Nonreciprocal Quantum Matter

Matteo Brunelli
Co-Authors (Tobias Nadolny, Christoph Bruder)

Collège de France, 11 Place Marcelin Berthelot, 75321 Paris Cedex 05, Paris, France

Matteo.brunelli@college-de-france.fr

Abstract

Nonreciprocal interactions, in which an agent A attracts another agent B while B repels A, lead to exciting phenomena in classical systems, such as novel phase transitions and time-crystal behavior. Whether such phenomena can emerge in quantum many-body systems remains an open question. In this talk, I will present a model of two collective driven quantum spins featuring attraction-repulsion type interactions, analogous to predator-prey dynamics [1]. The model can be realized with two atomic ensembles coupled via chiral waveguides. In the thermodynamic limit, nonreciprocal interactions result in a nonreciprocal phase transition into time-crystalline states, associated with spontaneous breaking of parity-time symmetry. Continuous monitoring of the waveguide's output field also induces a time-crystal state in finite-size systems, where parity-time symmetry is spontaneously broken, and the corresponding quantum trajectories reveal quantum traveling-wave states. I will then show that nonreciprocal interactions arise in a model of superradiant laser in which a fraction of the atoms are not driven, resulting in frequency shift and spectral broadening of the emitted radiation [2]. This represents a fundamental limitation for the operation of super radiant lasers ultra-stable frequency reference.

References

[1] T. Nadolny, C. Bruder, M. Brunelli, Phys. Rev. X **15** 011010 (2025).
[2] T. Nadolny, M. Brunelli, C. Bruder, arXiv:2501.13808 (2025)