Non-equilibrium thermodynamic equality works at the single-spin level

With the support by the National Natural Science Foundation of China and in collaboration with the researchers from Shanghai Jiaotong University and Oxford University, the research group led by Prof. Feng Mang (冯芒) from Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences demonstrates experimentally that a thermodynamic equality works at the single-spin level even in a non-equilibrium dynamic process, which was published in *Physical Review Letters* (2018, 120: 010601) and selected as Editor's Suggestion.

Thermodynamics conventionally applies to macroscopic systems and the non-equilibrium dynamic process is ubiquitous in thermodynamic evolutions. In general, the non-equilibrium dynamics is extremely complicated, which can be described only by inequalities. However, a simple and general relation named "Jarzynski equality" was proposed in 1997 to connect the physical quantities in the non-equilibrium process to the free-energy change of the system. This equality was further generalized in 2012 as an "information-theoretic equality" for the change of information between two different measurements during the time evolution. The new equality, which is more suitable for quantum domain, can be reduced to the Jarzynski equality when the system is initially in a Gibbs state.

They have verified experimentally this information-theoretic equality by employing a single ultracold trapped $^{40}Ca^{+}$ ion confined in an electromagnetic field. The single-qubit implementation includes two projective measurements with a completely positive trace preserving map in between (See Figure below). Since the ion is cooled down to the vibrational ground state, the experiment was carried out at the level of 0.7% error of single-spin operations under the influence of quantum and classical noises. This is the first experimental demonstration of non-equilibrium thermodynamics of information at a single-spin level, which showed clearly that the information-theoretic equality, including the Jarzynski equality, works nearly perfectly at the fundamental level of a single spin.

This work would be helpful for understanding the thermodynamic behavior in the quantum regime and also for further exploring the interplay between non-equilibrium phenomena and information at the nanoscale.

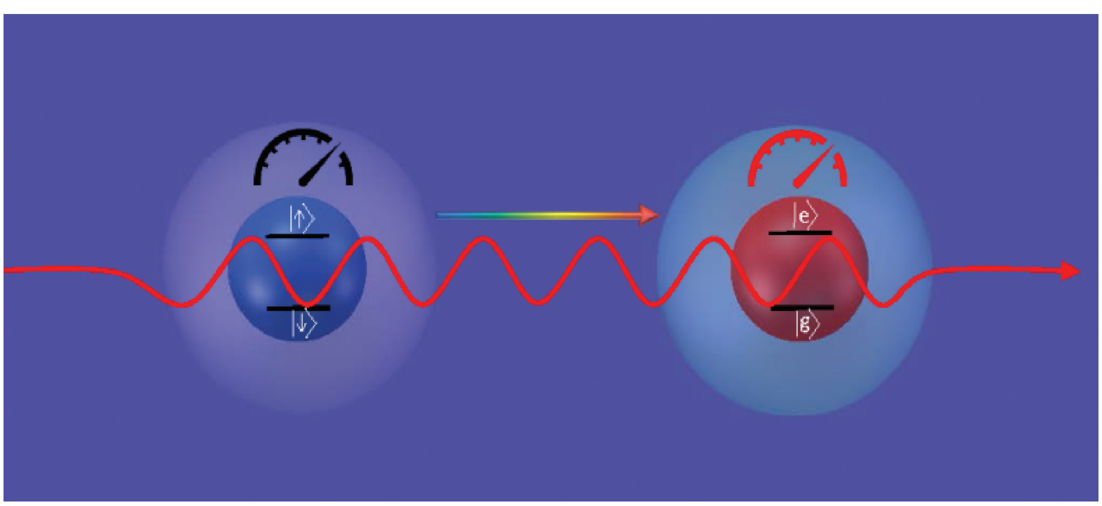

Figure Schematic diagram of the experiment: A completely positive trace preserving map sandwiched by two measurements on the spin levels in a $^{40}Ca^{+}$ ion.