A novel framework for describing how certain quantum systems avoid equilibrium

Researchers establish a robust theoretical description of many-body localization (MBL) -a phenomenon that prevents quantum many-body systems from reaching equilibrium. This advancement enables understanding and demonstrating MBL in a wider range of quantum many-body systems.

November 18, 2024

When many quantum particles evolve over time, they typically end up arriving to an equilibrium state through a process called thermalization. Something similar happens in many classical systems. For example, if you place an ice cube in a thermos with water, the ice melts and the final (equilibrium) state is just colder water than before.

In classical physics, complex systems eventually reach equilibrium (if you wait long enough, the ice always melts). However, certain quantum many-body systems defy this norm. For them, thermalization does not occur, and the system remains out of equilibrium. That is the case of a large class of strongly disordered systems -where features like particle interactions or individual energies exhibit a certain degree of randomness. This behavior is due to many-body localization (MBL), a mechanism that preserves the system's initial conditions over time.

Local integrals of motion (LIOMs) constitute a theoretical framework broadly used for the study of MBL. Nevertheless, a recent article published in Physical Reviews Letters led by Uniwersytet Jagiellonski and with the collaboration of ICFO researchers **Dr. Piotr Sierant** and **ICREA Prof. Maciej Lewenstein** shows that LIOMs are insufficient to describe the behavior of a wide class of systems, in particular, those with more complex types of disorder. They propose a new framework, the real space renormalization group for excited states (RSRG-X), which can explain MBL in a larger amount of quantum many-body systems.

The team knew that LIOMs can capture the behavior of MBL when the disorder of the system affects properties of particles individually (on-site disorder). However, they suspected that LIOMs failed to account for systems where randomness influences the interactions between particles (bond disorder).

To test this hypothesis, researchers applied RSRG-X to a bond-disordered chain of spin particles (that is, particles that behave like tiny magnets). The results showed that, indeed, **RSRG-X provides a theoretical description of MBL in such systems, where LIOMs do not even exist**. Their framework uncovers new features of MBL in quantum many-body systems, including the presence of anomalously small energy level spacings, the emergence of non-trivial entanglement structures and observable quantities that enable experimental demonstration of the phenomenon. The obtained description turned out to be qualitatively accurate and, this way, researchers demonstrated the validity of the procedure.

i¿½We have provided a **framework applicable to a wider range of systems** and, thanks to that, we have shown that the physics of MBL is richer than previously thoughti¿½, explains Dr. Pio r Sierant. Furthermore, the novel approach has implications which can be tested n experiments, for instance, with ultracold atom gases or superconducting qubits. Dr. Siera t adds: i¿½Rydberg atoms are just one platform, among many others, in which the system we have in mind could be realized. That is very convenient because, as theoreticians, we w uld be thrilled to see our framework implemented in a real-world scenario

Reference:

Adith Sai Aramthottil, Piotr Sierant, Maciej Lewenstein, and Jakub Zakrzewski, Phys. Rev. Lett. 133, 196302.

DOI: https://doi.org/10.1103/PhysRevLett.133.196302

Acknowledgements:

The work of A.S.A. has been realized within the Opus grant 2019/35/B/ST2/00034, financed

by National Science Centre (Poland). P.S. acknowledges support from: ERC AdG NOQIA;
MICIN/AEI
(PGC2018-0910.13039/501100011033, CEX2019-000910-S/10.13039/501100011033, Plan
National FIDEUA PID2019-106901GB-I00, FPI; MICIIN with funding from European Union
NextGenerationEU (PRTR-C17.I1): QUANTERA MAQS PCI2019-111828-2);
MCIN/AEI/10.13039/501100011033 and by the i¿½European Union NextGeneration EU/PRT
" QUANTERA DYNAMITE PCI2022-132919 within the QuantERA II Programme that has receiv
d funding from the European Union's Horizon 2020 research and innovation programme und
r Grant Agreement No 101017733Proyectos de I+D+I i¿½Retos Colaboracioni¿½
USPIN RTC2019-007196-7); Fundacio Cellex; Fundacio Mir-Puig; Generalitat de Catalunya (Eu
opean Social Fund FEDER and CERCA program, AGAUR Grant No. 2021 SGR 01452, Quan
umCAT U16-011424, co-funded by ERDF Operational Program of Catalonia 2014-2020); Bar
elona Supercomputing Center MareNostrum (FI-2024-1-0043); EU (PASQuanS2.1, 10111369
); EU Horizon 2020 FET-OPEN OPTOlogic (Grant No 899794); EU Horizon Europe Program
Grant Agreement 101080086- NeQST), ICFO Internal i¿½QuantumGaudii¿½ project
European Union's Horizon 2020 research and innovation program under the Marie-Sk?odo
ska-Curie grant agreement No 101029393 (STREDCH) and No 847648 (i¿½La Caixai¿½
unior Leaders fellowship
ID100010434: LCF/BQ/PI19/11690013, LCF/BQ/PI20/11760031, LCF/BQ/
R20/11770012, LCF/BQ/PR21/11840013). E.P. is supported by i¿½Ayuda (PRE2021-098926
financiada por MCIN/AEI/ 10.13039/501100011033 y por el FSE+". The work of J.Z. w
s funded by the National Science Centre, Poland, project 2021/03/Y/ST2/00186 within
the QuantERA II Programme that has received funding from the European Union Horizon 2
20 research and innovation programme under Grant agreement No 101017733. A partia
support by the Strategic Programme Excellence Initiative at Jagiellonian University is acknowledged.