

## **Reverse-engineering quantum theory: (anti-)matter waves, interferometry, and clocks.**

Holger Müller, University of California - Berkeley

Interpreting quantum mechanics still holds profound mysteries. Finding alternative formulations is one way to improve our understanding. We will discuss the "clock picture:" Matter-wave packets are viewed as oscillators at the Compton frequency  $mc^2/h$  that are red-shifted and time-dilated by gravity and relative motion ( $m$  is the particle mass). From this picture, one may use path integrals to obtain the Schrödinger equation for spinless, slow particles in weak gravity. Starting with a relativistic ansatz, however, should be a way to obtain a relativistic result. We will extend the clock picture and derive the Dirac equation for particles with spin, of any velocity, in curved-space time, with and without electromagnetic fields. All results are shown to agree with quantum mechanics. The clock picture is not just valid, but indeed powerful enough to re-derive the theory.

The talk will give an overview of experiments that were inspired by this picture: tests of the equivalence principle at  $10^{-9}$  accuracy; a clock that measures time by the Compton frequency of cesium atoms; and a realization of the unit of mass with state of the art precision. Moreover, I will present our ongoing measurement of the fine structure constant. At  $2 \times 10^{-9}$  accuracy, it has been the world's third best. We have since reduced the leading systematic error about 8-fold and the statistical error about 10-fold. As an outlook, we will discuss atom interferometry in space, with antimatter, and for gravitational wave detection.