Proposal for a new quantum theory of gravity

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Our understanding of the gravitational force has been evolving over centuries, and 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 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? There hence 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' [STM atom]. An STM atom is an elementary particle which produces and carries around its own curved space-time geometry. This geometry is not that of Einstein's theory, but a new concept known as non-commutative geometry (NCG). NCG is the great work of the French mathematician Alain Connes, who generalized the geometry of space-time to the situation when space-time coordinates do not commute with each other. NCG is much more in tune with quantum theory, than Einstein's gravity is, if we keep in mind that non-commutativity (of position and momentum) is a key feature of quantum theory. The STM atom is described by a beautifully simple action principle, which couples a closed string to its non-commutative curvature. There are only two fundamental constants in the action – the square of Planck length, and the speed of light. An STM atom, by virtue of its non-commutative geometry, has an intrinsic new measure of time evolution, which we have named as Connes time. What is more, the evolution of a state of the STM atom is non-linear and non-unitary, yet norm-preserving – these features play a crucial role in what follows.

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

Statistical fluctuations, which represent a departure from thermodynamic equilibrium, play an extremely significant role in this theory. These fluctuations contain a non-unitary component, which nonetheless preserve norm during evolution of the state. If we try to entangle a large number of STM atoms (thereby making a macroscopic object), the non-unitary fluctuations cause a very rapid loss of superposition [`spontaneous localisation']. This spontaneous localization is responsible for the emergence of the classical space-time and macroscopic objects of classical general relativity. In this way, Einstein's gravity is seen as a far from equilibrium approximation of the underlying non-commutative geometry of STM atoms. We have brought about a harmonious unification of quantum theory and general relativity. The various levels of gravitational dynamics are depicted in Figure 1. 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 Zeitschrift fur Naturforschung A.

Reference:
[1] Proposal for a new quantum theory of gravity
https://arxiv.org/abs/1903.05402

Figure caption: The four layers of gravitational dynamics [From Ref. 1]