Moonshot International Symposium for Goal 6,
Zoom Webinar, 23rd April 2021

Quantum Cyberspace with Networked Quantum Computer

Takashi Yamamoto

Osaka University

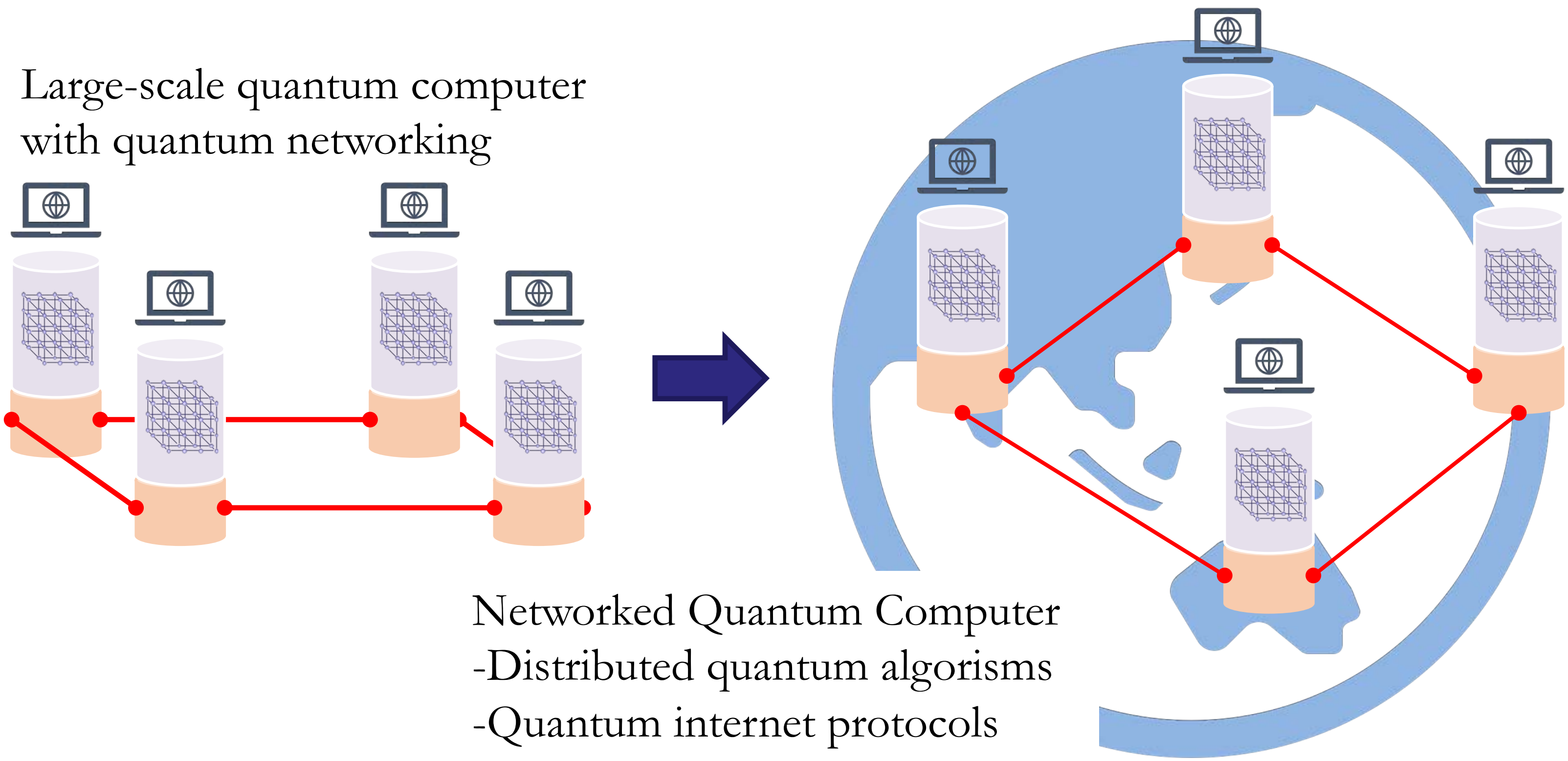
Center for Quantum Information and Quantum Biology,

International Advanced Research Institute (IARI),

Graduate School of Engineering Science,

Our Vision

This project aims to develop elemental technologies for networking quantum computers with photons, atoms, semiconductors and so on, aiming to network small and medium quantum computers. We further promote networked quantum computers on a larger scale towards the achievement of universal quantum computation by 2050.



Finally, our project will end-up with a quantum version of the current cyberspace.

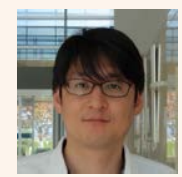
Our Research Team

Atom networking tech.
Osaka University
Takashi Yamamoto

Photon networking tech.
Waseda University
Takao Aoki

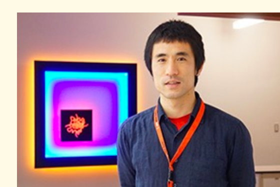
Superconducting photon-detector tech.
Hamamatsu Photonics
Hideki Shimoi,
Takeshi Kodama

NICT
Shigehito Miki



Semiconductor networking tech.
Osaka University
Akira Oiwa

Superconductor networking tech.
OIST
Yuimaru Kubo



Other QComp.& Theory Teams and Q-LEAP projects etc

Atom networking technology

(Atom-photon multiple channel quantum networking)

Yamamoto Group: GSES, Osaka University

Photonic quantum technology development

-Linear optics based all-photonic quantum repeater

Nature Communications 10, 378(2019).

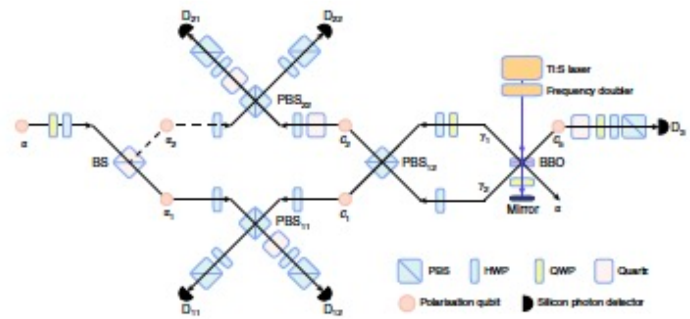
-Quantum frequency convertor to telecom photon

Nature Communications 2,1544(2011).

Nature Photonics 10,441(2016).

-Entanglement distillation for quantum error correction

Nature 421, 343(2003).



All-Photonic Quantum repeater in collaboration with NTT, Toyama Univ., Toronto Univ.

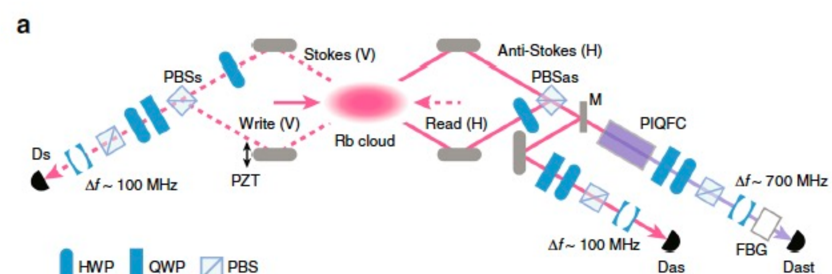
Atom-photon quantum system development

-Atom-telecom photon entanglement generation

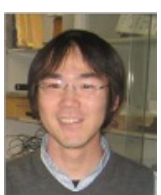
Nature Communications 9,1997(2018).

-Trapped Ion based telecom photon generation

PRL 120 , 203601, 2018.



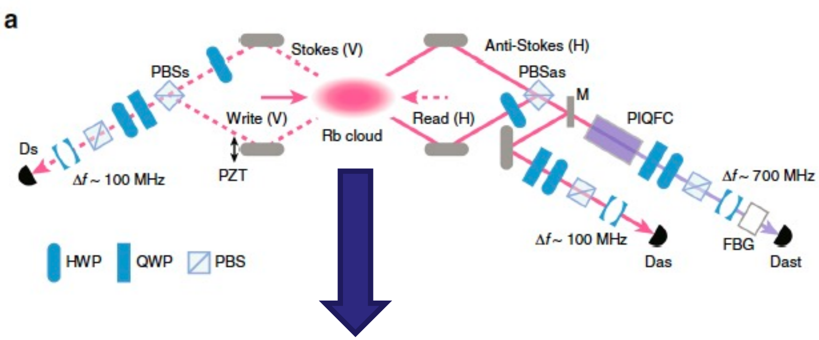
Atom-telecom photon entanglement in collaboration with NTT, NICT, Tokyo Univ.



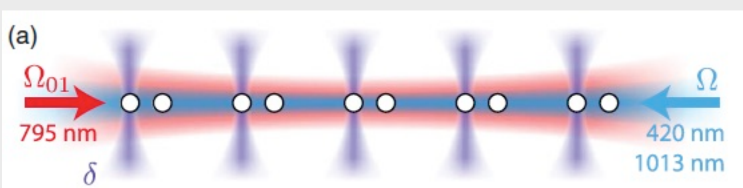
T. Yamamoto R. Ikuta T. Kobayashi

Atom networking technology

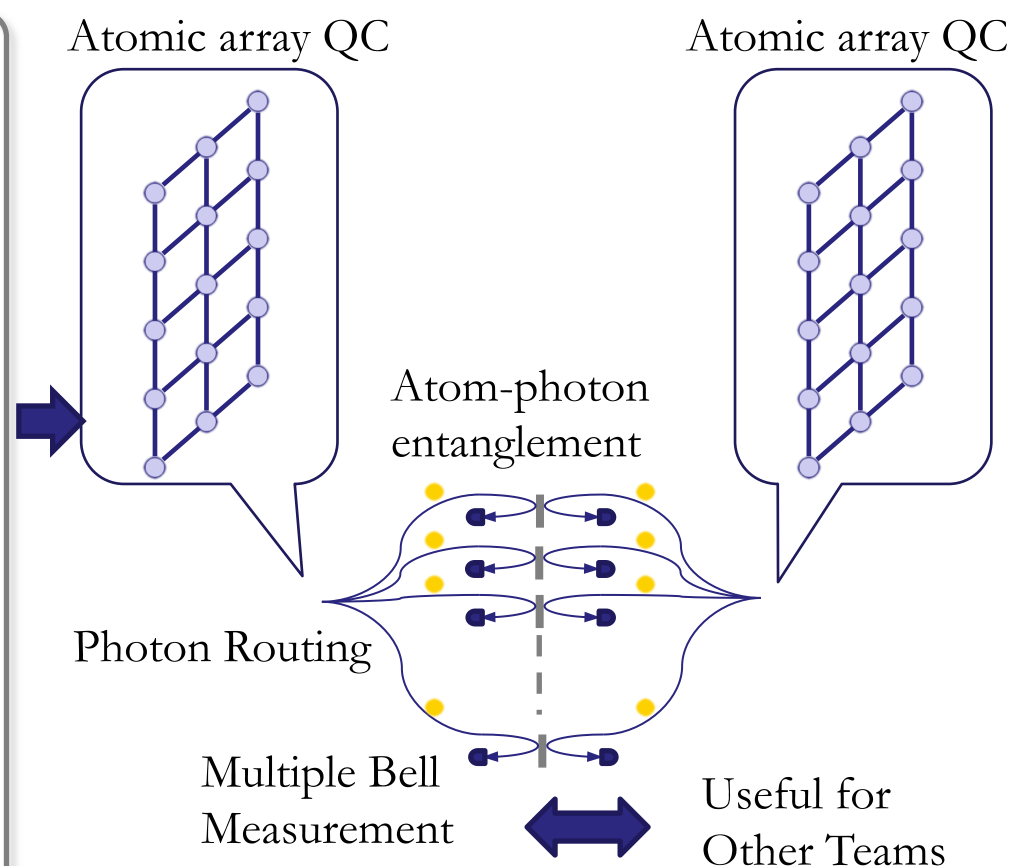
Atomic ensemble quantum memory



Atom array quantum computer



Entanglement generation with 1D atomic array
Fidelity>95.0(2)%, Gate fidelity >97.4(3)%,
Harvard University (PRL 123, 170503 2019)



5-years target: Atom-photon entanglement and connecting atom array quantum computers

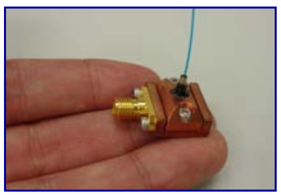
High performance photon detection technology

Miki Group:

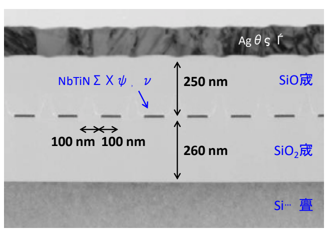
National Institute of Information and Communications Technology (NICT)

SNSPD system

SNSPD system



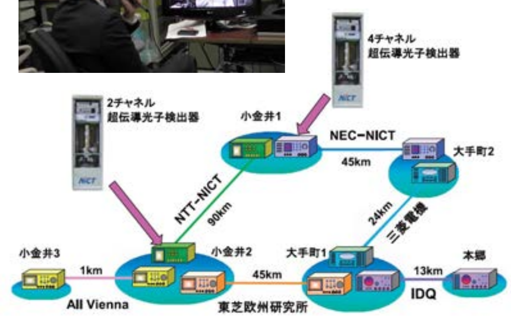
Fiber coupled package



Superconducting nanowire device

Development of SNSPD system with 80% system DE at λ=1550nm [1]

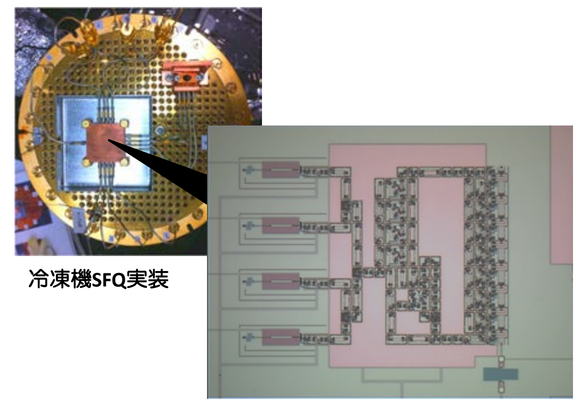
SNSPD application



Tokyo QKD network

QKD[2]、Quantum optics[3]、Fluorescence Correlation Spectroscopy [4], etc.

SNSPD array



SFQ素子写真

Development of SNSPD array with superconducting digital read out technology [5,6]

[1] S. Miki et al., ***Opt. Exp.*** 21,10208 (2013) , [2] M. Sasaki et al., ***Opt. Exp.*** 19, 10387 (2013) [3] T. Kobayashi et al., ***Nat. Phot.*** 2016 [4] T. Yamashita et al., ***Opt. Exp.*** 22, 28783 (2014) [5] S. Miki et al., ***Appl. Phys. Lett.*** 99, 111108 (2011)

High performance photon detection technology

● High performance SNSPD

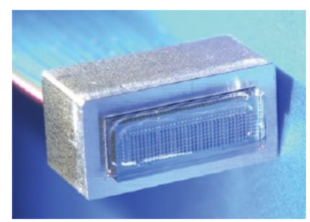
	Wavelength (nm)	Detection efficiency(%)	Dark count rate (counts/sec)
Current performance	780、1550	～80%	～10
MS target (5years)	**310、710、780、850、1550**	**95%**	**0.1**

● Scalable multi channel system

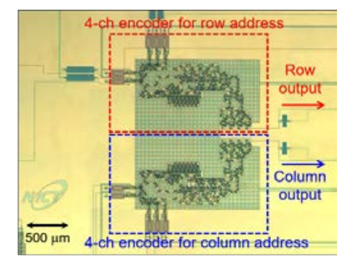
・SNSPD array device technology

・Multi optical input coupling technology

・Multiplexing technology at cryogenic environment



Fiber array



Superconducting SFQ circuit

● Monolithic integration with Q-bit device

Monolithic integration of Ion trap device in collaboration with Takahashi team

MOONSHOT
RESEARCH & DEVELOPMENT PROGRAM

Multi channel photon detection technology

Shimoi Group:
HAMAMATSU PHOTONICS K.K., Electron Tube Division,
Research & Development Department, R&D Group #1

Photomultiplier Tube (PMT)

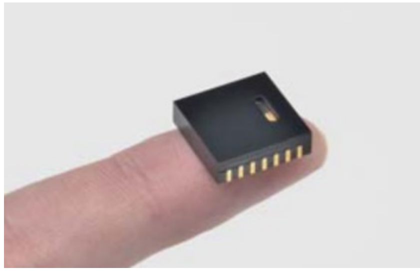
HIDEKI SHIMOI TSUYOSHI KODAMA

HAMAMATSU
PHOTON IS OUR BUSINESS

Core technology

- High Vacuum Packaging
- Thin Film Deposition
- Single Photon Detection

ex. Micro PMT

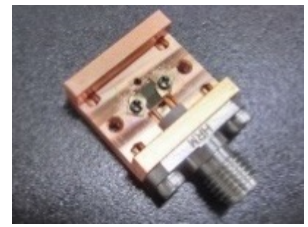


PMT + MEMS technology
= The world's smallest and lightest PMT

Multi channel photon detection technology

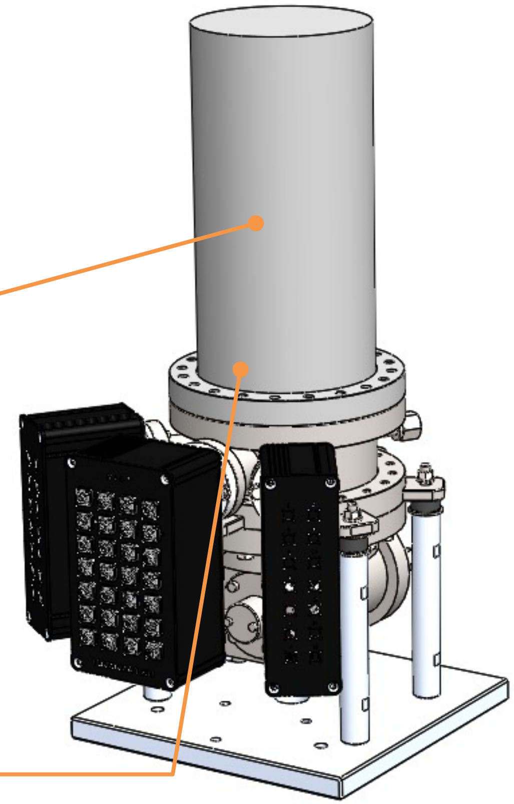
- Manufacturing technology of superconducting thin film
- Stable production of SNSPD
- High performance photon detection technology (from NICT)

SNSPD



- High performance cryostat
- Mounted a large number of SNSPD
- Stable operation for long time

Multi channel SNSPD cryostat system



The 5-year target

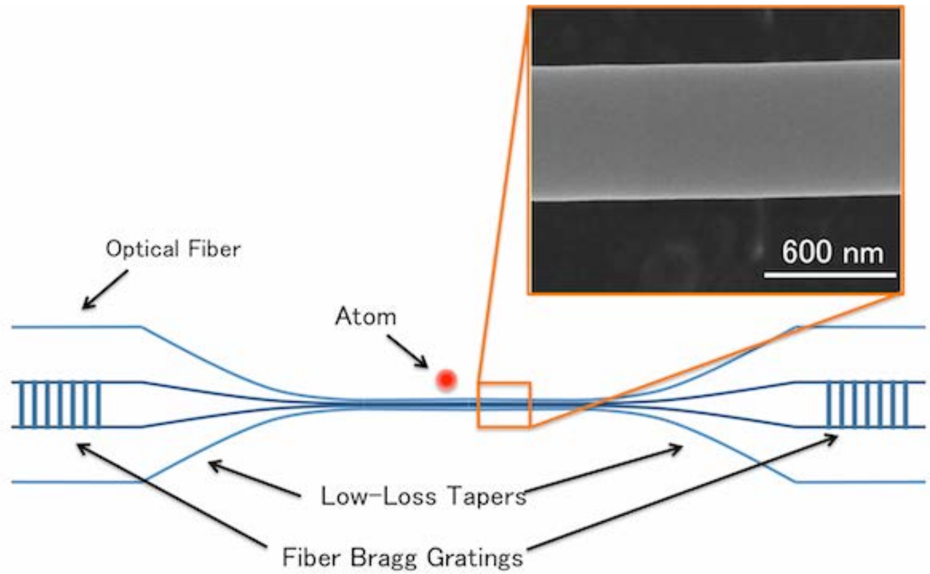
Development of 100-ch scale multi channel SNSPD system and provision of research project

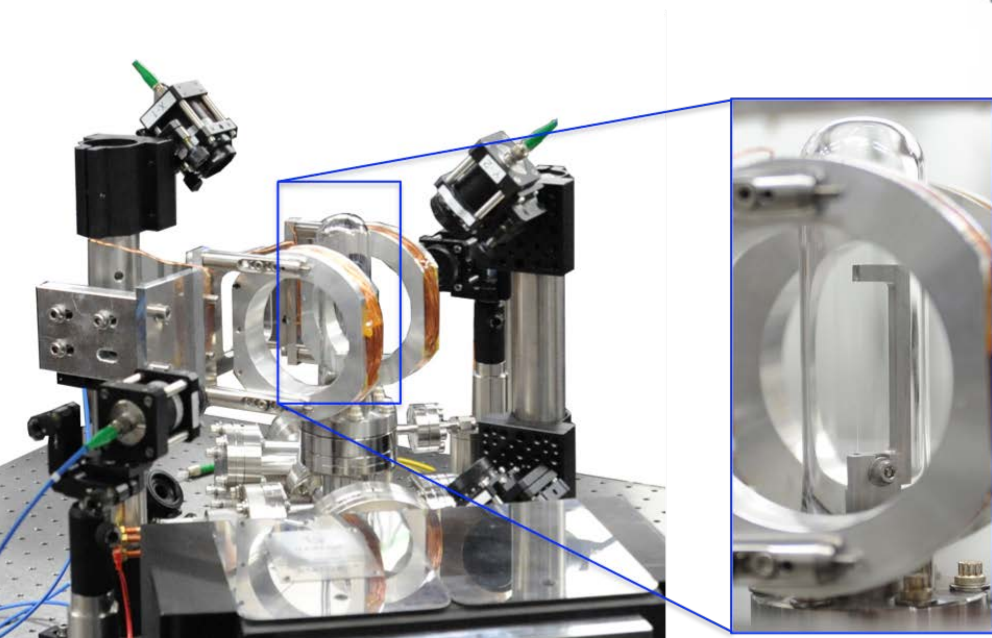
Photon (Cavity QED) networking technology

Aoki Group: Waseda University

Nanofiber cavity QED system

- ✓ All fiber
- ✓ High Scalability
- ✓ High cooperativity





Strong coupling with a single trapped atom

PRL 115, 093603 (2015)

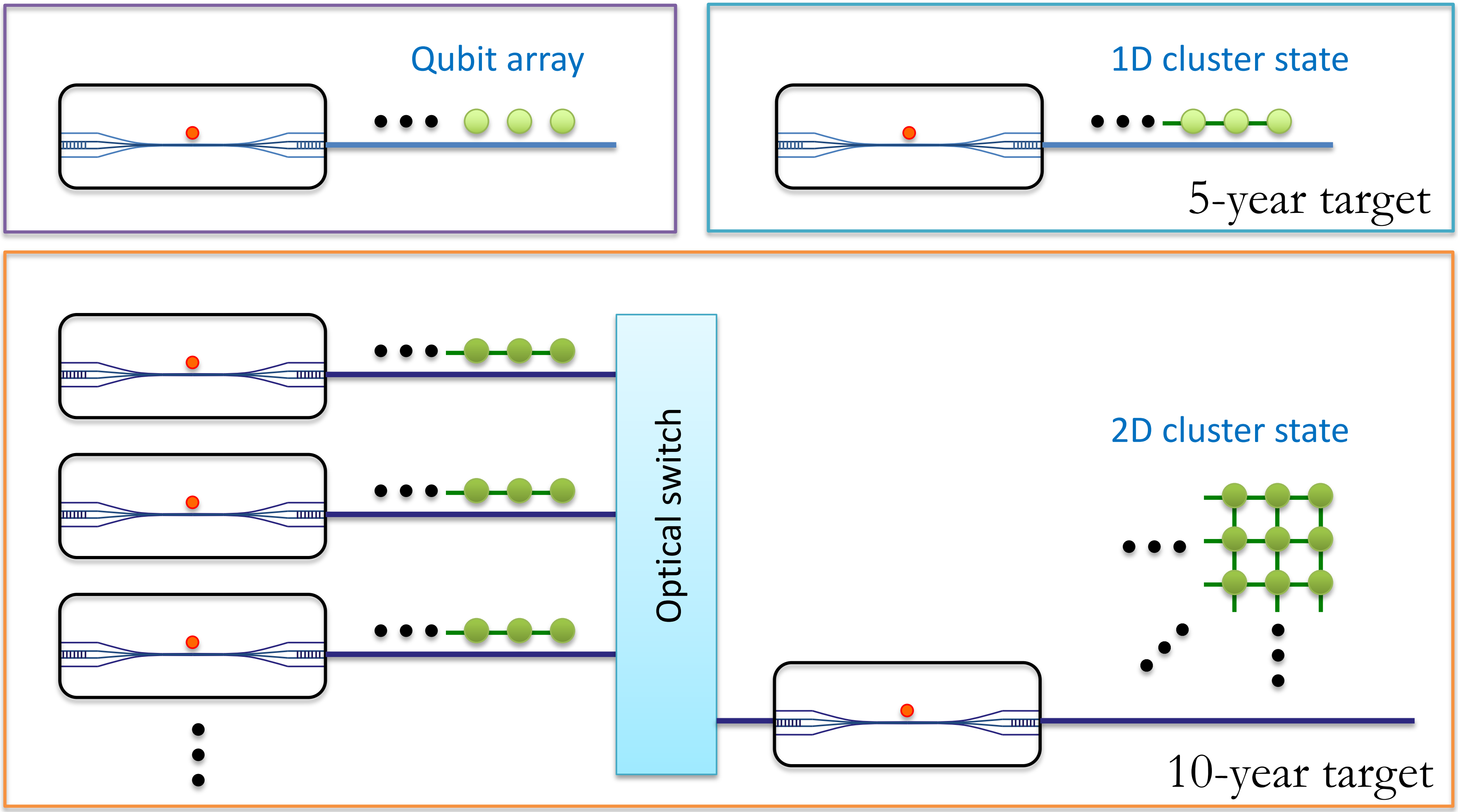
Coupled-cavities QED

Nat. Commun. 10, 1160 (2019)

PRL 122, 253603 (2019)

Photon (Cavity QED) networking technology

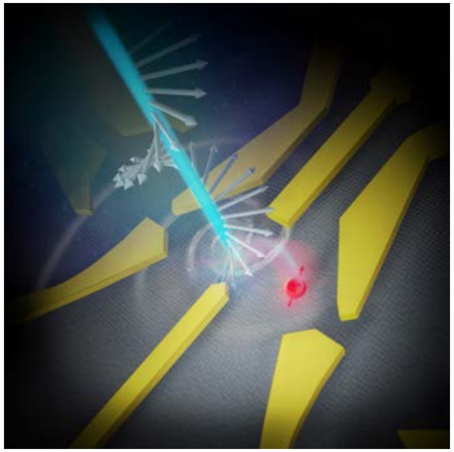
Generation of various photonic states with nanofiber cQED system



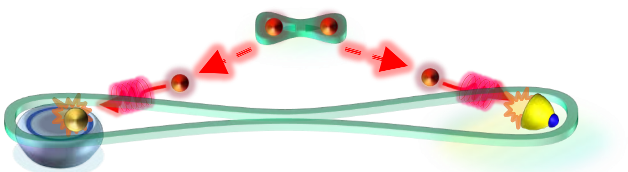
Semiconductor qubit networking technology

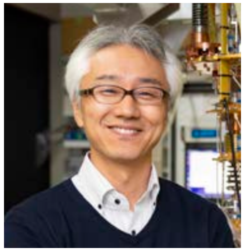
Oiwa Group: The Institute of Scientific and Industrial Research, Osaka University

Development of photon-spin quantum interface and semiconductor spin multiqubit



- **Quantum state transfer from single photon to single electron spins in gate-defined quantum dot**
  -Demonstration of fundamental technology for semiconductor qubit networking-
  Nature Communications 10, 2991 (2019), Phys. Rev. B 99, 085203 (2019)
- **Creation of photon-electron pair from entangle photon pair**
  –Towards the remote entanglement among spins in QDs-
  Scientific Reports 7, 16968 (2017).
- **Trapping and detection of single photoelectron using gate-defined quantum dots**
  Physical Review Letters 110, 226803(2013), Physical Review Letters 106, 146804 (2011).





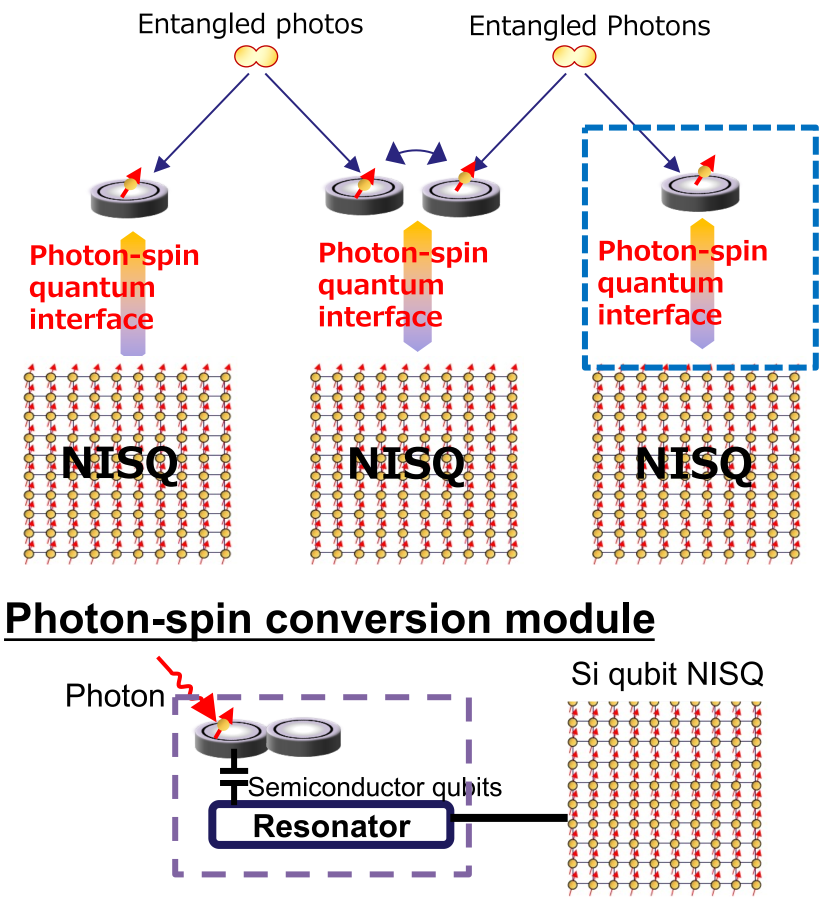
A. Oiwa

H. Kiyama

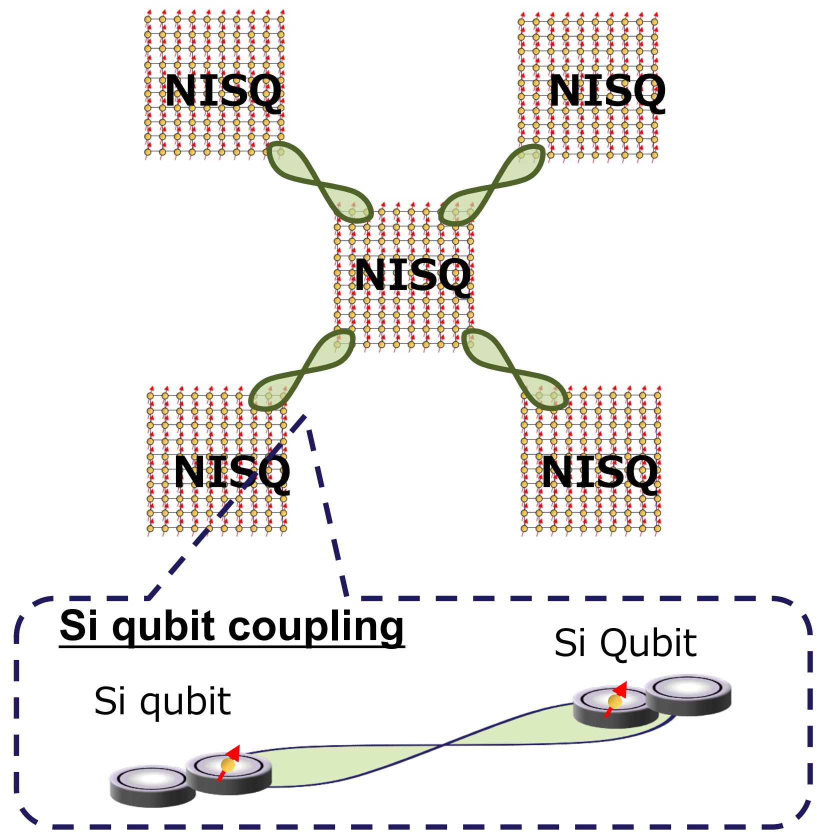
T. Fujita

Semiconductor qubit networking technology

Theme 1: Photon-Si qubit interfaces for larger scale networking



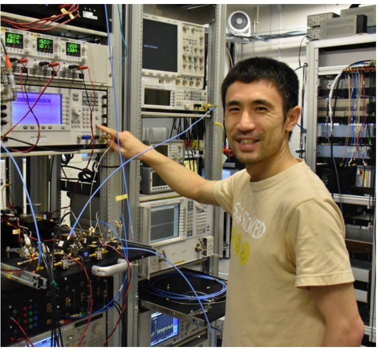
Theme 2: Coupling between Si qubits for semiconductor NISQ connections



5 year: we will develop the photon-Si qubit interface and Si qubit coupling suitable for NISQ connections

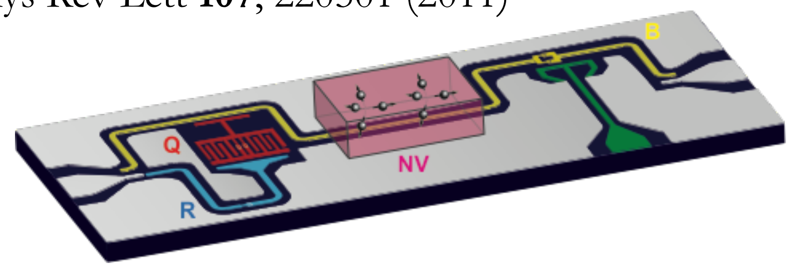
Superconducting qubit networking technology

Kubo Group: OIST Quantum Dynamics Unit

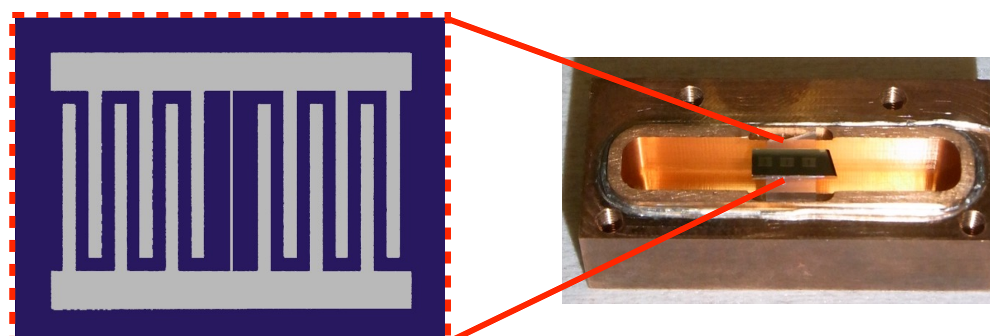


Previous work:

- Hybrid quantum system with a superconducting qubit and a spin ensemble
    - Phys Rev Lett **105**, 140502 (2010);
      Phys Rev Lett **107**, 220501 (2011)

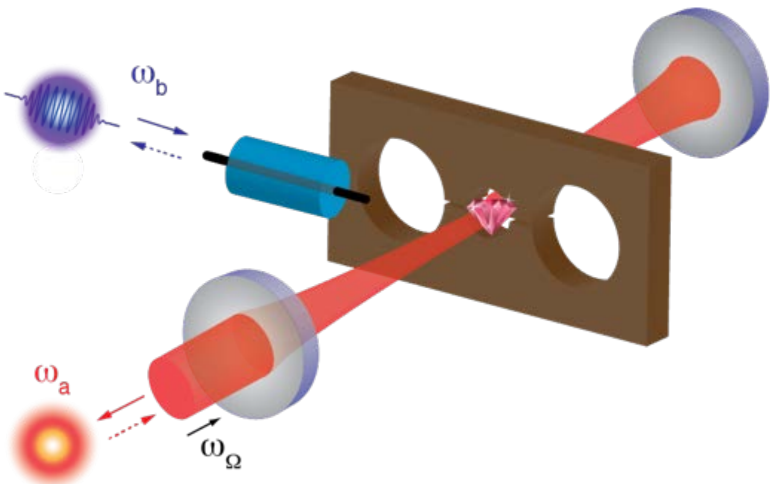


- Quantum-limited electron spin resonance
    - Nature Nanotech. **11**, 253 (2016)
- Purcell effect on spins in solid
    - Nature **531**, 74 (2016).



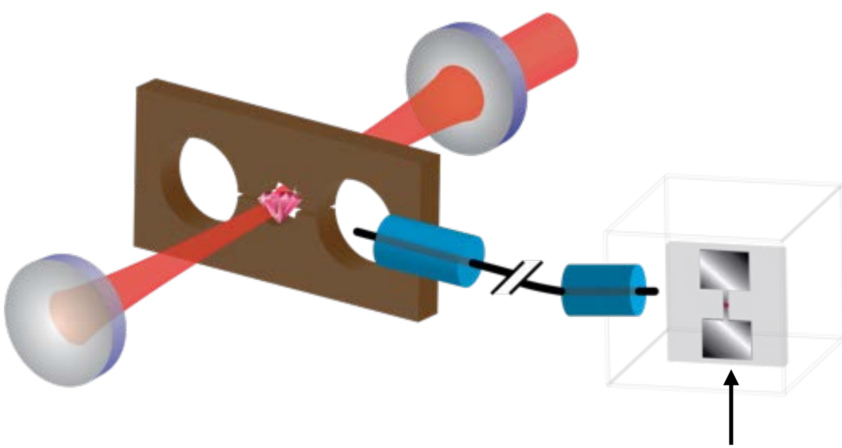
Superconducting qubit networking technology

Quantum transducer with spins in diamond

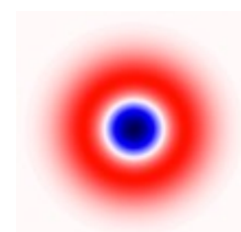


Theory proposal (with erbium spins):
Williamson et al. PRL 113 203601 (2014)
(With diamond spins: Kubo and Longdell, in preparation)

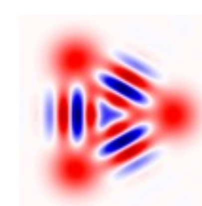
5Y Milestone: conversion of non-classical states from a superconducting qubit



Superconducting qubit



Fock state



Cat state

Summary of our project

- Development of elemental technologies with quantum network for divers quantum computers.
- 5-year target: Full lineup of elemental technologies for networking quantum computers
- 10-year target: Large-scale quantum computers with quantum networking
- To achieve those targets, we will collaborate with other teams

MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

大阪大学 OSAKA UNIVERSITY

NICT 国立研究開発法人 情報通信研究機構

早稲田大学 理工学術院 Faculty of Science and Engineering

QIQB 大阪大学先導的学際研究機構 量子情報·量子生命研究センター

HAMAMATSU PHOTON IS OUR BUSINESS

OIST 沖縄科学技術大学院大学