Quantum Gravity: Has Spacetime Quantum Properties?

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Abstract

The conceptual incompatibility between General Relativity and Quantum Mechanics is generally seen as a sufficient motivation for the development of a theory of Quantum Gravity. If - so a typical argumentation - Quantum Mechanics gives a universally valid basis for the description of the dynamical behavior of all natural systems, then the gravitational field should have quantum properties, like all other fundamental interaction fields. And, if General Relativity can be seen as an adequate description of the classical aspects of gravity and spacetime - and their mutual relation -, this leads, together with the rather convincing arguments against semi-classical theories of gravity, to a strategy which takes a quantization of General Relativity as the natural avenue to a theory of Quantum Gravity. And, because in General Relativity the gravitational field is represented by the spacetime metric, a quantization of the gravitational field would in some sense correspond to a quantization of geometry. Spacetime would have quantum properties.
But, this direct quantization strategy to Quantum Gravity will only be successful, if gravity is indeed a fundamental interaction. Only if it is a fundamental interaction, the given argumentation is valid, and the gravitational field, as well as spacetime, should have quantum properties. - What, if gravity is instead an intrinsically classical phenomenon? Then, if Quantum Mechanics is nevertheless fundamentally valid, gravity can not be a fundamental interaction; a classical and at the same time fundamental gravity is excluded by the arguments against semi-classical theories of gravity. An intrinsically classical gravity in a quantum world would have to be an emergent, induced or residual, macroscopic effect, caused by a quantum substrate dominated by other interactions, not by gravity. Then, the gravitational field (as well as spacetime) would not have any quantum properties. And then, a quantization of gravity (i.e. of General Relativity) would lead to artifacts without any relation to nature.
The serious problems of all approaches to Quantum Gravity that start from a direct quantization of General Relativity (e.g. non-perturbative canonical quantization approaches like Loop Quantum Gravity) or try to capture the quantum properties of gravity in form of a 'graviton' dynamics (e.g. Covariant Quantization, String Theory) - together with the, meanwhile, rich spectrum of (more or less advanced) theoretical approaches to an emergent gravity and/or spacetime - make this latter option more and more interesting for the development of a theory of Quantum Gravity. The most advanced emergent gravity (and spacetime) scenarios are of an information-theoretical, quantum-computational type. A paradigmatic model for the emergence of gravity and spacetime comes from the Pregeometric Quantum Causal Histories approach.

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