Current Research on the History of Quantum Gravity at the MPIWG

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Working Program

1. The Complementary roles of matter and spacetime in the relativity and quantum revolutions
   - What has relativity taught us about matter?
   - The quantum revolution and its spacetime implications
2. Conceptual intersections and clashes of principles
   - Conflicting conceptualizations of space, time and matter
   - Principles of superposition, uncertainty, equivalence, and general covariance
   - Measurement conundrums
3. Epistemic nodes and borderline problems
   - Thermodynamic aspects, early universe, and black holes
4. The interaction between representation and conceptualisation
   - The model of quantum field theory in flat spacetime
   - The model of canonical quantization
   - The model of Feynman quantization
5. Conceptual novelties, relation to available knowledge and epistemological implications

Einsteinian Approach to a Quantum Equivalence Principle

- Apply the elevator equivalence principle to a matter wave
  - Elevator Equivalence Principle: Physics in a locally homogeneous gravitational field and in a rigidly accelerated frame is indistinguishable.
  - Matter wave: Plane wave solution to the free Klein-Gordon equation
- Identify Einstein's 1912 transformation as an approximate Rindler transformation

$$\xi = \left(\frac{C^2}{A_0} + x\right)\left(1 + \frac{1}{2}\left(\frac{A_0 t}{C}\right)^2\right) - \frac{C^2}{A_0}$$

$$\tau = \frac{1}{C}\left(\frac{C^2}{A_0} + x\right)\left(\frac{A_0 t}{C} + \frac{1}{6}\left(\frac{A_0 t}{C}\right)^3\right)$$

- Derive Einsteinian Schrödinger equation in complementary ways

$$i\hbar\dot{\Psi} = mC^2\Psi + mAx\Psi - \frac{\hbar^2}{2m}\left(1 + \frac{Ax}{C^2}\right)\Psi'' - \frac{\hbar^4}{8m^3C^2}\Psi''''$$

  - Einstein-Rindler boost of matter wave
  - Kiefer-Singh expansion of minimally coupled Klein-Gordon equation
  - Hamilton-Jacobi superposition in Einstein-Rindler frame

Main Results

- A version of the strong equivalence principle (elevator equivalence) has been shown to hold without the need of introducing a mass-dependent phase factor. Hence the transformation to an accelerated frame must precede taking the non-relativistic limit.
- A full strong quantum equivalence principle can be construed through the Hamilton-Jacobi approach to quantum mechanics proceeding from particle geodesic motion in an arbitrary spacetime.
- The phase arising from the Hamilton principal function is the rest mass times the classical proper time. The phase of the wave function is thus proportional to the proper time elapsed along the classical path.
- Even when starting from a Weyl geometry, self-consistency of the Hamilton-Jacobi procedure requires that the Weyl gauge potential vanishes, thus enforcing a Riemannian geometry.