Quantum clocks: time-energy uncertainty relations and the emergence of non-unitarity

Eliahu Cohen and Ismael Lucas de Paiva

Bar-Ilan University, Max VeAnna Webb St, Ramat Gan, Israel

Time is a concept that lies at the heart of the foundations of physics. Recently, much effort has been put towards a broader understanding of time in quantum mechanics within a relational approach. This approach, originally due to Page and Wootters, consists of having one or more quantum systems used as references for time to study the dynamics of other systems of interest. In this talk, we first use this framework to study the von Neumann measurement scheme of the total energy of a system that contains an internal clock. We analyze whether quantum mechanics requires a minimum duration for the measurement from the perspective of this clock or of others external to the system and derive new time-energy uncertainty relations [1]. Moreover, we show that the dynamics from the perspective of the internal clock is non-unitary [1]. Further studying this aspect, we prove that, in general, non-inertial clock frames lead to non-unitary dynamics [1]. Accelerating and gravitating quantum clocks are given as key examples [2]. Finally, we discuss the implications of the above for dynamical nonlocality in space [3] and time [4].

[1] Paiva I.L., Lobo A.C., Cohen E., "Flow of time during energy measurements and the resulting time-energy uncertainty relations", Quantum 6, 683 (2022).

[2] Paiva I.L., Te'eni A., Peled B., Cohen E., Aharonov Y., "Noninertial quantum clock frames lead to non-Hermitian dynamics", arXiv:2204.04177.

[3] Aharonov Y., Cohen E., Colombo F., Landsberger T., Sabadini I., Struppa, D.C., Tollaksen J., "Finally Making Sense of the Double-Slit Experiment", Proc. Natl. Acad. Sci. USA 114, 6480-6485 (2017).

[4] Paiva I.L., Nowakowski M., Cohen E., "Nonlocality in quantum time via modular operators", Phys. Rev. A 105, 042207 (2022).