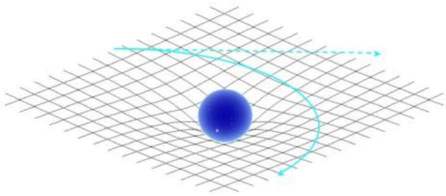
TIFR Science News

Proposal for a new quantum theory of gravity

Our understanding of the gravitational force has been evolving over centuries, but we still do not have the final picture. Newton showed that the force which makes planets go around the sun is the same as the gravitational force which makes objects fall to the ground. This led to the discovery of the famous inverse square law of gravitation.

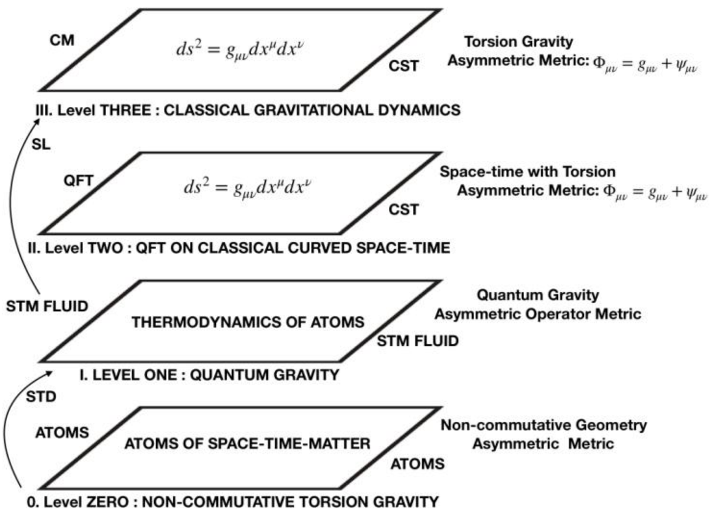
It was known to Galileo and Newton that the acceleration of a body in a gravitational field is independent of its mass. This remarkable fact has profound implications, and it was Einstein who first grasped its significance. He showed that gravitation is the curvature of space-time; the curvature being produced by massive bodies. Test bodies move along 'straight' lines in the curved space-time geometry. Thus the earth moves in an elliptical orbit around the sun, because this orbit is a straight line in the curved geometry produced by the sun.



This view of gravitation is in serious conflict with quantum theory. This is because while a quantum particle needs a background geometry for its description, it does not move in a straight line in a curved space-time. On the contrary, it moves from an initial space-time point to the final point as if it traverses all possible paths connecting these two points. This leads to a problem. The macroscopic bodies of Einstein's gravity (which produce curvature) are, after all, made of microscopic quantum particles. Now imagine a Universe in which there are only distinct quantum particles, and no macroscopic objects. What kind of space-time geometry will these particles produce? Certainly not the kind found in Einstein's gravity — because the quantum particles do not move along straight lines. And if we do not have a background space-time geometry, how are we to even describe the evolution of quantum particles? Hence, there must exist a way to describe quantum theory without making any reference to space-time geometry.

This is the question addressed in our present work. In a Universe consisting of only distinct quantum particles, we do not make any distinction between space-time and matter. Rather, we introduce a mathematically well-defined concept of an 'atom of space-time-matter', or in short, an STM atom. This is an elementary particle which produces and carries around its own curved space-time geometry, which is not that of Einstein's theory, but a new concept known as non-commutative geometry. The STM atom is then described by a beautifully simple action principle, which couples a closed string to its non-commutative curvature. There are only two fundamental constants in this action – the square of Planck length, and the speed of light.

The dynamics of many such STM atoms leads to our new proposal for the much-sought-after quantum theory of gravity. At the most fundamental level, i.e. at the Planck scale, there is no classical space-time. The universe consists of enormously many STM atoms, which interact via quantum entanglement. But if we are not observing the universe at this resolution, we can do a coarse-graining, i.e., a statistical thermodynamics of this underlying 'gas' of STM atoms. Remarkably enough, the emergent theory of this gas at equilibrium is the sought-after description of quantum theory without a background space-time geometry. It is also a candidate for the quantum theory of gravity. Planck's constant and Newton's gravitational constant emerge only at this level.



If we try to entangle a large number of STM atoms — thereby creating a macroscopic object — a very rapid loss of entanglement occurs, which is responsible for spontaneous localization and the emergence of the classical space-time and macroscopic objects of classical general relativity. These various levels of gravitational dynamics are depicted in Figure 1.

We have thus brought about a harmonious unification of quantum theory and general relativity. Einstein gravity is seen as a far-from-equilibrium approximation of the underlying non-commutative geometry of STM atoms. The idea of STM atoms is being tested by ongoing experiments which seek to verify the phenomenon of spontaneous localization.

These findings will be published in a forthcoming issue of the *Zeitschrift für Naturforschung* A.

Reference: *Proposal for a new quantum theory of gravity*, https://arxiv.org/abs/1903.05402

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