Time as a “which path” witness

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In Einstein’s general theory of relativity, time depends locally on gravity; in standard quantum theory, time is global - all clocks “tick” uniformly. In my talk I will present our demonstration [1] of a new tool for investigating time in the overlap of these two theories: a self-interfering clock, comprising two atomic spin states. We prepare the clock in a spatial superposition of quantum wave packets, which evolve coherently along two paths into a stable interference pattern. If we make the clock wave packets “tick” at different rates, to simulate a gravitational time lag, the clock time along each path yields “which path” information, degrading the pattern’s visibility. In contrast, in standard interferometry, time cannot yield “which path” information. This proof-of-principle experiment may have implications for the study of time and general relativity and their impact on fundamental effects such as decoherence and the emergence of a classical world.

Clock interference patterns, in which clock time acts as a “which path” witness. (A) A single experimental shot of a clock interfering with itself. As the clock rate is approximately the same in the two wave packets, interference is visible ($T_G$ corresponds to the simulated redshift). (B) An average of 100 consecutive experimental shots such as that in (A), proving the coherence of the clock spatial splitting. (C) A single shot in which the clock differential rotation angle $\phi_0 + \Delta \omega T_G = \pi$. The interference is gone, showing that clock time acts as a “which path” witness. (D) Similar to (B), but where indistinguishability is restored by using $\phi_0 + \Delta \omega T_G = 2\pi$, and interference is again visible.