CESQ Colloquium

Tuesday March 25 @ 3 PM

Seminar Room, Centre Européen de Sciences Quantiques,
Campus de Cronenbourg

Kenji Ohmori

Institute for Molecular Science, National Institute of Natural Sciences, Japan

Contact: Jérôme Dubail (j.dubail@unistra.fr), Guido Pupillo (pupillo@unistra.fr)

Ultrafast quantum simulation and quantum computing with ultracold atom arrays at quantum speed limit

Many-body correlations drive a variety of important quantum phenomena and quantum machines including superconductivity and magnetism in condensed matter as well as quantum computers. Understanding and controlling quantum many-body correlations is thus one of the central goals of modern science and technology. My research group has recently pioneered a novel pathway towards this goal with nearby ultracold atoms excited with an ultrashort laser pulse to a Rydberg state far beyond the Rydberg blockade regime [1-7]. We first applied our ultrafast coherent control with attosecond precision [2,3] to a random ensemble of those Rydberg atoms in an optical dipole trap, and successfully observed and controlled their strongly correlated electron dynamics on a sub-nanosecond timescale [1]. This new approach is now applied to arbitrary atom arrays assembled with optical lattices or optical tweezers that develop into a pathbreaking platform for quantum simulation and quantum computing on an ultrafast timescale [4-7].

In this ultrafast quantum computing, as schematically shown in Fig. 1, we have recently succeeded in executing a controlled-Z gate, a conditional two-qubit gate essential for quantum computing, in only 6.5 nanoseconds at quantum speed limit, where the gate speed is solely determined by the interaction strength between two qubits [5]. This is faster than any other two-qubit gates with cold-atom hardware by two orders of magnitude. It is also two orders of magnitude faster than the noise from the external environment and operating lasers, and thus can suppress those noise effects. Moreover, this two-qubit gate is faster than the fast two-qubit gate demonstrated recently by "Google AI Quantum" with superconducting qubits [8]. This disruptive progress has been made possible not only by the ultrafast laser technologies, but also by our ultra-precise optical tweezers array and high-NA microscope technologies.

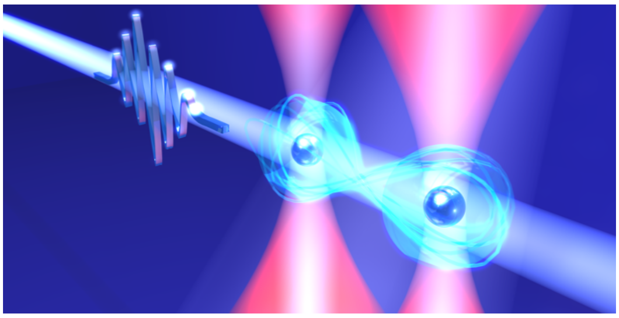

Figure 1. Conceptual diagram of the ultrafast two-qubit gate for quantum computing with cold atoms. Two single atoms captured in optical tweezers (red light) with a separation of a micrometer are entangled with an ultrafast laser pulse (blue light) shone for only 10 picoseconds [5]. Image source: Dr. Takafumi Tomita (IMS).

References

[1] N. Takei *et al.*, *Nature Commun.* **7**, 13449 (2016). Highlighted by *Science* **354**, 1388 (2016); *IOP PhyscisWorld.com* (2016).
[2] H. Katsuki *et al.*, *Acc. Chem. Res.* **51**, 1174 (2018).
[3] C. Liu *et al.*, *Phys. Rev. Lett.* **121**, 173201 (2018).
[4] M. Mizoguchi *et al.*, *Phys. Rev. Lett.* **124**, 253201 (2020).
[5] Y. Chew *et al.*, *Nature Photonics* **16**, 724 (2022). (Front Cover Highlight)
[6] V. Bharti *et al.*, *Phys. Rev. Lett.* **131**, 123201 (2023).
[7] V. Bharti *et al.*, *Phys. Rev. Lett.* **133**, 093405 (2024).
[8] B. Foxen *et al.*, *Phys. Rev. Lett.* **125**, 120504 (2020).

CENTRE EUROPÉEN DE SCIENCES QUANTIQUES

Université de Strasbourg

cnrs