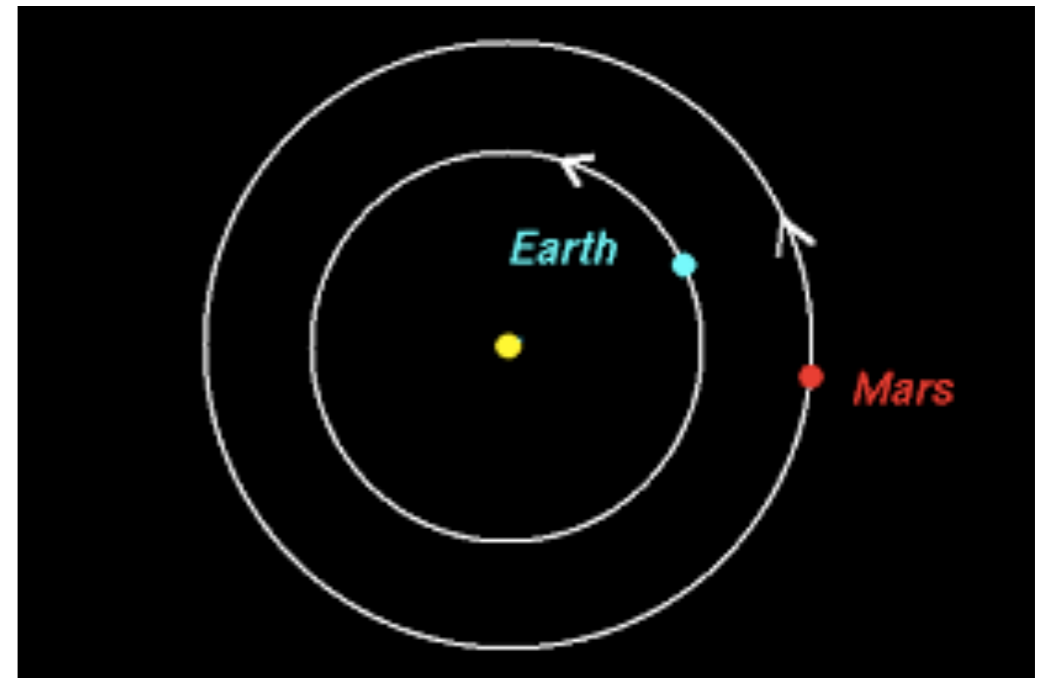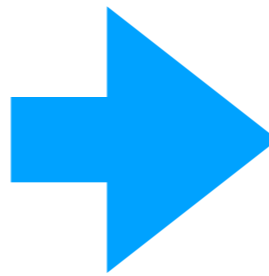
But...

- **Things which move like this**
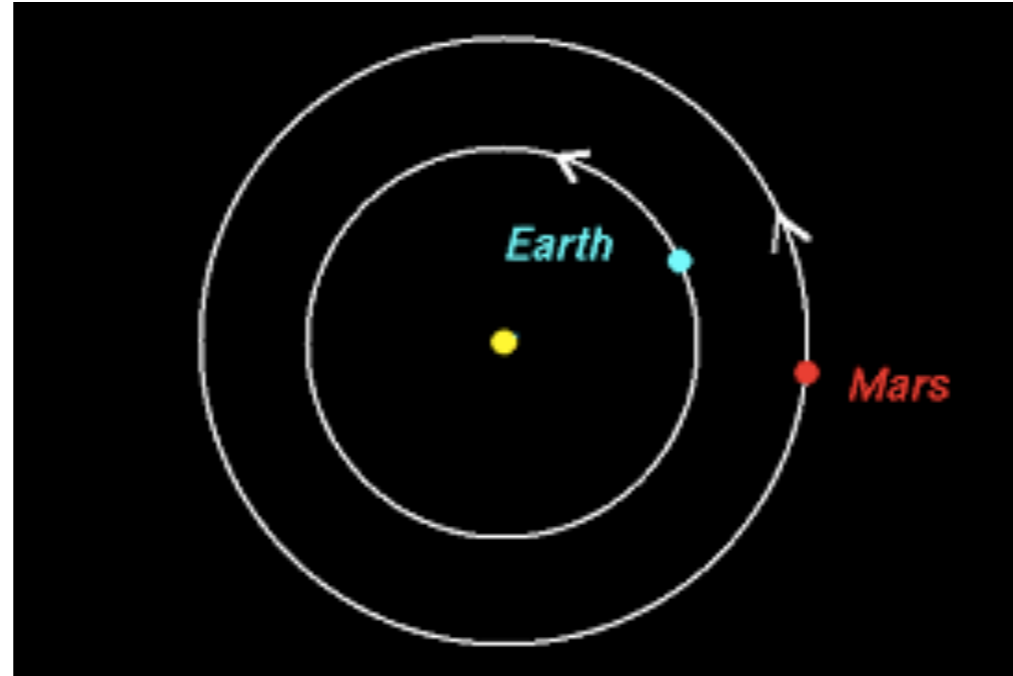
- **are made of things which move like this**
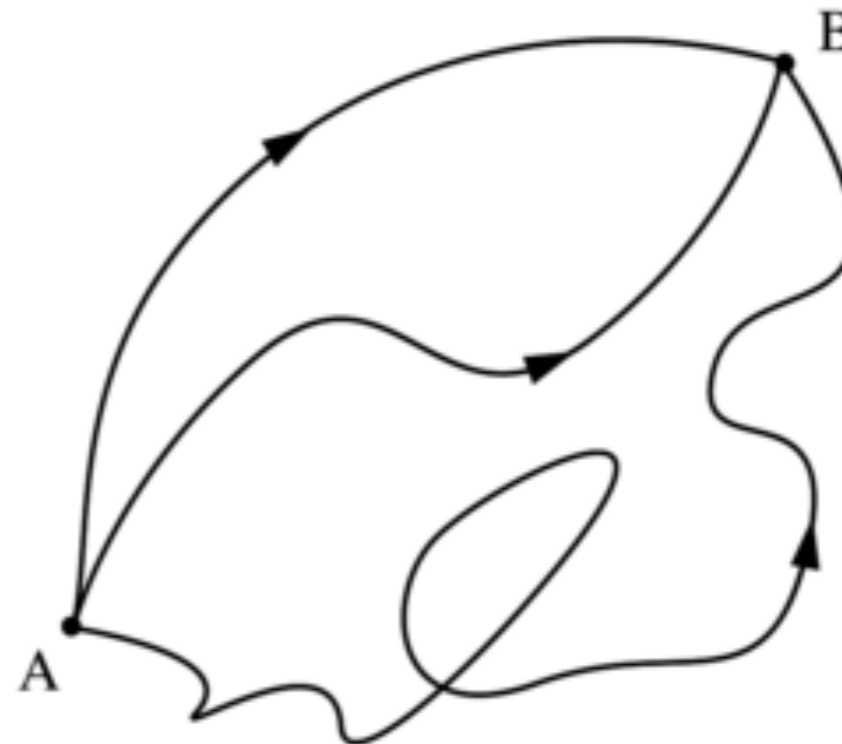
Suppose the world only had things which behave like this:
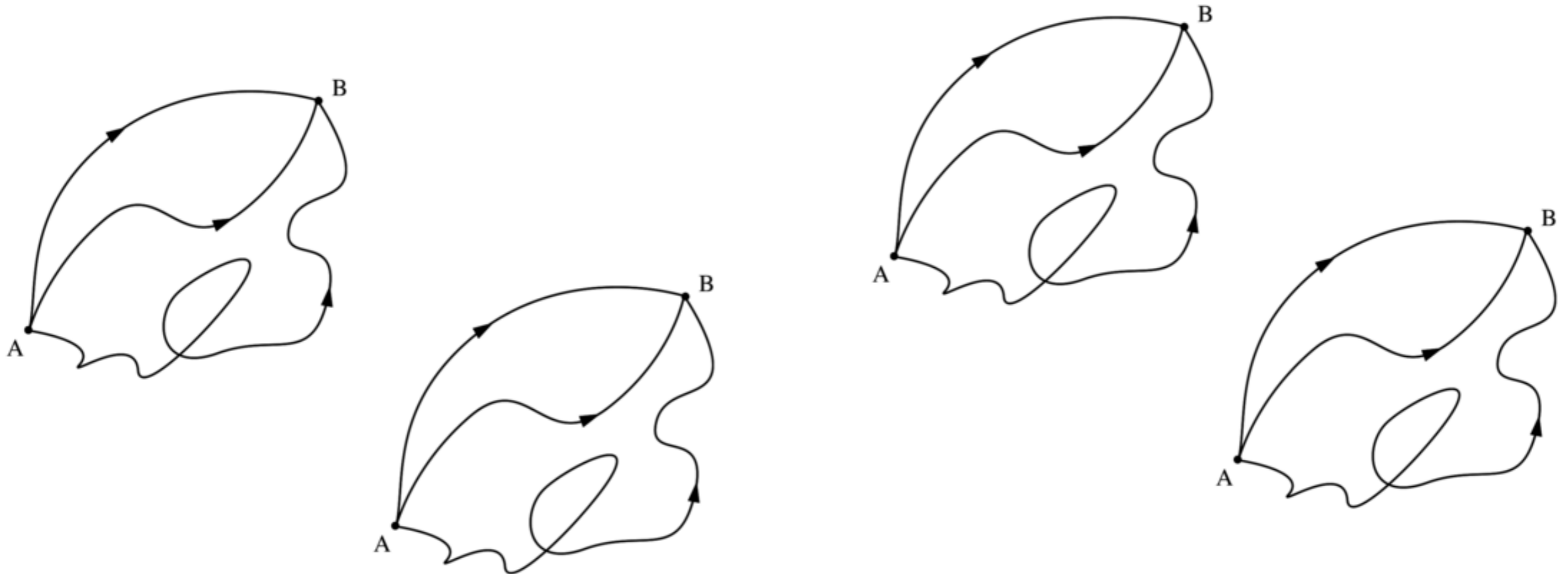
What kind of a space-time will such things produce?

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?

[Proposal for a new quantum theory of gravity, TPS, arXiv:1903.05402 [gr-qc]]

"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**

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

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

In Non-Commutative Geometry:

$$S_{NCG} = \frac{1}{L_{pl}^2} \int_{geom} d\hat{s}^2 \quad + \quad \frac{1}{L^2} \int_{matter} d\hat{s}^2$$

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What is non-commutative geometry?

EUCLIDEAN GEOMETRY

NON-EUCLIDEAN GEOMETRY
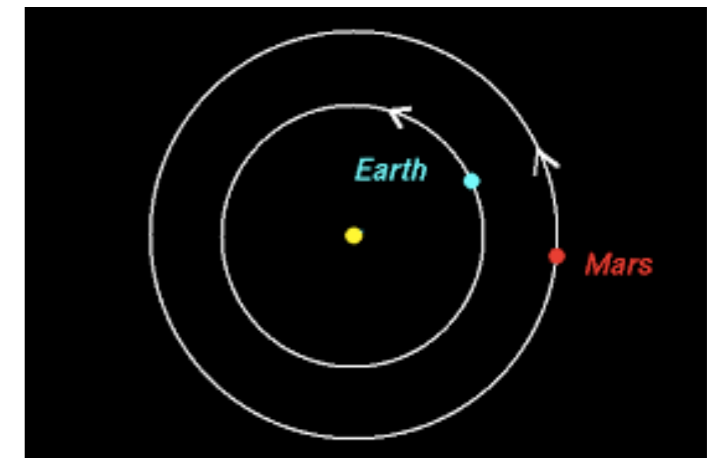
NON-COMMUTATIVE GEOMETRY

[Space-time coordinates do not commute]

+
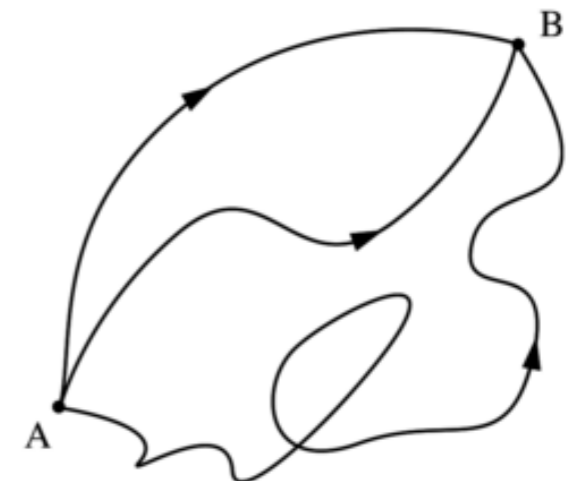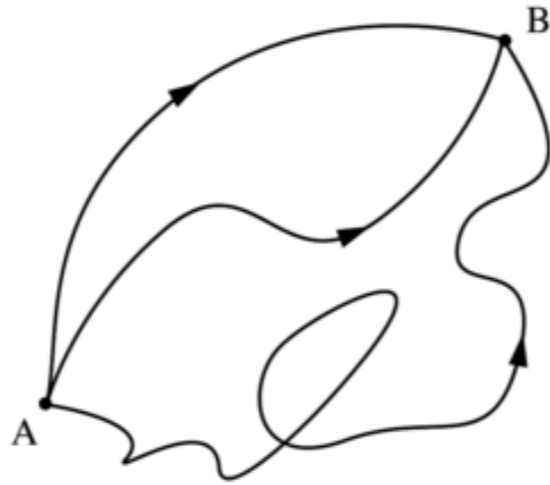
THE NON-COMMUTATIVE GEOMETRY IT PRODUCES

=

An STM Atom

Non-commutative Spaces Evolve with Time!!!!

Understanding non-commutative gravity
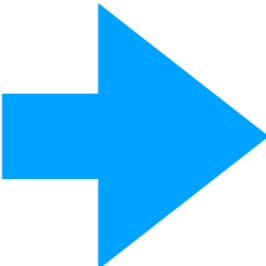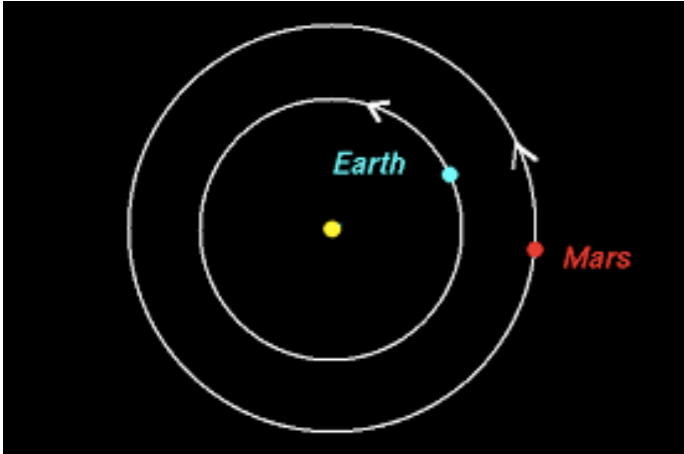
Identify the Position and Momentum Variables

The set of q and p

Make them non-commutative

**Non-commutative Gravity
=
An STM atom**
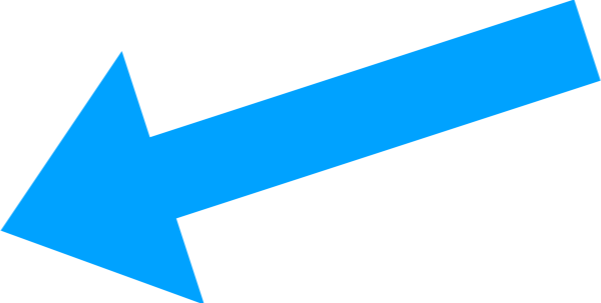
Classical Gravity Theory

QUANTIZE

Quantum Gravity ?

Classical Gravity Theory
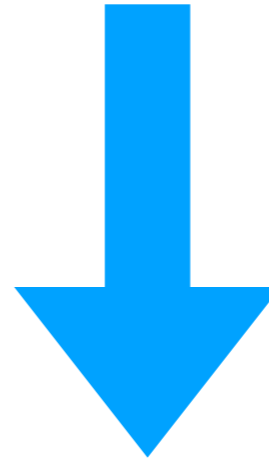
DO NOT QUANTIZE

Classical Gravity Theory

DO NOT QUANTIZE

↓

Non-commutativize

↓

Classical Non-Commutative Gravity

= An STM Atom

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The evolution of an STM atom is non-linear, and non-unitary, but geodesic

The entanglement of STM atoms

$$|1a> |2a> + |1b> |2b>$$

Space-time Emerges from Entanglement

THE FOUR LEVELS OF

GRAVITATIONAL DYNAMICS

LEVEL 0

- **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
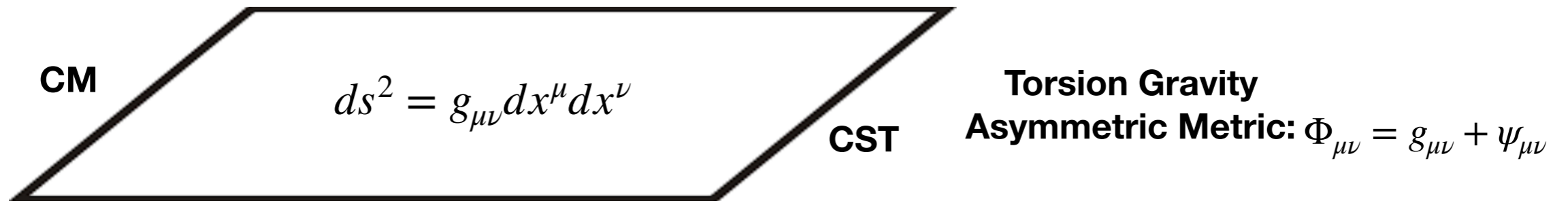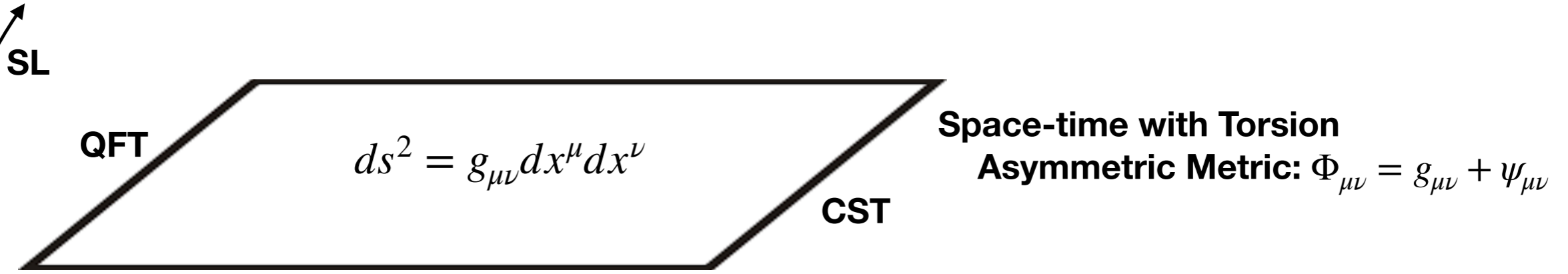
CM

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

CST

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

III. Level THREE : CLASSICAL GRAVITATIONAL DYNAMICS

SL

QFT

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

CST

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

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

STM FLUID

THERMODYNAMICS OF ATOMS

STM FLUID

Quantum Gravity
Asymmetric Operator Metric

I. LEVEL ONE : QUANTUM GRAVITY

STD

ATOMS

ATOMS OF SPACE-TIME-MATTER

ATOMS

Non-commutative Geometry
Asymmetric Metric

0. Level ZERO : NON-COMMUTATIVE TORSION GRAVITY

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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 EQUIIBRIUM.**

- **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

CM

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

CST

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

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I. LEVEL ONE : QUANTUM GRAVITY

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Non-commutative Geometry
Asymmetric Metric

0. Level ZERO : NON-COMMUTATIVE TORSION GRAVITY

FROM LEVEL I TO LEVEL III

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

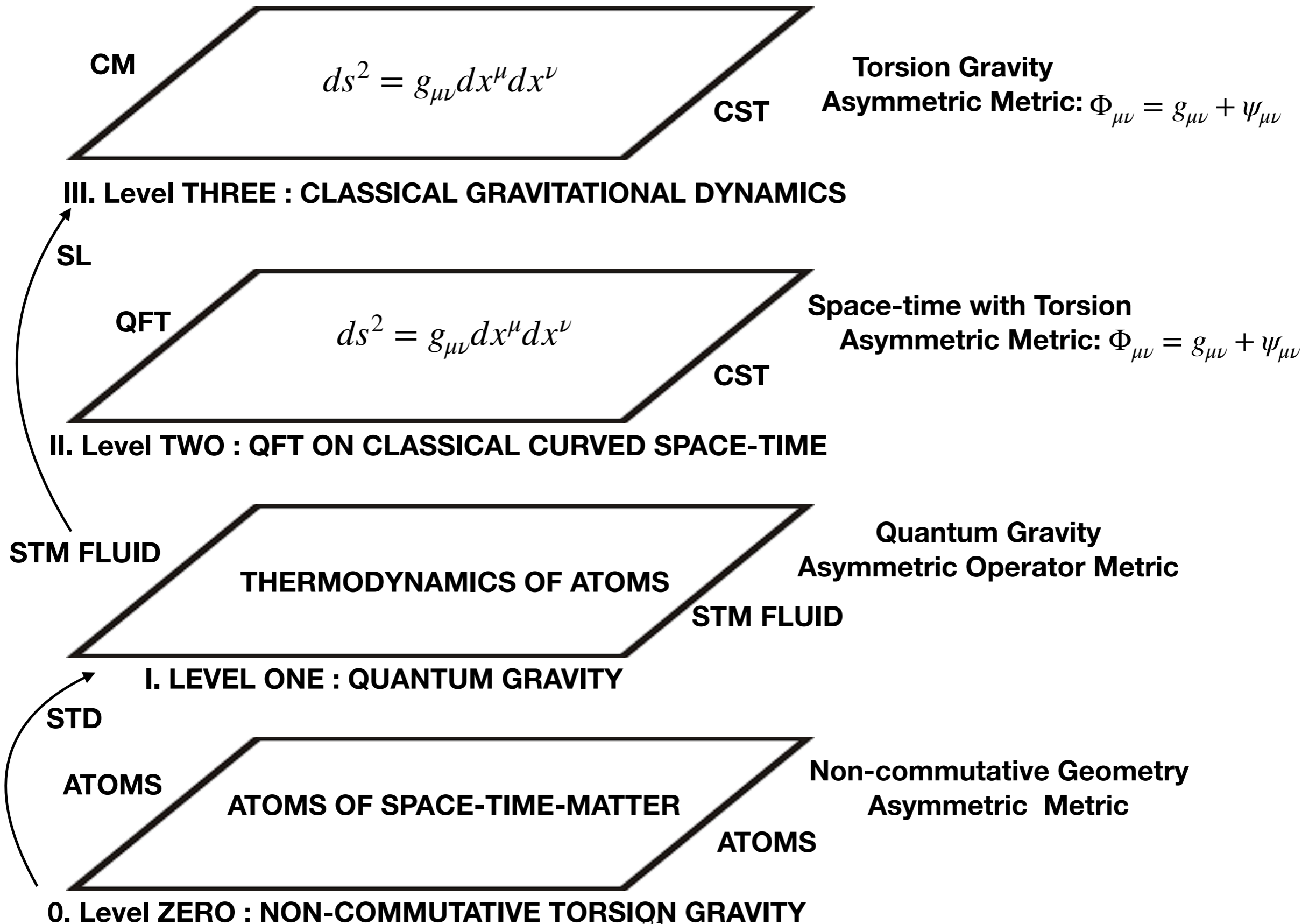- THE FERMIONIC (MATTER) PART OF STM ATOMS UNDERGOES SPONTANEOUS LOCALISATION, THUS SEPARATING MATTER FROM SPACE-TIME.

- CLASSICAL GENERAL RELATIVITY EMERGES FROM THE LEVEL 0. NONCOMMUTATIVE GRAVITY.

THE FOUR LEVELS OF GRAVITY

CM

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

CST

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

III. Level THREE : CLASSICAL GRAVITATIONAL DYNAMICS

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QFT

$$ds^2 = g_{\mu\nu}dx^\mu dx^\nu$$

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

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

STM FLUID

THERMODYNAMICS OF ATOMS

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Asymmetric Operator Metric

I. LEVEL ONE : QUANTUM GRAVITY

STD

ATOMS

ATOMS OF SPACE-TIME-MATTER

ATOMS

Non-commutative Geometry
Asymmetric Metric

0. Level ZERO : NON-COMMUTATIVE TORSION GRAVITY

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- **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 <u>NON-COMMUTATIVE</u> space-time.

THANK YOU!