Exploring Quantum-Classical Boundary

Department of Photo-Molecular Science
Division of Photo-Molecular Science II

OHMORI, Kenji
Professor
[ohmori@ims.ac.jp]

Education
1987 B. E. The University of Tokyo
1992 Ph.D. The University of Tokyo

Professional Employment
1992 Research Associate, Tohoku University
2001 Associate Professor, Tohoku University
2003 Professor, Institute for Molecular Science
Professor, The Graduate University for Advanced Studies
2004 Visiting Professor, Tohoku University (–2005)
2007 Visiting Professor, Tokyo Institute of Technology (–2008)
2009 Visiting Professor, The University of Tokyo (–2011)
2012 Visiting Professor, University of Heidelberg
2014 Visiting Professor, University of Strasbourg

Awards
1998 Award by Research Foundation for Opto-Science and Technology
2007 JSPS Prize
2007 Japan Academy Medal
2009 Fellow of the American Physical Society
2012 Humboldt Research Award

Member
Assistant Professor
TAKEI, Nobuyuki
SOMMER, Christian
TAKEDA, Shuntaro
IMS Research Assistant Professor
TANAKA, Akira
Post-Doctoral Fellow
GOTO(SHIKANO), Haruka
Visiting Scientist
SOUQUET BASIÈGE, Hubert*
TIRUMALASETTY PANDURANGA, Mahesh*
Graduate Student
MIZOGUCHI, Michiteru
RASTI, Soroush
KONDO, Norihisa†
Secretary
INAGAKI, Itsuko
YAMAGAMI, Yukiko

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It is observed in a double-slit experiment by Tonomura and coworkers that single electrons recorded as dots on a detector screen build up to show an interference pattern, which is delocalized over the screen.[1)] This observation indicates that a delocalized wave function of an isolated electron interacts with the screen, which is a bulk solid composed of many nuclei and electrons interacting with each other, and becomes localized in space. This change, referred to as "collapse" in quantum mechanics, is often accepted as a discontinuous event, but a basic question arises: When and how the delocalized wave function becomes localized? Our dream is uncovering this mystery by observing the spatiotemporal evolution of a wave function delocalized over many particles interacting with each other. Having this dream in mind, we have developed coherent control with precisions on the picometer spatial and attosecond temporal scales. Now we apply this ultrafast and ultrahigh-precision coherent control to delocalized wave functions of macroscopic many-particle systems such as an ensemble of ultracold Rydberg atoms and a bulk solid, envisaging the quantum-classical boundary connected smoothly.

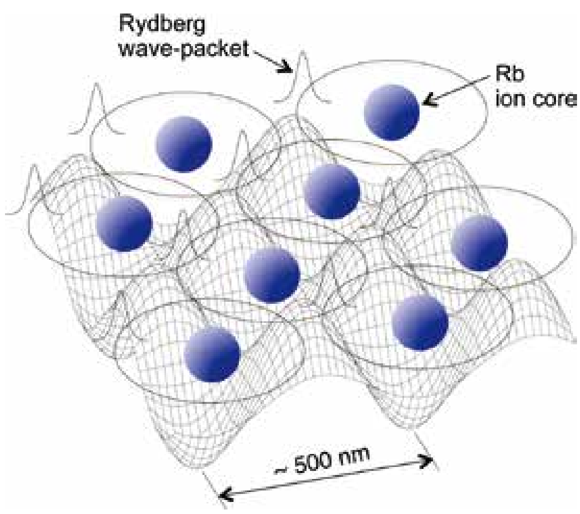

Figure 1. Schematic of the many-body system of ultracold Rydberg atoms.[2)]

Selected Publications

- H. Katsuki *et al.*, "Visualizing Picometric Quantum Ripples of Ultrafast Wave-Packet Interference," *Science* **311**, 1589–1592 (2006).
- H. Katsuki *et al.*, "Actively Tailored Spatiotemporal Images of Quantum Interference on the Picometer and Femtosecond Scales," *Phys. Rev. Lett.* **102**, 103602 (2009).
- K. Hosaka *et al.*, "Ultrafast Fourier Transform with a Femtosecond-Laser-Driven Molecule," *Phys. Rev. Lett.* **104**, 180501 (2010).
- H. Goto *et al.*, "Strong-Laser-Induced Quantum Interference," *Nat. Phys.* **7**, 383–385 (2011).
- H. Katsuki *et al.*, "All-Optical Control and Visualization of Ultrafast Two-Dimensional Atomic Motions in a Single Crystal of Bismuth," *Nat. Commun.* **4**, 2801 (2013).
- N. Takei *et al.*, "Direct Observation of Ultrafast Many-Body Electron Dynamics in a Strongly-Correlated Ultracold Rydberg Gas," *arXiv:1504.03635* (2015).

1. Time Domain Ramsey Interferometry with Interacting Rydberg Atoms[3)]

We theoretically investigate the dynamics of a gas of strongly interacting Rydberg atoms subject to a time domain Ramsey interferometry protocol. The many-body dynamics is governed by an Ising-type Hamiltonian with long range interactions of tunable strength. We analyze and model the contrast degradation and phase accumulation of the Ramsey signal and identify scaling laws for varying interrogation times, ensemble densities and ensemble dimensionalities.

References

1) K. Tonomura *et. al.*, *Am. J. Phys.* **57**, 117 (1989).
2) K. Ohmori, *Found. Phys.* **44**, 813–818 (2014).
3) C. Sommer *et al.*, *arXiv:1604.02314* (2016).

Awards

TAKEDA, Shuntaro; Young Scientist Award of the Physical Society of Japan (2016).
TAKEDA, Shuntaro; Inoue Research Award for Young Scientists (2016).

* IMS International Internship Program
† carrying out graduate research on Cooperative Education Program of IMS with Tokyo Institute of Technology