Quantum complementarity of clocks in the context of general relativity

Zhifan Zhou, Yair Margalit*, Daniel Rohrlich, Yonathan Japha, and Ron Folman

Department of Physics, Ben-Gurion University of the Negev, Beer-Sheva, Israel

* Present address: Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, Massachusetts 02139, USA

Clocks play a key role at the interface of general relativity (GR) and quantum mechanics (QM) [1]. By reversing the famous Einstein-Bohr debate, we assume that red-shift exists and therefore must impose the equivalence principle. Consequently, we analyze a clock-interferometer thought experiment [2], where we theoretically define and experimentally demonstrate a complementarity relation for quantum clocks in the context of GR [3]. We analyze this relation in detail and point out special cases. Our analysis highlights a fundamental principle in the interplay between GR and QM and may shed light on ongoing debates.

Figure 1: 339 experimental shots of a clock interference pattern in a combined plot (one on top of the other, no alignment or corrections) when the clock distinguishability $D_I(T_G) = 0$. The visibility is 0.789±0.001, while the mean of the single-shot visibility is 0.879±0.002. The errors are standard error of the mean (SEM).

Figure 2: Experimentally measured value of the clock complementarity relation $V^2 + (C \cdot D_I)^2$, where $V$ is the interference pattern visibility, $D_I$ is the ideal clock distinguishability, and $C$ accounts for imperfect clock preparation (“clockness”). In this figure all three parameters are measured independently: (a) for four values of $C$ when $D_I$ is scanned, and (b) for four values of $D_I$ when $C$ is scanned. $V_N$ is the visibility normalized to the single-state interferometer (i.e. without an initialization of a clock), accounting for experimental imperfections. Error bars are SEM.