Quantum Time Crystal Clock and its Performance

Gonzalo Manzano

Understanding different aspects of time is at the core of many areas in theoretical physics. Minimal models of continuous stochastic and quantum clocks have been proposed to explore fundamental limitations on the performance of timekeeping devices. Owing to the level of complexity in the clock structure and its energy consumption, such devices show trade-offs whose characterization remains an open challenge. Indeed, even conceptual designs for thermodynamically efficient quantum clocks are not yet well understood.

On the other side, in condensed matter theory, time crystals were found as an exciting new phase of matter that spontaneously breaks time-translational invariance, featuring oscillations in (pseudo)-equilibrium. They are attracting a constantly increasing attention in the last decade, and first experimental observations appeared recently. Besides the intrinsic fundamental interest on time crystals as a new state of matter, the question of whether time crystals can be of any relevance for quantum technological applications arises. This is a promising avenue to explore and initial steps in this directions have been taken, mainly in the context of quantum sensing.

This naturally prompts the question: *can time crystals be used as quantum clocks and what is their performance from a thermodynamic perspective?* In this talk I will discuss this point basing on our recent results published in Ref. [1]. There we propose a class of dissipative time crystals for time-keeping purposes, making them natural candidates for high-precision clocks. More precisely, I will discuss a quantum clock model based on continuous monitoring of a time crystal, composed by a many-body spin system (the clockwork) interacting with a non-equilibrium environment. When appropriately monitoring the nonequilibrium dynamics of such system the time-crystalline properties become apparent and can be conveniently used to count ticks, providing a continuous time-reference in a observable that becomes more and more macroscopic as the number of spins is increased. I will discuss methods developed to asses the thermodynamic performance of such clocks and show how the properties of the clock can be enhanced by the spontaneous breaking of time-translation symmetry.

[1] L. Viotti, M. Huber, R. Fazio and G. Manzano. Quantum time crystal clock and its performance. Phys. Rev. Lett. - **Accepted** 28 January, 2026. DOI: https://doi.org/10.1103/dj21-gmdj [arXiv:2505.08276].