Quantum gravity with two forms of time

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Abstract

Fundamental problems with quantum gravity such as the measurement problem and the problem of time suggest that cherished concepts about spacetime may be flawed. In this work, 4D spacetime is turned into a dynamic structure as a function of a second form of time, τ [1]. The 4D+τ construction allows to explain classical gravitational observations as well as quantum phenomena and offers an interesting path towards a theory of quantum gravity. The concept is illustrated for the case of double slit interference and EPR entanglement. Implications for laboratory tests of quantum gravity and the cosmological constant problem are analysed. Additionally, it is shown that the 4D+τ formalism agrees with our experience of the flow of time, and that realism and locality are rescued at a fundamental level.

[1] Strubbe, F. Single-Photon Double-Slit Interference in the 4+1 Formalism. *Universe* **2022**, *8*, 511.
[2] Strubbe, F. Quantum gravity based on a second form of time. *Under review*

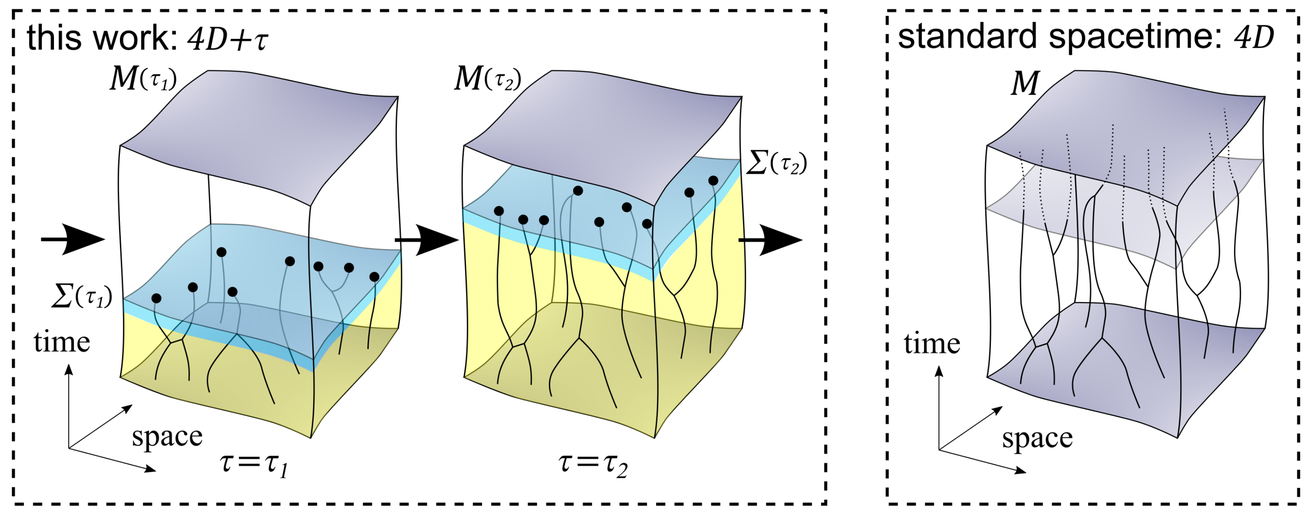
The 4D+τ formalism

Basic theory:

- an evolution parameter τ is added to 4D spacetime
- particles are described as τ-dynamic worldlines
- a crystallization hypersurface Σ is introduced

Advantages (conceptually):

- both classical gravitational observations and quantum phenomena can be understood
- solves measurement problem and problem of time
- offers a fundamentally realist and local framework
- explains experience flow & arrow of time

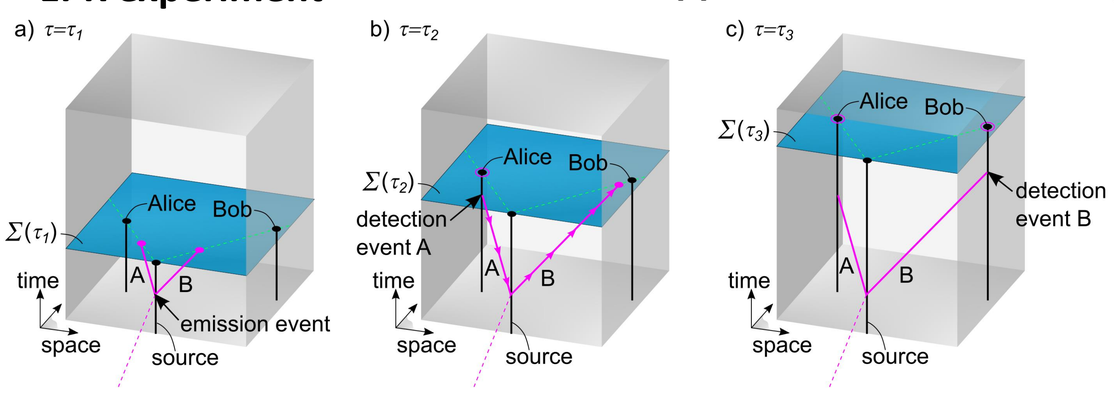


Left: Illustration of a crystallizing 4D spacetime as a function of τ. Observations originate from the crystallized region of worldlines (yellow) in the past, which corresponds to a standard spacetime of general relativity (Right). Quantum phenomena can be understood from dynamics as a function of τ near the crystallization interface (blue).

Quantum phenomena in the 4D+τ formalism

EPR experiment

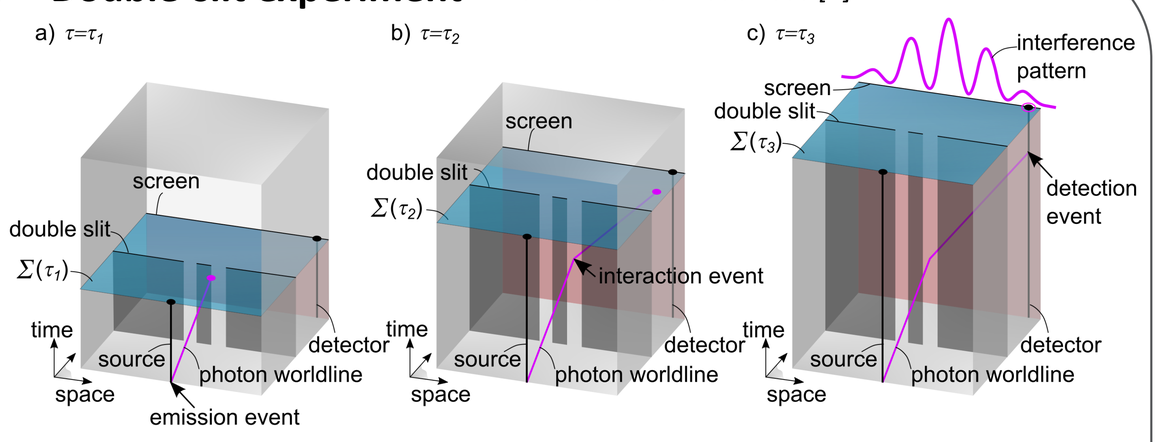
For a detailed model: see [2]



Nonlocal EPR correlations can be understood in a fundamentally local way in the 4D+τ formalism, following the idea of Costa de Beauregard. When Alice measures photon A, an influence travels along the worldline to the creation event and further towards Bob (arrows in b). Hence, Bob's measurement outcome is influenced by Alice's measurement setting.

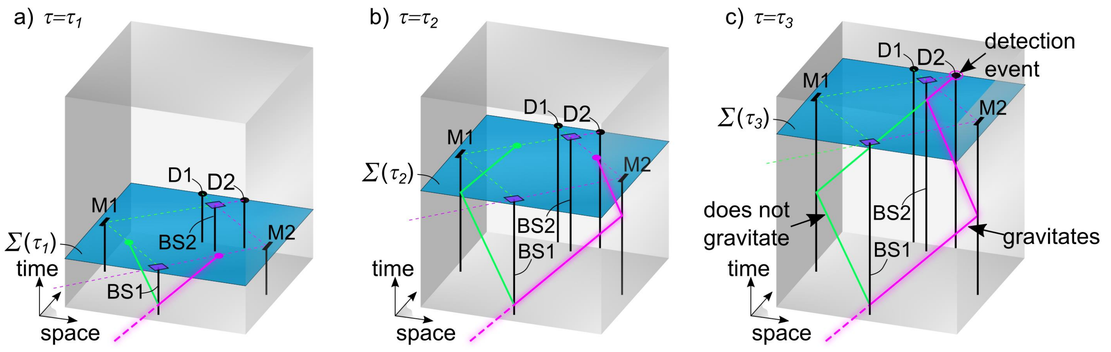
Double-slit experiment

For a detailed model: see [1]



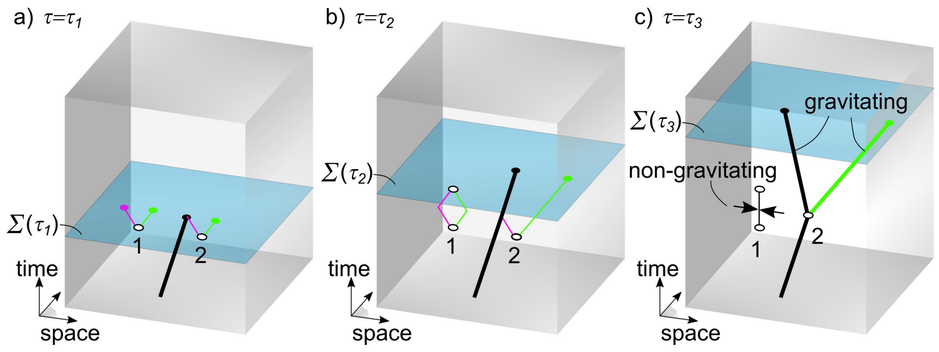
A photon worldline transfers momentum in one interaction event at the double slit, with otherwise a constant momentum in free space. As the worldline grows, its spatial orientation is altered as a function of τ to reproduce the desired interference pattern.

Interferometer / Laboratory tests of gravity



Only one path (magenta) of the interferometer actually carries momentum and gravitates. The other path (green) does not gravitate, yet co-determines the behaviour of the momentum-carrying worldline at the second beamsplitter. Since at each value of τ there is a classical spacetime, it is expected that gravity cannot induce entanglement.

Cosmological constant problem



The 4D+τ formalism offers a way to solve the cosmological constant problem. Isolated vacuum fluctuations (1) are assumed to have no gravitational effect. Only vacuum fluctuations that interact with real particles produce real quantum and gravitational effects.

Conclusions & Prospects

- The 4D+τ formalism offers an interesting path towards a theory of quantum gravity (free of problems with measurement & time)
- By relying on τ-dynamic worldlines quantum phenomena can be reproduced (details see [1] and [2])
- It produces an intuitive single-world view, and rescues concepts like realism and locality at a more fundamental level
- Since gravity is essentially classical in the 4D+τ formalism, tests of gravitationally-induced entanglement are expected to turn out negative
- Still missing: detailed matter equations are needed to replace the standard quantum formalism

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