

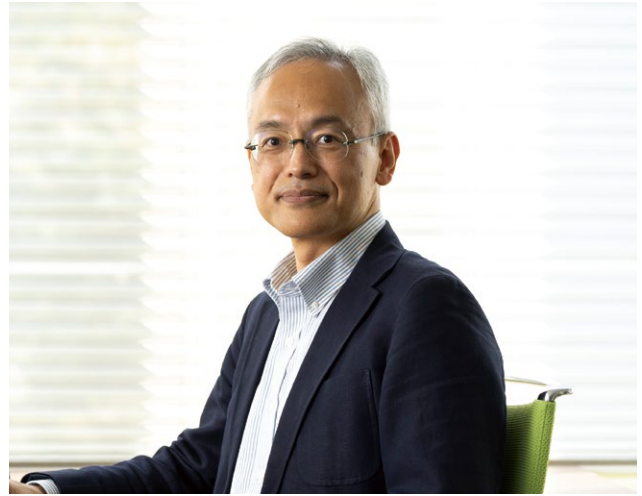
2025

**RIKEN Center for
Quantum Computing**
Annual Report

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Director's Greetings



The RIKEN Center for Quantum Computing (RQC) was established in April 2021. Our mission is to develop quantum computers and pioneer the frontier of quantum information science. We engage in full-stack research and development encompassing layers of science and technology from hardware to software and basic science to applications.

Quantum mechanics is the most fundamental theory of physics, which has evolved through the collective efforts of numerous researchers. It has contributed widely to the development of science and technology in general. Quantum information science, which emerged in the late 20th century, has also attracted attention for exploiting new possibilities by applying the principles of quantum mechanics to information science.

Last year, various events and symposia were held to mark the 100th anniversary of the quantum mechanics theory. For example, the Osaka-Kansai Expo hosted a special exhibition titled “entangle moment: [quantum / earth / universe] x art,” which attracted many visitors. Quantum mechanics is now widely recognized not only within the academic community but also by the public.

The global research and development of quantum computers are rapidly gaining momentum, with new ideas and technologies constantly emerging. At RQC, we are at the forefront of this dynamic landscape, conducting research on various quantum computing platforms, such as superconducting, optical, and semiconducting. In FY2025, we established a new research team on computer engineering and are accelerating our research and development. We foster a culture of mutual discovery and learning, generating new ideas through synergy by pursuing multiple approaches simultaneously. RQC also houses other experimental research teams developing basic technology for quantum information processing through novel techniques and several theoretical teams covering quantum information theory, quantum computing theory, quantum algorithms, quantum architecture, quantum software, etc. Our diverse teams collaborate on various topics, from basic science to applications and from experiments to theories, striving for breakthrough research every day.

In April of last year, RIKEN and Fujitsu Limited developed a 256-qubit superconducting quantum computer that will significantly expand their joint quantum computing capabilities. The new system overcomes some key technical challenges, including appropriate cooling within the dilution refrigerator, which is achieved through the incorporation of high-density implementation and cutting-edge thermal design.

In March of this year, we launched a quantum computing cloud service featuring the “A-II” quantum computer, which is equipped with a 144-qubit chip. Compared to the domestically developed “A” quantum computer released in 2023, this system more than doubles the number of qubits, enabling quantum computations on a scale that cannot be achieved by classical computers.

Furthermore, RQC plays a pivotal role as the headquarters and the quantum computer development hub at the core of all twelve Quantum Technology Innovation Hubs under the Quantum Technology and Innovation Strategy promoted by the Government of Japan. We spearhead advancements and collaborations in Japanese quantum technology research and development. Through activities connecting participants in academia, industry, and the government, as well as by sharing knowledge across diverse subfields and tightening lateral collaborations, we accelerate innovation cycles, promote the development of science and technology, and contribute value to society.

The fusion of quantum information science with rapidly evolving cutting-edge technologies, such as artificial intelligence, high-performance computers, semiconductors, and optical communication, is also emerging as an essential topic. We will further strengthen collaborations among researchers inside and outside RIKEN, encourage interdisciplinary discussions among researchers with diverse backgrounds and expertise, and foster future leaders who will shape the next generation of quantum science and technology, while continuing our persistent research and development efforts towards realizing quantum computers.

June 30, 2026

Overview of RIKEN Center for Quantum Computing

The RIKEN Center for Quantum Computing (RQC) launched a new team in FY2025, giving it a lineup of 21 research laboratories in total. It is developing quantum computers with various physics-related teams that cover the superconducting method, the optical method, the semiconductor method, cold-atom platforms, and so on, and promoting research and development by theoretical teams that cover quantum algorithms, quantum computation theory, and other fields.

RQC adopts various approaches to develop quantum computers, enhance their functions, and combine them with computational science and electronics technologies, while striving to expand their computable capabilities toward resolving social challenges, as well as promoting basic research in order to establish the next generation of quantum computer technology, with the aim of realizing quantum computers as innovative information processing units based on the principles of quantum mechanics.

RIKEN Center for Quantum Computing

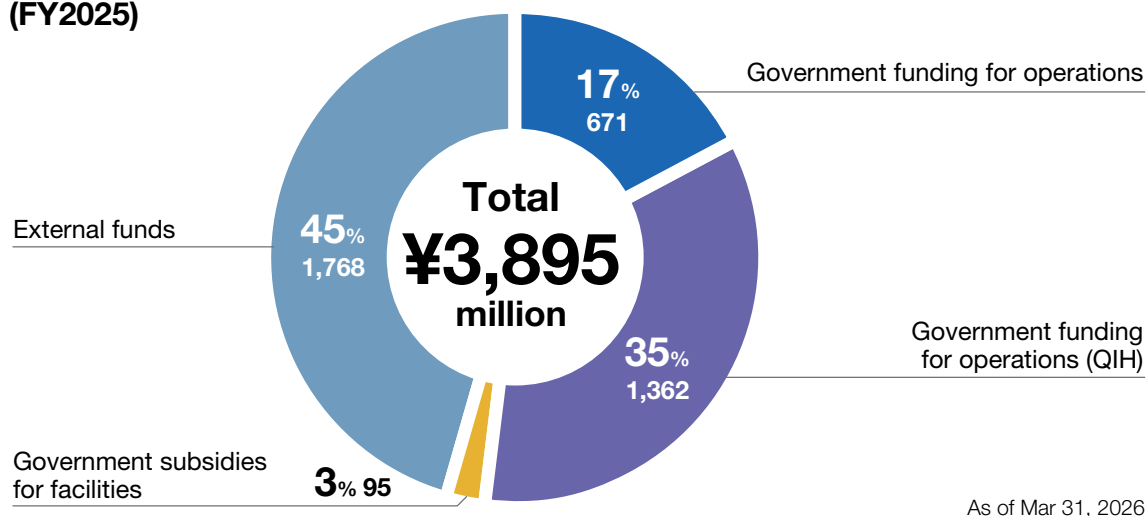
Director: Yasunobu Nakamura
Deputy director: Akira Furusawa, Shinichi Yorozu

■	Superconducting Quantum Electronics Research Team: Yasunobu Nakamura
■	Superconducting Quantum Simulation Research Team: Jaw-Shen Tsai
■	Superconducting Quantum Electronics Joint Research Unit: Eisuke Abe
■	Superconducting Quantum Computing System Research Unit: Yutaka Tabuchi
■	Hybrid Quantum Circuits Research Team: Atsushi Noguchi
■	Optical Quantum Computing Research Team: Akira Furusawa
■	Optical Quantum Control Research Team: Hidehiro Yonezawa
■	Nanophotonic Cavity Quantum Electrodynamics Research Team: Takao Aoki
■	Quantum Many-Body Dynamics Research Team: Takeshi Fukuhara
■	Cold-Atom Quantum System Research Team: Sylvain de Léséleuc
■	Floating-Electron-Based Quantum Information RIKEN Hakubi Research Team: Erika Kawakami
■	Semiconductor Quantum Information Device Research Team: Seigo Tarucha
■	Semiconductor Quantum Information Device Theory Research Team: Daniel Loss
■	Quantum Computing Theory Research Team: Keisuke Fujii
■	Quantum Information Physics Theory Research Team: Franco Nori
■	Quantum Computational Science Research Team: Seiji Yunoki
■	Quantum Computer Architecture Research Team: Hayato Goto
■	Quantum Computer System Design Research Team: Yasunari Suzuki
■	Analytical Quantum Complexity RIKEN Hakubi Research Team: Tomotaka Kuwahara
■	Mathematical Quantum Information RIKEN Hakubi Research Team: Bartosz Regula
■	RIKEN RQC-FUJITSU Collaboration Center: Yasunobu Nakamura
■	Office of the Center Director: Shinichi Yorozu

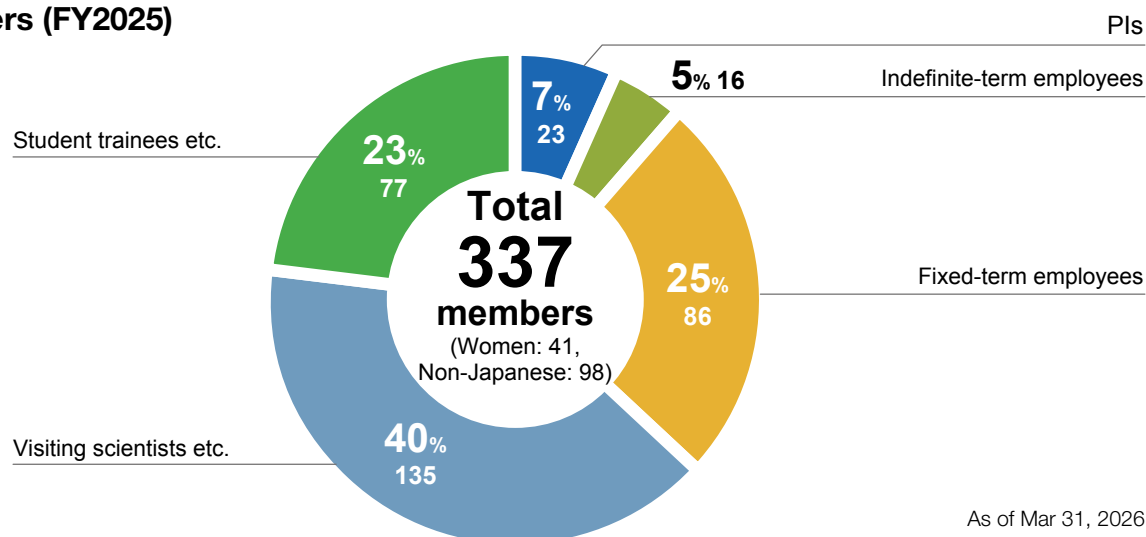
■ Superconductivity
 ■ Optics
 ■ Atoms
 ■ Electrons
 ■ Semiconductor
 ■ Theory
 ■ Administration

Overview of RIKEN Center for Quantum Computing (Continued)

Budget (FY2025)



Members (FY2025)



RQC Colloquiums and RQC Seminars

FY2025 RQC Colloquiums

At the RQC, we regularly invite renowned researchers and hold RQC Colloquiums. RQC Colloquiums were held 12 times in FY2025, and vigorous discussions took place as a result of making the events known to other centers as well, not just the RQC.

No.	Date	Speaker	Affiliation	Title
33	April 4, 2025	Prof. Dong Daoyi	Australian AI Institute, University of Technology Sydney (Australia)	Optimization and error analysis in quantum tomography, and quantum autoencoders
34	May 12, 2025	Prof. Sabrina Maniscalco	Algorithmiq Ltd. the University of Helsinki (Finland)	Making Quantum Matter: A Case Study in Application-Driven Quantum Computing for Chemistry and Life Sciences
35	May 29, 2025	Prof. Kim Yoon-Ho	Department of Physics, Pohang University of Science and Technology (Korea)	Learning more about Quantum Systems via Weak Interactions and Measurements
36	July 23, 2025	Dr. Thomas Noel	Infleqtion, Inc. (USA)	Benchmarking and Fault-Tolerant Operation of a Neutral Atom Quantum Processor
37	September 10, 2025	Prof. Radim Filip	Palacky University Olomouc (Czech Republic)	Quantum Non-Gaussianity
38	October 21, 2025	Prof. Naoki Yamamoto	Keio University (Japan)	Quantum Algorithmic Primitive for Quantum Machine Learning
39	November 7, 2025	Prof. Kae Nemoto	Okinawa Institute of Science and Technology (Japan)	Quantum Computer Architecture from FTQC to Near-Future Quantum Processors
40	December 25, 2025	Prof. Leonid Glazman	Yale University (USA)	Non-Equilibrium Quasiparticles in Superconducting Qubits
41	January 9, 2026	Dr. Matthias Troyer	Microsoft Inc. (USA)	Quantum, AI and the Path to Commercial Advantage
42	February 5, 2026	Prof. Barry C. Sanders	University of Calgary (Canada)	Superposing Coherent States for Fun & Profit
Special	February 19, 2026 (onsite)	Dr. John Martinis	Qolab inc. (USA)	Do Macroscopic Variables Obey Quantum Mechanics?
43	March 11, 2026	Dr. Jaw-Shen Tsai	RIKEN (Japan)	Science and Technology of Superconducting Macroscopic Quantum States - A Journey around Josephson Qubits

FY2025 RQC Seminars

Additionally, at the RQC we also hold RQC Seminars, which each PI organizes independently. RQC Seminars were held 69 times in FY2025, and vigorous discussions were held that went beyond the team framework with the aim of making breakthroughs related to the research and development of quantum computers.

No.	Date	Speaker	Affiliation
189	April 16, 2025	Prof. Xiao Zheng	Fudan University (China)
190	April 17, 2025	Dr. Sorawis Sangtawesin	School of Physics, Institute of Science, Suranaree University of Technology (Thailand)
191	April 10, 2025	Mr. Lee Yun-Yan	Australian National University (Australia)
192	April 10, 2025	Dr. Xiao Shuixin	Australian National University (Australia)
193	April 23, 2025	Dr. Daniel Herr	d-fine (Switzerland)
194	May 8, 2025	Dr. Thomas Isaac Layton	JSPS, RIKEN (Japan)
195	May 15, 2025	Prof. Sandro Wimberger	University of Parma, and INFN (Italy)
196	May 16, 2025	Mr. Daniele Lamberto	University of Messina (Italy)
197	May 19, 2025	Mr. Gabriele Orlando	University of Messina (Italy)
198	May 23, 2025	Mr. Andrea Zappalà	University of Messina (Italy)
199	May 26, 2025	Mr. Samuel Napoli	University of Messina (Italy)
200	May 21, 2025	Mr. Michael Tschaffon	Institut für Quantenphysik, Universität Ulm (Germany)
201	May 22, 2025	Dr. Roberto Stassi	University of Messina (Italy)
202	May 28, 2025	Prof. Salvatore Savasta	University of Messina (Italy)
203	May 30, 2025	Prof. Yuto Ashida	The University of Tokyo (Japan)
204	July 28, 2025	Dr. Alex W. Chin	Sorbonne University & CNRS (France)
205	June 26, 2025	Prof. Gokul Subramanian Ravi	University of Michigan, Computer Science and Engineering (USA)
206	July 23, 2025	Dr. Yasunari Suzuki	RIKEN (Japan)
207	August 6, 2025	Prof. Hossein Sadeghpour	Harvard University, Institute for Theoretical Atomic, Molecular and Optical Physics (USA)
208	July 30, 2025	Mr. Thomas Lagoutte - Ferre	ENS Paris-Saclay (France)
209	August 18, 2025	Dr. Haruna Katayama	Hiroshima University (Japan)
210	July 25, 2025 (onsite)	Prof. Matthias Christandl	University of Copenhagen (Denmark)
211	July 25, 2025 (onsite)	Prof. Wang Xin	Hong Kong University of Science and Technology (China)
212	July 25, 2025 (onsite)	Prof. Li Yinan	School of Artificial Intelligence, Wuhan University (China)
214	August 12, 2025	Mr. Zheng Ri-Hua	Fuzhou University (China)
215	August 8, 2025	Prof. Chen Ye-Hong	Fuzhou University (China)
216	August 14, 2025	Mr. Yan Ke-Xiong	Fuzhou University (China)
217	August 13, 2025	Prof. Liu Tao	South China University of Technology (China)
218	August 15, 2025	Prof. Yang Chuiping	Hangzhou Normal University (China)
219	August 20, 2025 (onsite)	Prof. Xiang Zeliang	Sun Yat-Sen University (China)
220	August 21, 2025 (onsite)	Mr. Gong RuiYang	Sun Yat-Sen University (China)
221	August 25, 2025	Dr. Chen MingYuan	Nanjing University (China)
222	November 10, 2025	Dr. Alexander Poddubny	Weizmann Institute of Science (Israel)
223	September 2, 2025	Ms. Zou YuHong	Nanjing University (China) College of Engineering and Applied Sciences (USA)
224	September 3, 2025	Ms. She Min	Nanjing University (China)

No.	Date	Speaker	Affiliation
225	September 22, 2025	Dr. Steven Mark Anlage	Quantum Materials Center, University of Maryland (USA)
226	September 25, 2025	Dr. Cheng-Yun Hsieh	National Taiwan University (Taiwan)
227	October 1, 2025	Dr. Mustafa Bakr	University of Oxford (UK)
228	September 25, 2025	Dr. Nikita Astrakhantsev	Google Quantum AI (USA)
229	November 4, 2025	Prof. Li FuLi	Xi'an Jiaotong University (China)
230	September 19, 2025	Dr. Zhou ZhengYang	Zhejiang Sci-Tech University School of Science (China)
231	September 17, 2025	Mr. Utkarsh Azad	Xanadu Quantum Technologies Inc. (Canada)
232	October 2, 2025	Dr. Korenobu Matsuzaki	RIKEN (Japan)
233	September 29, 2025	Dr. Mostafizur Rahaman Laskar	IBM Quantum, IRL Bangalore (India)
234	November 11, 2025	Prof. Li FuLi	School of Physics, Xi'an Jiaotong University (China)
235	September 25, 2025	Prof. Stefan Ulmer	Heinrich-Heine-Universität Düsseldorf (Germany) RIKEN (Japan)
236	October 17, 2025	Dr. Tyler A. Cochran	QuEra Computing Inc. (USA)
237	October 20, 2025	Dr. Chu Kai-I	National Central University (Taiwan)
238	October 21, 2025	Dr. David Herrera-Martí	CEA-List, Grenoble (France)
239	October 22, 2025	Prof. Ku Huan-Yu	National Taiwan Normal University (Taiwan)
240	October 24, 2025 (onsite)	Mr. Chen Po-Yang	National Taiwan Normal University (Taiwan)
241	October 24, 2025 (onsite)	Mr. Wu Chao-Hsien	National Taiwan Normal University (Taiwan)
242	October 28, 2025	Dr. Svend Krøjer Møller	Niels Bohr Institute (Denmark)
243	December 9, 2025	Mr. Linus Ekstrom	Honda Research Institute Europe (Japan)
244	November 7, 2025	Prof. XueYue (Sherry) Zhang	Columbia University (USA)
245	November 20, 2025	Dr. Pawel Wocjan	IBM Quantum (USA)
246	December 4, 2025	Dr. Chung-Ting Ke	Academia Sinica (Taiwan)
247	November 20, 2025 (onsite)	Dr. Jeroen Verjauw	IQM Quantum Computers (Finland)
248	December 15, 2025	Prof. Kay Brandner	University of Nottingham (UK)
249	December 22, 2025	Prof. Jens Koch	Department of Physics and Astronomy, Northwestern University (USA)
250	December 19, 2025	Prof. Hoi IoChun	City University of Hong Kong (China)
251	January 8, 2026	Dr. Maxwell Drimmer	Department of Physics, ETH Zürich (Switzerland)
252	February 4, 2026	Prof. William D. Oliver	MIT, EECS and Physics (USA)
253	January 22, 2026	Prof. Jean-Jacques Slotine	MIT (USA)
254	March 13, 2026	Prof. En-Jui Kuo	National Yang Ming Chiao Tung University (Taiwan)
255	February 13, 2026	Dr. Graeme Pleasance	University of Stellenbosch (South Africa)
256	March 3, 2026	Dr. Robert Loew	University of Stuttgart (Germany)
257	February 19, 2026	Prof. Adrian Lupascu	University of Waterloo (Canada)
258	March 3, 2026	Dr. Raymond W. Simmonds	National Institute of Science and technology (USA)

Collaborations

International

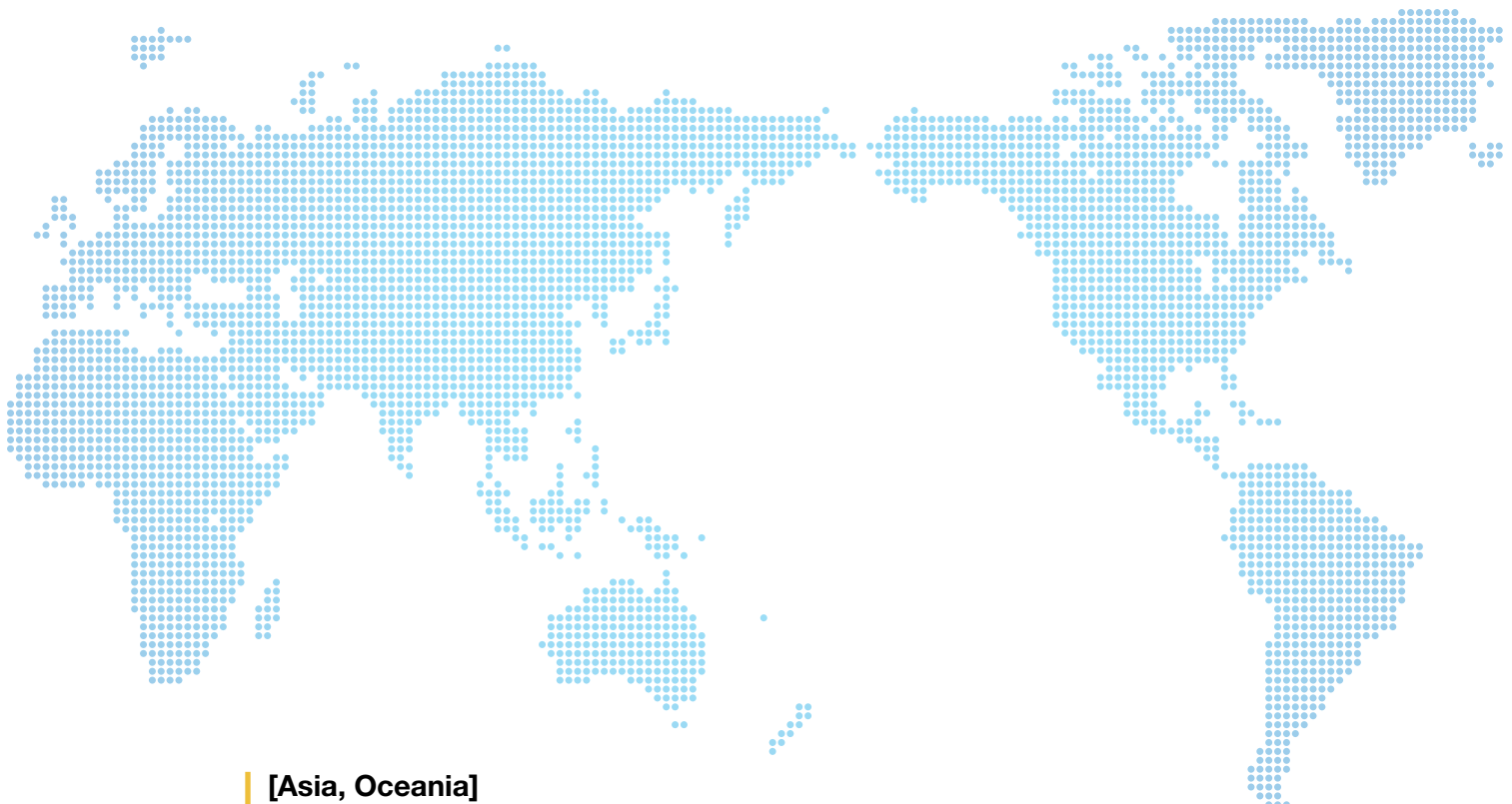
[Europe]

- B. Verkin ILTPE of NASU
- Centre national de la recherche scientifique (CNRS)
- Delft University of Technology (TU Delft)
- École normale supérieure (ENS)
- École polytechnique
- Freie Universität Berlin (FU Berlin)
- Imperial College London (ICL)
- Institute of Science and Technology Austria (ISTA)
- Interuniversity Microelectronics Centre (IMEC)
- Johannes Gutenberg University Mainz
- Kazan Federal University
- Lancaster University
- Marietta Blau Institute
- Max Planck Institute of Quantum Optics
- National Physical Laboratory (NPL)

- Niels Bohr Institutet
- Palacky University
- RWTH Aachen University
- Scuola Normale Superiore di Pisa
- Swiss Federal Institute of Technology in Lausanne (EPFL)
- University of Augsburg
- University of Basel
- University of Glasgow
- University of Hamburg
- University of Stuttgart
- University of the Basque Country
- University of Tübingen
- University of Vienna etc.

[North America]

- Cornell University
- Florida State University
- Harvard University
- IBM
- Intel Corporation
- McGill University
- Massachusetts Institute of Technology (MIT)
- Princeton University
- University of Notre Dame
- University of California, Berkeley
- University of Sherbrooke etc.



[Asia, Oceania]

- Australian National University
- Center for Axion and Precision Physics Research, Institute for Basic Science
- Griffith University
- King Fahd University of Petroleum and Minerals (KFUPM)

- National Tsing Hua University (NTHU)
- National University of Singapore (NUS)
- The University of New South Wales (UNSW) etc.

National

[Research Institute]

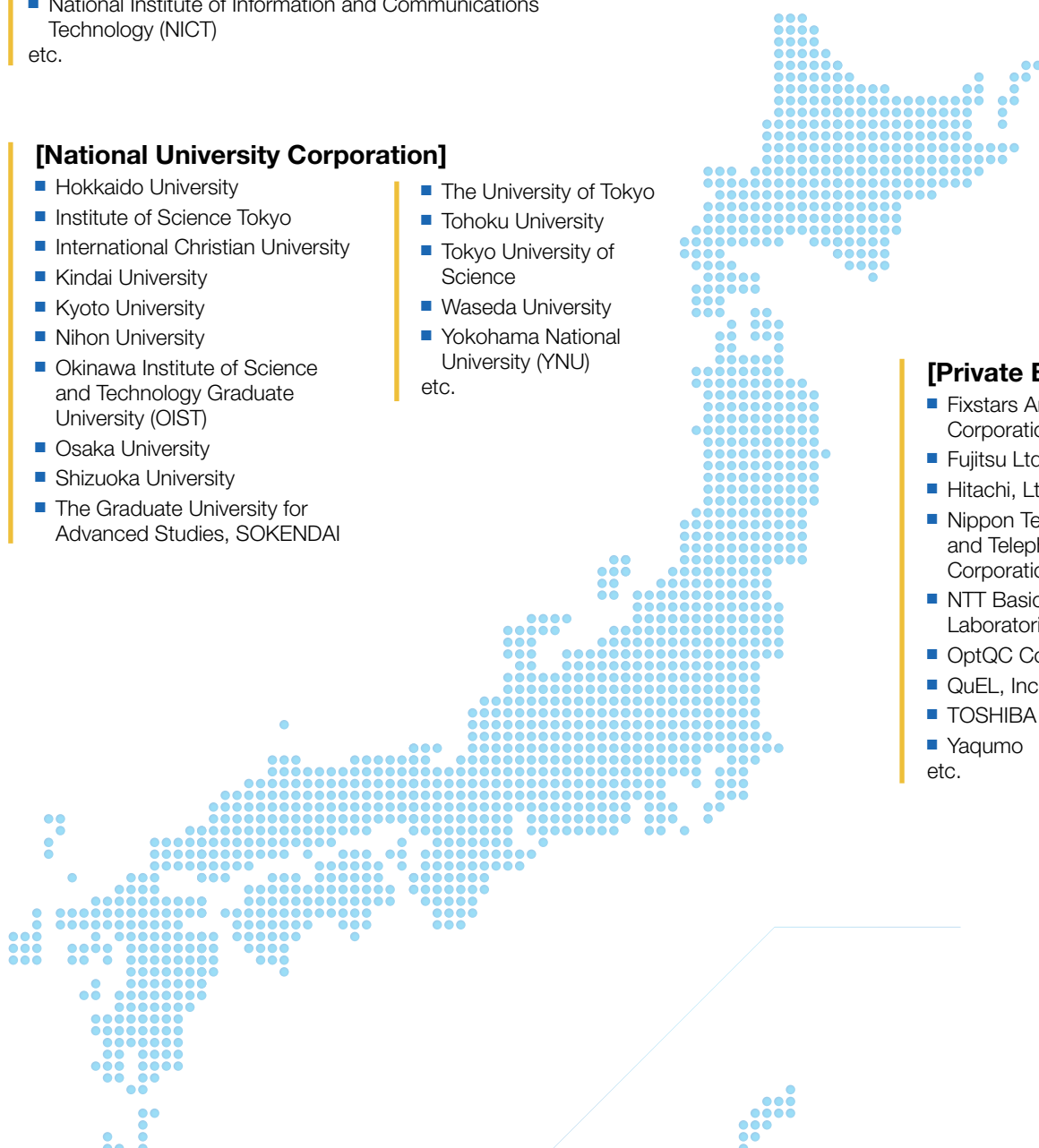
- Institute for Molecular Science (IMS)
- High Energy Accelerator Research Organization
- National Institute of Advanced Industrial Science and Technology (AIST)
- National Institute of Information and Communications Technology (NICT)
- etc.

[National University Corporation]

- | | |
|--|---|
| <ul style="list-style-type: none">■ Hokkaido University■ Institute of Science Tokyo■ International Christian University■ Kindai University■ Kyoto University■ Nihon University■ Okinawa Institute of Science and Technology Graduate University (OIST)■ Osaka University■ Shizuoka University■ The Graduate University for Advanced Studies, SOKENDAI | <ul style="list-style-type: none">■ The University of Tokyo■ Tohoku University■ Tokyo University of Science■ Waseda University■ Yokohama National University (YNU)etc. |
|--|---|

[Private Business]

- Fixstars Amplify Corporation
- Fujitsu Ltd.
- Hitachi, Ltd.
- Nippon Telegraph and Telephon Corporation (NTT)
- NTT Basic Research Laboratories (NTT-BRL)
- OptQC Corp.
- QuEL, Inc.
- TOSHIBA CORPORATION
- Yaquomo
- etc.

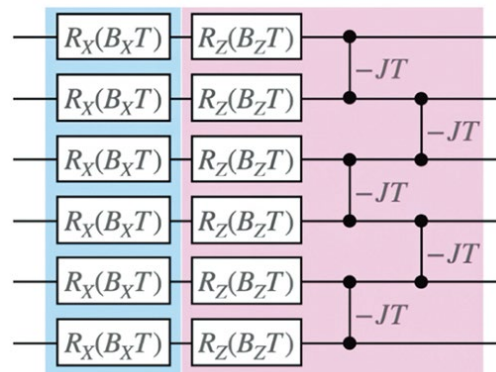


Press Releases

April 11, 2025

Simulating Floquet scrambling circuit on trapped-ion quantum computers

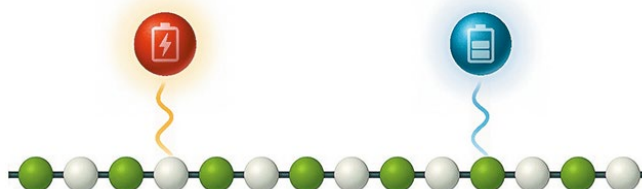
Quantum Computational Science Research Team



May 13, 2025

Advent of the topological quantum battery

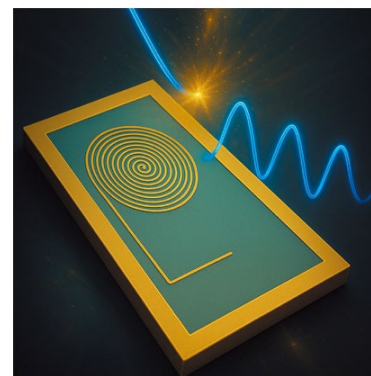
Analytical Quantum Complexity RIKEN Hakubi Research Team



June 13, 2025

Intrinsic quality factors approaching 10 million in superconducting planar resonators enabled by spiral geometry

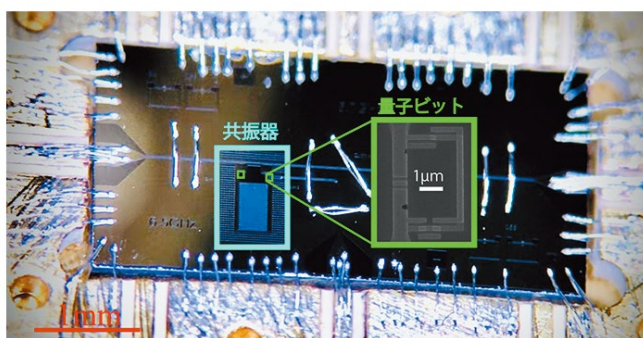
Hybrid Quantum Circuits Research Team



June 17, 2025

Spectral properties of two superconducting artificial atoms coupled to a resonator in the ultrastrong coupling regime

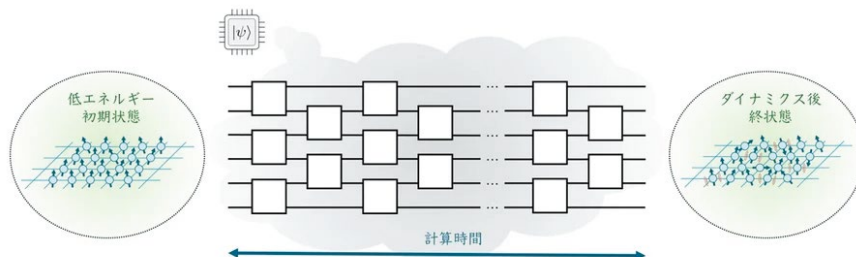
Superconducting Quantum Simulation Research Team



September 25, 2025

**Quantum computing can be made more efficient for low-energy states:
Toward faster simulation of quantum materials**

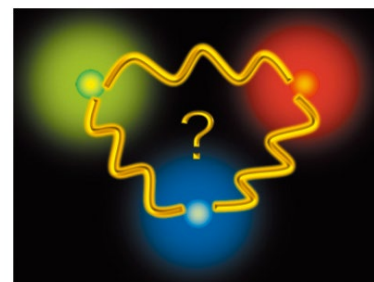
Analytical Quantum Complexity RIKEN Hakubi Research Team



October 17, 2025

**Clustering of conditional mutual information and
quantum Markov structure at arbitrary temperatures**

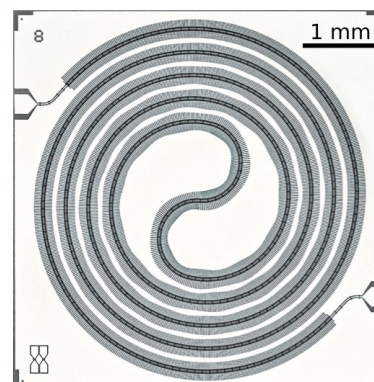
Analytical Quantum Complexity RIKEN Hakubi Research Team



October 30, 2025

**Josephson traveling-wave parametric amplifier based
on a low-intrinsic-loss lumped-element coplanar waveguide**

Superconducting Quantum Electronics Research Team

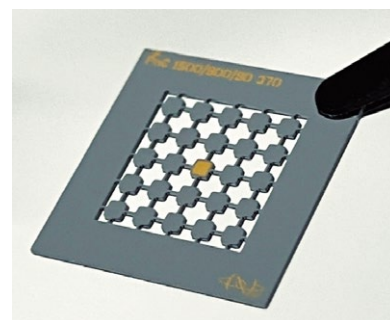


December 9, 2025

**High-Q membrane resonators using ultra-high-stress
crystalline TiN films**

Superconducting Quantum Electronics Research Team

Hybrid Quantum Circuits Research Team

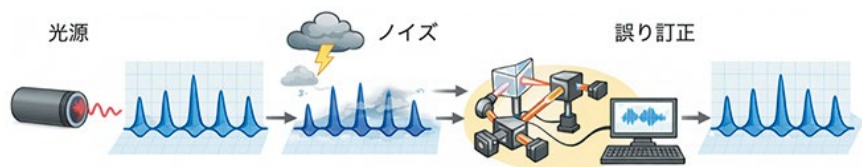


Press Releases (Continued)

February 26, 2026

Continuous-variable fault-tolerant quantum computation under general noise

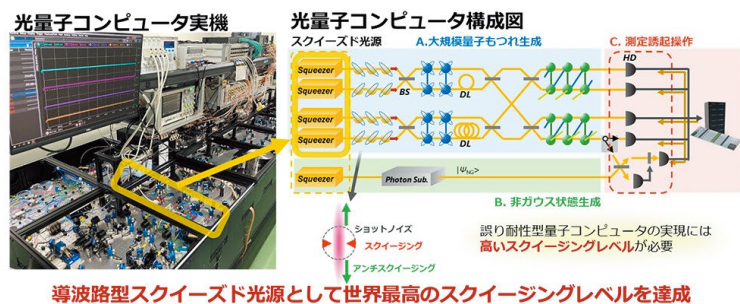
Quantum Computing Theory Research Team



March 6, 2026

Generation of 10-dB squeezed light from a broadband waveguide optical parametric amplifier with improved phase locking method

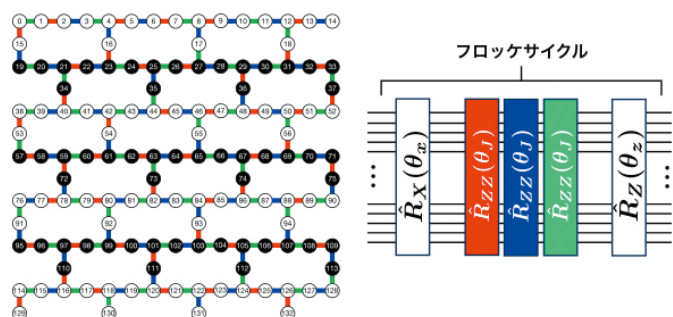
Optical Quantum Computing Research Team



March 12, 2026

Unveiling clean two-dimensional discrete time crystals on a digital quantum computer

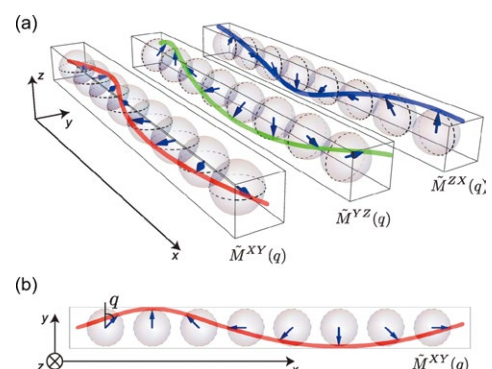
Quantum Computational Science Research Team



March 23, 2026

Measuring entanglement without local addressing in quantum many-body simulators via spiral quantum state tomography

Quantum Many-Body Dynamics Research Team



Awards

August 12, 2025

Postdoctoral Researcher Dr. Asher Curtis Jennings and five others awarded Best Poster Award

Postdoctoral Researcher Dr. Asher Curtis Jennings of the Floating-Electron-Based Quantum Information RIKEN Hakubi Research Team and five other researchers have received the Best Poster Award at the Low Temperature Physics Conference, the largest and most prestigious international conference in the field of low-temperature physics. This award recognizes the originality, clarity, and future potential of research, and is presented to encourage the academic activities of presenters, including early-career researchers. Dr. Jennings and colleagues received the award in recognition of their research on RF reflectometry measurements of electrons on the surface of helium.

November 12, 2025

Team Director Dr. Takao Aoki was awarded the 29th Matsuo Foundation Hiroshi Takuma Memorial Academic Award (FY2025)

Dr. Takao Aoki, Team Director of the Nanophotonic Cavity Quantum Electrodynamics Research Team, has received the 29th Matsuo Foundation Takuma Hiroshi Memorial Academic Award (FY2025). This award is presented annually to a researcher who has made particularly distinguished contributions to the fields of atomic and molecular physics and quantum electronics. Dr. Aoki was honored in recognition of his outstanding research achievements demonstrating remarkable and widespread impact in the field of physics.



January 9, 2026

Student Trainee Hochan Chung awarded Best Student Poster Presentation Award

Student Trainee Hochan Chung of the Floating-Electron-Based Quantum Information RIKEN Hakubi Research Team has received the Best Student Poster Presentation Award. This award is presented to the student poster judged most outstanding by participant vote at the 2nd Interdisciplinary Quantum Roundtable (IQuRa). Mr. Chung received the award for his poster presentation on the foundations for creating quantum memory using cryogenic floating electrons.

March 23, 2026

RIKEN Hakubi Team Leader Dr. Erika Kawakami awarded the 4th JSAP Diversity & Inclusion Award – Women Researchers Encouragement Award (FY2025)

Dr. Erika Kawakami, RIKEN Hakubi Team Leader of the Floating-Electron-Based Quantum Information RIKEN Hakubi Research Team, has received the 4th JSAP Diversity & Inclusion Award – Women Researchers Encouragement Award (FY2025). This award honors women researchers or engineers who have achieved outstanding results in research and development in the field of applied physics, as well as researchers, engineers, organizations, and groups that have made significant contributions to diversity and inclusion in the field. Dr. Kawakami received the award for her research on a quantum information processing platform using floating electrons.



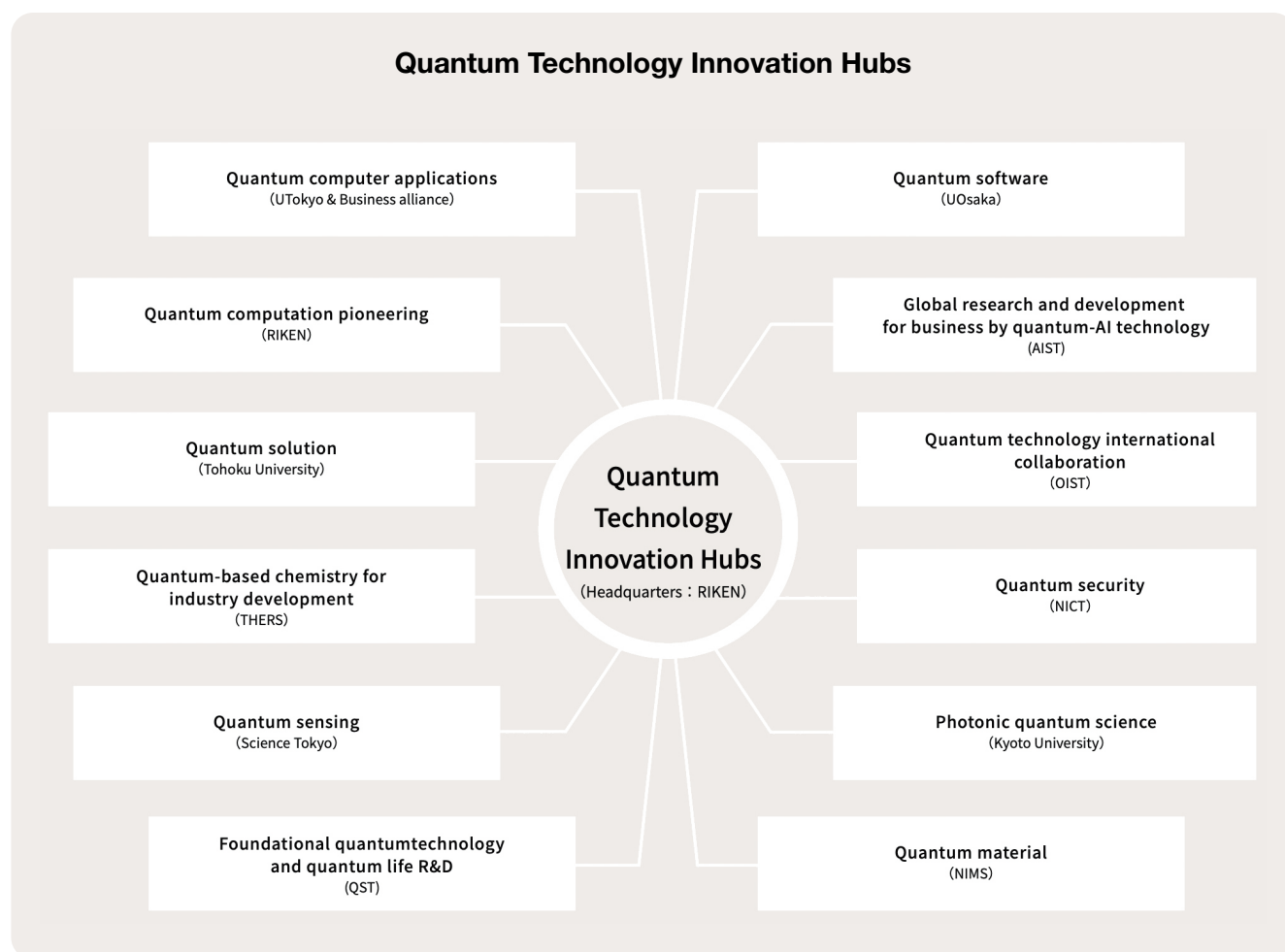
Overview of Quantum Technology Innovation Hubs

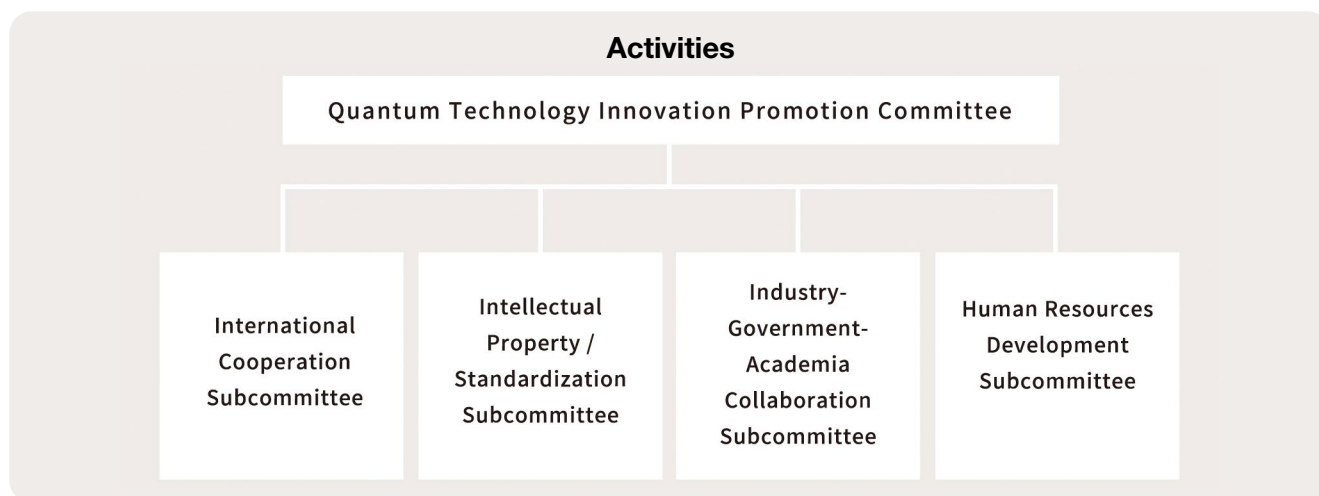


The twelve Quantum Innovation Hubs (QIH), working together as one, are accelerating the social implementation of quantum technology.

Quantum Innovation Hubs (hereinafter QIH) were established with the aim of strengthening international competitiveness in quantum technology, based on the government strategy known as the Quantum Technology and Innovation Strategy (January 2020). They collaborate with academia, industry, and government to engage in activities ranging from basic research on quantum technology to technology verification, intellectual property management, and human resources development. QIH initially began with eight hubs and has since expanded to twelve.

As the core organization of the QIH, RIKEN performs a headquarters function that facilitates coordination among the twelve hubs. At the same time, RIKEN is one of the twelve hubs, and it operates as a quantum computation pioneering hub that carries out research and development of quantum computer systems.





Subcommittees of the QIH

The QIH established and operate the Quantum Technology Innovation Promotion Committee, which promotes the social implementation of quantum technology and makes proposals for the implementation. It has four subcommittees where the hubs discuss themes of each subcommittee field and share strategies in the field.

- International Cooperation Subcommittee: Holds international symposiums and promotes international collaborations such as international joint research.
- Intellectual Property / Standardization Subcommittee: Shares strategies between the hubs on intellectual property and international standardization.
- Industry-Government-Academia Collaboration Subcommittee: Promotes industry-government-academia collaborations aimed at the social implementation of quantum technology.
- Human Resources Development Subcommittee: Promotes an increase in the number of young researchers in the quantum field and the strengthening of human resources development across institutions and research fields.

Pick-up activities in FY2025

As a QIH activity, the International Symposium on Quantum Science, Technology, and Innovation, “Quantum Innovation 2025,” was held at Congress Square Grand Green Osaka from July 29 to August 2, 2025, in conjunction with Expo 2025 Osaka, Kansai, Japan. For its fifth edition, a Moonshot Goal 6 Session aimed at realizing fault-tolerant universal quantum computers and an SIP Session focused on building a quantum society of the future were newly added to the conventional three-day program, extending the event to five days in total. With approximately 1,000 participants from Japan and abroad, Quantum Innovation 2025 became one of the largest international quantum events held in Japan.



Sponsor exhibition



SIP session

In addition, the QIH implemented the MEXT Quantum Science School Program, which is responsible for developing the next generation of talent in quantum technology. In FY2025, Summer School 2025 was held at OIST and other venues. Alongside this, Job Festa was held to promote mobility within the quantum workforce, providing a forum for matching quantum professionals with quantum-related companies.

The QIH are also focusing on outreach activities. Virtual Reality experiences featuring the quantum computer “A” and other exhibits have been showcased at Expo 2025 Osaka, Kansai, Japan, as well as at various other events, receiving highly positive feedback.

Furthermore, to enhance the circulation of quantum-related information, the QIH operate Q-Portal¹, a platform that aggregates information on quantum technology. April 2026 marked three years since its launch, and the Q-Portal's X² account has now surpassed 3,100 followers.

¹ Q-Portal <https://q-portal.riken.jp/> ² Q-Portal's X account https://x.com/Q_Portal_

Overview of Quantum Technology Innovation Hubs (Continued)

Outreach activities in FY2025



A quantum computer VR experience was exhibited at the Expo 2025 Osaka, Kansai, Japan exhibition “entangle moment: [quantum / earth / universe] x art” (August 14-20)



A quantum computer VR experience was exhibited in Science Agora (October 25-26, at the Telecom Center Building)



Job Festa 2027 was held (March 2, 2026, at Ochanomizu Solacity)



Summer School 2025 “Learning Quantum Technology with Leading Instructors” was held (August 31 - September 6, 2025, Okinawa)



Toshio Tonouchi (Ph.D.), Coordinator

Selected Publications

- 1 Toshio Tonouchi *et al.*, “A fast method of verifying network routing with back-trace header space analysis”, IEEE/IFIP IM 2015
- 2 CS Hong, Toshio Tonouchi ed., Internet for Changing Business and New Computing Services: 12th Asia-Pacific Network Operations and Management Symposium, APNOMS 2009, LNCS 5787
- 3 Yoshinori Watanabe *et al.* “UTRAN O&M Support System with Statistical Fault Identification and Customizable Rule Sets”, NOMS 2008
- 4 Nicholas Damianou, Naranker Dulay, Emil Lupu, Morris Sloman, Toshio Tonouchi, “Tools for Domain-Based Policy Management of Distributed Systems”, IEEE/IFIP NOMS 2002
- 5 Toshio Tonouchi *et al.*, “An Implementation of OSI Management Q3 Agent Platform for Subscriber Networks”, IEEE Int Conf on Communication (ICC) 1997

Brief resume

- 1990 B.S. in Information Science, The University of Tokyo
- 1992 M.S. in Information Science, The University of Tokyo
- 1992 Researcher, C&C Systems Research Laboratories, NEC Corporation
- 1999 Visiting Researcher, Imperial College
- 2004 Principal Researcher, Internet System Research Laboratories, NEC Corporation
- 2008 Ph.D. (Information Science), Osaka University
- 2011 Senior Principal Researcher, Service Platform Research Laboratories, NEC Corporation
- 2018 Director, Council for Science, Technology and Innovation, Cabinet Office
- 2020 Deputy Manager, Planning Office for the Quantum Computing Center
- 2021 Research Administrator, Office of the Center Director, RIKEN Center for Quantum Computing
- 2022 Coordinator, Office of the Center Director, RIKEN Center for Quantum Computing (-present)

Dr. Toshio Tonouchi is engaged in work of the headquarters of QIH as a coordinator.

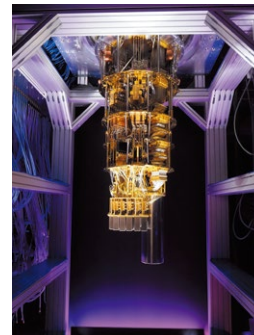
RQC FY2025 Pick-up Topics

Development of one of the world's largest 256-qubit superconducting quantum computers –Quadrupling the number of qubits in the hybrid quantum computing platform to expand computational capacity–

The RIKEN RQC-FUJITSU Collaboration Center was established in April 2021 in collaboration with Fujitsu Limited, and has since conducted joint research aimed at scaling up superconducting quantum computers. Building on the technology developed for the 64-qubit superconducting quantum computer—Japan's second domestically developed quantum computer—launched at this Collaboration Center in October 2023, and applying newly developed high-density implementation technology, we successfully developed a 256-qubit superconducting quantum computer in April 2025 that is among the world's largest.*

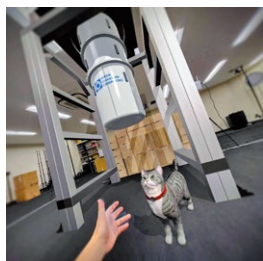
*Among the world's largest: One of the world's largest superconducting quantum computers available to external users (as of April 2025, according to Fujitsu)

256-qubit superconducting quantum computer developed

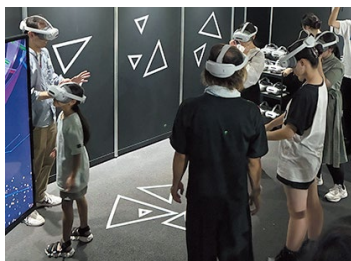


Quantum computer XR experience exhibited at Expo 2025 Osaka, Kansai

From August 14 to 20, 2025, the exhibition “entangle moment: [quantum / earth / universe] x art” (organizers: Cabinet Office, Ministry of Education, Culture, Sports, Science and Technology) was held at the EXPO Exhibition Center “WASSE” at Expo 2025 Osaka, Kansai, attracting 62,360 visitors over the seven-day period. At our booth, we offered an interactive XR experience in which visitors could learn about a quantum computer faithfully reproduced in virtual space using XR technology that integrates virtual and real-world environments, with approximately 1,750 participants taking part. The exhibit was so popular that queues formed throughout the day, with some visitors commenting that it was “the most enjoyable exhibit at the Expo.”



Quantum computer “A” reproduced using XR

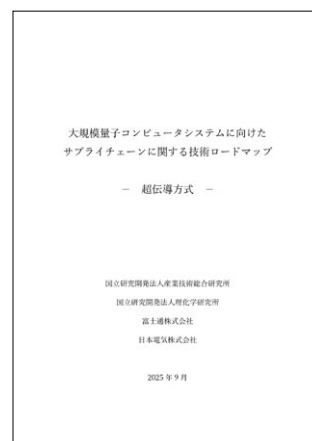


Participants enjoying the VR experience

Technical report on the supply chain for large-scale quantum computer systems released

–(First report) Supply chain for superconducting quantum computers–

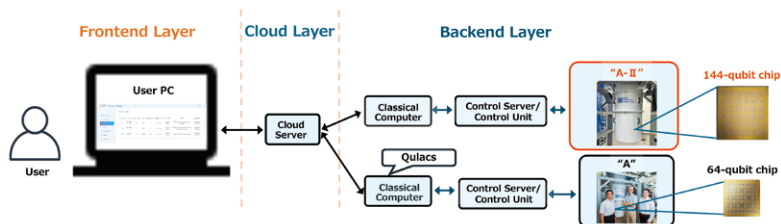
Our center, in collaboration with the National Institute of Advanced Industrial Science and Technology (AIST), NEC Corporation, and Fujitsu Limited, has been working on developing an overview and roadmap for large-scale quantum computer systems. As the first report in this series, a technical report on the supply chain for superconducting quantum computers was released on September 9, 2025.



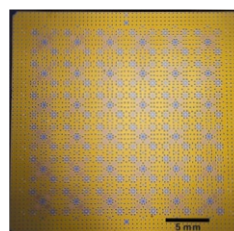
Technical report (Japanese only)
[PDF]
https://www.aist.go.jp/Portals/0/resource_images/aist_j/press_release/pr2025/pr20250909/pr20250909.pdf

Start of operation of quantum computer “A-II” –Accelerating the practical application of quantum computers with a 144-qubit chip–

On March 26, 2026, a joint research group comprising our center and the University of Osaka launched a quantum computing cloud service for the new quantum computer “A-II,” equipped with a 144-qubit chip. Compared to “A,” the domestically developed quantum computer with a 64-qubit chip released in March 2023, the number of qubits has been more than doubled, enabling quantum computations at a scale that cannot be achieved with classical computers. Furthermore, the qubit coherence time has been significantly extended, and the entire “A-II” system, including the refrigerator used to cool the system, has been successfully housed within approximately the same overall dimensions as the entire “A” system.



System configuration diagram of “A-II,” “A,” and “Qulacs”



144-qubit chip (photo)



Quantum computer “A-II”

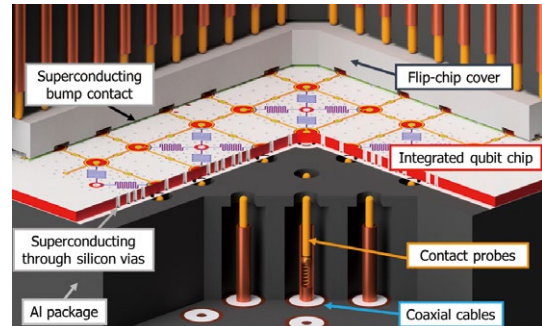
Superconducting Quantum Electronics Research Team

Keywords: Quantum computing, Superconducting circuits, Josephson junction, Microwave quantum optics, Circuit quantum electrodynamics

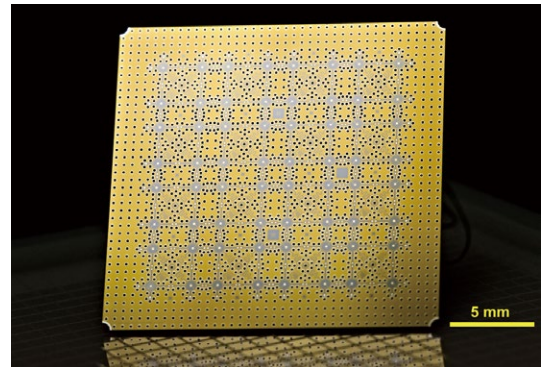
Research Outline

Our team, in collaboration with other teams in RQC as well as collaborators outside RIKEN, is conducting research and development on superconducting quantum circuits for quantum computing and other quantum technologies. We are especially aiming at realizing large-scale superconducting quantum computers. We have been designing and fabricating scalable superconducting qubit chips in parallel with developing wiring and packaging technologies. We have proposed a unique architecture to scale up superconducting quantum computers by combining superconducting qubit chips with through-silicon vias and vertical wiring through spring-probe contacts. This architecture has enabled the development of 64-qubit superconducting quantum computer “A” and 144-qubit superconducting quantum computer “A-II”. We have been improving both gate and readout performances by implementing novel schemes of a high-fidelity all-microwave two-qubit gate and a filter circuit for fast multiplexed readout. To improve the performance of our superconducting quantum computers as a whole system, we have also been developing peripheral technologies including high-performance traveling-wave parametric amplifiers and kinetic inductance parametric amplifiers.

Through these activities, we deepen our understanding of quantum computers further and master superconducting quantum electronics, which leads us to the next breakthroughs.



Schematics of the package for an integrated superconducting-qubit circuit



Photograph of a 64-qubit chip



Yasunobu Nakamura (Ph.D.), RQC Director, Team Director

Selected Publications

- 1 R. Li, K. Kubo, Y. Ho, Z. Yan, S. Inoue, Y. Nakamura, and H. Goto, “Capacitively shunted double-transmon coupler realizing bias-free idling and a high-fidelity CZ gate”, *Phys. Rev. Appl.* 23, 064069 (2025).
- 2 P.A. Spring, L. Milanovic, Y. Sunada, S. Wang, A.F. van Loo, S. Tamate, and Y. Nakamura, “Fast multiplexed superconducting-qubit readout with intrinsic Purcell filtering using a multiconductor transmission line”, *PRX Quantum* 6, 020345 (2025).
- 3 R. Li, K. Kubo, Y. Ho, Z. Yan, Y. Nakamura, and H. Goto, “Realization of high-fidelity CZ gate based on a double-transmon coupler”, *Phys. Rev. X* 14, 041050 (2024).
- 4 Y. Sunada, K. Yuki, Z. Wang, T. Miyamura, J. Ilves, K. Matsuura, P. A. Spring, S. Tamate, S. Kono, and Y. Nakamura, “Photon-noise-tolerant dispersive readout of a superconducting qubit using a nonlinear Purcell filter”, *PRX Quantum* 5, 010307 (2024).
- 5 S. Kono, K. Koshino, Y. Tabuchi, A. Noguchi, and Y. Nakamura, “Quantum non-demolition detection of an itinerant microwave photon”, *Nature Physics* 14, 546 (2018).

Brief resume

- 1992 Researcher, Fundamental Research Laboratories, NEC Corporation
- 1997 Senior Researcher, Fundamental Research Laboratories, NEC Corporation
- 2001 Principal Researcher, Fundamental Research Laboratories, NEC Corporation (-2005)
- 2001 Visiting Researcher, Department of Applied Physics, Delft University of Technology (-2002)
- 2002 Researcher, Frontier Research System, RIKEN (-2013)
- 2005 Research Fellow, Fundamental and Environmental Research Laboratories, NEC Corporation (-2012)
- 2007 Research Fellow, Nanoelectronics Research Laboratories, NEC Corporation
- 2010 Research Fellow, Green Innovation Research Laboratories, NEC Corporation (-2012)
- 2012 Professor, Research Center of Advanced Science and Technology, The University of Tokyo (-2022)
- 2014 Team leader, RIKEN Center for Emergent Matter Science
- 2020 Group Director, RIKEN Center for Emergent Matter Science
- 2021 Director, RIKEN Center for Quantum Computing (-present)
- 2022 Professor, Department of Applied Physics, Graduate School of Engineering, The University of Tokyo (-present)

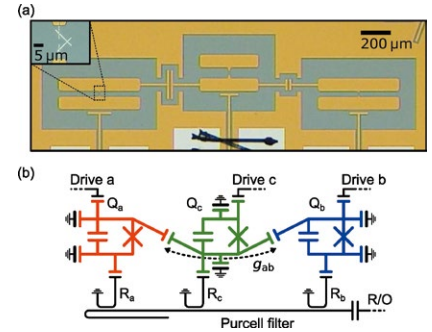
Recent Achievements

Realization of high-fidelity all-microwave two-qubit gate

In collaboration with the Hybrid Quantum Circuits Research Team, we have realized a high-fidelity all-microwave two-qubit gate aiming at large-scale integration of fixed-frequency superconducting qubits. Such a gate scheme is one of the promising approaches to integrate superconducting qubits from the viewpoint of longer coherence time and reduction of wiring cost. However, there were difficulties in improving the two-qubit gate fidelity because of its relatively longer gate time and residual interaction between the qubits.

We have proposed a new two-qubit gate scheme with all-microwave control that can operate faster while suppressing unwanted residual interaction. We introduced a fixed frequency coupler qubit and suppressed residual interaction by almost an order of magnitude. At the same time, we achieved strong dispersive interaction between the coupler and data qubits used for fast two-qubit gate. The two-qubit gate this scheme provides is the so-called CZ gate that is insensitive to the phase of the control microwave pulse. The calibration of the gate is easier than conventional all-microwave two-qubit gates and will be a promising candidate for constructing larger-scale quantum computers.

S. Shirai *et al.*, “High-fidelity all-microwave CZ gate with partial erasure-error detection via a transmon coupler”, arXiv:2511.01260 (2024).

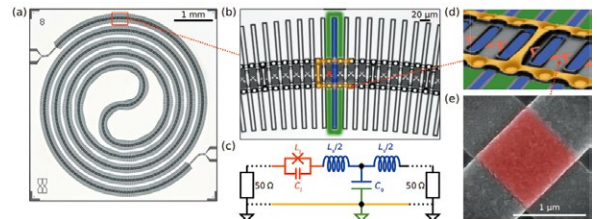


(a) Superconducting qubit circuit used for all-microwave two-qubit gate. The circuit consists of two data qubits on the left and right, and a coupler qubit in the middle. (b) Equivalent circuit for the superconducting qubit circuit shown in (a). The residual interaction between data qubits is suppressed by tuning the ratio between direct coupling and coupler-mediated coupling.

Development of broad-band low-noise Josephson parametric amplifiers

Our team has developed a novel traveling-wave Josephson parametric amplifier (JTWPA) that can achieve an added-noise level close to the quantum limit. Conventional JTWPAs have an issue of having larger added noise introduced by internal loss originating from device structures and gain ripples due to imperfect phase matching. To mitigate these imperfections, we designed a JTWPA consisting of a low-loss Josephson-junction-array coplanar transmission line with stub capacitors. We also mitigate the gain ripples by introducing smooth window modulation superposed on the periodic impedance modulation for phase matching. As a result, we developed a high-performance JTWPA with more than 20-dB gain over 5 GHz of operating frequency, added noise of 0.18 quantum, and saturation power of -99 dBm. This technology significantly improves the performance of superconducting qubit readout.

C.W. Sandbo Chang *et al.*, “Josephson traveling-wave parametric amplifier based on a low-intrinsic-loss lumped-element coplanar waveguide”, Phys. Rev. Applied 24, 044081 (2025).



(a) Chip image of JTWPA. Transmission line forms a spiral shape to minimize the circuit footprint. (b) Enlarged view of the unit cell structure composed of a Josephson junction and stub capacitors. (c) Equivalent circuit of the unit cell structure. (d) Three-dimensional view of the unit cells. Ground planes are connected by air bridges. (e) Enlarged view of a Josephson junction.

Core members

(Research Scientist) **Shuhe Tamate**
(Research Scientist) **Alexander Badrutdinov**
(Research Scientist) **Chung Wai Sandbo Chang**
(Research Scientist) **Shotaro Shirai**
(Postdoctoral Researcher) **Zhiguang Yan**
(Postdoctoral Researcher) **Chih-Chiao Hung**
(Postdoctoral Researcher) **Zhiling Wang**
(Postdoctoral Researcher) **Shiyu Wang**
(Postdoctoral Researcher) **Peter Anthony Spring**
(Postdoctoral Researcher) **Arvind Mamgain**

(Postdoctoral Researcher) **Andras Marton Gunyho**
(Postdoctoral Researcher) **SeongJae Bae**
(Visiting Researcher) **Yu-Chiang Hsieh**
(Senior Technical Staff) **Koichi Kusuyama**
(Senior Technical Staff) **Hikota Akimoto**
(Technical Staff I) **Laszlo Szikszai**
(Technical Staff I) **Harumi Hayakawa**
(Technical Staff I) **Yuji Sakoda**
(Technical Staff I) **Machie Kaito**
(Technical Staff I) **Koki Muto**

Superconducting Quantum Simulation Research Team

Keywords: Superconductivity, Josephson effect, Macroscopic quantum coherence, Superconducting qubit, Superconducting quantum information processing

Research Outline

We are conducting research aimed at realizing superconducting quantum computers and quantum simulators. Here, one-way quantum computers and gate-model quantum computers are considered. Superconducting qubit possesses high degree of freedoms in the circuit design and ability to local control as well as readout quantum states.

Bosonic code, which is relatively easy to correct errors in quantum computers, protects quantum information from errors by taking advantage of the infinite number of degrees of freedom of the resonator. We are conducting research on Cat Qubit, which realizes Cat code, which is one of the practical bosonic codes, using a car parametric oscillator (KPO) using superconducting circuits. By generating a cat state with a two-dimensional KPO circuit (Fig 1 and 2) and evaluating the fidelity using a quantum tomography method, we succeeded in realizing a universal quantum gate that can operate 1-bit and 2-bit gates.

In the 2-bit circuit, we used the unique properties of KPO to generate an entangled cat state in two ways. The first method is to convert the entangled state (bell state) based on the Fock state to the entangled cat state. In the second method, a $\sqrt{i}$ SWAP gate is added to two independent cat states to create an entangled cat state.

These results indicate that the planar superconducting KPO circuit successfully developed in this study has the potential to become a new platform of scalable quantum information processing.

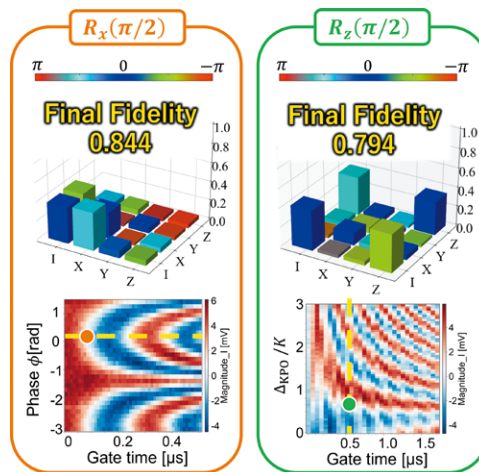


Fig 1. KPO 1-bit operation

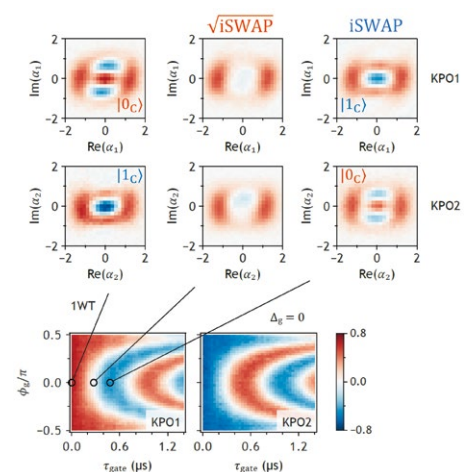


Fig 2. KPO 2-bit operation



Jaw-Shen Tsai (Ph.D.), Team Director

Selected Publications

- 1 D. Hoshi, T. Nagase, S. Kwon, D. Iyama, T. Kamiya, S. Fujii, H. Mukai, S. Ahmed, A. F. Kockum, S. Watabe, F. Yoshihara, and J. S. Tsai, "Entangling Schrödinger's cat states by bridging discrete- and continuous-variable encoding", *Nature Communications*, 16, 1309 (2025).
- 2 A. O. Niskanen, K. Harrabi, F. Yoshihara, Y. Nakamura, S. Lloyd, and J. S. Tsai, "Quantum Coherent Tunable Coupling of Superconducting Qubits", *Science*, 316, 723 (2007).
- 3 T. Yamamoto, Yu. Y. Pashkin, O. Astafiev, Y. Nakamura, and J. S. Tsai, "Demonstration of conditional gate operation using superconducting charge qubits", *Nature*, 425, 941 (2003).
- 4 Yu. A. Pashkin, T. Yamamoto, O. Astafiev, Y. Nakamura, D. V. Averin, and J. S. Tsai, "Quantum oscillations in two coupled charge qubits", *Nature*, 421, 823 (2003).
- 5 Y. Nakamura, Yu. A. Pashkin, and J. S. Tsai, "Coherent Control of Macroscopic Quantum States in a Single-Cooper-pair Box", *Nature*, 398, 786 (1999).

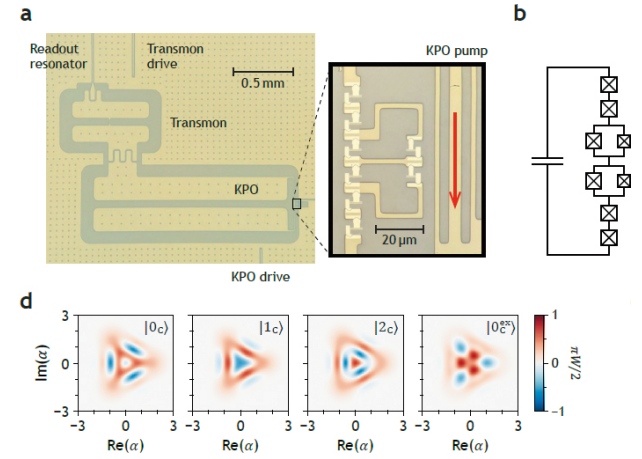
Brief resume

- 1975 Bachelor of Arts degree in Physics at University of California at Berkeley
- 1983 Ph.D. State University of New York at Stony Brook
- 1983 Research Scientist, Microelectronics Research Laboratories, NEC
- 2001 Fellow, Nano Electronics Research Laboratories, NEC
- 2001 Team Leader, Macroscopic Quantum Coherence Team, RIKEN
- 2012 Group Director, Single Quantum Dynamics Research Group, RIKEN
- 2012 Team Leader, Macroscopic Quantum Coherence Research Team, RIKEN
- 2014 Team Leader, Superconducting Quantum Simulation Research Team, RIKEN (present)
- 2015 Professor, Department of Physics, Tokyo University of Science (-present)
- 2022 Professor, Research Institute for Science and Technology, Tokyo University of Science (-present)

Recent Achievements

Protected cat-qutrit

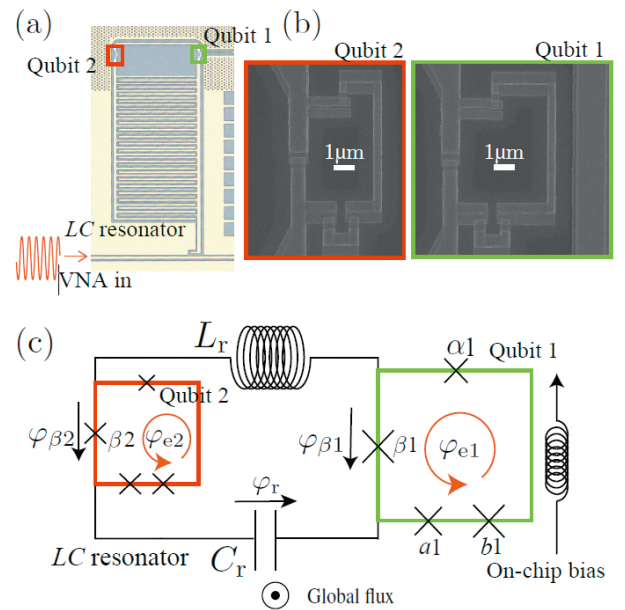
We implement a three-photon KPO and explore its potential as a protected bosonic qutrit. We confirm quantum coherence by demonstrating three-photon Rabi oscillations and performing direct Wigner function measurements that reveal the formation of three-component catlike states. Crucially, we observe a breathing-like dynamic in phase space, a characteristic feature of driven quantum systems. This dynamic arises from macroscopic temporal interference between the cat-qutrit manifold and the excited states. The frequency of resulting oscillations in the mean photon number provides a direct, time-domain measurement of the energy gap separating the qutrit from the excited states, thereby establishing an experimental hallmark of qutrit manifold protection. Furthermore, we identify a parasitic higher-order pump term as the primary mechanism constraining the mean photon number, highlighting its mitigation as a requisite for maximizing protection. Our findings elucidate the basic quantum properties of the three-photon KPO and establish the first step towards its use as an alternative qutrit platform.



Bosonic qutrit picture and states

One photon simultaneously excites two atoms

We experimentally investigate a superconducting circuit composed of two flux qubits ultrastrongly coupled to a common LC resonator. Owing to the large anharmonicity of the flux qubits, the system can be correctly described by a generalized Dicke Hamiltonian containing spin-spin interaction terms. In the experimentally measured spectrum, an avoided level crossing provides evidence of the exotic interaction that allows the simultaneous excitation of two artificial atoms by absorbing one photon from the resonator. This multi-atom ultrastrongly coupled system opens the door to studying nonlinear optics where the number of excitations is not conserved. This enables novel processes for quantum-information processing tasks on a chip.



Ultra-strong coupled flux qubit, photos and circuit diagrams

Core members

(Postdoctoral Researcher) **Hang Xue**

Superconducting Quantum Electronics Joint Research Unit

Keywords: Superconducting quantum circuit, Quantum technology, Microwave engineering, Quantum computing, Quantum error correction

Research Outline

We develop scalable, multi-qubit quantum computers, in collaboration with the Superconducting Quantum Electronics Research Team. We design a superconducting quantum circuit consisting of Josephson junctions, microwave resonators, transmission lines, filter circuits and so on to implement superconducting qubits and functionalities for coherent controls and non-demolition measurements of their quantum states on a single chip. We integrate a chip, a device package for connecting the chip and coaxial cables, cryogenic microwave components such as Josephson parametric amplifiers, a dilution refrigerator to realize the ultracold environment, and room-temperature electronics for qubit control into a single hardware operating as an intermediate-scale quantum computer with 50 –150 qubits. We have constructed a 64-qubit system named “A” and a 144-qubit system named “A-II”, both deployed for cloud service. We aim to improve the fabrication yield and uniformity of qubit chips as well as extending the coherence times of the qubits. We also evaluate control fidelities for single- and two-qubit gates, initialization, and readout and aim to improve them. At the same time, we explore the potential of the system for NISQ (noisy intermediate-scale quantum) applications, implement a proof-of-principle experiment of quantum error correction, and simulate many-body quantum systems, using our quantum computer. We also work on developing element technologies necessary for further scaling up the number of available qubits, such as packing more microwave cables and components in a limited space, and realizing quantum control across different chips. Ultimately, we aim to pave the way for realizing a system capable of large-scale quantum error correction, and to bring a quantum computer that executes computations intractable with classical computers closer to reality.



64-qubit superconducting quantum computer “A”



Eisuke Abe (D.Sci.), Unit Leader

Selected Publications

- 1 K. Ishibashi *et al.*, “Research on Quantum Materials and Quantum Technology at RIKEN”, *ACS Nano* 19, 12427 (2025).
- 2 K. Sasaki and E. Abe, “Suppression of Pulsed Dynamic Nuclear Polarization by Many-Body Spin Dynamics”, *Phys. Rev. Lett.* 132, 106904 (2024).
- 3 E. Abe, “Superconducting route to quantum computing”, *Proceeding of 2023 International Conference on Simulation of Semiconductor Processes and Devices (SISPAD)*, P.1–4 (2023).
- 4 K. Sasaki, H. Watanabe, H. Sumiya, K. M. Itoh, and E. Abe, “Detection and control of single proton spins in a thin layer of diamond grown by chemical vapor deposition”, *Appl. Phys. Lett.* 117, 114002 (2020).
- 5 S. Ishizu, K. Sasaki, D. Misonou, T. Teraji, K. M. Itoh, and E. Abe, “Spin coherence and depths of single nitrogen-vacancy centers created by ion implantation into diamond via screening masks”, *J. Appl. Phys.* 127, 244502 (2020).

Brief resume

- 2005 Research Fellow DC2, Japan Society for the Promotion of Science
- 2006 D. Sci., Keio University
- 2006 Research Associate, The Institute for Solid State Physics, The University of Tokyo
- 2010 Postdoctoral Research Assistant, Department of Materials, University of Oxford
- 2011 Specially-Appointed Researcher, Institute for Nano Quantum Information Electronics, The University of Tokyo
- 2012 Specially-Appointed Researcher, Principles of Informatics Research Division, National Institute of Informatics
- 2013 Research Scientist, Center for Emergent Matter Science, RIKEN
- 2015 Project Lecturer, Faculty of Science and Technology, Keio University
- 2016 Project Associate Professor, Keio Advanced Research Centers, Keio University
- 2019 Unit Leader, RIKEN Center for Quantum Computing (-present)

Recent Achievements

Deployment of a 144-qubit system “A-II” for cloud service, and development of a testbed system

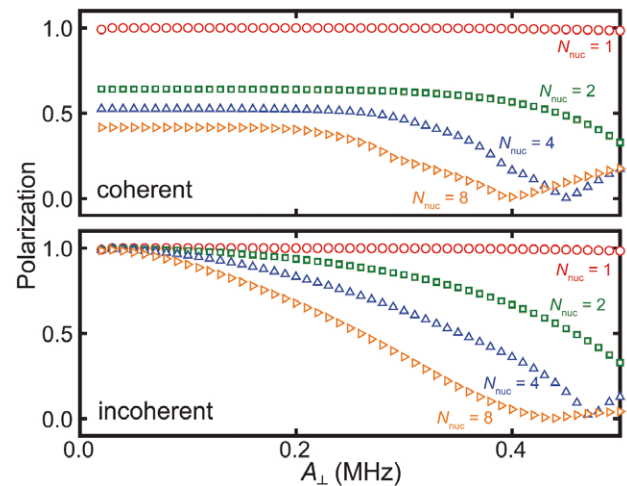
A salient feature of the tileable square-lattice qubit design with coaxial cables for qubit control and readout addressing the backside of the chip from the vertical direction, which has been adopted in the 64-qubit superconducting quantum computer “A,” is its natural extendibility to larger systems. We have constructed a new system consisting of 144 qubits in the form of a 12-by-12 square lattice, for which we have been able to extend the qubit coherence time. The size of the dilution refrigerator for the 144-qubit system is the same as that of the 64-qubit system, whilst accommodating the more-than-doubled cryogenic microwave components within the same volume. This system, named “A-II,” has been deployed for cloud service since March 2026. In parallel, we have developed a testbed system which can host two 64-qubit chips in tandem within a single sample package and started testing the performance of the qubit chips. This testbed system will be utilized for efficient evaluation of newly-designed qubit chips as well as for the test of inter-chip connections.



144-qubit superconducting quantum computer “A-II” (front right) and a testbed system (back left)

Suppression of pulsed dynamic nuclear polarization by many-body spin dynamics

The initialization of qubits is the first step of quantum control in any physical system. Nuclear spin systems, with weak interactions with their environments and small Zeeman splitting under the magnetic fields, exhibit notoriously small initialization fidelities (spin polarization). Recently, pulsed dynamic nuclear polarization (DNP) methods, in which the electron-nuclear spin interaction is engineered via a microwave pulse sequence to improve the nuclear polarization, has attracted attention. In this work, we reveal that, in a system with multiple nuclear spins with negligible spin-spin interactions and longitudinal relaxation, there exists a mechanism that suppresses the polarization achievable by pulsed DNP via higher-order nuclear spin dynamics mediated by an electron spin, using analytical and numerical calculations. The formation of a dark state is a well-known phenomenon whereby nuclear polarization is suppressed by a many-body effect, but we discuss under a certain condition higher-order effect cooperatively suppress the polarization. This work highlights the importance of taking the higher-order many-body effect into account when designing control sequences of nuclear spin systems.



Numerical simulation of nuclear spin polarization as a function of the hyperfine interaction strength ($A_{\perp}$) and the number of nuclear spins (N_{nuc}). The increase in both the hyperfine interaction strength and the number of nuclear spins results in suppressed polarization. The upper (lower) figure takes (does not take) into account the formation of the nuclear spin dark state.

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<https://doi.org/10.1103/PhysRevLett.132.106904>

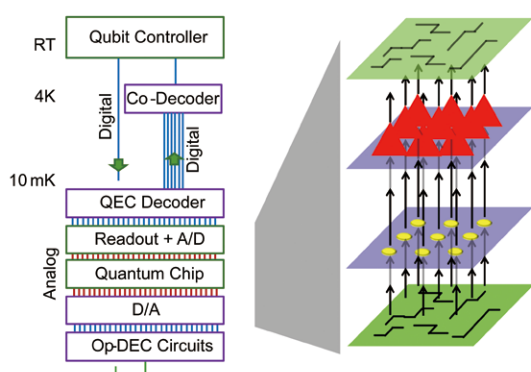
Superconducting Quantum Computing System Research Unit

Keywords: Superconducting quantum computers, System in Package (SIP), Heterogeneous integration

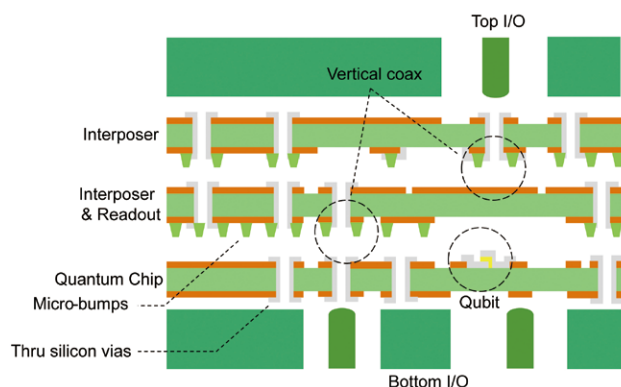
Research Outline

Our unit pursues the realization of practical quantum computers. We study a quantum mechanical system that integrates qubits, readout circuits, wiring, control electronics, cooling units, signal processing circuits, etc., to exploit and maximize a quantum-mechanical feature in superconducting quantum chips. Each component has strengths and weaknesses, and the combination of those gives trade-offs. We establish a design method that harmonizes the elements to expand the performance and scalability of a quantum computing system.

For example, we explore scalable arrangements of qubits, inter-qubit wirings, and control lines in a realistic three-dimensional space as device design. The error-correction mechanism in fault-tolerant quantum computation demands continuous refresh (or update) operation to superconducting qubits, losing room for time division multiplexing to simplify the device structure. Whereas the surface code is extendable in a two-dimensional plane for redundancy and scalability, only one more dimension remains to introduce the control and readout lines to the qubit chip. We seek possibilities in stacked module systems that integrate qubits, control, and readout circuitry in a few substrates with essential scalability toward fault-tolerant quantum computation. Furthermore, the structure brings heterogeneous integration where various signal processing circuits, e.g., optical interconnects, single flux quantum circuits, etc., are organized in a single module.



Stacked modules in superconducting quantum computer



Implementation of stacked module systems



Yutaka Tabuchi (D.Eng.), Unit Leader

Selected Publications

- 1 Y. Sunada, S. Kono, J. Ilves, T. Sugiyama, Y. Suzuki, T. Okubo, S. Tamate, Y. Tabuchi, and Y. Nakamura, "Efficient Tomography of Microwave Photonic Cluster States," *PRX Quantum* 7, 010323 (2026).
- 2 Y. Ueno, S. Imamura, Y. Tomida, T. Tanimoto, M. Tanaka, Y. Tabuchi, K. Inoue, and H. Nakamura, C3-VQA: Cryogenic counter-based co-processor for variational quantum algorithms, *IEEE Transactions on Quantum Engineering* 6, 1-17 (2025).
- 3 D. Lachance-Quirion, S. Wolski, Y. Tabuchi, S. Kono, K. Usami, and Y. Nakamura. "Entanglement-based single-shot detection of a single magnon with a superconducting qubit," *Science*, 367, pp.425-428 (2020).
- 4 Y. Tabuchi, S. Ishino, A. Noguchi, T. Ishikawa, R. Yamazaki, K. Usami, and Y. Nakamura. "Coherent coupling between a ferromagnetic magnon and a superconducting qubit," *Science*, 348, pp.405-408 (2015).
- 5 Y. Tabuchi, S. Ishino, T. Ishikawa, R. Yamazaki, K. Usami, and Y. Nakamura. "Hybridizing ferromagnetic magnons and microwave photons in the quantum limit," *Physical Review Letters*, 113, p.083603 (2014).

Brief resume

2012 Postdoctoral Researcher, RCAST, The University of Tokyo
 2015 JSPS Research Fellowship for Young Scientists
 2017 Associate Professor, RCAST, The University of Tokyo
 2020 Unit Leader, Center for Emergent Matter of Science, RIKEN
 2021 Unit Leader, RIKEN Center for Quantum Computing (-present)

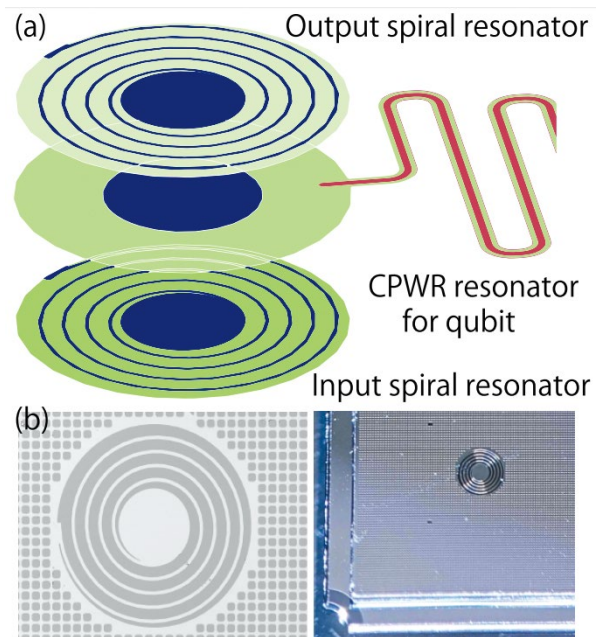
Recent Achievements

Three-dimensional integration is essential for scaling superconducting quantum computers

Three-dimensional integration of superconducting qubits and peripheral circuits is essential for scaling superconducting quantum computers. In conventional multilayer implementations, direct electrical contact between substrates is required, imposing stringent hardware requirements on alignment accuracy and contact reliability.

In this study, we propose an inter-substrate signal transmission technology that does not rely on through-substrate vias or perfectly formed electrical contacts. By exploiting displacement currents in the microwave frequency range, spiral resonators fabricated on each surface of stacked silicon substrates enable electromagnetic coupling-based signal transmission. This approach allows reliable inter-substrate communication even when physical wiring contacts between substrates are incomplete.

Experimental characterization demonstrates favorable transmission characteristics near the resonance frequency, as well as successful coupling to a superconducting qubit readout circuit located in the inner layer. The proposed method significantly relaxes hardware requirements for interconnect formation in three-dimensional integration and provides enhanced flexibility in quantum hardware design. This work was reported at the 73rd Spring Meeting of the Japan Society of Applied Physics in 2026.



Coupled spiral resonators and coupling-control aperture for vertical signal transmission

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System improvement of fixed-frequency transmon superconducting quantum computers

In the system improvement towards the practical application of superconducting quantum computers, noise associated with quantum gates poses a significant challenge. Achieving the error rate of 10^{-3} or less while maintaining scalability, which is necessary for quantum error correction, requires further research of system design. The challenge with parametrically activated two-qubit gates is the increased error rate caused by unwanted Floquet sidebands generated by microwave drive acting on neighboring qubits. This issue is particularly significant for fixed-frequency qubits where we are faced with taking fabrication variation of qubit resonance frequency into account.

This research focuses on the unwanted sidebands specific to parametrically driven quantum gates and precisely simulates their frequencies. Furthermore, it investigates the optimal frequency configuration to address the frequency variations among qubits. By leveraging the arbitrariness of the driving frequency inherent in microwave-induced ZZ interaction, we demonstrate that selecting the optimal frequency can suppress non-adiabatic transitions such as incoherent leakage. Moreover, a high yield is anticipated in a 100-qubit scale quantum computer. These research findings were reported at the March Meeting of the American Physical Society in 2025.

[1] Kazuhisa Ogawa, Yutaka Tabuchi, Makoto Negoro, High-yield integration design of fixed-frequency superconducting qubit systems using siZZle-CZ gates, arXiv:2603.21537 (2026)

Core members

(Special Postdoctoral Researchers) **Yosuke Ueno**
(Technical Staff) **Bunpei Masaoka**

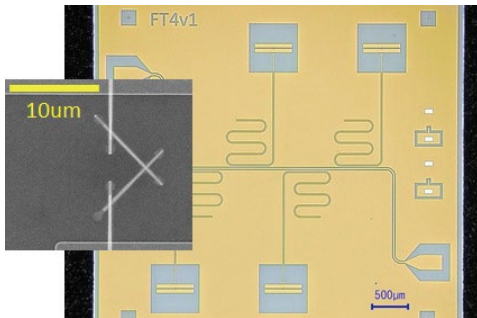
(Technical Staff) **Miyuki Ozawa**
(Technical Staff) **Shigeru Kawakami**

Hybrid Quantum Circuits Research Team

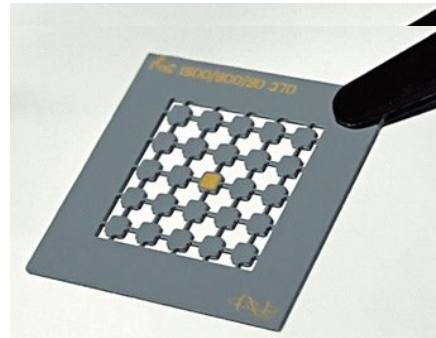
Keywords: Hybrid quantum systems, Microwave quantum optics, Electron trap, Quantum manipulations

Research Outline

A superconducting circuit is not merely a circuit without electrical resistance; with the Josephson junction, various quantum functions such as qubits and parametric circuits can be realized. In particular, our team has recently succeeded in fabricating superconducting qubits with an extremely long lifetime. In addition, taking advantage of the designability of superconducting circuits, we have been investigating various kinds of quantum gates and their fidelity improvement. Furthermore, we are interested in research and development of hybrid quantum systems that combine such high-performance superconducting circuits with other quantum systems, such as microwave resonators, trapped electrons, and micro-mechanics. They can be ultra-long lifetime quantum systems. By observing and controlling these systems with superconducting circuits, we are trying to establish quantum control technology that greatly surpasses existing performance. The realization of ultimate quantum technologies, such as fault-tolerant quantum computers, will depend on the availability of high-precision quantum control that is far beyond the current state-of-the-art. To address these issues, we aim to realize bosonic quantum error-correcting codes based on superconducting circuits, and quantum manipulations of trapped electrons in the vacuum. Furthermore, we aim to develop new quantum fundamental technologies through the coexistence and collaboration of quantum systems.



Transmon qubits made from TiN electrode. We are fabricating the qubit with state-of-the-art.



Mechanical membrane oscillator made from high-stress TiN film.



Atsushi Noguchi (Ph.D.), Team Director

Selected Publications

- 1 Y. Matsuyama, S. Shirai, I. Nakamura, M. Tokunari, H. Terai, Y. Hishida, R. Sasaki, Y. Tominaga, and A. Noguchi, "High-Q membrane resonators using ultra-high-stress crystalline TiN films", *Appl. Phys. Lett.* 127, 222202 (2025).
- 2 Y. Tominaga, S. Shirai, Y. Hishida, H. Terai, and A. Noguchi, "Enhancing Intrinsic Quality Factors Approaching 10 Million in Superconducting Planar Resonators via Spiral Geometry", *EPJ Quantum Technology* 12, 60 (2025).
- 3 Y. Tsuchimoto, I. Nakamura, S. Shirai, and A. Noguchi, "Superconducting surface trap chips for microwave-driven trapped ions", *EPJ Quantum Technology* 11, 56 (2024).
- 4 S. Shirai, Y. Okubo, K. Matsuura, A. Osada, Y. Nakamura, and A. Noguchi, "All-Microwave Manipulation of Superconducting Qubits with a Fixed-Frequency Transmon Coupler", *Phys. Rev. Lett.* 130, 260601 (2023).
- 5 A. Noguchi, R. Yamazaki, Y. Tabuchi, and Y. Nakamura, "Single-photon quantum regime of artificial radiation pressure on a surface acoustic wave resonator", *Nat. Commun.* 11, 1183 (2020).

Brief resume

- 2013 Postdoc researcher, Osaka University
- 2014 Postdoc researcher, RCAST, The University of Tokyo
- 2015 Postdoc researcher, RCAST, The University of Tokyo
- 2015 Project Associate, RCAST, The University of Tokyo (-2018)
- 2016 Researcher, JST PREST (-2019)
- 2019 Associate Professor, Graduate School of Arts and Science, The University of Tokyo (-present)
- 2020 Fellow, Inamori Research Institute for Science (-present)
- 2020 Team leader, CEMS (-2021)
- 2021 Team Director, RQC (-present)

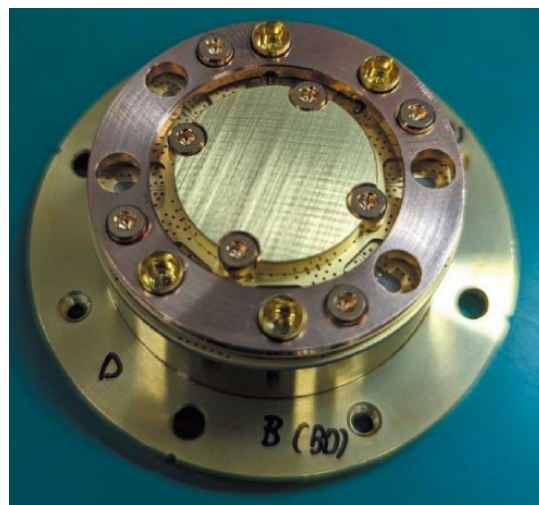


Recent Achievements

■ Packaging for high-performance superconducting microwave circuits

We released as open source a high-performance packaging technology for superconducting quantum circuits, including design data, implementation know-how, and evaluation information [1]. This technology provides a practical packaging platform that enables high-density integration and high-frequency interconnects while suppressing unwanted modes and package-induced losses that degrade the performance of superconducting qubits and high-Q microwave resonators. Evaluation using superconducting microwave resonators demonstrated internal quality factors reaching the 10^8 range, providing a benchmark for minimizing package-related losses such as radiation loss. The released data include CAD designs and fabrication/assembly information that can be directly utilized for practical quantum-device implementation, enabling reproducible use across different research institutions. By making superconducting quantum-circuit packaging technology—traditionally developed independently within individual laboratories—openly accessible, this work contributes to accelerating research, promoting standardization, and fostering human resource development in the quantum technology community. Furthermore, the open-source framework enables community-driven improvements and derivative designs, thereby strengthening the research infrastructure for superconducting quantum computing.

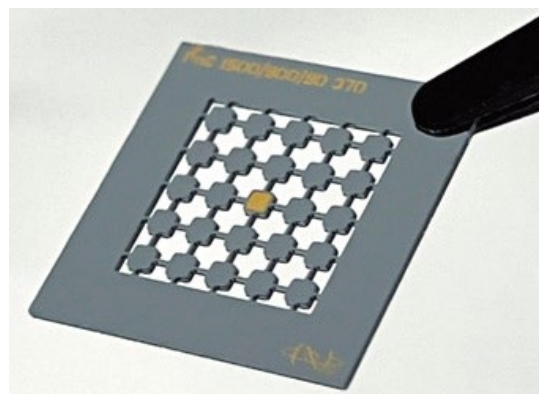
[1] S. Shirai. (2026). OS-PAQAGE (v1.0.1). Zenodo.



Package for high-performance superconducting circuits

■ High-Q membrane oscillator made from superconducting TiN film

We developed high-Q membrane mechanical resonators using ultra-high-stress crystalline TiN thin films and evaluated their mechanical properties. Crystalline TiN is a promising material that combines extremely high internal stress with low mechanical loss, and in this work we achieved exceptionally high mechanical quality factors in membrane resonators operating in the MHz frequency range. We further demonstrated that this material platform is well suited for hybrid integration with superconducting microwave circuits and quantum devices, highlighting its potential applications in quantum sensing and quantum information processing. In addition, intriguing phenomena related to the interaction between superconductivity and mechanical motion, such as magnetic-field-induced shifts in the mechanical resonance characteristics, were observed. These results demonstrate that crystalline TiN thin films are a highly promising platform for low-loss mechanical quantum devices. Furthermore, cooling the devices to even lower temperatures, particularly into the ultra-low-temperature regime, is expected to further suppress thermal excitations and internal dissipation, potentially leading to even higher mechanical quality factors in the future.



A thin-film mechanical resonator made of superconducting titanium nitride is embedded within a phononic crystal structure for vibrational shielding.

Core members

(Special Postdoctoral Researcher) **Ryo Sasaki**
(Postdoctoral Researcher) **Yusuke Tominaga**
(Postdoctoral Researcher) **Shotaro Shirai**
(Postdoctoral Researcher) **Markus Fleck**

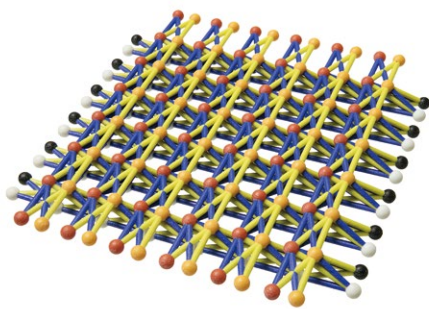
(Special Postdoctoral Researcher) **Masaki Roppongi**
(Postdoctoral Researcher) **Yue Tian**
(Postdoctoral Researcher) **Geobae Park**

Optical Quantum Computing Research Team

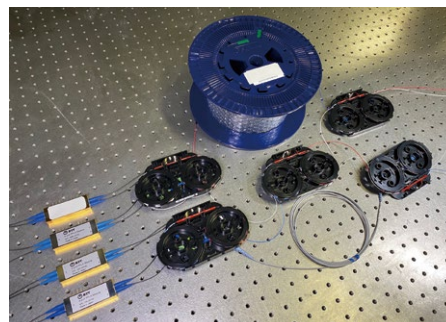
Keywords: Quantum information science, Quantum optics

Research Outline

Quantum computers use interference coming from the wave nature of quantum mechanics to surpass classical computers. There are two types of waves, standing waves and traveling waves, and the feature of our method using light is that it handles traveling waves. Whereas most other methods deal with standing waves, where short decoherence times matter, our method has no decoherence problems because quantum states are generated one after another as traveling light pulses, which are then destroyed by measurement. In our method, quantum teleportation is repeated to pass quantum information to successively generated optical pulses. The huge quantum entanglement for repeated quantum teleportation is called a cluster state, which can be considered as a quantum look-up table containing all input-output relations as a superposition. In our method, this can be created on a large scale in a compact optical system by the time-domain multiplexing technique. The great advantage of our method is high-speed computation. The bandwidth of optical parametric amplifiers that generate quantum light can be as high as 10 THz. Although teleportation is a speed bottleneck, when combined with 5G technology, it is possible to realize quantum computers with very fast clocks of tens of gigahertz. Furthermore, when combined with all-optical teleportation in the future, a super-fast quantum computer that effectively utilizes the bandwidth of 10 THz can be expected.



Graph of large-scale entangled states for quantum computation



Simplified optical setup to create large-scale entangled states



Akira Furusawa (Ph.D.), RQC Deputy Director, Team Director

Selected Publications

- 1 K. Hirota, T. Kashiwazaki, G. Ha, T. Yamashima, P. Jaturaphagorn, T. Suzuki, K. Takahashi, A. Kawasaki, A. Inoue, W. Asavanant, M. Endo, T. Umeki, and A. Furusawa, "Generation of 10-dB squeezed light from a broadband waveguide optical parametric amplifier with improved phase locking method", *Opt. Express* 34, 7958 (2026).
- 2 S. Yokoyama, A. Sakaguchi, W. Asavanant, K. Takase, Y. Chen, H. Nagayoshi, J. Yoshikawa, T. Kashiwazaki, A. Inoue, T. Umeki, T. Hashimoto, T. Hiraoka, A. Furusawa, and H. Yonezawa, "Full-stack analog optical quantum computer with a hundred inputs", arXiv:2506.16147 [quant-ph] (2025).
- 3 A. Kawasaki, H. Brunel, R. Ide, T. Suzuki, T. Kashiwazaki, A. Inoue, T. Umeki, T. Yamashima, A. Sakaguchi, K. Takase, M. Endo, W. Asavanant, and A. Furusawa, "Real-time observation of picosecond-timescale optical quantum entanglement toward ultrafast quantum information processing", *Nature Photonics* 19, 271–276 (2025).
- 4 A. Kawasaki, R. Ide, H. Brunel, T. Suzuki, R. Nehra, K. Nakashima, T. Kashiwazaki, A. Inoue, T. Umeki, F. China, M. Yabuno, S. Miki, H. Terai, T. Yamashima, A. Sakaguchi, K. Takase, M. Endo, W. Asavanant, and A. Furusawa, "Broadband generation and tomography of non-Gaussian states for ultra-fast optical quantum processors", *Nature Communications* 15, 9075 (2024).
- 5 S. Konno, W. Asavanant, F. Hanamura, H. Nagayoshi, K. Fukui, A. Sakaguchi, R. Ide, F. China, M. Yabuno, S. Miki, H. Terai, K. Takase, M. Endo, P. Marek, R. Filip, P. van Loock, and A. Furusawa, "Logical states for fault-tolerant quantum computation with propagating light", *Science* 383, 6680 (2024).

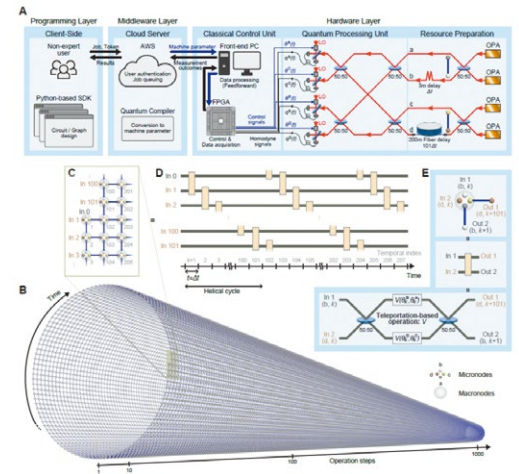
Brief resume

- 1991 Ph.D. in Physical Chemistry, The University of Tokyo
- 1986 Research staff member of Nikon Corporation (-2000)
- 1988 Visiting faculty member at Research Center for Advanced Science and Technology (RCAST), The University of Tokyo
- 1996 Visiting faculty member at California Institute of Technology
- 2007 Professor of Applied Physics, The University of Tokyo (-present)
- 2021 Deputy Director of the RIKEN Center for Quantum Computing / Team Leader of the Optical Quantum Computing Research Team (-present)
- 2024 Director of OptQC

Recent Achievements

Characterization of optical quantum computer

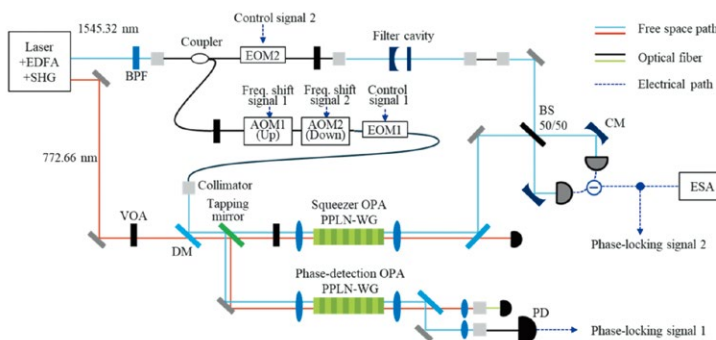
Our team, in collaboration with the Optical Quantum Control Research Team, has advanced the development of an optical quantum computer and conducted a comprehensive performance evaluation. This system is a measurement-based, analog optical quantum computer utilizing a time-division multiplexing (TDM) approach. Specifically, the system generates large-scale quantum entanglement in the time domain (Fig. A) and performs sequential measurements on four optical modes existing simultaneously. By controlling the measurement bases (measurement phases), various linear transformations are realized. The fundamental unit of operation is a 2-input 2-output linear transformation via generalized teleportation, a process in which two of the four concurrent modes serve as inputs and are teleported to two subsequent modes (Fig. E). To verify these 2-input 2-output operations, we evaluated the quantum operations using quantum correlations between the reference and output optical modes. We derived various transformation matrices, including squeezing, rotation, beam splitter, and CNOT, and demonstrated their validity by comparing them with theoretical predictions. Furthermore, as demonstrations of multi-step operations, we performed experiments such as multi-step quantum teleportation and quantum state routing, confirming that the actual device operates as designed.



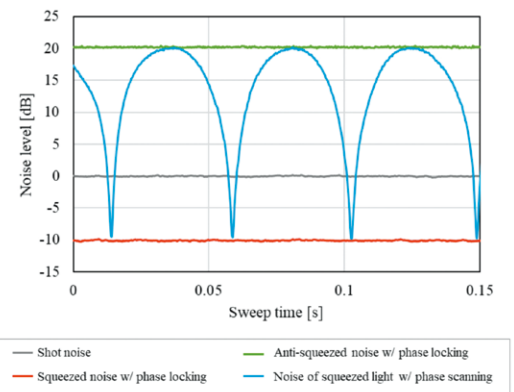
Our optical quantum computer

Generation of 10-dB squeezed light from a broadband waveguide optical parametric amplifier

Our optical quantum computer generates large-scale quantum entanglement from squeezed light to perform measurement-induced analog computations. Since we use a time-division multiplexing technique to generate large-scale entanglement in the time domain, we require broadband squeezed light. However, in conventional cavity-based squeezed light generators, the cavity limits the bandwidth of the squeezed light. Through collaborative research with NTT Device Technology Laboratories, we have developed a highly efficient waveguide-based squeezed light generator and succeeded in generating squeezed light with a bandwidth of several terahertz. The next challenge is to improve the precision of the optical quantum computer by increasing the squeezing level. We introduced a new method for phase-locking the squeezed light and succeeded in measuring 10-dB squeezing from the waveguide-type broadband squeezed light generator.



Experimental setup incorporating a new optical phase-locking system
©Opt. Express 34, 7958 (2026).



Measurement results of the generated squeezed light
©Opt. Express 34, 7958 (2026).

Core members

(Research Scientist) **Jun-ichi Yoshikawa**

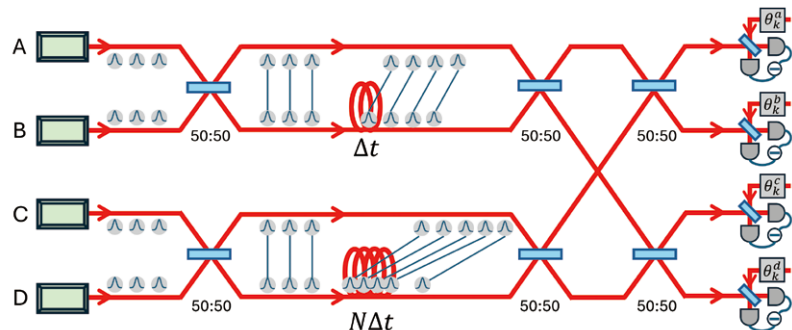
Optical Quantum Control Research Team

Keywords: Quantum computing, Quantum optics, Quantum control, Optical quantum computing, Quantum estimation

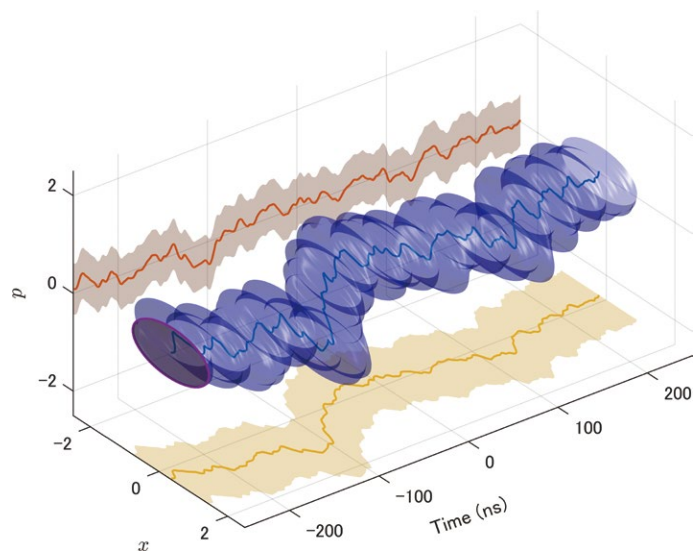
Research Outline

The goal of our team is to develop an optical quantum computer. In particular, we investigate optical quantum control technology and measurement-based optical quantum computation. There are many advantages in an optical platform, including compatibility with room temperature, high scalability, and applicability to communication technology. The key technology for optical quantum information processing is quantum control. Quantum states often fluctuate due to environmental disturbances or measurements. It is critical to develop effective control technology of quantum states, which may involve maintaining or manipulating quantum states in a noisy environment, or realising high-performance measurements through control of basic measurement devices. In addition, quantum estimation is a core technique because it is the basis for quantum control technology.

To build a scalable measurement-based optical quantum computer, we employ time-domain multiplexing technique. We generate large-scale entanglement in the time domain and sequentially measure it using various measurement bases to perform quantum operations. We are also developing a cloud-based system to enhance usability, with the aim of exploring applications of optical quantum computing and promoting its practical use.



Measurement-based optical quantum computer



Estimation of optical quantum state



Hidehiro Yonezawa (Ph.D.), Team Director

Selected Publications

- 1 S. Yokoyama, *et al.*, "Feasibility study of a coherent feedback squeezer," *Phys. Rev. A* 101, 033802 (2020).
- 2 S. Yokoyama, *et al.*, "Characterization of entangling properties of quantum measurement via two-mode quantum detector tomography using coherent state probes," *Opt. Express* 27, 34416 (2019).
- 3 W. Asavanant, *et al.*, "Generation of time-domain-multiplexed two-dimensional cluster state," *Science* 366, 373 (2019).
- 4 S. Yokoyama, *et al.*, "Ultra-large-scale continuous-variable cluster states multiplexed in the time domain," *Nature Photon.* 7, 982 (2013).
- 5 H. Yonezawa, *et al.*, "Quantum-Enhanced Optical-Phase Tracking," *Science* 337, 1514 (2012).

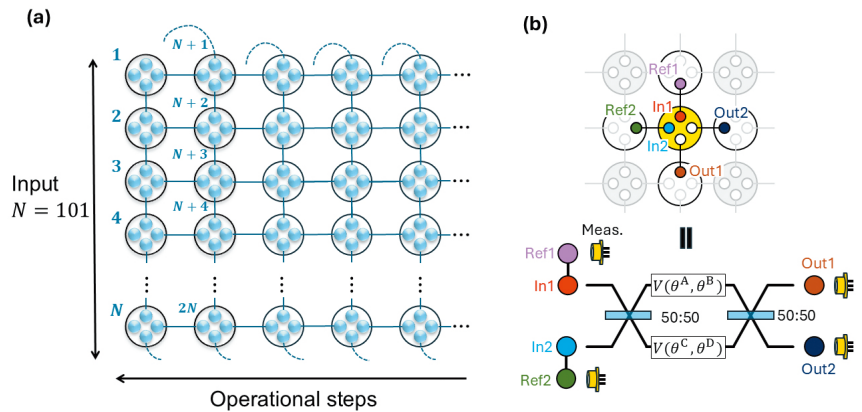
Brief resume

- 2007 Ph.D. in Engineering, The University of Tokyo
- 2007 Research associate, The University of Tokyo
- 2009 Project Assistant Professor, The University of Tokyo
- 2013 Senior lecturer, University of New South Wales
- 2023 Team Director, Optical Quantum Control Research Team, RIKEN Center for Quantum Computing, RIKEN (-present)

Recent Achievements

Characterization of optical quantum computer

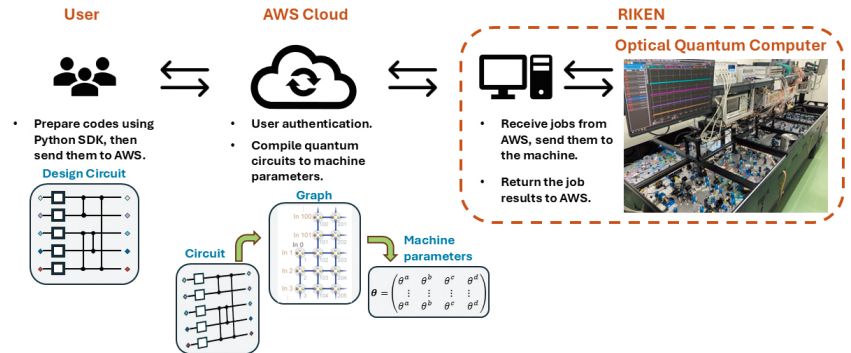
Our team, in collaboration with the Optical Quantum Computing Research Team, has advanced the development of an optical quantum computer and conducted a comprehensive performance evaluation. This system is a measurement-based, analog optical quantum computer utilizing a time-division multiplexing (TDM) approach. Specifically, the system generates large-scale quantum entanglement in the time domain (Fig. a) and performs sequential measurements on four optical modes existing simultaneously. By controlling the measurement bases (measurement phases), various linear transformations are realized. The fundamental unit of operation is a 2-input 2-output linear transformation via generalized teleportation, a process in which two out of the four concurrent modes serve as inputs that are mapped onto two subsequent modes (Fig. b). To verify these 2-input 2-output operations, we evaluated the quantum operations using quantum correlations between the reference and output optical modes. We derived various transformation matrices, including squeezing, rotation, beam splitter, and CNOT, and demonstrated their validity by comparing them with theoretical predictions. Furthermore, as demonstrations of multi-step operations, we performed experiments such as multi-step quantum teleportation and quantum state routing, confirming that the actual device operates as designed.



Characterization of the optical quantum computer. (a) Generated large-scale quantum entanglement. (b) Basic operation and its evaluation scheme.

Cloud release and operation of the optical quantum computer

In addition to developing the optical quantum computing hardware, our team has established a cloud-based system leveraging Amazon Web Services (AWS) and a Python Software Development Kit (SDK) to facilitate user job execution. During fiscal year 2025, the cloud system was opened to collaborators, with the number of registered users reaching nearly 40 by the end of the year. To provide consistent computational resources for our collaborators, we maintained near-continuous operation of the optical quantum computer throughout the year, excluding maintenance periods. This long-term operation demonstrated the exceptional stability of the system, proving it can be sustained with only a few adjustments per year. While collaborative research is in its early stages, we have successfully established a robust foundation for exploring diverse quantum applications, including optimization and neural networks.



Optical quantum computer cloud system

Core members

(Senior Research Scientist) **Shota Yokoyama**
(Senior Technical Staff) **Shigenari Suzuki**

Nanophotonic Cavity Quantum Electrodynamics Research Team

Keywords: Nanophotonics, Cavity QED, Quantum optics, Quantum computing, Quantum network

Research Outline

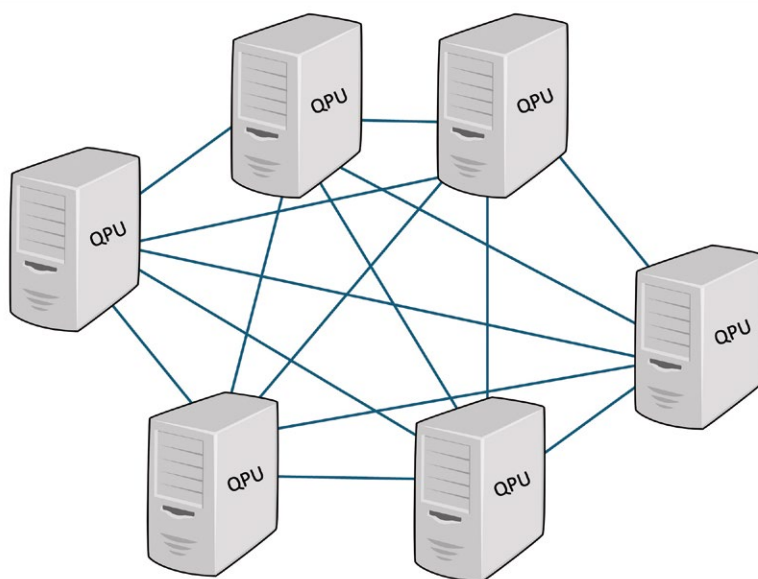
Our team is advancing experimental studies in cavity quantum electrodynamics (QED) using nanophotonic devices. A cavity QED system is a hybrid platform consisting of photons confined in an optical cavity and atoms, and it serves as an ideal quantum interface between atomic and photonic qubits.

In conventional cavity QED experiments, systems based on free-space optical cavities using bulk mirrors have enabled the deterministic generation of non-classical states of light, such as single photons and Schrödinger cat states, as well as quantum non-demolition measurements of photons.

However, such free-space optical cavities suffer from poor compatibility with fiber optics and require extremely complex and precise alignment and control. As a result, it has been difficult to connect multiple cavity QED systems while maintaining low loss.

To address these issues of connectivity and integrability, our team is developing a novel cavity QED system based on nanophotonic devices, aiming to realize scalable quantum technologies.

Specifically, we are developing nanophotonic devices with strong light confinement capabilities, leveraging state-of-the-art nanofabrication techniques, to achieve strong coupling with laser-cooled and trapped atoms. Furthermore, we aim to realize key technologies for distributed quantum computing and quantum networks with high efficiency and high fidelity, and to build an integrated photonic quantum system.



Schematic of distributed quantum computing / quantum network system based on nanophotonic cavity QED.



Takao Aoki (Ph.D.), Team Director

Selected Publications

- 1 S. K. Ruddell, K. E. Webb, M. Takahata, S. Kato, and T. Aoki, "Ultra-low-loss nanofiber Fabry–Perot cavities optimized for cavity quantum electrodynamics", *Opt. Lett.* 45, 4875 (2020).
- 2 D. H. White, S. Kato, N. Német, S. Parkins, and T. Aoki, "Cavity Dark Mode of Distant Coupled Atom-Cavity Systems", *Phys. Rev. Lett.* 122, 253603 (2019).
- 3 S. Kato, N. Német, K. Senga, S. Mizukami, X. Huang, S. Parkins, and T. Aoki, "Observation of dressed states of distant atoms with delocalized photons in coupled-cavities quantum electrodynamics", *Nature Communications* 10, 1160 (2019).
- 4 S. Kato and T. Aoki, "Strong Coupling between a Trapped Single Atom and an All-Fiber Cavity", *Phys. Rev. Lett.* 115, 093603 (2015).
- 5 R. Nagai and T. Aoki, "Ultra-low-loss tapered optical fibers with minimal lengths", *Opt. Express* 23, 28427-28436 (2014).

Brief resume

2001 Ph.D. in Engineering, The University of Tokyo
 2001 Research Associate, The University of Tokyo
 2006 PRESTO Researcher, JST
 2008 Program-Specific Associate Professor, Kyoto University
 2011 Associate Professor, Waseda University
 2014 Professor, Waseda University
 2024 Team Leader, RIKEN
 2025 Team Director, RIKEN (position title change)

Recent Achievements

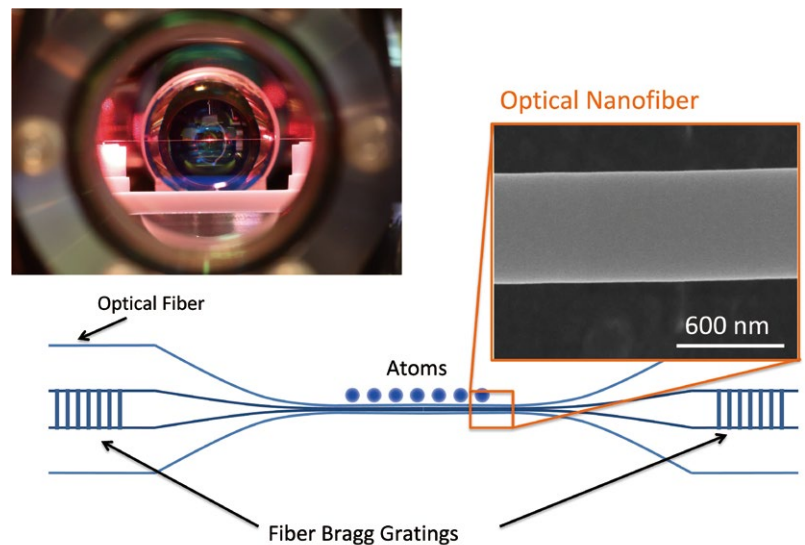
Realization of nanofiber cavity QED system

We have realized a cavity QED system in the strong coupling regime between a trapped single atom and a nanofiber cavity, using a nanofiber cavity developed based on our original ideas and technologies [S. Kato and T. Aoki, Phys. Rev. Lett. 115, 093603 (2015)]. This achievement marks the first realization of a cavity QED system using an all-fiber optical cavity.

Furthermore, we have constructed, for the first time, a “coupled cavity QED system” in which two nanofiber cavity QED systems are coherently connected entirely via fiber. We successfully observed all five eigenmodes of this system [S. Kato *et al.*, Nature Communications 10, 1160 (2019); D. White *et al.*, Phys. Rev. Lett. 122, 253603 (2019)].

These results represent a significant step toward the realization of high-efficiency distributed quantum computing and quantum networks.

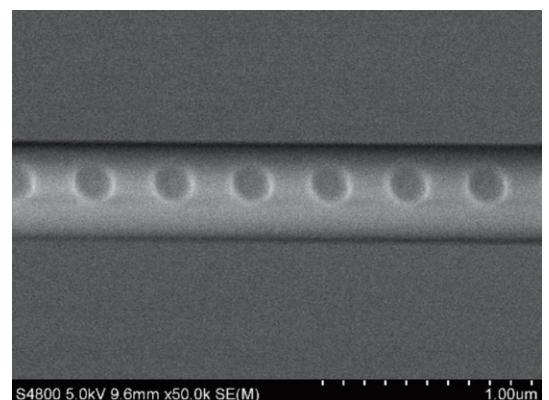
Furthermore, we developed a new technique in which a one-dimensional array of single-atom optical tweezers is formed on the surface of the nanofiber, enabling optical access to individually addressable atoms coupled to the nanofiber.



Schematic of nanofiber cavity QED system.

Development of nanofiber photonic crystal cavities

We have developed defect-free optical-nanofiber photonic-crystal Fabry-Perot cavities with quality factors exceeding ten million using single-shot femtosecond laser ablation. An investigation of the nonlinear optical properties reveals that thermo-optic effects dominate within the entire cavity bandwidth, even when interrogating with pulses one order of magnitude shorter than the 6.6-microsecond thermal cutoff time. The combination of high-Q and small mode volume of these resonators could facilitate the creation of high-speed quantum nodes for cavity QED based quantum computing and networking, as well as low-power in-line fiber optical switches.



Photonic crystal resonators fabricated on an optical nanofiber by femtosecond laser ablation

Core members

(Senior Research Scientist) **Shinya Kato**

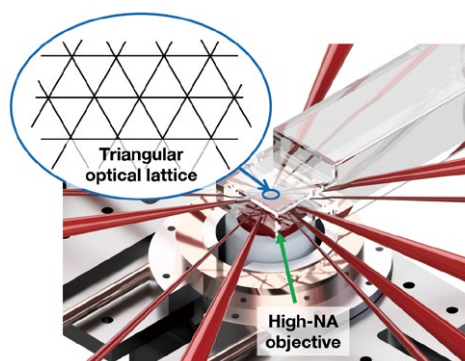
Quantum Many-Body Dynamics Research Team

Keywords: Quantum simulation, Quantum dynamics, Cold atom, Optical lattice

Research Outline

Research on quantum many-body systems contributes not only to the discovery and understanding of diverse physical phenomena, but also to the development of next-generation quantum technologies. In recent years, quantum simulation—an approach that experimentally reproduces and investigates complex quantum many-body systems using highly controllable quantum platforms—has attracted significant attention. Our team aims to realize quantum simulation using ultracold atoms in optical lattices. Optical lattice systems provide an excellent experimental platform for exploring important issues in condensed matter physics, such as high-temperature superconductivity and quantum frustration. Furthermore, owing to less dissipation and decoherence, they are also suitable for investigating non-equilibrium dynamics in quantum many-body systems.

We especially focus on frustrated spin systems. These systems are known to host various quantum phases and exotic quantum states, including quantum spin liquids, yet a systematic understanding of their properties remains lacking. Moreover, theoretical studies predict the existence of quantum phases that have not yet been observed experimentally. To address these challenges, we have constructed a geometrically frustrated triangular optical lattice loaded with quantum gases. We have also implemented a quantum gas microscope capable of observing ultracold atoms in optical lattices at the single-atom level, enabling direct microscopic investigation of quantum correlations and dynamics. With these experimental techniques, we aim to deepen our understanding of frustrated spin systems and explore unknown quantum many-body phenomena and quantum phases.



Schematic of experimental setup. A high-numerical-aperture (NA) objective allows to observe atomic ensembles in triangular optical lattices at the single-atom level.



Takeshi Fukuhara (D.Sci.), Team Director

Selected Publications

- 1 G. Marmorini, T. Fukuhara, and D. Yamamoto, "Measuring Entanglement Without Local Addressing in Quantum Many-Body Simulators via Spiral Quantum State Tomography", *PRX Quantum* 7, 010355 (2026).
- 2 H. Ozawa, R. Yamamoto, and T. Fukuhara, "Observation of chiral-mode domains in a frustrated XY model on optical triangular lattices", *Phys. Rev. Res.* 5, L042026 (2023).
- 3 R. Yamamoto, H. Ozawa, D. C. Nak, I. Nakamura, and T. Fukuhara, "Single-site-resolved imaging of ultracold atoms in a triangular optical lattice", *New J. Phys.* 22, 123028 (2020).
- 4 F. Schäfer, T. Fukuhara, S. Sugawa, Y. Takasu, and Y. Takahashi, "Tools for quantum simulation with ultracold atoms in optical lattices", *Nat. Rev. Phys.*, 2, 411 (2020).
- 5 I. Nakamura, A. Kanemura, T. Nakaso, R. Yamamoto, and T. Fukuhara, "Non-standard trajectories found by machine learning for evaporative cooling of 87Rb atoms", *Opt. Express*, 27, 20435 (2019).

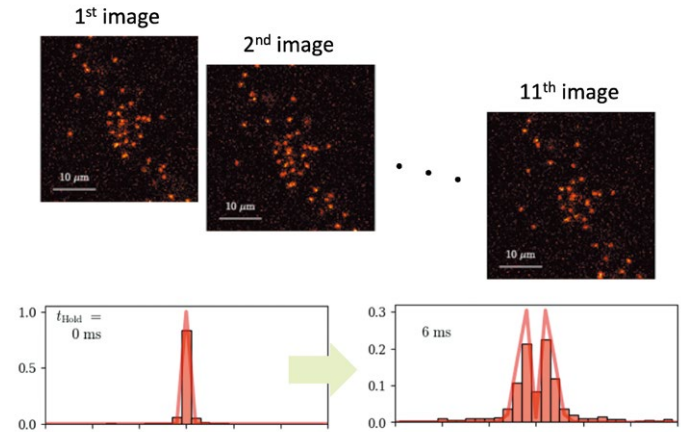
Brief resume

- 2009 D. Sci., Kyoto University
- 2009 Researcher, ERATO Ueda Macroscopic Quantum Control Project, Japan Science and Technology Agency
- 2010 Postdoctoral researcher, Max Planck Institute of Quantum Optics, Germany
- 2014 Unit Leader, Quantum Many-Body Dynamics Research Unit, Cross-Divisional Materials Research Program, RIKEN Center for Emergent Matter Science
- 2021 Unit Leader, Quantum Many-Body Dynamics Research Unit, RIKEN Center for Quantum Computing (RQC)
- 2022 Team Leader, Quantum Many-Body Dynamics Research Team, RIKEN Center for Quantum Computing (RQC) (-present)
- Position name has been changed to Team Director as of April 1, 2025
- 2024 Professor (non-tenure-track), Waseda University (-present)

Recent Achievements

Observation of single-atom quantum walks using repetitive measurement techniques

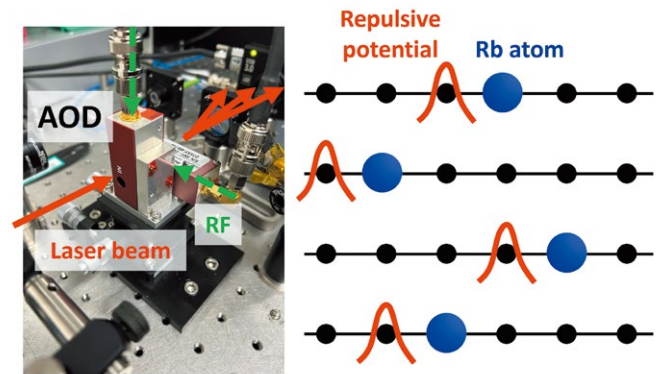
Quantum gas microscopes enable to detect atomic ensembles in optical lattices with single-atom and single-site resolution. However, conventional measurements heat the atoms and induce vibrational excitations, making it difficult to reuse the sample after imaging. As a result, characterization of quantum states typically requires repeated preparation of identical samples. In this study, we developed a repetitive measurement technique in which atoms are recooled to the vibrational ground state after imaging by applying Raman sideband cooling, thereby enabling sample reuse. By optimizing the parameters of cooling lasers, we successfully cooled approximately 80% of the atoms back to the vibrational ground state after measurement. Furthermore, we acquired 11 consecutive images within a single experimental sequence and reconstructed the time-evolved atomic distribution from the differences between successive images. Using this technique, we observed quantum walks of single atoms in an optical lattice. This approach is expected to accelerate data acquisition in quantum dynamics experiments and enable measurement-based control of quantum systems.



Eleven consecutive images acquired in a single experimental sequence (top). The atomic distribution after dynamical evolution can be reconstructed from the differences between successive images (bottom left: 0 ms, bottom right: 6 ms).

Development of feedback control for ultracold atoms in optical lattices

Feedback (feedforward) operations based on measurement outcomes are an important technique in quantum information processing. Examples include atom rearrangement in optical tweezer arrays and error correction based on mid-circuit measurements. In this study, we aim to implement measurement-based feedback control for ultracold atoms in optical lattices and thereby control the dynamics of quantum many-body systems. To achieve this goal, we have developed a system using a two-axis acousto-optic deflector (AOD), which enables rapid light addressing at arbitrary positions in a two-dimensional plane. Specifically, the system can generate a repulsive potential using 760 nm light depending on the measured position of rubidium atoms. This technique can be used for atom transport, opening a route toward the exploration of novel quantum transport phenomena induced by measurement feedback.



Optical system using an acousto-optic deflector (AOD) (left) and schematics of feedback control for ultracold atoms in an optical lattice (right).

Core members

(Research Scientist) **Ryuta Yamamoto**
 (Postdoctoral Researcher) **Keegan McGehee**
 (Postdoctoral Researcher) **Siti Chalimah**
 (Technical Staff I) **Yoichiro Otsuka**
 (Technical Staff I) **Shigeru Toyama**



Cold-Atom Quantum System Research Team

Keywords: Cold atoms, Quantum physics, Quantum optics, Quantum computer, Photonics

Research Outline

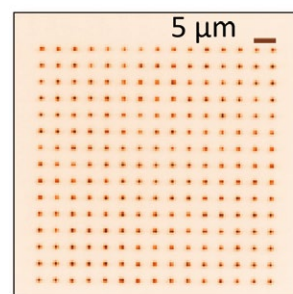
We invent quantum technologies based on individual atoms manipulated with laser beams. For example, lasers can cool atoms to absolute zero temperature, trap and move them with optical tweezers, and excite their electrons to the giant Rydberg orbitals. This allows us to exploit the quantum nature of atoms and to build quantum systems atom-by-atom for both fundamental research as well as practical applications.

Working towards such a practical, long-term outcome, our team is part of the Japan-wide Moonshot Goal 6 “Neutral-Atom Quantum Computer” program targeting the realization of a fault-tolerant quantum computer based on neutral atoms. In particular, we are joining the development of a first machine located at the Institute for Molecular Science (Okazaki). We are also participating in an ASPIRE program connecting the Japanese and German community researching neutral-atom quantum computers and simulators.

A more fundamental research direction is the study of collective light-matter emission, where an assembly of atoms emits spontaneous photons in a collaborative manner, rather than individually. Reaching this fascinating regime in free-space, i.e. in absence of any confinement of the light, puts stringent requirements on the control of the atoms’ positions. We are developing a completely new approach based on flying atoms.



The collaboration team for the first neutral-atom quantum computer of the Moonshot Goal 6 program in front of the Quantum Processing Unit (QPU). The QPU consists of an array of atoms which will be manipulated by a myriad of precisely-positioned laser beams, and has started operating from mid-2025. The members are from the Institute for Molecular Science (Okazaki, JP), the company Inflection (Boulder, USA), and the “Cold-Atom Quantum System” team director.



An array of single Rubidium atoms trapped in optical tweezers. The atoms are made to fluoresce with a resonant laser beam, and their light is collected on a sensitive camera, giving the image shown here. Each optical tweezer has a diameter of around 1 micrometer and a separation of 5 micrometers in this example, but they can be shaped and organized arbitrarily using holography techniques. Such arrays are the core of our neutral-atom-based quantum technologies.



Sylvain de Léséleuc (Ph.D.), Team Director

Selected Publications

- 1 V. Lienhard, R. Martin, Y. T. Chew, T. Tomita, K. Ohmori and S. de Léséleuc, “Generation of Motional Squeezed States for Neutral Atoms in Optical Tweezers”, *Phys. Rev. Lett.* 135, 253404 (2025).
- 2 T. Denecker, Y.T. Chew, O. Guillemant, G. Watanabe, T. Tomita, K. Ohmori, and S. de Léséleuc, “Measurement and feedforward correction of the fast phase noise of lasers”, *Phys. Rev. A* 111 (4), 042614 (2025).
- 3 Y.T. Chew, T. Tomita, T.P. Mahesh, S. Sugawa, S. de Léséleuc, K. Ohmori, “Ultrafast energy exchange between two single Rydberg atoms on a nanosecond timescale”, *Nat. Photonics* 16 (10), 724 (2022).
- 4 S. de Léséleuc, V. Lienhard, P. Scholl, D. Barredo, S. Weber, N. Lang, H.P. Buchler, T. Lahaye, and A. Browaeys, “Observation of a symmetry protected topological phase of interacting bosons with Rydberg atoms”, *Science* 365, 775 (2019).
- 5 D. Barredo, S. de Léséleuc, V. Lienhard, T. Lahaye, and A. Browaeys, “An atom-by-atom assembler of defect-free arbitrary 2d atomic arrays”, *Science* 354, 1021 (2016).

Brief resume

- 2010 Engineer Degree at Ecole Polytechnique (Palaiseau, France) (-2013)
- 2013 Master of Science at ETH Zurich (Master Thesis at U. Tokyo as an exchange student) (-2015)
- 2015 PhD at University Paris-Saclay, Institut d’Optique (Palaiseau, France) on “Quantum simulation of spin models with assembled arrays of Rydberg atoms” (-2018)
- 2018 Post-doctoral researcher at Institut d’Optique (-2019)
- 2019 Assistant Professor at Institute for Molecular Science, National Institutes of Natural Sciences (Okazaki, Japan) (-2023)
- 2023 Project Associate Professor at IMS, NINS (-present)
- 2024 Team Director at RIKEN, Center for Quantum Computing (-present)
- 2025 Co-founder and scientific advisor of Yaqumo

Recent Achievements

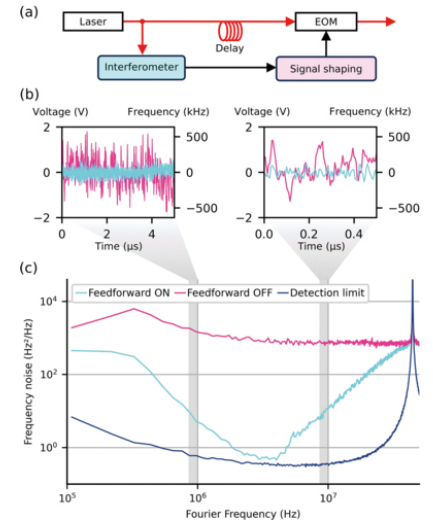
Measurement and feedforward correction of the fast phase noise of lasers

As part of our quantum computing effort, we have investigated the phase noise of lasers. For entangling two atoms separated by a micrometer distance, it is required to excite the atoms' outermost electron to a giant Rydberg orbital. To realize this operation with the outstanding precision required to make a quantum computer, it is crucial to use lasers with very low noise of their phase in the micro and sub-microsecond timescale. We have developed a fully-fiberized instrument that can detect and even correct such fast phase fluctuations of lasers. We demonstrated a measurement noise floor of less than $0.1 \text{ Hz}^2/\text{Hz}$, and a noise suppression of more than 20 dB for Fourier frequencies in the 1 to 10 MHz region (reaching up to 30 dB at 3 MHz).

Published as *Phys. Rev. A* 111 (4), 042614 (2025).

Measurement and correction of fast phase noise. (a) Schematic of the phase noise eater. (b) Time traces of the measured frequency noise with (in blue) and without (in pink) the feedforward correction. (c) Frequency noise PSD with and without the correction. The dark blue curve is the noise floor. A cancellation of more than 30 dB is achieved at a Fourier frequency of 3 MHz, where the noise is suppressed down to $0.5 \text{ Hz}^2/\text{Hz}$.

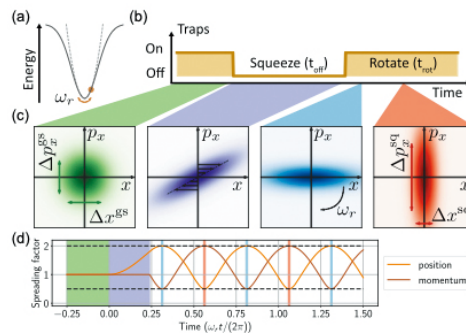
<https://doi.org/10.1103/PhysRevA.111.042614>



Generation of motional squeezed states for neutral atoms in optical tweezers

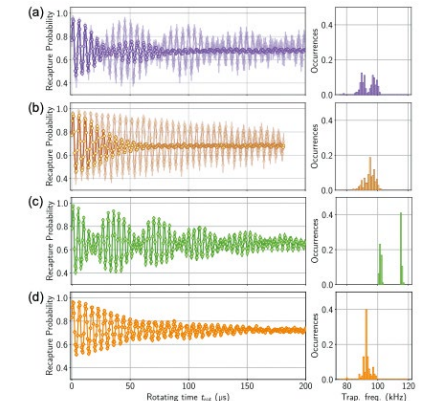
Optical tweezers are a powerful tool for the precise positioning of a variety of small objects, including single neutral atoms. Once trapped, atoms can be cooled to the motional ground state of the tweezers. For a more advanced control of their spatial wave function, we report here a simple method to squeeze their motion, and the protocol to measure the squeezing factor based on momentum spreading estimation. We explore the limitations set by the technical imperfections of the tweezers, as well as the more fundamental limit set by their anharmonicity, and finally demonstrate a squeezing of 5.4 dB. The implementation of motional squeezing allows us to push back the limit set by the position quantum noise and thus to explore more extreme situations requiring atoms positioned with nanometric precision.

Published as *Phys. Rev. Lett.* 135, 253404 (2025).



Generation of squeezed states. (a) Optical tweezer potential (solid line), and its harmonic approximation (dashed line). (b) Experimental sequence and (c) sketches of the Wigner quasiprobability distribution of the atomic state in the x - p_x phase space through the sequence. (d) Theoretical standard deviations of x and p_x , normalized to the motional ground-state fluctuations, as a function of time.

<https://journals.aps.org/prl/pdf/10.1103/3kwz-ny2h>



Oscillations of squeezed states averaged over an array of optical tweezers. The displayed data correspond to the experimental parameters $t_{\text{off}} \frac{1}{4} 2.0 \mu\text{s}$ and $t_{\text{rel}} \frac{1}{4} 20 \mu\text{s}$, while varying the rotating time t_{rot} . The subfigures show the recapture probability for different corrections: (a) no corrections, (b) anisotropy compensation, (c) inhomogeneity compensation and (d) both corrections. The trapping frequencies, extracted from Fourier transforms of the individual atomic signals [shown in the lighter curve in (a) and (b)], are plotted in the right panels.

<https://journals.aps.org/prl/pdf/10.1103/3kwz-ny2h>

Core members

(Postdoctoral Researcher) **Luisa Loranca Cruz**
(Visiting PhD Student) **Robin Kocik**

(Visiting PhD Student) **Tom Denecker**
(Technical Staff I) **Valentin Anthoine**

Floating-Electron-Based Quantum Information RIKEN Hakubi Research Team

Keywords: Quantum technology, Quantum computer, Quantum bit, Two-dimensional electron system, Microwave

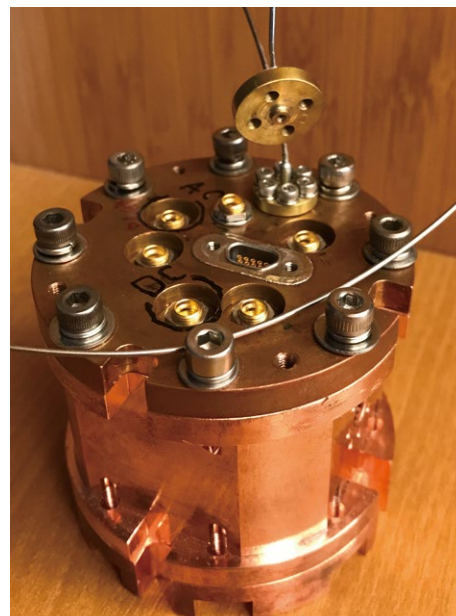
Research Outline

Our research focuses on electrons floating above liquid helium and solid neon as promising platforms for quantum information processing. Suspended in vacuum just above the surface, these electrons exist in an exceptionally clean and nearly defect-free environment, enabling long coherence times that are attractive for quantum computing applications.

Using electrons on helium, we are able to prepare a highly uniform electron system—a cleanliness reflected in the record-high mobility observed in this two-dimensional electron system, the highest among all known 2D electron platforms. This uniformity opens the door to exploring rich many-body electron physics, including plasmon excitations and quantum simulation, as well as pursuing spin-based single-electron qubits.

Solid neon, being a solid, has a surface that does not oscillate, and is therefore expected to support even longer coherence times than liquid helium. Both charge and spin quantum states are anticipated to exhibit comparably long coherence times, making solid neon a compelling candidate for use as a quantum memory.

In parallel with these studies, we are developing cryogenic electronics for large-scale quantum systems, including cryogenic microwave sources and related circuitry operating at millikelvin temperatures. These technologies are important for improving scalability and enabling future quantum computation.



Sealed chamber for quantum experiments, where helium or neon gas is introduced through a thin metal tube and condensed into liquid helium or solid neon inside



Erika Kawakami (Ph.D.), RIKEN Hakubi Team Leader

Selected Publications

- 1 A. Jennings, I. Grytsenko, T. Giovansili, I. J. Barabash, O. Rybalko, Y. Tian, J. Wang, H. Ikegami, and E. Kawakami, "Strong Coupling Between RF Photons and Plasmons of Electrons on Liquid Helium", *arXiv:2601.22552* (2026).
- 2 Y. Tian, I. Grytsenko, A. Jennings, J. Wang, H. Ikegami, X. Zhou, S. Tamate, H. Terai, H. Kutsuma, D. Jin, M. Benito, and E. Kawakami, "Nb-Ti-N nanowire resonators and prospects for spin-photon coupling with electrons on solid neon", *Phys. Rev. Applied* 25, 024011 (2026).
- 3 A. Jennings, I. Grytsenko, Y. Tian, O. Rybalko, J. Wang, I. J. Barabash, and E. Kawakami, "Probing the Quantum Capacitance of Rydberg Transitions of Surface Electrons on Liquid Helium via Microwave Frequency Modulation", *Phys. Rev. Lett.* 135, 087001 (2025).
- 4 I. Grytsenko, S. van Haagen, O. Rybalko, A. Jennings, R. Mohan, Y. Tian, and E. Kawakami, "Characterization of Tunnel Diode Oscillator for Qubit Readout Applications", *J. Low Temp. Phys.* 219, 282 (2025).
- 5 A. Jennings, X. Zhou, I. Grytsenko, and E. Kawakami, "Quantum computing using floating electrons on cryogenic substrates: Potential And Challenges", *Appl. Phys. Lett.* 124, 120501 (2024).

Brief resume

2016 Ph.D., Delft University of Technology, The Netherlands
 2016 Postdoctoral researcher, Okinawa Institute of Science and Technology
 2017 PRESTO, Japan Science and Technology Agency
 2020 RIKEN Hakubi Team Leader, Floating-Electron-Based Quantum Information RIKEN Hakubi Research Team (-present)

Recent Achievements

Coherent coupling between plasmons and photons in a clean two-dimensional electron system

A plasmon is a collective oscillation of many electrons that interacts strongly with electromagnetic waves. Plasmons have been widely used in sensing applications and are now attracting interest for quantum information technologies such as quantum computing.

Electrons floating on liquid helium exist in an exceptionally clean environment, free of impurities and defects. This cleanliness preserves high-quality plasmon oscillations, enabling strong coherent coupling with RF photons in an LC resonator. Time-resolved measurements directly revealed periodic energy exchange between the two modes, confirming their coherent coupling.



The frequency of collective electron oscillations (plasmons) is tuned via the electrode voltage toward the resonance frequency of an electrical circuit (LC resonator). As the two frequencies approach each other, an avoided crossing appears—a phenomenon in which the two modes repel each other rather than crossing. This is key evidence that the plasmon and the LC circuit are coherently coupled in a quantum mechanical sense. When the two systems are strongly coupled, the originally independent modes hybridize and form two new mixed modes. The experimental data shown in the left panel agree well with the simulation results (right panel), validating the model. The blue dashed lines overlaid on the simulation data represent the theoretical plasmon frequency and reproduce the observed mode well.

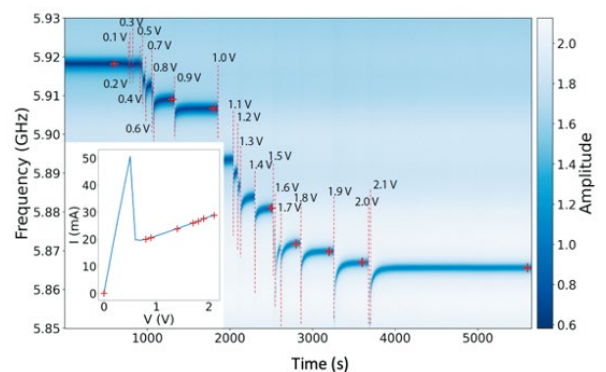
This figure shows the time evolution of the reflected signal intensity after applying a 20 ns RF pulse. In the experimental results (left), periodic energy exchange between the plasmon and photon modes is clearly observed, demonstrating strong coherent coupling between the two. The right panel shows the theoretical simulation results, where the color indicates the RF electric field intensity stored in the LC resonator. The simulated energy exchange between the plasmon and photon modes reproduces the experimental observations well.

Electrons on solid neon: toward high-fidelity qubits

Electrons floating on solid neon can maintain quantum states for a long time, making them a promising candidate for qubits.

In this work, we first demonstrated that superconducting resonators retain their high performance even after solid neon is deposited on them and electrons are loaded onto the neon surface. This is an important result showing that quantum devices based on electrons on solid neon can be realistically fabricated.

Furthermore, we theoretically analyzed designs in which carefully arranged micromagnets enable strong coupling between the electron spin and microwave photons. Our analysis shows that, even using naturally occurring neon, single-qubit gate fidelities exceeding 99.99% and two-qubit gate fidelities exceeding 99.9% are achievable—precision sufficient for practical quantum computing.



Time evolution of the superconducting resonator's resonance peaks (red crosses) during the deposition of electrons onto the solid neon surface. Each time a voltage is applied to the filament (red dashed lines), electrons are emitted and the resonance frequency shifts stepwise. After sufficient time has elapsed, the frequency stabilizes, confirming that the electrons have settled onto the solid neon surface. The inset (bottom left) shows the current-voltage characteristics of the filament.

Core members

(Technical Scientist) **Ivan Grytsenko**
(Postdoctoral Researcher) **Asher Jennings**

(Postdoctoral Researcher) **Jun Wang**
(Research Part Timer I) **Oleksiy Rybalko**

Semiconductor Quantum Information Device Research Team

Keywords: Quantum computer, Semiconductor, Quantum bit, Quantum dot, Electron spin

Research Outline

We perform research and development to apply semiconductor electron (or hole) spins as units (qubits) of quantum information to quantum computing. Studies on semiconductor quantum computing have been motivated by advantages of long coherence time, compatibility with existing semiconductor device integration technology and capability of high-temperature (> 1 Kelvin) operation. To date we have achieved various kinds of major quantum operations, including single qubit and two-qubit gates, initialization and readout with high enough fidelities exceeding fault tolerant thresholds using spin qubits in Si quantum dots. Based on these achievements we are now aiming to build up basic technologies of constructing medium to large scale quantum computers in Si. In this line we will develop relevant quantum logic calculation methods, advanced quantum architectures, qubit devices that have compatibility with semiconductor device integration technology.



Inside the laboratory

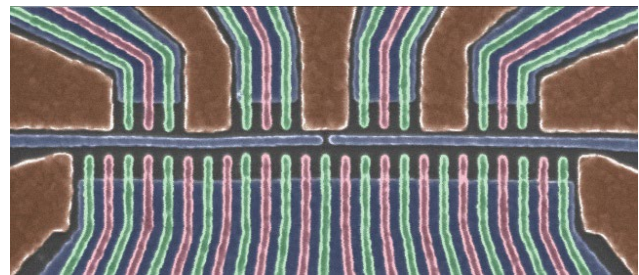
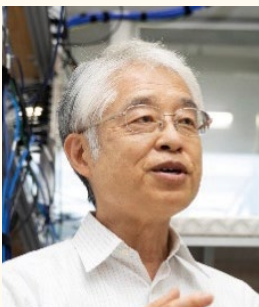


Photo of 12-qubit device currently in production



Seigo Tarucha (D.Eng.), Team Director

Selected Publications

- 1 J.S. Rojas-Arias, Y. Kojima, K. Takeda, P. Stano, T. Nakajima, J. Yoneda, A. Noiri, T. Kobayashi, D. Loss, and S. Tarucha, "The origins of noise in the Zeeman splitting of spin qubits in natural-silicon devices", *npj Quantum Info.* 12, 9 (2025).
- 2 K. Takeda, A. Noiri, T. Nakajima, L. C. Camenzind, T. Kobayashi, A. Sammak, G. Scappucci, and S. Tarucha, "Rapid single-shot parity spin readout in a silicon double quantum dot with fidelity exceeding 99 %", *npj Quantum Info.* 10, 22 (2024).
- 3 T. Kobayashi, T. Nakajima, K. Takeda, A. Noiri, J. Yoneda, and S. Tarucha, "Feedback-based active reset of a spin qubit in silicon", *npj Quantum Information* 9, 52 (2023).
- 4 J.S. Rojas-Arias, A. Noiri, P. Stano, P. (Stano, P.), T. Nakajima, J. Yoneda, K. Takeda, T. Kobayashi, A. Sammak, G. Scappucci, D. Loss, and S. Tarucha, "Spatial noise correlations beyond nearest neighbors in $^{28}\text{Si}/\text{Si-Ge}$ spin qubits", *Phys. Rev. Appl.* 20, 5 (2023).
- 5 K. Takeda, A. Noiri, T. Nakajima, T. Kobayashi, and S. Tarucha, "Quantum error correction with silicon spin qubits", *Nature*, 608, 682-686 (2022).

Brief resume

- 1978 Basic Research Laboratories of Nippon Tel. & Tel. Corp.
- 1986 Dr of Engineering
- 1990 Research group leader, NTT Basic Research Laboratory
- 1998 Professor, Department of Physics, The University of Tokyo
- 2004 Professor, Department of Applied Physics, The University of Tokyo
- 2013 Division Director, Quantum Information Electronics Division, RIKEN Center for Emergent Matter Science (-present)
- 2013 Group Director, Quantum Functional System Research Group, Division Director, Quantum Information Electronics Division, RIKEN Center for Emergent Matter Science (-present)
- 2018 Deputy Director, RIKEN Center for Emergent Matter Science
- 2019 Guest Professor, Department of Physics, Tokyo University of Science (-present)
- 2020 Team Director, Semiconductor Quantum Information Device Research Team, RIKEN Center for Quantum Computing (-present)

Recent Achievements

High-fidelity spin readout in silicon qubits

It is difficult to directly detect spin orientation in a single shot measurement. Therefore, a combined method of spin to charge information conversion and charge sensing is employed. For the spin-charge conversion spin dependent tunneling is often utilized. However, this method is slow and not so accurate. Here we use spin blockade effect instead to significantly improve the speed and accuracy of spin readout in silicon (Si) qubit devices.

We fabricate a Si quadruple quantum dot (QD) device made in Si/SiGe and use a double QD having two electron spins for the spin readout experiment (Fig.1). When the two spins are antiparallel, either electron can move between the two dots, generating double occupation (2,0) while when they are parallel, the double occupancy does not appear, according to Pauli exclusion. We improve the charge sensor design for detecting the electron occupancy either (2,0) or (1,1) (Fig.2), and in addition the sensitivity of the charge sensor and have finally raised visibility of the charge sensor signal for distinguishing the spin state up to 99.6% (highest in the world), and shortened the measurement time as well.

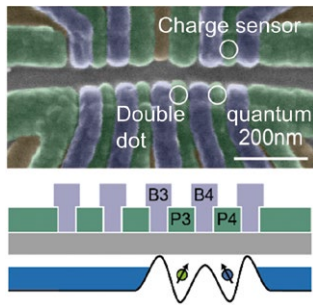


Fig. 1 Two qubit device

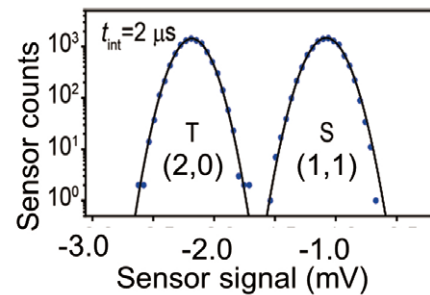


Fig. 2 Spin readout

Measurement of phase errors in silicon qubits induced by electron move in multi-quantum-dot systems

Silicon spin qubits are an excellent platform for large-scale quantum computers due to their compatibility with existing semiconductor fabrication technologies. In these systems, quantum information is encoded in the spin orientation and phase of electrons. For practical quantum computation, operations involving electron transfer such as measurement and long-range coupling are also essential. In this study, we measure qubit phase errors caused by changes in electron positions, and discuss their impact and possible strategies for suppression.

The time evolution of the qubit phase was measured and compared while varying the electron configuration in a triple quantum dot system. The observed phase shift was significant even in comparison with other sources of phase errors, indicating that electron transfer can constitute a major source of error.

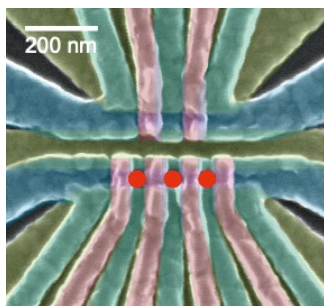


Fig. 1 Triple quantum dot device used to investigate influences of charge states on a spin qubit

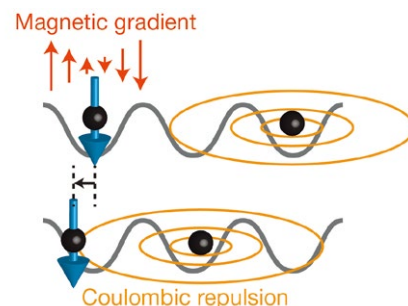


Fig. 2 Mechanism in which charge state configuration in the surrounding influences a spin qubit

Core members

(Senior Research Scientist) **Takashi Kobayashi**

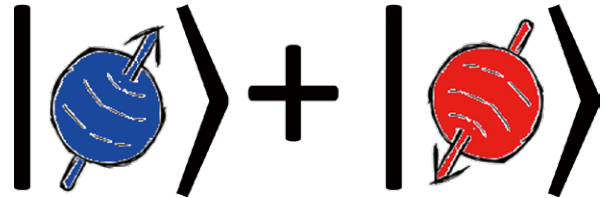
(Technical staff I) **Reiko Kuroda**

Semiconductor Quantum Information Device Theory Research Team

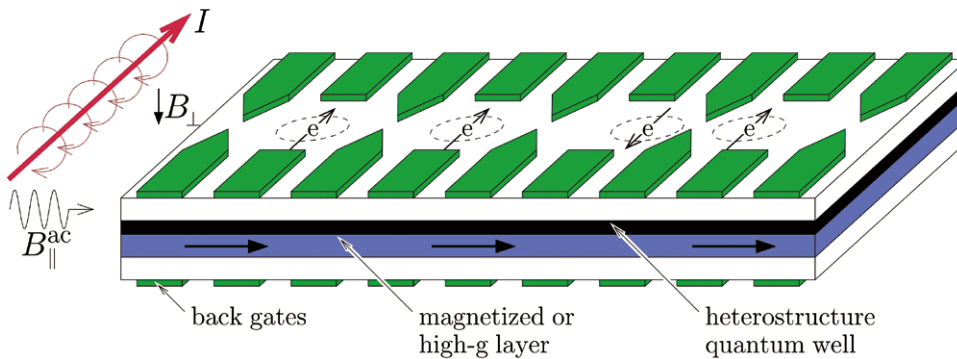
Keywords: Quantum dots, Spin-based quantum information science, Qubit, Spin-orbit interaction, Quantum information processing

Research Outline

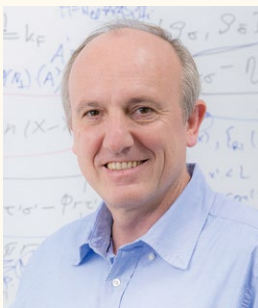
Our team is working on the theory of a spin-based quantum computer. We design its CMOS-compatible components deriving from Si and Ge gated quantum dots. We focus on spin qubits that can be manipulated by electric fields through various spin-orbit interactions. Using advanced band-structure models, we investigate the properties of holes and electrons confined in low-dimensional geometries. We search for optimal setups and ways of protecting the qubits from noise. We analyze perspective qubit interconnects which would allow assembling a large number of qubits into networks. Our ultimate goal is to identify fast, small, and scalable elements of the future quantum computer.



Spin-based quantum computing uses the spin of an electron in a solid to represent a quantum bit.



An array of quantum dots envisioned to realize a quantum processor.



Daniel Loss (Ph.D.), Team Director

Selected Publications

- 1 J. S. Rojas-Arias, A. Noiri, J. Yoneda, P. Stano, T. Nakajima, K. Takeda, T. Kobayashi, G. Scappucci, S. Tarucha, and D. Loss, "Inferring charge-noise source locations from correlations in spin qubits", *Phys. Rev. Lett.* 136, 027001 (2026).
- 2 J. S. Rojas-Arias, Y. Kojima, K. Takeda, P. Stano, T. Nakajima, J. Yoneda, A. Noiri, T. Kobayashi, D. Loss, and S. Tarucha, "The origins of noise in the Zeeman splitting of spin qubits in natural-silicon devices", *npj Quantum Information* 12, 9 (2026).
- 3 J. S. Rojas-Arias, A. Noiri, P. Stano, T. Nakajima, J. Yoneda, K. Takeda, T. Kobayashi, A. Sammak, G. Scappucci, D. Loss, and S. Tarucha, "Spatial noise correlations beyond nearest neighbors in $^{28}\text{Si}/\text{Si-Ge}$ spin qubits", *Phys. Rev. Appl.* 20, 054024 (2023).
- 4 P. Stano and D. Loss, "Review of performance metrics of spin qubits in gated semiconducting nanostructures", *Nat. Rev. Phys.* 4, 672 (2022).
- 5 D. Loss, D. DiVincenzo, "Quantum computation with quantum dots", *Phys. Rev. A* 57, 120 (1998).

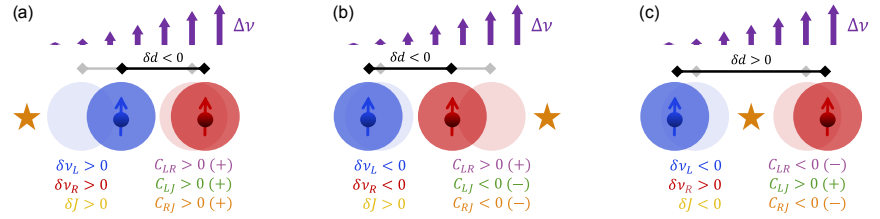
Brief resume

- 1985 Ph.D. in Theoretical Physics, University of Zurich, Switzerland
- 1985 Postdoctoral Research Associate, University of Zurich, Switzerland
- 1989 Postdoctoral Research Fellow, University of Illinois at Urbana-Champaign, USA
- 1991 Research Scientist, IBM T. J. Watson Research Center, USA
- 1993 Assistant/Associate Professor, Simon Fraser University, Canada
- 1996 Professor, Department of Physics, University of Basel, Switzerland (-present)
- 2012 Team Leader, Emergent Quantum System Research Team, RIKEN
- 2013 Team Leader, Quantum System Theory Research Team, Quantum Information Electronics Division, RIKEN Center for Emergent Matter Science (-present)
- 2021 Team Leader, Semiconductor Quantum Information Device Theory Research Team, RIKEN Center for Quantum Computing (-present)

Recent Achievements

Inferring charge-noise source locations from correlations in spin qubits

We developed a new method to infer the spatial location of charge-noise sources in semiconductor spin-qubit devices using correlations between fluctuations of qubit Zeeman energies and exchange interaction. By analyzing the signs and amplitudes of the measured cross-correlations, the method allows individual charge two-level fluctuators (TLFs) to be triangulated relative to the qubit array. In collaboration with experimentalists, we demonstrated the technique in an actual silicon spin-qubit device, where we identified dominant fluctuators located on opposite sides of the qubits and extracted their characteristic switching times. We further showed that the approach naturally generalizes to larger qubit arrays, providing a scalable framework to spatially characterize microscopic charge-noise sources in semiconductor quantum processors.

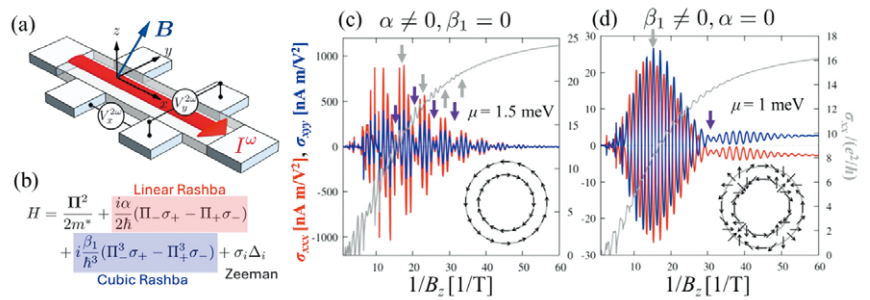


Determining the position of charge fluctuators from correlated qubit noise. Illustration of three possible locations of a charge two-level fluctuator (TLF) relative to a pair of spin qubits: (a) to the left of the array, (b) to the right, and (c) between the qubits. The blue and red arrows represent the left and right qubits, respectively, while the orange star denotes the fluctuator. The purple arrows indicate the spatial gradient of the qubit Zeeman energy, and the black segment marks the interqubit separation. Faint-colored shapes indicate the qubit positions before the fluctuator switches state. The lower panels summarize the induced shifts in qubit and exchange energies together with the corresponding signs of the measured noise cross-correlations.

©Phys. Rev. Lett. 136, 027001 (2026)

Probing Fermi-surface spin-textures via the nonlinear Shubnikov-de Haas effect

We have developed a microscopic theory of the nonlinear Shubnikov-de Haas (NSdH) effect, namely quantum oscillations in the second-order electric-field response. We show that the NSdH effect is highly sensitive to momentum-space spin textures generated by spin-orbit interaction (SOI). In particular, the beating nodes of NSdH oscillations exhibit a characteristic π -phase shift relative to those of conventional linear SdH oscillations, providing a direct signature of SOI. As a concrete example, we further demonstrate that the NSdH effect can distinguish linear from cubic Rashba SOI in Ge-based planar heterostructures by comparing the phase difference between the longitudinal and Hall components of the nonlinear conductivity. These results establish the NSdH effect as a sensitive probe of SOI and provide a framework for characterizing materials relevant to spintronics and quantum information technologies.



Nonlinear Shubnikov-de Haas effect. (a) Schematic illustration of the setup. (b) Hamiltonian used in the analysis. (c,d) Linear and nonlinear Shubnikov-de Haas oscillations induced by (c) linear Rashba and (d) cubic Rashba spin-orbit interactions. The gray and purple arrows indicate the positions of the beating nodes. Insets show the in-plane spin textures on the Fermi surfaces for each case.

Core members

(Postdoctoral Researcher) **Juan Rojas-Arias**
 (Research Scientist) **Kazuki Nakazawa**
 (Senior Research Scientist) **Peter Stano**



Quantum Computing Theory Research Team

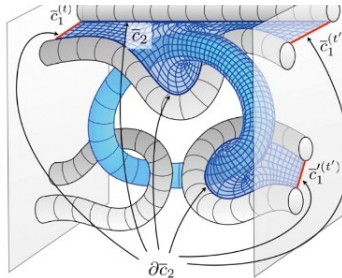
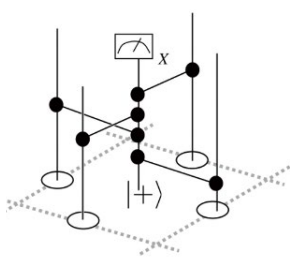
Keywords: Quantum computing, Quantum information science, Quantum machine learning, Quantum error correction

Research Outline

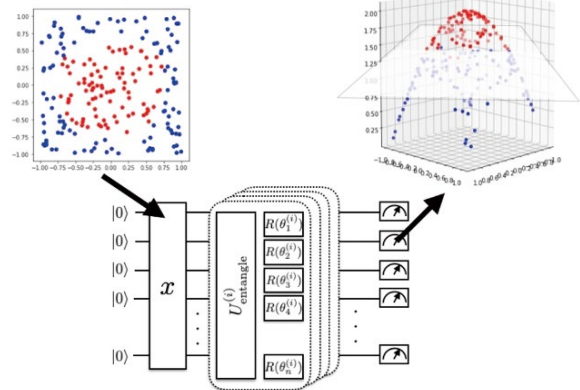
Quantum computing is revolutionizing technology, and Quantum Computing Theory Research team is at the forefront of this transformation. Our focus is on developing quantum computing theory and software essential for realizing quantum computers, designing new quantum algorithms, and analyzing their performance.

Our team is working on near-term technologies to harness the power of quantum computers on scales achievable now and in the near future. We explore applications in fundamental physics, quantum chemistry, and quantum machine learning while addressing quantum computer architectures optimization of quantum circuits. Another target is designing large-scale, fault-tolerant quantum computers being equipped with quantum error correction, that are capable of performing complex calculations with high reliability.

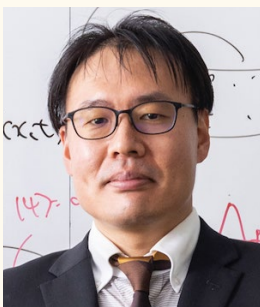
Embracing interdisciplinary research, we foster connections between quantum information science and fields like fundamental physics, quantum chemistry, machine learning, and high-performance computing. We aim to open up new scientific frontiers with quantum computers or through the lens of quantum information science. This collaborative approach drives advancements in quantum computing and its real-world applications, positioning RQC as a key player in shaping the future of quantum technology.



A quantum circuit for quantum error correction (Left), fault-tolerant quantum computing using the surface code (Right).



Quantum Circuit Learning: A supervised machine learning using parameterized quantum circuits.



Keisuke Fujii (Ph.D.), Team Director

Selected Publications

- 1 R. Toshio, Y. Akahoshi, J. Fujisaki, H. Oshima, S. Sato, and K. Fujii, "Practical Quantum Advantage on Partially Fault-Tolerant Quantum Computer", *Phys. Rev. X* 15, 021057 (2025).
- 2 Y. Akahoshi, K. Maruyama, H. Oshima, S. Sato, and K. Fujii, "Partially fault-tolerant quantum computing architecture with error-corrected Clifford gates and space-time efficient analog rotations", *PRX Quantum* 5, 010337 (2024).
- 3 K. Fujii, K. Mizuta, H. Ueda, K. Mitarai, W. Mizukami, and Y. O. Nakagawa, "Deep Variational Quantum Eigensolver: a divide-and-conquer method for solving a larger problem with smaller size quantum computers", *PRX Quantum* 3, 010346 (2022).
- 4 K. Mitarai, M. Negoro, M. Kitagawa and K. Fujii, "Quantum Circuit Learning", *Phys. Rev. A*, 98, 032309 (2018).
- 5 K. Fujii and K. Nakajima, "Harnessing Disordered-Ensemble Quantum Dynamics for Machine Learning", *Phys. Rev. Applied* 8, 024030 (2017).

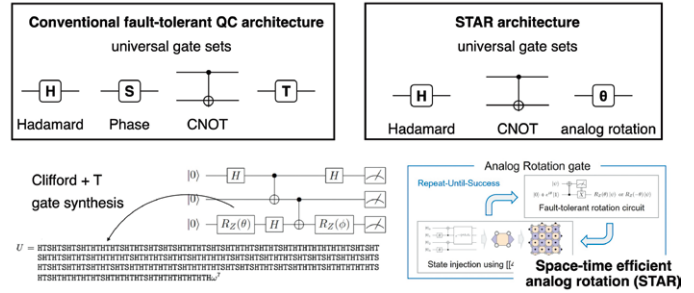
Brief resume

- 2011 Ph.D. (Engineering), Kyoto University
- 2011 Postdoc, Osaka University
- 2013 Program-Specific Assistant Professor, Kyoto University
- 2016 Assistant Professor, The University of Tokyo
- 2017 Program-Specific Associate Professor, Kyoto University
- 2019 Professor, Graduate School of Engineering Science, Osaka University (-present)
- 2020 Deputy Director, Center for Quantum Information and Quantum Biology, Osaka University (-present)
- 2020 Team Leader, Quantum Computation Theory Research Team, RIKEN
- 2024 Team Director, Quantum Computation Theory Research Team, RIKEN (-present)

Recent Achievements

Partially fault tolerant quantum computing architecture with analog rotation gates

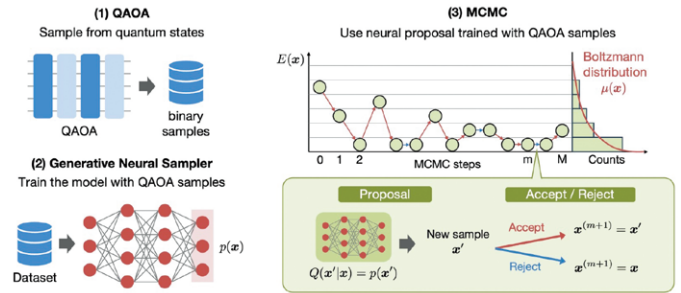
In this research, we proposed a new quantum computing paradigm called the STAR architecture toward the realization of practical fault tolerant quantum computers. In conventional approaches, implementing arbitrary angle quantum rotations requires a large number of T gates and costly magic state distillation protocols to protect them from errors, which has been a major obstacle to practical realization. Our approach significantly reduces this overhead by directly treating continuous rotation gates as fundamental operations. Furthermore, we introduced the concept of “partial fault tolerance,” where essential operations are protected by quantum error correction while certain errors are tolerated within a controllable range. This framework enables advanced applications such as quantum chemistry calculations and quantum simulations to be executed at an earlier stage, even with a limited number of qubits. The research is positioned as an effort to establish a practical quantum computing architecture that bridges the gap between the NISQ era and fully fault tolerant quantum computing (FTQC).



Elementary gate sets in conventional fault tolerant quantum computing and the STAR architecture. In conventional approaches, implementing continuous rotation gates requires a large number of T gates. In contrast, the STAR architecture can circumvent this overhead, while also suppressing errors when the rotation angles are small.

Quantum enhanced MCMC using sampling from quantum computers

In the utilization of NISQ computers, variational quantum algorithms have been extensively studied, where expectation values of quantum states are estimated through repeated measurements. However, expectation value estimation requires a large number of measurements and is highly susceptible to noise, motivating the development of algorithms that directly exploit the intrinsic sampling capability of quantum computers. In this research, we developed a quantum enhanced Markov chain Monte Carlo (MCMC) framework that utilizes samples generated by quantum computers as proposal distributions, and proposed a new hybrid approach combining quantum circuits with generative neural networks. Conventional quantum enhanced MCMC methods typically require strong restrictions on quantum circuits in order to guarantee convergence. Our method relaxes these constraints by allowing neural networks to learn the quantum generated samples, thereby more effectively leveraging the expressive power of quantum computers. Applying the method to the generation of Boltzmann distributions for spin glass models, we demonstrated substantial acceleration compared with conventional approaches. The results highlight the potential of practical sampling-based quantum algorithms suitable for NISQ devices.



Learning probability distributions with neural networks using samples generated from quantum computers. The constructed surrogate model is then employed as a proposal distribution to accelerate Markov chain Monte Carlo simulations.

Core members

(Special Postdoctoral Researcher) **Yasushi Yoneta**
(Postdoctoral Researcher) **Takaya Matsuura**
(Postdoctoral Researcher) **Wataru Setoyama**
(Visiting Scientist) **Tatsuhiko Ikeda**
(Visiting Scientist) **Kaoru Mizuta**



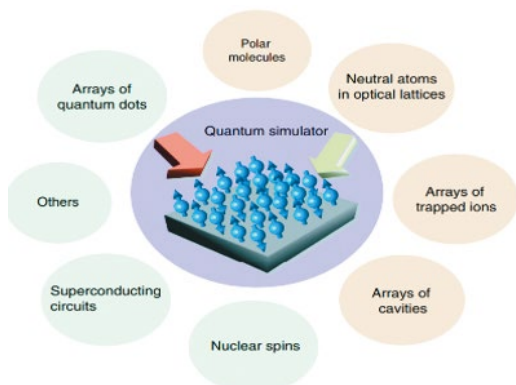
Quantum Information Physics Theory Research Team

Keywords: Quantum physics, Quantum optics, Quantum information processing and quantum computing, Artificial intelligence, Machine learning, Software for quantum physics, Superconducting qubits

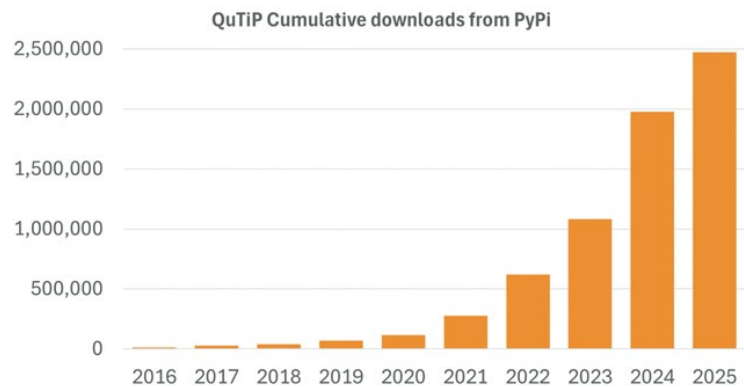
Research Outline

Our group is doing research on various quantum simulators and on machine learning and AI applied to quantum physics and quantum information. These are attracting growing interest in the research community.

Our quantum software (QuTiP: Quantum Toolbox in Python = quantum simulator) is having a large impact in this field. QuTiP is a free and open-source library for efficient simulation of a wide variety of quantum systems. QuTiP has been downloaded more than four million times, and it is used all over the world. We plan to make this indispensable software tool much stronger and more powerful.



Quantum analog simulations



QuTiP has been downloaded more than four million times, and it is used all over the world.



Franco Nori (Ph.D.), Team Director

Selected Publications

- 1 Y. Zeng, W. Qin, Y.H. Chen, C. Gneiting, F. Nori, "Neural-Network-Based Design of Approximate Gottesman-Kitaev-Preskill Code", *Phys. Rev. Lett.* 134, 060601 (2025).
- 2 W. Qin, A. Miranowicz, F. Nori, "Exponentially Improved Dispersive Qubit Readout with Squeezed Light", *Phys. Rev. Lett.* 133, 233605 (2024).
- 3 Y. Zeng, Z.Y. Zhou, E. Rinaldi, C. Gneiting, F. Nori, "Approximate Autonomous Quantum Error Correction with Reinforcement Learning", *Phys. Rev. Lett.* 131, 050601 (2023).
- 4 W. Qin, A. Miranowicz, F. Nori, "Beating the 3 dB Limit for Intracavity Squeezing and Its Application to Nondemolition Qubit Readout", *Phys. Rev. Lett.* 129, 123602 (2022).
- 5 W. Qin, A. Miranowicz, H. Jing, F. Nori, "Generating Long-Lived Macroscopically Distinct Superposition States in Atomic Ensembles", *Phys. Rev. Lett.* 127, 093602 (2021).

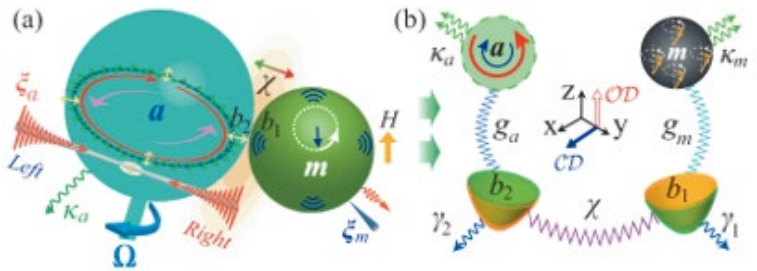
Brief resume

- 1982 Conicit Fellow and Graduate Research Assistant; Physics Department. Also at the Materials Research Laboratory; University of Illinois, USA
- 1987 Postdoctoral Research Fellow, Institute for Theoretical Physics, University of California, Santa Barbara, USA
- 1990 Assistant Professor, Associate Professor, Full Professor and Research Scientist, Department of Physics, University of Michigan, Ann Arbor, USA. (-present)
- 2002 Team Leader, Frontier Research System and, afterwards, Advanced Science Institute, RIKEN, Saitama, Japan.
- 2013 Concurrent positions as: Group Director of the Quantum Condensed Matter Research Group, CEMS, and also Team Leader at iTHES (Interdisciplinary Theoretical Sciences). RIKEN
- 2013 Chief Scientist. Theoretical Quantum Physics Laboratory, Cluster for Pioneering Research, RIKEN, Japan. (-present)
- 2020 Team Leader and afterwards Team Director for the Quantum Information Physics Theory Research Team, Quantum Computing Center, RIKEN, Japan. (-present)

Recent Achievements

Nonreciprocal quantum synchronization

Nonreciprocal physics is garnering enormous attention in both classical and quantum resource fields. Surprisingly, previous demonstrations have not explored nonreciprocal quantum synchronization of phonons, one of the most obvious examples of nonreciprocal quantum resources. Here we fill this gap to demonstrate the possibility of nonreciprocal quantum synchronization, revealing its counterintuitive robustness against random fabrication imperfections and thermal noise of practical devices. Specifically, phonons are synchronized in a chosen direction of light (magnetic field) but unsynchronized in the other, yielding a unique nonreciprocity of quantum synchronization. This happens by harnessing the synergy of the Sagnac and magnon Kerr effects, leading to an opposite Sagnac-Fizeau shift and an exceptional magnon Kerr-induced transition.



Nonreciprocal quantum synchronization

©D.-G. Lai, A. Miranowicz, F. Nori

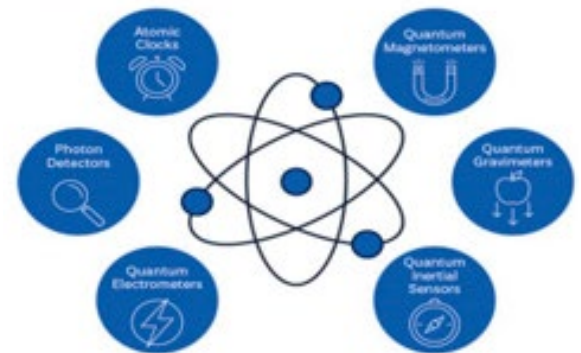
Nonreciprocal quantum synchronization

Nature Communications. 16, 8491 (2025). [PDF]

Quantum information bound in sensors

Non-Hermitian systems give rise to nontrivial phenomena due to their ability to exhibit peculiar spectral singularities known as exceptional points. Especially, the dynamical encirclement of exceptional points in a system parameter space enables chiral state switching. Although this chiral behavior can be effectively controlled in two-mode structures, extending such control to higher-dimensional systems with multiple exceptional points presents significant challenges, particularly when aiming to steer the system toward a specific target state, a capability crucial for advancing such fields as optical communication and quantum information processing. In this work, we overcome this challenge by experimentally demonstrating a genuine programmable symmetric-asymmetric multistate switching in a four-mode optical system. This is achieved through the controlled dynamic interplay between exceptional and diabolic points in the Hamiltonian spectrum. Our results lay the groundwork for the development of light manipulation protocols in multimode photonic setups.

Figure 1. Types of Quantum Sensors



Quantum information bound in sensors

©I. Arkhipov, F. Nori, S. K Özdemir

Achieving the quantum Fisher information bound in pseudo-Hermitian sensors

Phys. Rev. Lett. 136, 080802 (2026). [PDF]

Core members

(Research Scientist) **Clemens Gneiting**
 (Research Scientist) **Fernando Quijandria**
 (Postdoctoral Researcher) **Deng-Gao Lai**
 (RIKEN SPDR) **Ran Huang**
 (Postdoctoral Researcher) **Oleh Ivakhnenko**
 (JSPS Postdoctoral Researcher) **Paul Menczel**
 (JSPS Postdoctoral Researcher) **Therese Karmstrand**
 (JSPS Postdoctoral Researcher) **Théo Sepulcre**
 (Technical Part-Timer) **Veronika Kurth**

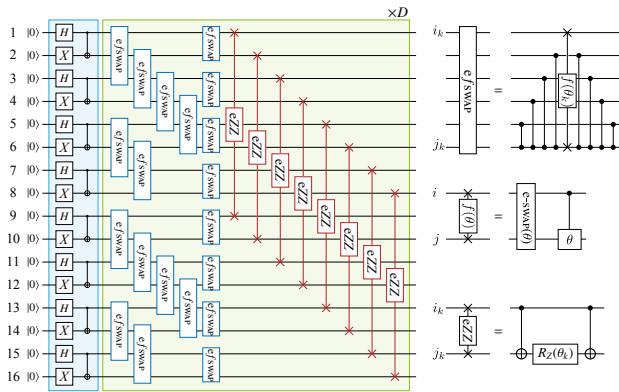


Quantum Computational Science Research Team

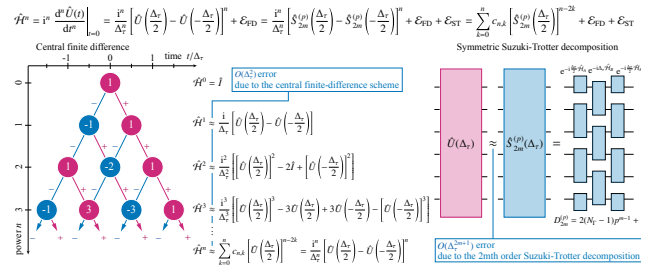
Keywords: Quantum many-body systems, Quantum dynamics, Quantum information physics, Tensor network, High performance computing

Research Outline

Our research focuses on the development of quantum-classical hybrid algorithms for simulating quantum many-body systems. We also investigate quantum dynamics in quantum computing from the perspective of quantum information theory. To support and validate these studies, we develop classical simulation methods for quantum computation. In addition, we are exploring quantum-HPC hybrid systems that integrate quantum computers with supercomputers as a future platform for high-performance computing.



Quantum circuits for VQE calculations of Hubbard model



Schematic figure for quantum power methods



Seiji Yunoki (Ph.D.), Team Director

Selected Publications

- 1 K. Seki, Y. Kikuchi, T. Hayata, and S. Yunoki, "Simulating Floquet scrambling circuits on trapped-ion quantum computers", *Phys. Rev. Research* 7, 023032 (2025).
- 2 Y. Otsuka, K. Seki, and S. Yunoki, "Quantum conditional mutual information as a probe of measurement-induced entanglement phase transitions", *Phys. Rev. B* 112, 054301 (2025).
- 3 S. Ejima, K. Seki, B. Fauseweh, and S. Yunoki, "Probabilistic imaginary-time evolution in state-vector-based and shot-based simulations and on quantum devices", *Phys. Rev. Research* 7, 043182 (2025).
- 4 K. Seki and S. Yunoki, "Energy-filtered random-phase states as microcanonical thermal pure quantum states", *Phys. Rev. B* 106, 155111 (2022).
- 5 K. Seki and S. Yunoki, "Spatial, spin, and charge symmetry projections for a Fermi-Hubbard model on a quantum computer", *Phys. Rev. A* 105, 032419 (2022).

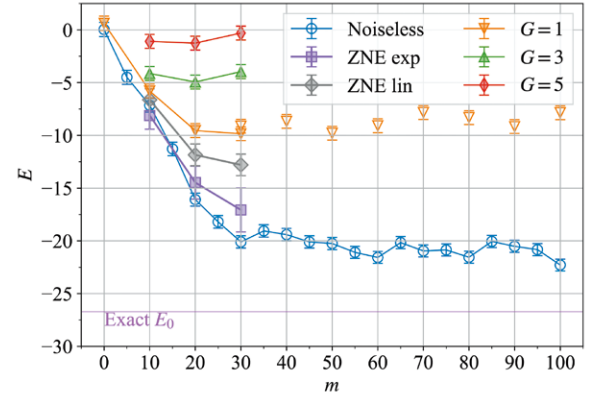
Brief resume

- 1996 Ph.D. (Engineering), Nagoya University
- 1996 Postdoc, National High Magnetic Field Laboratory (USA)
- 1999 Postdoc, Groningen University (The Netherlands)
- 2001 Postdoc, SISSA (Italy)
- 2006 Long-Term Visiting Scientist/Research Assistant Professor, Oak Ridge National Laboratory & University of Tennessee
- 2008 Associate Chief Scientist, Computational Condensed Matter Physics Laboratory, RIKEN
- 2010 Team Leader, Computational Materials Science Research Team, Advanced Institute of Computational Science, RIKEN
- 2012 Team Leader, Computational Quantum Matter Research Team, RIKEN Center for Emergent Matter Science (-present)
- 2017 Chief Scientist, Computational Condensed Matter Physics Laboratory, RIKEN (-present)
- 2018 Team Leader, Computational Materials Science Research Team, RIKEN Center for Computational Science (-present)
- 2021 Team Leader, Quantum Computational Science Research Team, RIKEN Center for Quantum Computing (-present)

Recent Achievements

Dissipative ground-state preparation of a quantum spin chain on a trapped-ion quantum computer

We investigated dissipation engineering as a method for preparing ground states of quantum many-body systems on quantum computers. This approach has recently become implementable on real quantum hardware with mid-circuit measurements and resets. Unlike conventional variational methods, which optimize circuit parameters, this method uses “dissipation” to release unwanted excitations into an environment, thereby driving the state toward the ground state. We derived a Kraus representation that correctly describes such dissipative processes for arbitrary time steps and showed that, under appropriate conditions, the fidelity with the ground state is monotonically nondecreasing. Furthermore, we implemented the method on the trapped-ion quantum computer Reimei for transverse-field Ising chains of up to 19 spins. Even for circuits containing up to 4,110 two-qubit gates, the dynamics converged to low-energy states. By further applying zero-noise extrapolation, we obtained energy estimates that agreed with noiseless simulations within statistical errors.

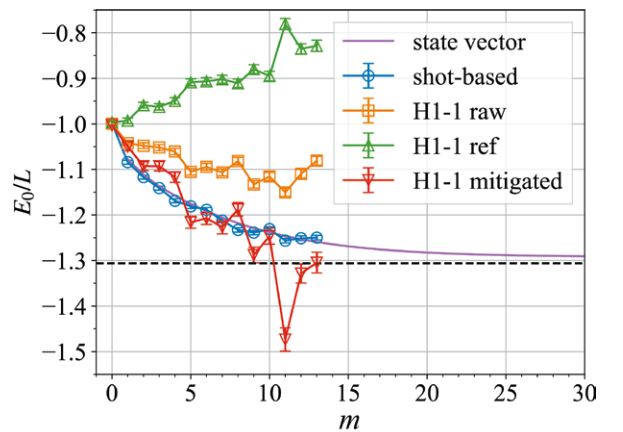


The energy of a 19-spin transverse-field Ising chain as a function of the time step in the dissipative process. The vertical axis represents the energy, and the horizontal axis represents the dissipative-process time step. Blue circles show the results of noiseless simulations, and the exact ground-state energy is indicated by the magenta horizontal line. Orange inverted triangles, green triangles, and red diamonds show the results obtained on the Reimei quantum computer with noise amplification factors $G=1$, 3 , and 5 , respectively. The results obtained by zero-noise extrapolation using exponential and linear fits are shown by purple squares and gray squares, respectively.

Probabilistic imaginary-time evolution in state-vector-based and shot-based simulations and on quantum devices

We studied probabilistic imaginary-time evolution as a method for finding ground states of quantum many-body systems on quantum computers. In conventional variational quantum algorithms, optimization becomes increasingly difficult as the system size grows. In this work, we treated imaginary-time evolution, which is effective in classical computation, as a probabilistic quantum algorithm in which the updated state is accepted only when the measurement outcome is successful. First, using state-vector simulations, we investigated how to choose initial parameters that increase the success probability. For Heisenberg chains and the transverse-field Ising model, we confirmed that the energy converges toward the ground state. Furthermore, we implemented the method on the trapped-ion quantum computer H1-1 using up to 17 qubits. Although the results were affected by noise, we devised and implemented an error-mitigation method based on reference circuits, obtaining results close to those of noiseless simulations.

The energy of the four-spin transverse-field Ising model as a function of the imaginary-time step. The vertical axis represents the energy, and the horizontal axis represents the imaginary-time step. Blue circles show the results of noiseless finite-shot simulations, while the magenta line shows the results of noiseless state-vector simulations corresponding to the infinite-shot limit. The exact ground-state energy is indicated by the dashed horizontal line. Orange squares show the results obtained on the H1-1 quantum computer, and green triangles show the results from the reference quantum circuit on the H1-1 quantum computer used for error mitigation. Red inverted triangles show the error-mitigated results obtained by estimating the depolarizing noise from the reference quantum circuit under the assumption of a depolarizing noise model.



Core members

(Research Scientist) **Kazuhiro Seki**

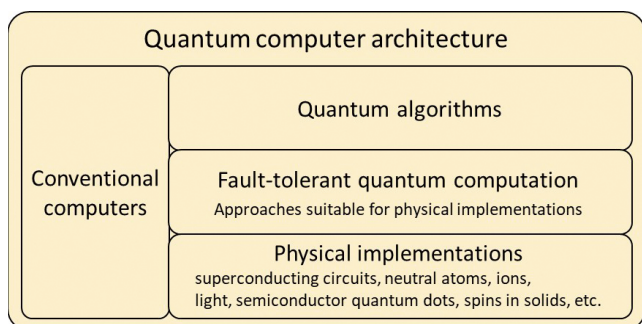
Quantum Computer Architecture Research Team

Keywords: Quantum computer, Quantum error correction, Fault-tolerant quantum computation, Physical implementation

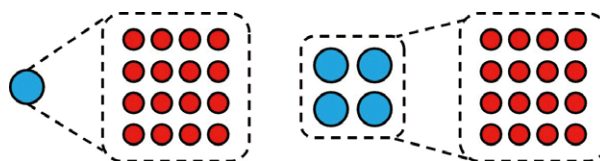
Research Outline

We are theoretically studying the total design of quantum computers, from the approaches to fault-tolerant quantum computation (FTQC) to their physical implementations, namely, quantum computer architecture. At present, various physical implementations of quantum computers, such as superconducting circuits, neutral atoms, ions, light, semiconductor quantum dots, and spins in solids, are under development. Since different implementations have different types of errors and different connectivity, it is effective to develop an approach to FTQC dedicated to each implementation. Also, since early quantum computers will be small, they should be designed for desirable quantum algorithms. Moreover, since conventional computers play important roles such as control of physical systems, decoding in error correction, and quantum-classical hybrid implementations of algorithms, quantum-classical cooperative system design is required. Thus, the research on quantum computer architecture requires to consider all aspects of quantum computers.

The requirement of large resource overheads for FTQC is a central problem at present. To solve this problem, we focus on high-rate codes. Conventional approaches to FTQC use the encoding of a single logical qubit into many physical qubits, leading to the resource problem. Thus high-rate codes encoding many logical qubits at once have recently attracted much attention. However, FTQC with them has not been established. We aim at solving the resource problem by developing FTQC with high-rate codes.



Quantum computer architecture



Conventional single-logical-qubit encoding (left) and high-rate code (right)



Hayato Goto (Ph.D.), Team Director

Selected Publications

- 1 R. Nakai and H. Goto, "Subsystem many-hypercube codes: High-rate concatenated codes with low-weight syndrome measurements", *Phys. Rev. Applied* 25, 014032 (2026).
- 2 H. Goto, "High-performance fault-tolerant quantum computing with many-hypercube codes", *Sci. Adv.* 10, eadp6388 (2024).
- 3 H. Goto, Y. Ho, and T. Kanao, "Measurement-free fault-tolerant logical-zero-state encoding of the distance-three nine-qubit surface code in a one-dimensional qubit array", *Phys. Rev. Research*, 5, 043137 (2023).
- 4 H. Goto, "Minimizing resource overheads for fault-tolerant preparation of encoded states of the Steane code", *Sci. Rep.*, 6, 19578 (2016).
- 5 H. Goto, "Step-by-step magic state encoding for efficient fault-tolerant quantum computation", *Sci. Rep.*, 4, 7501 (2014).

Brief resume

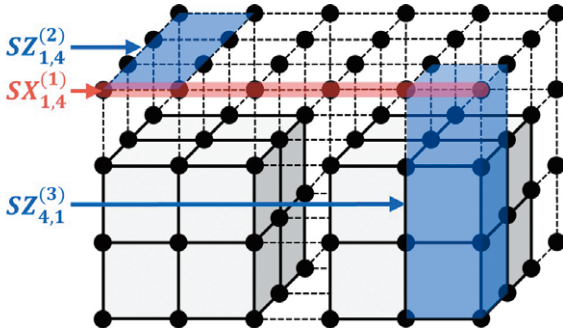
- 2003 Researcher, Toshiba Corporation
- 2007 Ph.D. (Science), The University of Tokyo
- 2016 Senior Research Scientist, Toshiba Corporation
- 2020 Fellow, Toshiba Corporation
- 2023 Senior Fellow, Toshiba Corporation (-present)
- 2023 Team Leader, Quantum Computer Architecture Research Team, RIKEN Center for Quantum Computing
- 2025 Team Director, Quantum Computer Architecture Research Team, RIKEN Center for Quantum Computing (-present)

Recent Achievements

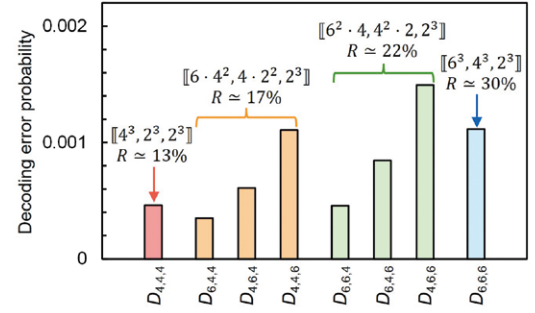
Improving performance and encoders of many-hypercube codes

As high-rate codes suitable for fault-tolerant quantum computation, we have proposed many-hypercube codes constructed by concatenating high-rate quantum error-detecting codes. In the original work, we studied the $[[6^L, 4^L, 2^L]]$ code (where L is the concatenation level), obtained by concatenating the $[[6, 4, 2]]$ code (a quantum error-detecting code of distance 2 that encodes four logical qubits into six physical qubits). We evaluated the performance of many-hypercube codes for all possible combinations of $[[6, 4, 2]]$ and $[[4, 2, 2]]$, and found that $D_{6,4,4}$ (the many-hypercube code using $[[6, 4, 2]]$ at level 1 and $[[4, 2, 2]]$ at levels 2 and 3) and $D_{6,6,4,4}$ exhibit the highest error-correction performance at levels 3 and 4, respectively. Furthermore, for the level-3 codes, $D_{4,4,4}$, $D_{6,4,4}$, $D_{6,6,4}$, and $D_{6,6,6}$, we newly developed efficient encoders that can reduce qubit resources by 60%.

H. Goto, "Optimized Many-Hypercube Codes toward Lower Logical Error Rates and Earlier Realization", arXiv:2512.00561 (2025).



Highest-performance level-3 many-hypercube code, $D_{6,4,4}$

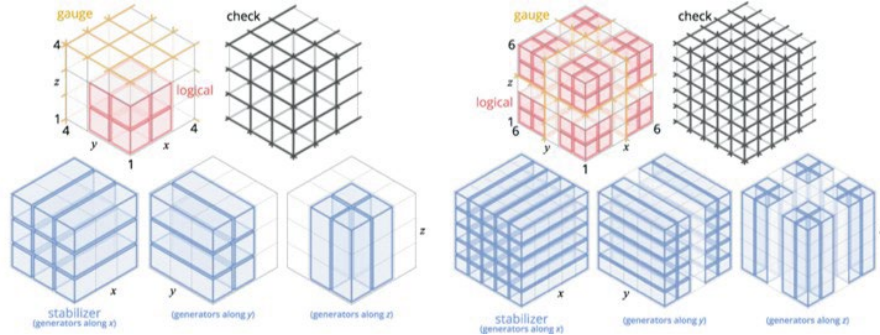


Performance comparison of level-3 many-hypercube codes

Subsystem many-hypercube codes

The drawback of many hypercube codes is their large-weight stabilizers requiring many ancilla qubits for their measurements. To address this issue, we introduced gauge degrees of freedom and proposed subsystem many-hypercube codes as an extension to subsystem codes. As a result, all measurement weights required for error correction are reduced to gauge-operator weight 4 or 6, and the stabilizer measurement outcomes are computed from the results of these gauge measurements. However, the gauge degrees of freedom make decoding more difficult than the original codes. To overcome this, we investigated several decoding methods and newly developed a neural-network-based decoder that offers both relatively high speed and high performance.

R. Nakai and H. Goto, "Subsystem many-hypercube codes: High-rate concatenated codes with low-weight syndrome measurements", *Phys. Rev. Applied* 25, 014032 (2026).



Level-3 subsystem many-hypercube codes (left: $D_{4,4,4}$, right: $D_{6,6,6}$)

Core members

(Research Scientist) **Ryota Nakai**

(Postdoctoral Researcher) **Naoyuki Kanomata**

Quantum Computer System Design Research Team

Keywords: Fault-tolerant quantum computing, Computer architecture, System software

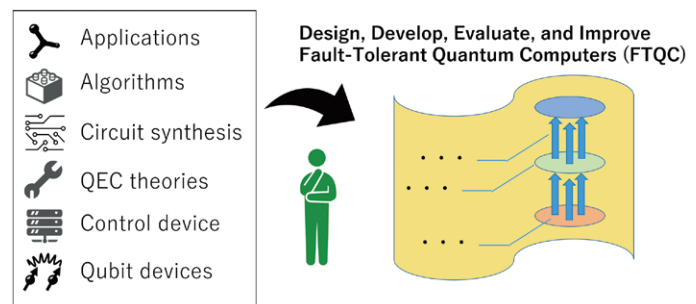
Research Outline

Our team conducts research and development on computing systems for realizing high-performance and scalable quantum computers. In particular, by incorporating ideas from modern computer science and software development, we explore methodologies for translating complex and abstract theories and tasks into concrete designs and implementations. We also collaborate with national projects developing quantum computers, and work on systems and software toward the realization of practical-scale fault-tolerant quantum computers.

Our research is broadly divided into three areas: computer architecture, system software, and device control. In computer architecture, we apply concepts from modern computer design to quantum computers and investigate how to build high-performance fault-tolerant quantum computers. Our goal is not merely to improve computational speed and qubit count, but also to design well-structured systems that possess properties expected of a “computer” such as reliability, versatility, and debuggability.

In system software, we develop compilers, profilers, and design-automation tools for fault-tolerant quantum computers. Through these foundations, we clarify the performance and characteristics required by realistic applications and provide design principles for quantum computers with high effective performance. We also formulate the challenges involved in maximizing quantum-computer performance as mathematical problems, and work on optimization and verification by leveraging algorithms and data structures.

In device control, we explore computer designs that make use of device-specific quantum functions, as well as implementation methods that can address realistic uncertainties such as device constraints and time-dependent variations in error characteristics. In collaboration with experimental teams, we also develop qubit-measurement infrastructures and realistic noise models. Through these efforts, we aim to bridge the gap between theoretical models and actual implementations, and to improve the feasibility of higher-layer system designs.



Research activities in our laboratory



Yasunari Suzuki (Ph.D.), Team Director

Selected Publications

- 1 K. Hamada, Y. Suzuki, and Y. Tokunaga, “Efficient and high-performance routing of lattice-surgery paths on three-dimensional lattice”, *Quantum* 10, 2061 (2026).
- 2 T. Kobori, Y. Suzuki, Y. Ueno, T. Tanimoto, S. Todo, and Y. Tokunaga, “LSQCA: Resource-Efficient Load/Store Architecture for Limited-Scale Fault-Tolerant Quantum Computing”, *HPCA2025*, pp. 304 (2025).
- 3 N. Yoshioka, T. Okubo, Y. Suzuki, Y. Koizumi, and W. Mizukami, “Hunting for quantum-classical crossover in condensed matter problems”, *npj QI* 4, 45 (2024).
- 4 Y. Suzuki, T. Sugiyama, T. Arai, W. Liao, K. Inoue, and T. Tanimoto, “Q3DE: A fault-tolerant quantum computer architecture for multi-bit burst errors by cosmic rays”, *MICRO2022*, pp. 1110 (2022).
- 5 Y. Suzuki, Y. Kawase, Y. Masumura, Y. Hiraga, M. Nakadai, J. Chen, K. M. Nakanishi, K. Mitarai, R. Imai, S. Tamiya, T. Yamamoto, T. Yan, T. Kawakubo, Y. O. Nakagawa, Y. Ibe, Y. Zhang, H. Yamashita, H. Yoshimura, A. Hayashi, and K. Fujii, “Qulacs: a fast and versatile quantum circuit simulator for research purpose”, *Quantum* 5, 559 (2021).

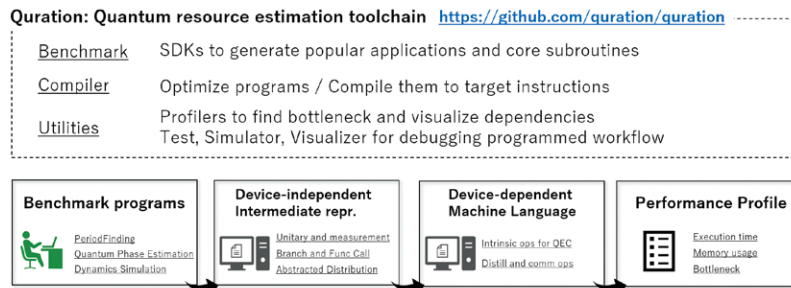
Brief resume

- 2018 The University of Tokyo, Ph.D. (Eng)
- 2018 Researcher, Secure Platform Laboratories, NTT Corporation
- 2019 Researcher, JST PRESTO
- 2021 Researcher, Computer and Data Science Laboratories, NTT Corporation
- 2023 Associate Distinguished Researcher, Computer and Data Science Laboratories, NTT Corporation
- 2025 Team Director, Quantum Computer System Design Research Team, Center for Quantum Computing, RIKEN (-present)
- 2026 Visiting Associate Professor, Quantum Computing System Center, Kyushu University (-present)
- 2026 Project Associate Professor, Center for Quantum Information and Quantum Biology, The University of Osaka (-present)
- 2026 Guest Professor, Department of Photo-Molecular Science, Institute for Molecular Science (-present)
- 2026 Guest Associate Professor, Department of Applied Physics, Graduate School of Engineering, The University of Tokyo (-present)

Recent Achievements

Quration: Quantum resource estimation toolchain for fault-tolerant quantum computer

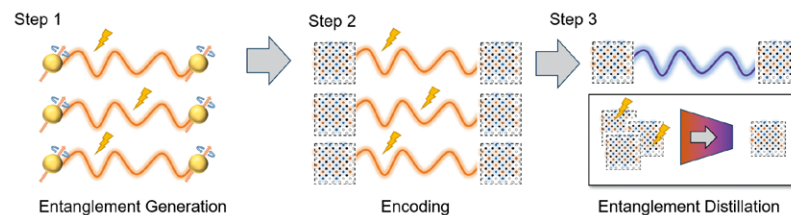
To build high-performance fault-tolerant quantum computers, it is necessary to combine various technologies developed through fundamental research and improve their performance. However, as more technologies are incorporated, the architecture of quantum computers becomes increasingly complex, making it difficult to evaluate how a given modification affects its entire performance. To address this issue, we developed Quration, a software tool that evaluates the performance of a given quantum computer design and analyzes how specific improvements affect the system. This software includes generators for representative benchmark programs such as phase estimation and period finding, compilers targeting architecture instruction sets based on popular quantum error-correction schemes and device constraints, and profilers and analyzers for evaluating and visualizing performance based on given device characteristics. Our work is available as open-source software at <https://github.com/quration/quration>.



Structure and computational flow of Quration

Logical entanglement distribution between distant 2D array qubits

To realize large-scale fault-tolerant quantum computers (FTQCs), it is important to develop distributed FTQC, in which multiple FTQC nodes perform computation while communicating with one another. In this work, we propose a protocol for efficiently performing communication between FTQC nodes. A typical inter-node communication process consists of four steps: (1) distributing physical entangled states, (2) encoding them to extend their lifetime, (3) distilling encoded entangled states to reduce error rates, and (4) consuming distilled entangled states to teleport qubits. This work proposes a framework to maximize the generation rate of encoded entangled states satisfying a target fidelity by performing post-selection according to the confidence in the success of step (2). We also present a process for implementing this framework on a two-dimensional qubit array and evaluate its performance.



Protocol of logical entanglement distribution

<https://journals.aps.org/prresearch/abstract/10.1103/m9gc-n3dl>

Core members

(Postdoctoral Researcher) **Takashi Imoto**
 (Research Scientist) **Yosuke Ueno**
 (Visiting Researcher) **Cheng-Yun Hsieh**
 (Junior Research Associate) **Asuka Koura**



Analytical Quantum Complexity RIKEN Hakubi Research Team

Keywords: Quantum computing, Quantum entanglement, Hamiltonian complexity, Quantum many-body physics, Quantum algorithm

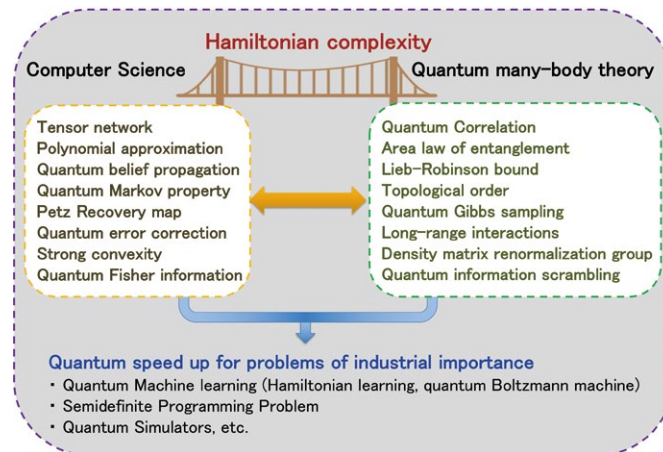
Research Outline

Over the past two decades, quantum computation within the realm of quantum information theory remained largely theoretical, with doubts cast on its practical applicability. This changed recently, especially in 2019, when Google's 53-qubit "Sycamore" quantum computer demonstrated "quantum supremacy" by performing specific calculations much faster than conventional computers. However, many issues still need resolution for practical use.

To meet these challenges, researchers worldwide are working on developing more useful algorithms, particularly in quantum many-body theory. In the realm of quantum physics, invisible particles like electrons and atoms play the main roles. Their interactions determine the properties of matter. These collections of particles, known as "quantum many-body systems," are central to understanding phenomena from electron movement to superconductivity and the development of quantum computers. This theory, which deals with the interactions of numerous quantum particles, can lead to unexpected phenomena, making it difficult to calculate. This area of study is known as Hamiltonian complexity.

Hamiltonian complexity research focuses on when and how quantum Hamiltonians can be efficiently simulated. Significantly, many problems in quantum computing belong to a class known as QMA (the quantum version of NP), which can be reduced to quantum many-body problems. Therefore, developing algorithms to solve quantum many-body problems is key to addressing all problems in the QMA class.

Hamiltonian complexity is a research area between computer science and physics with many mathematically defined unsolved problems. Our laboratory explores solutions to these mathematical challenges, having already achieved partial or complete solutions to significant issues such as the quantum entanglement boundary law conjecture, the quantum Markov conjecture, the line-ar-light-cone problem in the Lieb-Robinson bounds, quantum Hamiltonian learning, and long-range quantum entanglement at finite temperatures. Our goal is to further develop our research findings and tackle new unsolved problems.



Schematic figure for quantum Hamiltonian



Tomotaka Kuwahara (Ph.D), RIKEN Hakubi Team Leader

Selected Publications

- 1 H. Li, C. Shang, T. Kuwahara, and T. V. Vu, "Macroscopic particle transport in dissipative long-range bosonic systems", *Nature Communications*, 17, 4289 (2026).
- 2 K. Mizuta and T. Kuwahara, "Trotterization is Substantially Efficient for Low-Energy States", *Physical Review Letters*, 135, 130602 (2025).
- 3 T. Kuwahara, "Clustering of Conditional Mutual Information and Quantum Markov Structure at Arbitrary Temperatures", *Physical Review X* 15, 041010 (2025).
- 4 R. Achutha, D. Kim, Y. Kimura, and T. Kuwahara, "Efficient Simulation of 1D Long-Range Interacting Systems at Any Temperature", *Physical Review Letters*, 134, 190404 (2025).
- 5 D. Kim, T. Kuwahara, and K. Saito, "Thermal Area Law in Long-Range Interacting Systems", *Physical Review Letters* 134 (2), 020402 (2025).

Brief resume

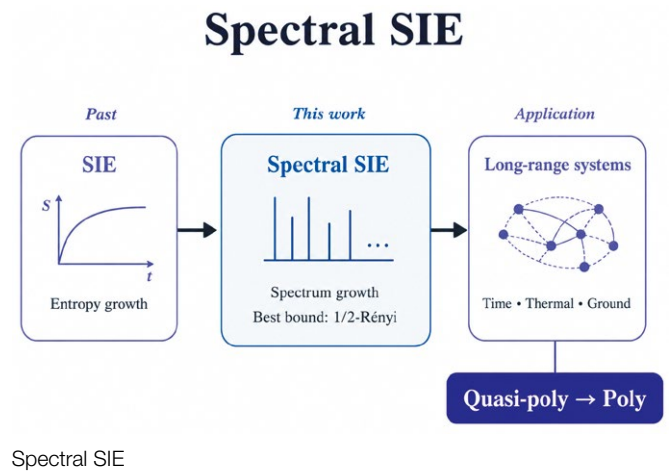
- 2015 JSPS Research Fellowship for Young Scientists (JSPS PD), The University of Tokyo
- 2016 Assistant Professor, Advanced Institute for Materials Research (AIMR), Tohoku University,
- 2017 Research scientist, Center for Advanced Intelligence Project, RIKEN
- 2021 Sakigake Researcher, Japan Science and Technology Agency (-present)
- 2022 RIKEN Hakubi Team Leader, RIKEN Cluster for Pioneering Research/RIKEN Center for Quantum Computing, RIKEN (-present)

Recent Achievements

Spectral Small-Incremental-Entangling theorem

This work is motivated by the Small-Incremental-Entangling (SIE) conjecture proposed by Kitaev and Bravyi, which concerns a universal upper bound characterizing how entanglement entropy can grow in time. The conjecture was independently resolved in 2013 by Van Acoleyen et al. and Audenaert, establishing what is now known as the conventional SIE theorem. However, while the classical SIE theorem provides bounds on how information-theoretic quantities evolve over time, it does not address the detailed structure of entanglement—namely the entanglement spectrum, which remained an open problem. In this work, we introduce a new quantity called Spectral Entangling Strength, and using this notion we prove that the optimal universal bound governing the entanglement spectrum is characterized by the $(1/2)$ -Rényi entanglement. Moreover, we complete the theorem by providing inequalities that are both qualitatively and quantitatively tight.

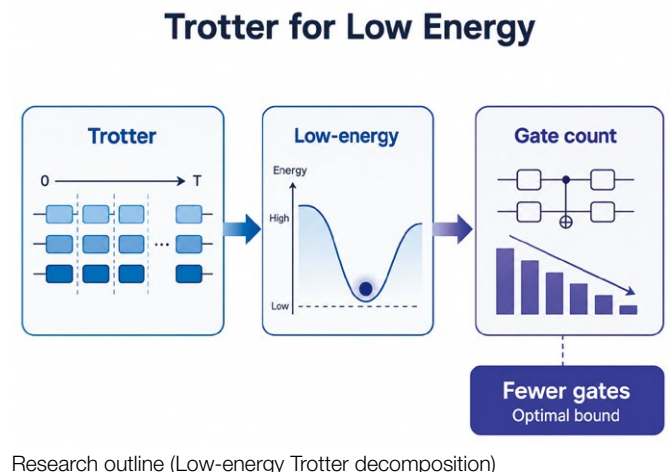
As an application, we analyze the simulation complexity of long-range interacting systems, including their time-evolved states, thermal equilibrium states, and ground states. Previously, the best known algorithms achieved only quasi-polynomial time complexity, and improving this to polynomial time had been regarded as a major open challenge. By exploiting the Spectral SIE theorem, we successfully prove a rigorous polynomial-time complexity bound, thereby breaking the quasi-polynomial barrier.



Simulation of low-energy states via Trotterization

Trotterization is among the most direct and easiest-to-implement approaches for describing quantum dynamics, and has attracted increasing attention. Estimating the optimal number of quantum gates required for Trotterization remains an important open problem. Recent developments suggest that low-energy states may be implementable with dramatically fewer gates than previously believed. In this work, we resolved this problem by deriving optimal gate-count estimates. This research was conducted jointly with Kaoru Mizuta (Assistant Professor, The University of Tokyo).

Our paper was selected for a contributed talk at QSim 2025 (acceptance rate $\sim 20\%$), a highly competitive international conference, and was also published in Physical Review Letters.



Core members

(Research Scientist) **Yusuke Kimura**
(Special Postdoctoral Researcher) **Donghoon Kim**
(Special Postdoctoral Researcher) **Yosuke Mitsuhashi**
(Postdoctoral Researcher) **Shang Cheng**

(JSPS Postdoctoral Researcher) **Toshihiro Yada**
(RIKEN JRA student) **Ayumi Ukai**
(RIKEN JRA student) **Hiroki Nakabayashi**
(Part Timer) **Hideaki Nishikawa**

Mathematical Quantum Information RIKEN Hakubi Research Team

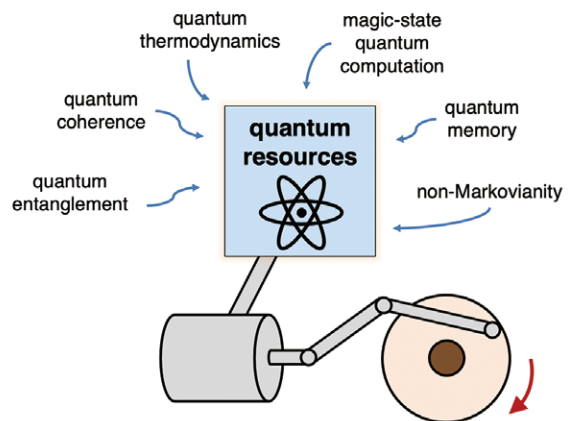
Keywords: Quantum information, Quantum resource theories, Quantum Shannon theory, Mathematical physics

Research Outline

Our group studies the mathematical underpinnings of quantum information theory, with a particular focus on the investigation of the mathematical structure of quantum resources — physical phenomena that underlie practical advantages of quantum technologies in areas such as communication and computation.

We aim to develop technical frameworks that help address the fundamental questions of how to quantify, manipulate, and take advantage of physical resources in quantum information and communication tasks. Our approach is to establish a solid and rigorous mathematical foundation which can be directly used to study a variety of physical settings, allowing for broad applications and generalisations. In addition to advancing the frontiers of knowledge on the fundamental laws governing quantum systems, we hope to provide insight into the physically achievable limits of the advantages of quantum resources, which can then find use in benchmarking practical quantum technologies. We will directly apply our methods to shed light on the properties of resources such as quantum entanglement, quantum coherence, magic-state quantum computation, as well as the dynamical quantum resources of quantum channels.

Beyond that, we are broadly interested in the mathematical problems of quantum information theory, e.g. the properties and applications of entropic quantities, the characterisation of operational tasks such as quantum hypothesis testing, and convex optimisation problems, which can be encountered in almost every area of quantum information.



Many different resources underlie the power of quantum information. We aim to develop tools to understand them better through general, mathematical approaches.



Bartosz Regula (Ph.D.), RIKEN Hakubi Team Leader

Selected Publications

- 1 L. Lami, M. Berta, and B. Regula, "Asymptotic quantification of entanglement with a single copy", *Nat. Phys.* 22, 439–445 (2026).
- 2 B. Regula and L. Lami, "Reversibility of quantum resources through probabilistic protocols", *Nat. Commun.* 15, 3096 (2024).
- 3 L. Lami and B. Regula, "No second law of entanglement manipulation after all", *Nat. Phys.* 19, 184–189 (2023).
- 4 B. Regula, "Probabilistic transformations of quantum resources", *Phys. Rev. Lett.* 128, 110505 (2022).
- 5 B. Regula and R. Takagi, "Fundamental limitations on distillation of quantum channel resources", *Nat. Commun.* 12, 4411 (2021).

Brief resume

- 2018 Ph.D. Mathematics, University of Nottingham, UK
- 2019 Presidential Postdoctoral Fellow, Nanyang Technological University, Singapore
- 2021 JSPS Postdoctoral Research Fellow, The University of Tokyo, Japan
- 2023 RIKEN Hakubi Team Leader, Mathematical Quantum Information RIKEN Hakubi Research Team, RIKEN, Japan (-present)

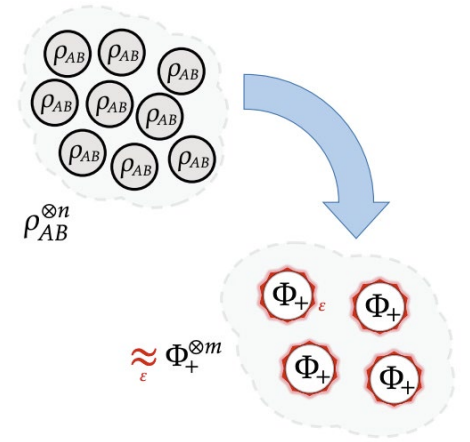
Recent Achievements

Simplifying the quantification of entanglement through hypothesis testing

The advantages provided by quantum entanglement rely on the fact that correlations between parts of a large quantum system make it more useful than the sum of its parts. However, this means that to optimally use entanglement, we need to understand the behavior of large systems, which leads to intractable asymptotic formulas involving many copies of quantum states.

Here we show that just a single copy of a state can tell us how to optimally detect and extract entanglement. Our approach relies on suitably adjusting the figures of merit in the fundamental task of entanglement distillation (purification) to connect it with entanglement testing (detecting entangled states). By developing novel mathematical techniques in quantum state discrimination, we show that the optimal solution is given by a measure of entanglement that involves no asymptotic limits and is easily computable.

L. Lami, M. Berta, and B. Regula, “Asymptotic quantification of entanglement with a single copy”, *Nature Physics* 22, 439–445 (2026).



Our approach shifts the focus of entanglement purification from the rate (yield) of distillation to the error of the process, which corresponds to the best achievable fidelity with the maximally entangled states Φ_+ . By focusing on this error as the figure of merit, we are able to relate it with a quantum hypothesis testing problem which we then solve using a new approach that extends state-of-the-art techniques.

Refining the mathematical tools of quantum information theory

The precise understanding of the performance of quantum information processing tasks is often based on connecting them with various entropic measures of quantum information. An improved understanding of these entropies can thus have meaningful consequences for how accurately we can benchmark and compare the performance of practical tasks. Here we introduce new mathematical techniques that provide major improvements over previously known bounds and relations between various quantities used in the practically meaningful one-shot quantum information theory. This leads to new insights into the structure of these information measures and has the potential to improve known constraints on problems such as rates of quantum communication, performance of quantum state discrimination, or the extraction of randomness in quantum cryptography.

B. Regula, L. Lami, and N. Datta, “Tight relations and equivalences between smooth relative entropies”, *IEEE Transactions on Information Theory* 72, 3051–3073 (2026).

$$D_{\max}^{\sqrt{\epsilon}, T, =}(\rho \| \sigma) + \log \frac{1}{\epsilon} \leq D_H^{1-\epsilon}(\rho \| \sigma) \leq D_{\max}^{\epsilon-\mu, T, =}(\rho \| \sigma) + \log \frac{1}{\mu},$$

$$D_{\max}^{\sqrt{\epsilon}, P, =}(\rho \| \sigma) + \log \frac{1}{\epsilon} \leq D_H^{1-\epsilon}(\rho \| \sigma) \leq D_{\max}^{\sqrt{\epsilon-\mu}, P, =}(\rho \| \sigma) + \log \frac{1}{\mu^2}.$$

One of the consequences of our approach is an improved understanding of duality relations between the smooth max-relative entropy (which finds use in problems such as quantum randomness extraction or quantum channel simulation) and the hypothesis testing relative entropy (which governs state discrimination, communication through quantum channels, and quantum source compression).

Core members

(Postdoctoral Researcher) **Vishal Singh**

(Research Part-time Worker) **Kaito Watanabe**

RIKEN RQC-FUJITSU Collaboration Center

Keywords: Quantum computer, Superconducting qubit, Error mitigation technology, Error correction technology, Quantum application

Research Outline

Our group, which was established on April 1, 2021, conducts research and development (R&D) to realize quantum computers for practical use. We integrate RIKEN's advanced quantum computer technology using superconducting circuits with FUJITSU's computing technology and knowledge of quantum technology applications based on customer perspectives.

Specifically, we develop hardware and software technologies that will enable large-scale quantum computers with 1,000 qubits. In addition, we develop quantum applications using the quantum computers developed. In terms of research on hardware, we conduct R&D of fundamental technologies, such as the improvement of uniformity in qubit manufacturing, the reduction of the size and noise of peripheral and wiring components, and the development of low-temperature packaging technology. Moreover, we integrate the hardware technologies above and develop a prototype superconducting quantum computer. In terms of software research, we develop middleware and a cloud computing system necessary for operating quantum computers and develop algorithms for quantum applications. We also verify the usefulness of error mitigation technologies in practical applications by executing quantum algorithms that integrate such mitigation technologies with quantum chemistry calculations on a prototype superconducting quantum computer. At the same time, we conduct basic experiments for quantum error detection and correction to identify issues and improve technologies for realizing quantum error correction.

We work together with various research institutions and companies to advance science and technology using quantum computers, and bring about innovations to realize a more sustainable world.



Opening of the "RIKEN RQC-Fujitsu Collaboration Center"



Shintaro Sato (Ph.D.), Deputy Director*

Selected Publications

- 1 R. Toshio, Y. Akahoshi, J. Fujisaki, H. Oshima, S. Sato, and K. Fujii, "Practical quantum advantage on partially fault-tolerant quantum computer", *Phys. Rev. X*, 15, 021057 (2025).
- 2 M. Ohfuchi and S. Sato, "Remote cross-resonance gate between superconducting fixed-frequency qubits," *Quantum Sci. Technol.* 9, 035014 (2024).
- 3 Y. Akahoshi, K. Maruyama, H. Oshima, S. Sato, and K. Fujii, "Partially Fault-tolerant Quantum Computing Architecture with Error-corrected Clifford Gates and Space-time Efficient Analog Rotations," *PRX Quantum* 5, 010337 (2024).
- 4 T. Takahashi, N. Kouma, Y. Doi, S. Sato, S. Tamate, and Y. Nakamura "Uniformity improvement of Josephson-junction resistance by considering sidewall deposition during shadow evaporation for large-scale integration of qubits", *Jpn. J. Appl. Phys.*, 62 SC1002 (2023).
- 5 T. Kurita, M. Morita, H. Ohshima, and S. Sato "Pauli String Partitioning Algorithm with the Ising Model for Simultaneous Measurements", *J. Phys. Chem. A*, 127, 4, 1068–1080 (2023).

Brief resume

- 1990 MS in Science and Engineering (Physics), University of Tsukuba
- 1990 Ushio Inc. (until 1997)
- 2001 Ph.D. in Mechanical Engineering, University of Minnesota, USA
- 2001 Electronic Devices Business Unit, Fujitsu Limited
- 2002 Researcher, Nanotechnology Research Center, Fujitsu Laboratories Ltd.
- 2006 Researcher (Senior Researcher from 2007), Semiconductor Leading-Edge Technology Inc. (concurrent position until 2010)
- 2007 Research Manager, Nanotechnology Research Center, Fujitsu Laboratories Ltd.
- 2010 Group Leader, Green Nanoelectronics Research Center, The National Institute of Advanced Industrial Science and Technology (AIST) (Sent from Fujitsu until 2014)
- 2014 Research Manager, Functional Devices Division, Devices and Materials Laboratory, Fujitsu Laboratories Ltd.
- 2018 Project Director, Next-Generation Materials Project, Devices and Materials Laboratory, Fujitsu Laboratories Ltd.
- 2018 Fellow, The Japan Society of Applied Physics
- 2020 Project Director, Quantum Computing Project, ICT Systems Laboratory, Fujitsu Laboratories Ltd.
- 2021 Head of Quantum Computing Research Center, Fujitsu Research, Fujitsu Limited
- 2021 Deputy Director, RIKEN RQC-Fujitsu Collaboration Center (-present)
- 2022 Head of Quantum Laboratory, Fujitsu Research, Fujitsu Limited
- 2023 Fellow, Head of Quantum Laboratory, Fujitsu Research, Fujitsu Limited (-present)

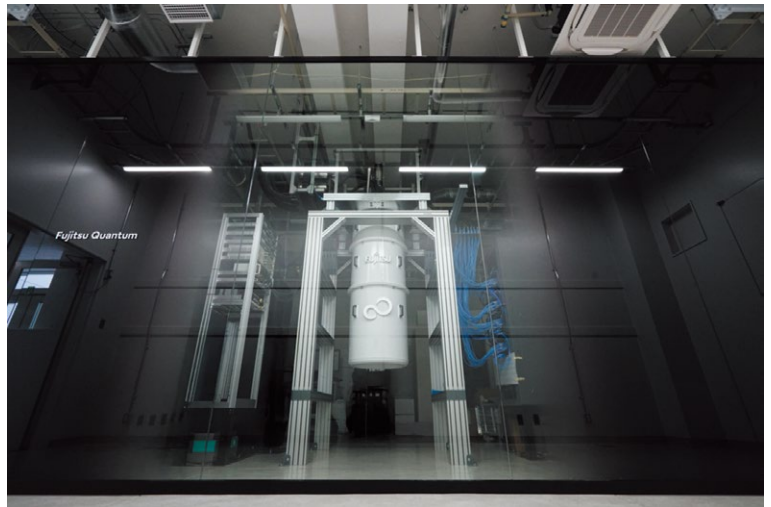
*Director is Dr. Yasunobu Nakamura

Recent Achievements

Contribution to development of Japan's first commercial superconducting quantum computer

We have developed a 64-qubit superconducting quantum computer, Japan's second domestically-made system, in October 2023, followed by a 256-qubit superconducting quantum computer, one of the world's largest systems, in April 2025. Leveraging the technologies cultivated through these developments, Fujitsu installed the first commercial superconducting quantum computer system by a Japanese vendor at the National Institute of Advanced Industrial Science and Technology (AIST).

The new superconducting quantum computer system is designed to scale to hundreds of qubits, one of the largest in the world, without upgrading the dilution refrigerators that constitute a superconducting quantum computer. It applies our newly developed technology for mounting high-density wiring inside refrigerators and packaging technology for large qubit chips. This quantum computer is expected to strengthen the research and development foundation for advanced quantum technologies and promote the development of practical quantum applications.

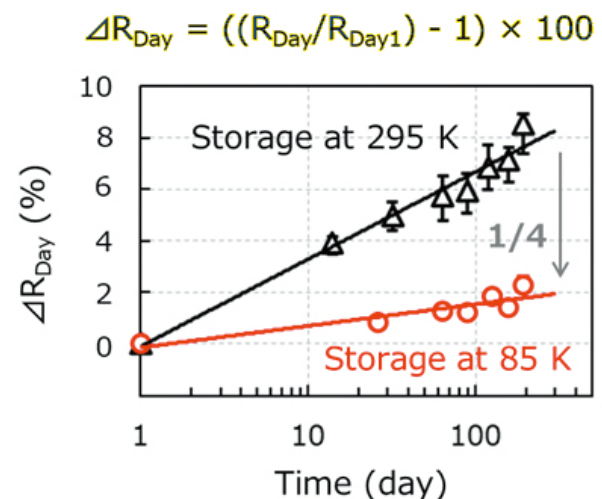


First commercial quantum computer system by a Japanese vendor

Development of technology to suppress aging of Josephson junctions

A transmon, which is a representative superconducting qubit, is a nonlinear resonant circuit consisting of a capacitor and a Josephson junction (JJ) connected in parallel. Here, a JJ is a device in which a thin insulating layer is sandwiched between two superconductors. We employ an Al/AIOx/Al structure fabricated using shadow evaporation, which is the current standard fabrication process. The electrical resistance of the JJ, measured at room temperature, is an important parameter for estimating qubit characteristics. However, it is known that this resistance gradually changes with storage at room temperature or similar conditions (aging). This means that even when qubits are fabricated with high precision, their characteristics degrade during the storage period until they are installed inside a dilution refrigerator.

To address this issue, we developed a technique to suppress the progression of aging by storing devices at low temperatures. Specifically, by holding the devices in a gaseous environment at -185°C generated using liquid nitrogen, we successfully suppressed the resistance increase to 2% after six months of low-temperature storage for 150nm-sized JJs. This corresponds to one-quarter of the resistance change rate observed with room-temperature storage.



Suppression of aging by low-temperature storage

Office of the Center Director

Keywords: Management of RQC, Head quarter of Quantum technology innovation hubs

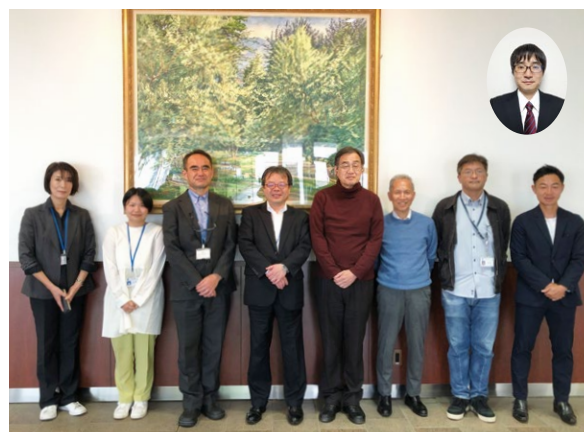
Outline

We are responsible for the management of the Quantum Computing Research Center's overall operations, including research on technology, intellectual property, and standardization trends, information dissemination, and the organization of events.

Based on the government's Quantum Technology Innovation Strategy, RIKEN is positioned as the core organization that coordinates the 12 domestic quantum technology innovation centers and their activities from basic research to social implementation of quantum technology. We are responsible for the management of this core organization. Furthermore, as the head quarter of Flagship Program for the Q-LEAP by MEXT, we are engaged in promotion activities for the quantum technology. We are also in charge of the operation and management of the superconducting quantum computer "A," which has been opened to the public in March 2023.

I am also involved in the following research and development.

- A project leader of "Building and operation of a domestically developed quantum computer testbed environment" on CSTI-SIP program "Promoting the application of advanced quantum technology platforms to social issues".
- A project leader of "Design and fabrication of hybrid chips of qubits and peripheral electronics" on "Development of Integration Technologies for Superconducting Quantum Circuits" of Moonshot Goal6 projects.
- A project leader of the "Operational Framework Project for the Quantum Science School Program" of the Q-LEAP project.



Members of Office of the Center Director

Core members

(Coordinator) **Toshio Tonouchi**

(Research Administrator) **Koji Ikado**

(Research Administrator) **Satoshi Tomita**

(Research Administrator) **Hideaki Oba**

(Research Administrative Support Staff) **Kimiko Kowashi**

(Temporary Employee) **Masanobu Arai**

(Temporary Employee) **Haruyuki Iwabuchi**

(Administrative Part-time Worker I) **Minako Yamaguchi**



Shinichi Yorozu (Ph.D.), RQC Deputy Director, Director of Office of the Center Director

Selected Publications

- 1 Y. Iwasaki, R. Sawada, V. Stanev, M. Ishida, A. Kiriara, Y. Omori, H. Someya, I. Takeuchi, E. Saitoh, S. Yorozu, Identification of advanced spin-driven thermoelectric materials via interpretable machine learning, *npj Computational Materials* volume 5, Article number: 103 (2019).
- 2 A. Kiriara, M. Ishida, R. Yuge, K. Ihara, Y. Iwasaki, R. Sawada, H. Someya, R. Iguchi, K. Uchida, E. Saitoh, S. Yorozu, Annealing-temperature-dependent voltage-sign reversal in all-oxide spin Seebeck devices using RuO₂, 2018 *J. Phys. D: Appl. Phys.* 51 154002.
- 3 K. Uchida, H. Adachi, T. Kikkawa, A. Kiriara, M. Ishida, S. Yorozu, S. Maekawa, E. Saitoh, Thermoelectric Generation Based on Spin Seebeck Effects, *Proceedings of the IEEE* (Volume: 104, Issue: 10, Oct. 2016) 1946 – 1973.
- 4 K. Takemoto, Y. Nambu, T. Miyazawa, Y. Sakuma, T. Yamamoto, S. Yorozu, Y. Arakawa, Quantum key distribution over 120 km using ultrahigh purity single-photon source and superconducting single-photon detectors, *Scientific Reports* 5, Article number: 14383 (2015).
- 5 A. Kiriara, K. Uchida, Y. Kajiwara, M. Ishida, Y. Nakamura, T. Manako, E. Saitoh, S. Yorozu, Spin-current-driven thermoelectric coating, *Nature Materials*, Vol. 11, pp. 686–689 (2012).

Brief resume

- 1993 Ph.D. in Applied Physics, The University of Tokyo
- 1993 Researcher, Fundamental Research Laboratories, NEC Corporation
- 1997 Visiting Researcher, State University of New York at Stony Brook
- 2015 Deputy General Manager, Smart Energy Research Laboratories, NEC Corporation
- 2018 Executive Chief Engineer, System Platform Research Laboratories, NEC Corporation
- 2019 Coordinator, RIKEN Center for Emergent Matter Science
- 2021 Deputy Director, RIKEN Center for Quantum Computing (-present)

Boosting quantum error correction using AI

A method for fixing errors that occur in quantum computers is made massively more efficient through deep learning

Category: Exploratory Physical Sciences **Field:** Physics/Astronomy

A way to greatly enhance the efficiency of a method for correcting errors in quantum computers has been realized by theoretical physicists at RIKEN¹. This advance could help to develop larger, more reliable quantum computers based on light.

Quantum computers are looming large on the horizon, promising to revolutionize computing within the next decade or so.

“Quantum computers have the potential to solve problems beyond the capabilities of today’s most powerful supercomputers,” notes Franco Nori of the RIKEN Center for Quantum Computing (RQC).

But some major hurdles need to be overcome before quantum computers can be used to tackle practical problems. In particular, ensuring that they perform calculations reliably is a critical issue.

“The reliability of quantum computers is constrained by their extreme sensitivity to the environment,” explains Nori. “Even minor environmental disturbances can corrupt quantum information.”

To unleash the potential of quantum computers, it is thus vital to develop techniques that can fix quantum errors.

One attractive method is the Gottesman–Kitaev–Preskill (GKP) code. Named after its inventors, the GKP code was proposed in 2001 as a way to encode a qubit, the quantum equivalent of a bit, in a harmonic oscillator—a system that resembles a pendulum.

“It’s a promising candidate to realize quantum error correction without requiring a lot of hardware,” says Nori.

However, GKP codes rely on squeezed states—quantum states that are difficult to generate and control. Consequently, GKP codes have been challenging to implement in practical experiments, particularly in light-based systems.

To overcome this problem, a team including Nori, Clemens Gneiting and Yexiong Zeng, both also at RQC, has developed a method that uses deep learning to optimize GKP states.

This optimization reduces the need to use large-amplitude squeezed states while preserving the code’s powerful error-correction capabilities.

“By leveraging AI, our method fine-tunes the structure of GKP states, striking an optimal balance between resource efficiency and error resilience,” says Zeng. “Our optimized GKP codes outperform conventional ones, requiring only a fraction of the squeezed states while achieving superior error correction.”

The method turned out to be remarkably efficient, exceeding the team’s expectations. “We were pleasantly surprised,” says

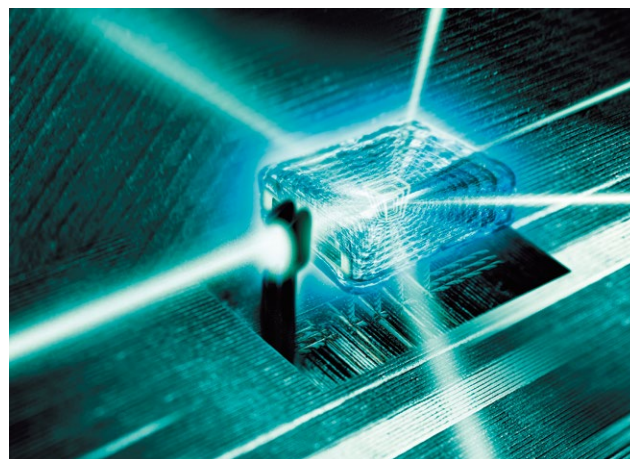


Figure: Quantum computers based on light stand to benefit from a technique that uses machine learning to enhance a method for fixing quantum errors.

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Zeng. “The neural network achieved a much more efficient encoding than we had initially expected.”

“By reducing resource demands and improving error resilience, our work accelerates the path toward scalable, fault-tolerant quantum computing, paving the way for significant advancements in science and technology,” says Gneiting.

The team is now planning to extend the code to a multi-logical system, says Zeng.

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Powerful quantum error correction with a beautiful geometry (https://www.riken.jp/en/news_pubs/research_news/pr/2024/20240905_1/index.html)

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These articles are edited versions of RIKEN Research Highlights.

Extending the applicability of a key quantum law

Even quantum systems with long-range interactions between particles can be analyzed using a key principle

Category: Exploratory Physical Sciences **Field:** Physics/Astronomy

By extending a key law in quantum information to systems with long-range interactions, RIKEN physicists have enhanced its usefulness¹. This advance could help to design better quantum computers.

Compared with their classical counterparts, systems made up of many quantum particles—such as quantum computers—are horrendously complex to analyze and simulate. This complexity is due in part to the strong correlations between particles, which can act over long distances.

One helpful principle for understanding systems in which the quantum particles are split into two groups is the area law. It states that the amount of information shared between the two parts of a quantum system depends on the boundary between them rather than the total size of the two parts.

“This idea provides profound insights into how information is structured in nature and has far-reaching implications across physics, helping researchers explore phenomena ranging from exotic phases of matter to black holes,” says Donghoon Kim of the RIKEN Center for Quantum Computing (RQC).

The area law simplifies the analysis of large quantum systems because it means it is not necessary to know all the details about the entire system, but just how the two parts are connected across their boundaries.

However, the area law has only been shown to apply to systems that have short-range interactions between their particles. That excludes many systems of great interest.

“In many important physical systems, particles interact with others far away—not just their neighbors,” explains Kim. “These long-range interacting systems are essential for understanding both the large-scale structure of the Universe and the behavior of complex quantum materials.”

Now, Kim, Tomotaka Kuwahara, also of RQC, and Keiji Saito of Kyoto University have shown that the area law at finite temperatures also applies to long-range interacting systems under certain conditions.

“Our result suggests that, by carefully choosing meaningful and realistic assumptions, we can extend the reach of mathematical analysis into areas that were once thought to be out of bounds,” says Kim.

The trio’s achievement has important implications for practical applications of quantum systems such as quantum computers.

“We now have a much clearer understanding of when and how quantum systems can be simulated efficiently at finite temperatures,” says Kim. “This is especially relevant for quantum computing and quantum simulation, where managing entanglement and thermal correlations is a major challenge.”

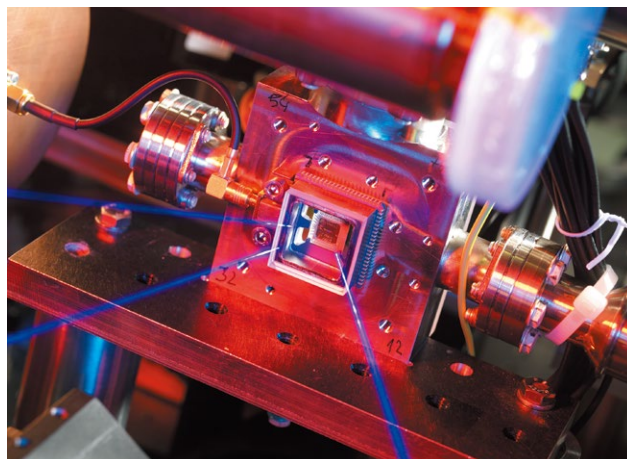


Figure: Ion traps such as the one shown here are one promising technology for developing quantum computers. Trapped ions are also an example of a long-range interacting system that the area law can be applied to.

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The result can help guide the design of algorithms and hardware by identifying the regimes where quantum information remains localized and tractable—even when long-range interactions are present, Kim notes.

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RIKEN Research Fall 2025

These articles are edited versions of RIKEN Research Highlights.

Using a quantum computer to simulate a quantum process

The gap between conventional and quantum computers is closing when it comes to simulating scrambling of quantum information

Category: Exploratory Physical Sciences **Field:** Physics/Astronomy

Four RIKEN researchers have used two small quantum computers to simulate quantum information scrambling, an important quantum-information process¹. This achievement illustrates a potential application of future quantum computers.

Still in their infancy, quantum computers are only just beginning to be used for applications. But they promise to revolutionize computing when they become a mature technology.

One possible application for quantum computers is simulating the scrambling of quantum information—a key phenomenon that involves the spread of information in quantum systems ranging from strange metals to black holes.

After encoding information in one part of a quantum system, it becomes diluted over time through various processes. Eventually, it spreads out across the whole system.

The original information is not lost, but it is much harder to reconstruct since you need access to the entire system. The quantum-information scrambler par excellence is the black hole, which is the ultimate shredder when it comes to quantum information.

Understanding how information scrambling occurs is critical for addressing fundamental problems in quantum physics.

“Quantum-information scrambling is of interest to us because we can use it to do some additional calculations, such as statistical physics calculations,” says Kazuhiro Seki of the RIKEN Center for Quantum Computing (RQC).

One way to study quantum-information scrambling is to perform simulations, which is where quantum computers can help since they are better suited for such simulations than conventional computers.

Now, Seki and Seiji Yunoki, also of RQC, and two co-workers have used two quantum computers with 20 qubits—the quantum equivalent of bits—to simulate quantum-information scrambling circuits (Figure).

For the simulation, the researchers used state-of-the-art quantum computers via the cloud, which are based on qubits formed from trapped ions. They used the quantum computers to perform three simulations, which included creating a scrambled state and using it to perform quantum statistical mechanical calculations.

While a powerful conventional computer could have been used to perform the simulation, the complexity of simulations is approaching the realm where quantum computers will be indispensable for such calculations.

“We only used 20 qubits to conduct the simulations in this study,” says Yunoki. “If we can use more than 50 qubits

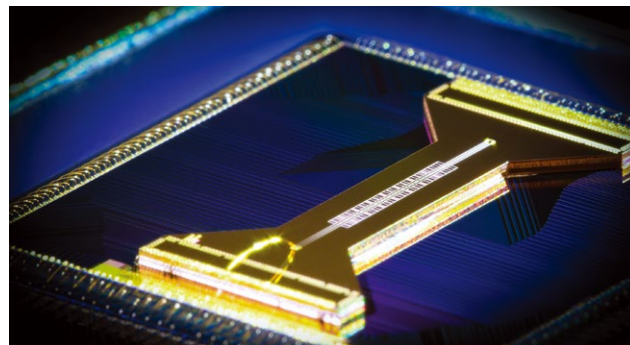


Figure: A close up of the trapped-ion quantum computer used to simulate quantum-information scrambling circuits.

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to perform similar calculations, it may be too difficult for a classical computer to handle.”

A 20-qubit, trapped-ion quantum computer was installed at RIKEN in February 2025. “We’re hoping to upgrade it in the next couple of years, so that it will have around 50 qubits,” Yunoki notes.

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Realizing clean qubits for quantum computers using electrons on helium [https://www.riken.jp/en/news_pubs/research_news/rr/20240328_2/index.html]

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RIKEN Research Winter 2025

These articles are edited versions of RIKEN Research Highlights.

Reading multiple superconducting qubits in record time

Qubits in superconducting quantum computers can now be read faster than ever thanks to a new measurement scheme

Category: Applied Physical Sciences **Field:** Physics/Astronomy

RIKEN physicists have found a way to speed up the readout of qubits in superconducting quantum computers, which should help to make them faster and more reliable¹.

After decades of being theoretical propositions, working quantum computers are just starting to emerge. For experimentalists such as Peter Spring of the RIKEN Center for Quantum Computing (RQC), it's an auspicious time to be working in the field.

"It's very exciting. It feels like this is a very fast-moving field that has a lot of momentum," says Spring. "And it really feels like experiments are catching up with theory."

When they come online, mature quantum computers promise to revolutionize computing, being able to perform calculations that are well beyond the capabilities of today's supercomputers. And it feels like that prospect is not so far off.

Currently, half a dozen technologies are jockeying to become the preferred platform for tomorrow's quantum computers. A leading contender is a technology based on superconducting electrical circuits. One of its advantages is the ability to perform calculations faster than other technologies.

Because of the very sensitive nature of quantum states, it is vital to regularly correct any errors that may have crept in. This necessitates repeatedly measuring a selection of qubits, the building blocks of quantum computers. But this operation is slower than quantum gate operations, making it a bit of a bottleneck.

"If qubit measurement is much slower than the other things you're doing, then basically it becomes a bottleneck on the clock speed," explains Spring. "So we wanted to see how fast we could perform qubit measurements in a superconducting circuit."

Now, Spring, Yasunobu Nakamura, also of RQC, and their co-workers have found a way to simultaneously measure four qubits in superconducting quantum computers in a little over 50 nanoseconds, which is about twice as fast as the previous record.

A special filter ensures that the measurement line used to send the measurement signals doesn't interfere with the qubit itself. Spring and colleagues realized the filter by 'coupling' a readout resonator with a filter resonator in such a way that energy from the qubits wasn't able to escape through the measurement line.

They were able to measure the qubits at very high

accuracies, or 'fidelities'. "We were surprised at how high fidelity the readout turned out to be," says Spring. "On the best qubit, we achieved a fidelity of more than 99.9%. We hadn't expected that in such a short measurement time."

The team aims to achieve even faster qubit measurements by optimizing the shape of the microwave pulse used for the measurement.

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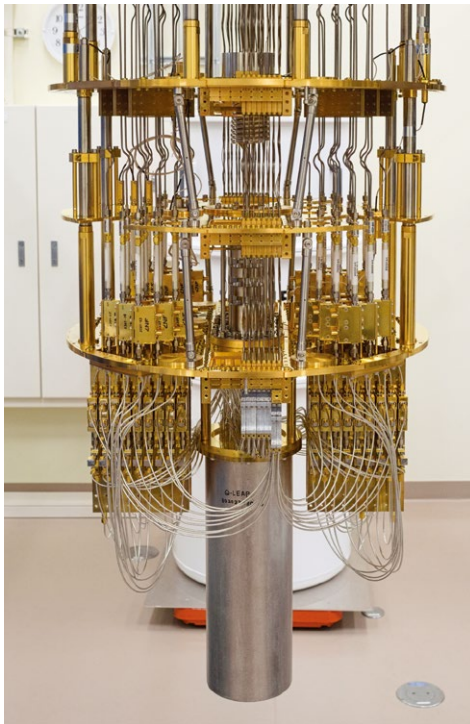


Figure 1: A photograph of a dilution refrigerator used to cool a superconducting quantum computer. The quantum circuit is inside the cylindrical metal shield at the bottom of the photo.
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[Researcher (unpublished)]



Peter Spring (top row, fourth from the right), Yasunobu Nakamura (bottom row, second from the right) and their team at the RIKEN Center for Quantum Computing, located in the city of Wako in Japan.
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[Researcher]

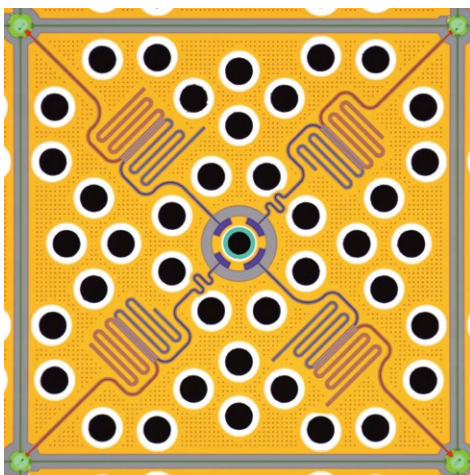


Figure 2: An image of the circuit used for the rapid readout of four qubits (green circles at each corner).
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[Fig. 4a in Ref. 1]

Reading qubits in an ultraclean environment

Microwaves should be able to probe qubits made from single electrons floating above liquid helium

Category: Exploratory Physical Sciences **Field:** Physics/Astronomy

One intriguing method that could be used to form the qubits needed for quantum computers involves electrons hovering above liquid helium. But it wasn't clear how data in this form can be read easily—now RIKEN researchers may have found a solution¹.

Conventional computers work by performing operations on bits encoded in silicon. But no one is really sure how qubits will be encoded in the quantum computers of the future. Half a dozen or so platforms are currently being pursued, including superconductors, silicon, light and trapped ions.

One of the most intriguing ideas for qubits is electrons that float above the surface of liquid helium at a temperature of about four degrees Celsius above absolute zero.

The great advantage of such a system is that it provides a very clean environment, with minimum interference from spins of nearby particles. This will allow qubits to maintain their quantum state for much longer than in noisier environments.

“For an electron floating in a vacuum above helium, the only thing close to it is helium atoms, which are highly inert,” explains Asher Jennings of the RIKEN Center for Quantum Computation (RQC) and RIKEN Center for Advanced Photonics. “That means the electron is very well protected, making it an excellent system for storing quantum information.”

But for such qubits to be used in quantum computers, the data they store needs to be readable. The small magnetic moment of an electron above helium makes direct readout of its spin infeasible. And so, scientists are exploring indirect schemes for reading out the electron spin.

A promising way to do that is to detect the transition of the electron from its lowest energy state to a higher one, known as the Rydberg state.

Now, scientists including Jennings and Erika Kawakami, also of RQC, have demonstrated it should be possible to detect the Rydberg transition of a single electron by measuring the change in capacitance.

They did this by using 10 million electrons floating above liquid helium, thereby creating a system that acts as a capacitor. The team were able to detect the change in the quantum capacitance that occurred when the electrons were promoted to the Rydberg state through changes in the microwave frequency.

While the system needs to be scaled down by a factor of 10,000 times, it demonstrates that such a scaled-down device should be able to detect the signal from a single qubit.

“Our measurements of the capacitance change in a large system indicate that it should be easily measurable for a single electron in a single-electron device,” says Jennings.

The team is now working on performing the same measurement in a one-electron system.

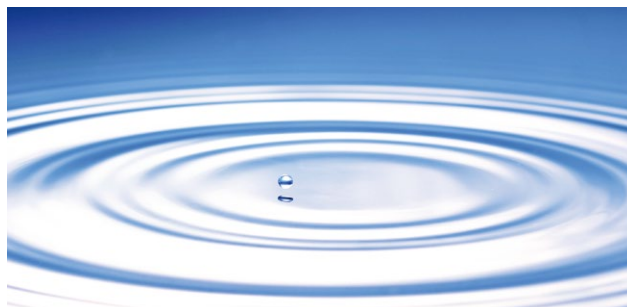


Figure: An electron hovering over a surface of liquid helium could be used as a qubit in future quantum computers.

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Asher Jennings (second from the left in the right row), Erika Kawakami (second from the left in the left row), and co-workers have used frequency modulation of microwaves to probe the quantum capacitance of Rydberg transitions of electrons on the surface of liquid helium.

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Floating quantum ideas [<https://www.riken.jp/en/about/people/2021fall-2/index.html>]

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RIKEN Research Spring 2026

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Quantum connections keep it local

Quantum correlations between more than two particles that give some quantum materials their exotic behavior can only exist over short distances

Category: Exploratory Physical Sciences **Field:** Physics/Astronomy

The properties of a quantum material are driven by links between its electrons known as quantum correlations. A RIKEN researcher has shown mathematically that, at non-zero temperatures, these connections can only exist over very short distances when more than two particles are involved¹.

This finding sets a fundamental limit on just how ‘exotic’ a quantum material can be under realistic, finite-temperature conditions.

A fascinating aspect of quantum physics is the concept that two particles that are spatially separated can communicate with each other. This so-called ‘spooky action at a distance’, as Einstein referred to it, is crucial for understanding the origin of the exotic properties that arise in some materials, particularly at low temperatures.

These unusual material properties are determined by the exact nature of the quantum correlation, and the material is said to be in a specific quantum phase. This is analogous to the traditional phases of matter—solid, liquid and gas—being defined by the chemical interactions between the atoms.

Many quantum phases can be explained by considering correlations between just two particles.

Recently, however, even more strange phases have been identified which can only be described by evoking connections between more than two particles. These correlations are less well understood than those between two particles. For example, it was unclear how far a correlation between more than two particles can exist.

Previous studies had only analyzed three-party correlations in special models and parameter regimes; for example, at high temperature or with strong simplifying assumptions.

Now, Tomotaka Kuwahara of the RIKEN Center for Quantum Computing has rigorously proved that genuinely three-way quantum correlations cannot stretch over long distances in any thermal equilibrium state at any temperature.

The first step was to define a measure of correlation strength. Kuwahara used a metric called conditional mutual information.

“I showed mathematically that the conditional mutual information between distant regions always decays exponentially with the distance between them,” explains Kuwahara.

Kuwahara proved that thermal quantum systems must obey a quantum analog of the Hammersley–Clifford rule, which states that if we know everything about a middle region, then the distant two regions are essentially independent, and genuinely three-way correlations cannot extend far.

Kuwahara next hopes to go beyond the thermal equilibrium case considered in this work.

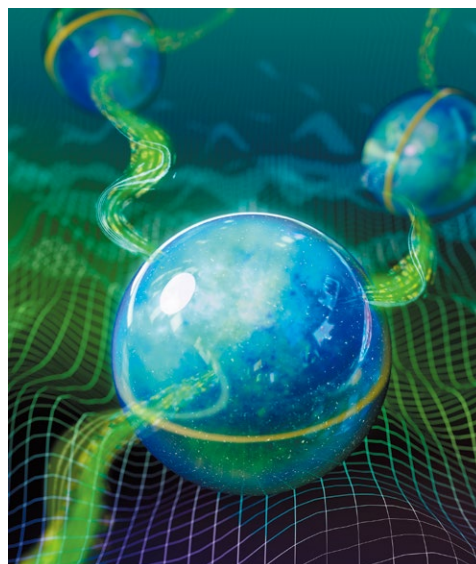


Figure: Multipartite quantum correlations give quantum materials their exotic properties.

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“A natural step is to build a similar universal theory of quantum entanglement for more general steady states, including systems that are driven or carry currents and are not exactly in equilibrium, and to tackle the much harder zero-temperature regime,” he says.

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Tightening the math behind a key quantum process [https://www.riken.jp/en/news_pubs/research_news/rr/20250423_1/index.html]

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These articles are edited versions of RIKEN Research Highlights.

Cutting down on quantum crosstalk

Precise measurements show that future quantum computers may need to correct for errors caused by interference between neighboring quantum dots

Category: Applied Physical Sciences **Field:** Physics/Astronomy

Developments that can confine individual electrons are potential building blocks for quantum information systems. But the electrons must be protected from external disturbances.

RIKEN researchers have now shown how quantum information encoded into a so-called quantum dot can be negatively affected by nearby quantum dots¹. This has implications for developing quantum information devices based on quantum dots.

Quantum computers process information using so-called qubits: physical systems whose behavior is governed by the laws of quantum mechanics. An electron, if it can be isolated and controlled, is one example of a qubit platform with great potential.

One way of controlling an electron is to use a quantum dot. These tiny structures trap charged particles using electric fields at the tips of metal electrodes separated by just a few tens of nanometers.

To be useful, quantum dots have to be able to store quantum information for a long time. But quantum states are very fragile and can be easily destroyed by interference from the outside world.

As Takashi Kobayashi of the RIKEN Center for Quantum Computing and co-workers have now shown, this problem is exacerbated when many quantum dots are placed close together, which will necessarily be the case in a fully functioning quantum computer.

“Our experimental results let the silicon quantum computing community recognize the impact of electron rearrangements in quantum circuits,” says Kobayashi. “This insight paves the way toward realizing a large-scale silicon quantum computer with an appropriate quantum error correcting code.”

The qubits constructed by the RIKEN team incorporated a micromagnet that made the electrons highly sensitive to electric fields. This meant the electron could be controlled by making only small changes to the voltage applied across the quantum-dot electrodes (Figure).

But this sensitivity had a downside: as the electrons in neighboring quantum dots move through the micromagnet's magnetic field, they generate an electric field that alters the energy of the qubit and disturbs the quantum information.

Kobayashi and co-workers have now directly measured this shift for the first time. They found that it is large enough to cause a considerable qubit error rate unless it is properly dealt with.

“Our next step is to develop methods to cancel or avoid the impact of this charge-induced energy shift,” says Kobayashi. “We are also seeking to harness the energy shift as a resource for a new class of qubit operations, which might give silicon spin qubits a distinctive advantage against other qubit platforms.”

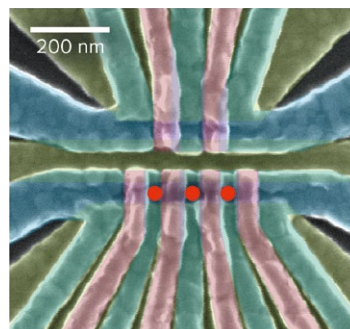
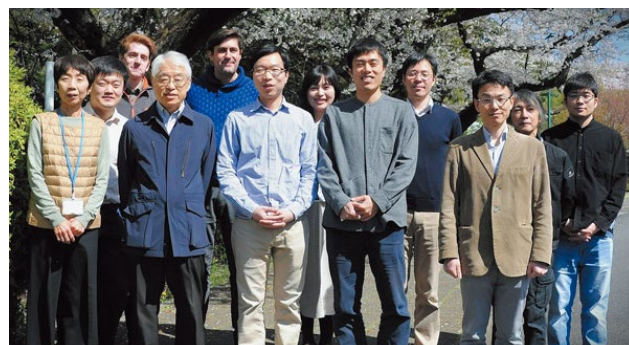


Figure: False-colored scanning electron microscope image of the quantum dot device. The red dots indicate the locations of the quantum dots.

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Takashi Kobayashi (third from the right) and co-workers have measured the energy shift of an electron-spin qubit induced by neighboring quantum dots.

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These articles are edited versions of RIKEN Research Highlights.

Less noise, more gain for quantum computers

A low-noise readout amplifier promises to accelerate progress on large-scale quantum computers

Category: Exploratory Physical Sciences **Field:** Physics/Astronomy

The low-noise, high-gain properties needed for high-performance quantum computing can be realized in a microwave photonic circuit device called a Josephson traveling-wave parametric amplifier (JTWPA), RIKEN researchers have shown experimentally¹. This advance stands to speed up development of superconducting quantum computer systems at the 100-qubit scale.

Quantum computers are extraordinary feats of research and engineering, combining highly advanced quantum physics with state-of-the-art fabrication techniques designed to physically manipulate light near the limits of quantum dynamics.

While the elemental quantum bits—qubits—are where the magic of quantum computing happens, they need to be ‘read’ in order for their computations to be useful. Unfortunately, the very act of reading the state of a qubit can introduce noise and interference that obscures the data.

The readout operation needs to meet several criteria: it needs to be fast enough with very high signal-to-noise ratio to be able to measure the qubit in a single shot, while operating with just a few quanta in energy (where a quantum is the energy of one microwave photon). Ideally, it should also comb multiple frequencies so it can read multiple qubits at once using the same circuit.

“So far, amplifiers based on an array of Josephson junctions fulfill all of these qualities except for noise, which is what we focused on in this study,” says Sandbo Chang of the RIKEN Center for Quantum Computing (RQC).

Chang, Yasunobu Nakamura, also of RQC, and co-workers have resolved a long-standing noise issue with JTWPA. This advance promises to strengthen this highly accessible scheme for qubit signal processing.

Noise is inevitably added to a readout signal when it is amplified. Quantum mechanics requires any phase-preserving amplifier with high gain to add at least half a quantum of noise. The best previous noise level achieved by a Josephson traveling-wave parametric amplifier is often one photon or more, which has limited the usefulness of this technology.

“This is mostly because previous approaches use lossy dielectric material in their design,” says Chang.

By dropping the use of lossy dielectric material and instead creating a spiraled fishbone-like tapered waveguide structure (Figure), the team was able to reduce the noise to 0.68 quanta, only 0.18 quanta above the quantum limit. They demonstrated this through performing simulations and creating an experimental device.

“Our goal was also to keep the fabrication recipe as

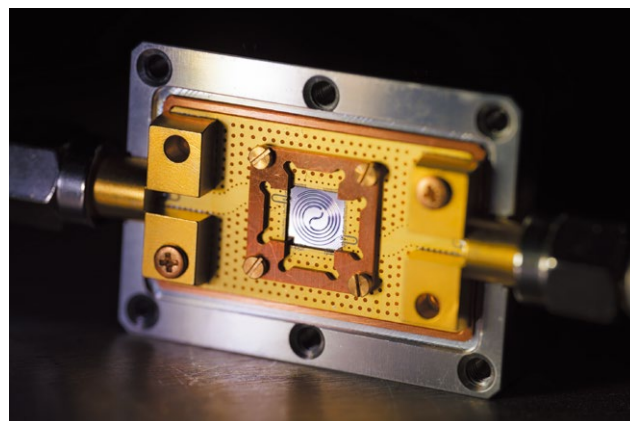


Figure: A long, spiral-wound waveguide with a fine-tapered, fishbone-like structure can amplify photon signals from quantum computing qubits with very low noise.

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[Researcher]

accessible as possible,” says Nakamura. “The hope is that most labs that can already fabricate superconducting qubits will already have the techniques and equipment they need to reproduce our results.”

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Boosting quantum error correction using AI [https://www.riken.jp/en/news_pubs/research_news/rr/20250509_2/index.html]

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These articles are edited versions of RIKEN Research Highlights.

Publication List

Data for FY2025

Title	Authors	Article
Room-temperature perpendicular-anisotropic ferrimagnet Co3Mo mediated by cobalt-kagome flat band	K. Ishida, K. Fujiwara, K. Nakazawa, T. Yamazaki, S. Souma, T. Seki, D. Shiga, H. Kumigashira, T. Sato, Y. Motome, A. Tsukazaki	Communications Materials 7 (2026).
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Observation of the nonlinear chiral thermoelectric Hall effect in tellurium	T. Nomoto, A. Kikkawa, K. Nakazawa, T. Yamaguchi, F. Kagawa	Nature Physics 21.1920 (2025).
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Scalable Optical Quantum State Synthesizer with Dual-Mode Resonator Memory	F. Hanamura, K. Takase, K. Hirota, R. Nehra, F. Lang, S. Miki, H. Terai, M. Yabuno, T. Kashiwazaki, A. Inoue, T. Umeki, W. Asavanant, M. Endo, J. Yoshikawa, A. Furusawa	PRX Quantum 6.040336 (2025).
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