World Premier International Research Center Initiative (WPI)
FY2023 WPI Project Progress Report

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Research Center	International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP)		
Center Director	Masashi Hazumi	Administrative Director	Katsuo Tokushuku

Common instructions:
* Unless otherwise specified, prepare this report based on the current (31 March 2024) situation of your WPI center.
* So as to execute this fiscal year's follow-up review on the "last" center project plan, prepare this report based on it.
* Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.

➢ Prepare this report within 10-20 pages (excluding the appendices, and including Summary of State of WPI Center Project Progress (within 2 pages)).

Summary of State of WPI Center Project Progress (write within **2 pages**)

1-1. Advanced Research of the Highest Global Level: QUP's vision is to invent and develop new quantum field measurement systems, or "new eyes", for particle physics and cosmology with broader societal applications in the long term. As stated in QUP's Research Center Project submitted at the project's start, the term "quantum field measurement system" has two meanings: 1) to measure new quantum fields and 2) to measure "with" known quantum fields. To realize the vision, we have set up our research agenda and milestones (Sec. 1-1). Organizationally, we have four research clusters and the theory group. Although approaches are different, they share the same intention to be a game changer in cosmology and particle physics. In 2023, we published 54 papers (282 papers, including related papers). These numbers are significantly larger than those in 2022 (16 and 149). Some selected developments and results of the research are described below.

[Quantum detectors] We proposed a new method to eliminate the Casimir force, an attractive force that can only be explained by the quantum field concept, and discussed the possibility of a new force search using the method [*Phys. Rev. D, App1:1*]. A new experimental apparatus has been prepared as a step towards demonstrating this. A new method for searching for light quantum fields (axion) using an NV diamond quantum detector, proposed in Feb. 2023 [*arXiv:2302.12756*], was demonstrated using existing equipment in FY23. A new experimental setup is also being developed to cool the NV diamond quantum detector and increase its sensitivity significantly.

[Radiation-hard detector systems for new quantum field searches] We continued developing a new semiconductor detector that can recover from radiation damage by annealing. For the first time in the world, annealing details were observed for CIGS semiconductors [*Jpn. J. Appl. Phys., App1:11*].

[Low-temperature detectors] A new prototype detector was designed and fabricated for SpaceTES for LiteBIRD, the QUP's flagship project. Ground-based observations of cosmic microwave background (CMB) with transition edge sensors (TES) as proof-of-principle for LiteBIRD published stringent search limits on light axion-like-particles [*App1:6*][*arXiv:2403.02096*]. The QUP-Kamioka-Dark Matter (DM) Project, the next flagship candidate, has made a clear concept for its first phase targeting liquid helium and is studying the 2nd phase with TES developed at QUP. Both studies are supported by the Systemology Support Section (SSS). Other TES developments for solar axion search [*App1:13,58*] and optical TES [*App1:2*] for various applications are underway.

[Data acquisition & analysis for searches of new quantum fields] The objective is to "improve the eyesight" of various measurement systems. We developed new machine learning (ML) methods to search for new physics beyond the standard model and published results on RPV SUSY searches [*Phys. Rev. D 109, L011702*][*JHEP, App1:25*], rare heavy resonance searches [*App1:77,282*], and Higgs boson decay studies [*Phys. Rev. D, App1:31*][*Phys. Lett. B, App1:28*].

[Theory] Papers were published on new methods of searching for light quantum fields (e.g., axions) including the use of qubits and their quantum entanglement [*App1:1,14,18,23,24,43*]. We also proposed new measurement principles to obtain clues about dark matter from space observations with and complementary to the LiteBIRD and XRISM satellites [*App1:15-17,20-22,79,82*].

1-2. Generating Fused Disciplines: We took several initiatives to advance research by fusing disciplines. 1) The SSS started earnestly in FY23 to support QUP projects with state-of-the-art, interdisciplinary systems engineering methods. That led to a new conceptual design of SpaceTES with an elaborate Faraday cage and an experimental concept for the QUP-Kamioka-DM Project. 2) The QUP Synergy Summit, a new pivotal platform for industry-academia collaboration, was launched in FY23. It fosters a symbiotic relationship to solve real-world "problems" in industry with KEK technology, a form of "deep tech" rooted in fundamental laws. The reverse case, where KEK's challenges are addressed with the industry's technology, is also in consideration to enhance the collaborative spirit. The secretariat is at the QUP satellite at Toyota Central R&D Labs., Inc. We chose the soft error problem caused by cosmic rays as the 1st theme. 3) The director formed a team of researchers in particle theory, astrophysical experiments, information science, materials physics, and measurement science to study new measurement principles systematically. 4) We held several workshops to discuss ML applications across disciplines.

2-1. Realizing an International Research Environment: The fraction of foreign researchers at QUP increased steadily and reached 34% in FY23. The female fraction is 17%, twice as large as the KEK average (8%). The second QUP symposium, QUPosium2023, was held in Dec. 2023 with 118 participants. We invited 31 distinguished speakers; a Nobel-prize laureate Prof. Adam Riess (Johns Hopkins Univ.) and those from top-level institutions including Caltech, Fermilab, MIT, Oxford, Lawrence Berkeley National Lab and UCLA. We held 12 QUP seminars in FY23. We announced them widely to the communities, and about 40 people joined each seminar on average. QUP received contacts from the ARC Center of Excellence for DM Particle Physics (Australia) and the National Research Council (Canada), and had online mini-workshops for each to discuss possible collaboration.

2-2. Making Organizational Reforms: QUP's recruitment and salary system allows special offers that are more attractive than KEK's standard. In FY23, we started the annual salary renewal procedure to provide more incentives. We introduced a new title, Principal Engineer, and hired the 1st one in May 2023, which will improve the technical staff's labor conditions. We reviewed KEK's rules for accepting/supporting graduate students as RAs. That will pave the way for admitting graduate students for an extended period with enough support under the QUP. We hired Dr. Kazuhisa Mitsuda as the new deputy director on April 1, 2024, replacing Dr. Kazunori Hanagaki. Following a suggestion by the WPI program committee, we hired a new PI, Dr. Volodymyr Takhistov, on April 1, 2024. He promotes theoretical research and stimulates collaboration among QUP's research clusters.

3-1. Outreach: Our outreach activities in FY23 have increased significantly than FY22. We gave public lectures at the "Science in Japan" forum sponsored by JSPS in June 2023 in Washington, DC. We started a public lecture series for high school students. After the lecture, we gave them a unique opportunity to communicate directly with non-Japanese QUP researchers in English or with translators. Junior high school students visited QUP and had an active Q&A time with QUP researchers. On social media X, the number of views for our posts in FY23 has more than tripled from FY22. The number of views of QUP YouTube channels also increased ten times. Two programs on QUP's research were broadcast on cable TV in Tsukuba, Japan in FY23.

3-2. Higher Education and Career Development: We launched the QUP Internship Program (QUPIP) in FY2023, allowing young researchers to stay at QUP and work with QUP researchers. We have accepted 20 interns (6 domestic and 14 overseas). As of the end of FY2023, QUP as a whole supervises ten students and employs eight students. The Berkeley satellite also has graduate students and supports them with satellite funding. Based on an MOU with SOKENDAI, QUP's senior scientists have been affiliated with the graduate school since September 2023.

3-3. Self-sufficient and Sustainable Center Development: QUP and KEK continued the extensive discussions on the support plans for making QUP sustainable beyond the WPI funding period and agreed to cooperate in creating a concrete financial plan. We need personnel costs of 400 million yen to maintain current activities after the 10th year. Requesting QUP to seek external funding of 200 million yen, KEK promises to cover at least 200 million yen. Following this discussion, the QUP acknowledged this support by updating QUP's Research Center Project. By renovating the old KEK facilities, KEK offers a new research building complex for QUP. Its construction started and will be completed by the end of FY24.

* Describe clearly and concisely the progress being made by the WPI center project from the following viewpoints.

1. World-Leading Scientific Excellence and Recognition

1-1. Advancing Research of the Highest Global Level

* Among the research results achieved by the center, concretely describe those that are at the world's highest level. In Appendix 1, list the center's research papers published in 2023.
* Regarding the criteria used when evaluating the world level of the center, note any updated results using your previous evaluation criteria and methods or any improvements you have made to those criteria and methods.

[Overview]

QUP's vision is to invent and develop new quantum field measurement systems, or "new eyes", for particle physics and cosmology with broader societal applications in the long term. Our concept of quantum field measurement systems expands on the traditional scope of quantum sensors to broadly include measurement systems described by and/or utilizing principles of quantum field theory. Thus, it involves not only observations and measurements of various manifestations of quantum fields themselves, but also possibility of utilizing quantum fields in measurement processes.

To realize the vision, we have set up the following research agenda:

Research agenda

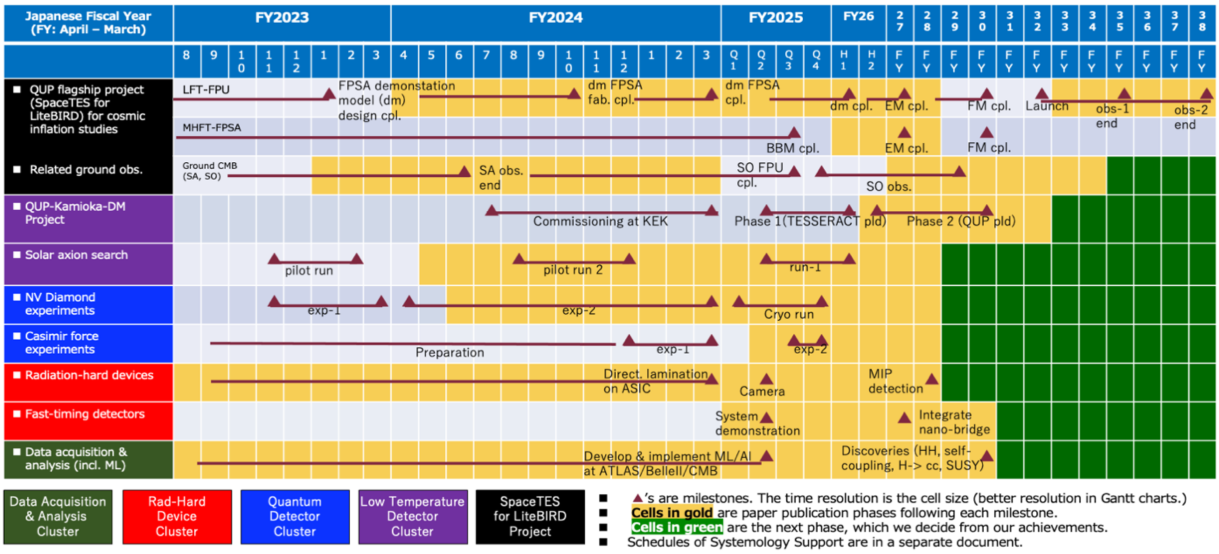
Quantum detectors
- Casimir force experiments
- NV diamond experiments

Radiation-hard detector systems for new quantum field searches
- Radiation-hard devices
- Fast-timing detectors

Low temperature detectors
- SpaceTES for LiteBIRD and related cosmic microwave background (CMB) observations on ground
- QUP-Kamioka-DM project
- Solar axion search
- Optical TES

Data acquisition & analysis for searches of new quantum fields
- Machine learning (ML) applications
- Automatic design of ASIC

Theory
- New principles of quantum field measurements (including use of qubits)
- New multi-messenger astrophysical observations to search for effects of new quantum fields



Abbreviations and acronyms:
LFT – low frequency telescope, FPU – focal plane unit, FPSA – focal-plane sub-assembly, dm – demonstration model, EM – engineering model, FM flight model, cpl. – completion, fab. – fabrication, obs – observation, pld – payload, exp – experiment, MIP – minimum ionizing particle, SA – Simons Array, SO – Simons Observatory

Fig. 1 Milestones of QUP's major research projects.

The rationale of our research agenda is the following: The new eyes we pursue shall be more sensitive than existing technology. Our low-temperature detector and quantum sensor research clusters provide solutions based on various quantum effects. New eyes for particle physics must often be used in very harsh radiation environments requiring our rad-hard device research cluster to deliver more radiation-hard sensors. The research cluster for the readout electronics and data analyses (including ML methodologies) corresponds to the "nerves and brain" for human beings, needed for any kind of measurement system. The theory group invents new concepts of measurements in particle physics and cosmology and enhances inter-research-cluster communications. These five groups share the same intention to be a game changer in cosmology and particle physics. Our research agenda is built to realize QUP's vision and has well defined milestones as summarized in Fig.1. To ensure the credibility of the milestones, we have set up reviews and support by the Systemology Support Section (SSS). In FY2023, the SSS supported SpaceTES for LiteBIRD and QUP-Kamioka-DM project, as described in Sec. 1-2. Each project listed in the research agenda can become a flagship project if it passes SSS's review and the director decides.

In 2023, we published 54 papers (282 papers including related papers,) which is much larger than those in 2022 (16 and 149). In the following, we concretely describe each topic in turn.

[Quantum detectors]

The quantum detector research cluster seeks new measurement systems utilizing quantum effects. Two novel projects are ongoing.

Casimir force experiments: Casimir force acts on the macroscopic boundaries of a confined space. It is usually an attractive force, but it can be repulsive in special conditions. One application is frictionless bearings, which have a very large impact on the industry.

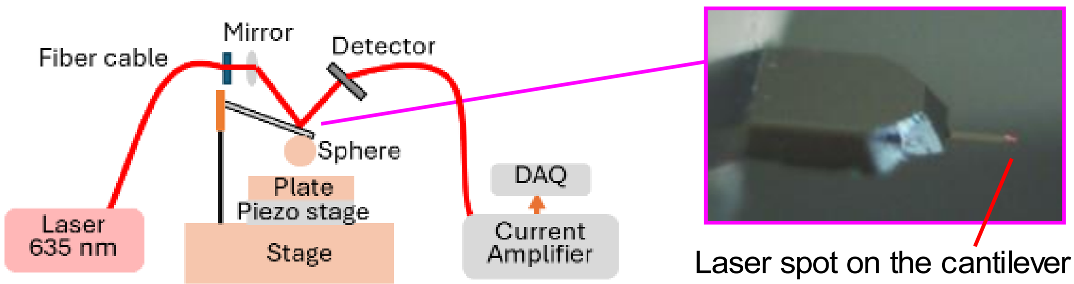


Fig. 2 Configuration of the experimental setup for new force search via Casimir forces. The photograph shows that the laser is illuminated on the cantilever.

In FY23, we published a paper on a novel method to search for a new force mediated by a new quantum field [*Phys. Rev. D., App1:1*]. The key finding here is that the direction of Casimir force can be controlled by introducing the magnetic Weyl semimetal, a new form of material discovered recently. By controlling the surface parameters at the boundary of two directions, we can extinguish the Casimir force. It can provide a new condition to search for new forces with unprecedented precision. We expect the world's best sensitivity for CP-even scalar particles with masses around 1 eV (Dilaton, radion, moduli, etc.; note that axions are CP-odd, so they do not fall into this category) and vector particles (B-L gauge boson, etc.). As the first step toward this experiment, we completed the design of the experimental setup (Fig. 2, left) that allows us to measure the Casimir force between a sphere (200 μm diameter) and a plate around 100 nm gap distance. We started building the experimental setup in the QUP satellite at Toyota Central R&D Labs. We installed the optical apparatus and checked its function by illuminating laser on the cantilever (Fig. 2, right). With the help of Professor Reddy at the University of Michigan, one of the world's leading experts in measurements at nanoscale, young researchers at the QUP satellite at Toyota Central R&D Labs. are learning the know-how. The project aims to pass the review by the SSS to become a flagship project.

NV diamond experiments: We presented a new idea to directly search for light bosonic dark matters such as axion-like particles (ALPs) and dark photons by using magnetometry with nitrogen-vacancy (NV) centers in diamond [*arXiv:2302.12756*]. We showed that the sensitivity could eventually be higher than existing experiments in low mass ranges (Fig. 3, left) with a diamond

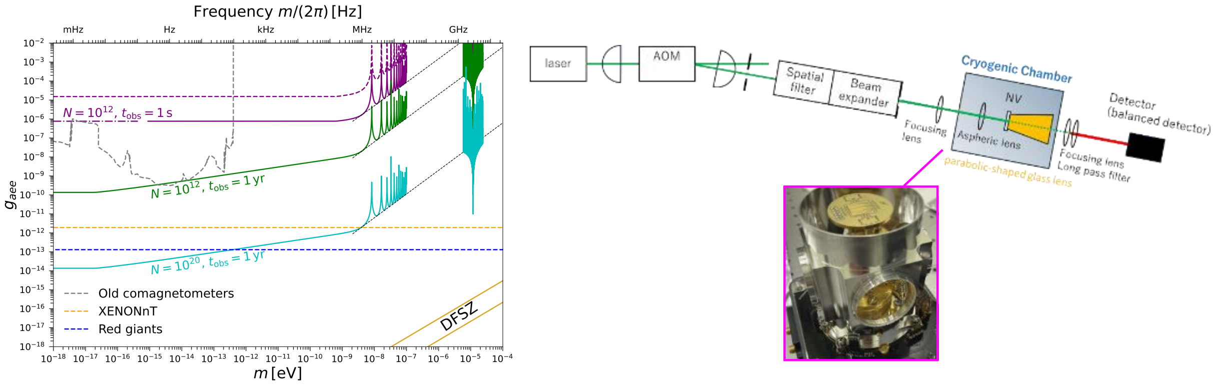


Fig. 3 (Left) Expected sensitivities on the axion-like particle (ALP) to electron spin coupling as a function of the ALP mass [*arXiv:2302.12756*]. (Right) Configuration of the experimental setup for light-dark matter search via nitrogen-vacancy centers in diamond. The photograph shows the cryogenic station installed in KEK.

sample with a sufficient number of NV centers. In FY23, Dr. Mizuochi, an affiliate member of QUP and a specialist of NV diamond, and his colleagues demonstrated the proposed method using existing equipment at Kyoto Univ. We also decided to target cryogenic evaluation (4K) for ensemble NV centers to achieve even higher sensitivity. We designed the experimental setup (Fig. 3, right top), and started building it in KEK. A tabletop cryogenic station has been installed (Fig. 3, right bottom).

[Radiation-hard detector systems for new quantum field searches]

Some key fundamental quantum field observations require high energy/luminosity and detectors can be damaged due to irradiation. The radiation-hard (rad-hard) detector systems research cluster seeks new measurement systems with which we can continue searching for new quantum fields in very harsh radiation environments, typically 100 times or more of the level at CERN's Large Hadron Collider (LHC), i.e. aiming for total ionization doze (TID) > 70 MGy and Non-Ionization Energy Loss (NIEL) > 10^{17} MeV/neq/cm^2, which we need to target for future high-luminosity collider experiments such as the Future Circular Collider (https://home.cern/science/accelerators/future-circular-collider). Both the detector and the readout electronics need to be rad-hard. We are developing the following components.

- The CIGS detectors [*Jpn. J. Appl. Phys., App1:11*]
- Rad-hard silicon detectors [*App1:62-67,273*]
- Fast-timing silicon detectors
- Rad-hard readout electronics for high-luminosity LHC [*App1:53*]
- Atom-switch FPGA

In the following, we describe our FY23 achievements on the CIGS semiconductor.

The CIGS semiconductor: The Cu(In,Ga)Se_2 (CIGS) semiconductor is expected to have high

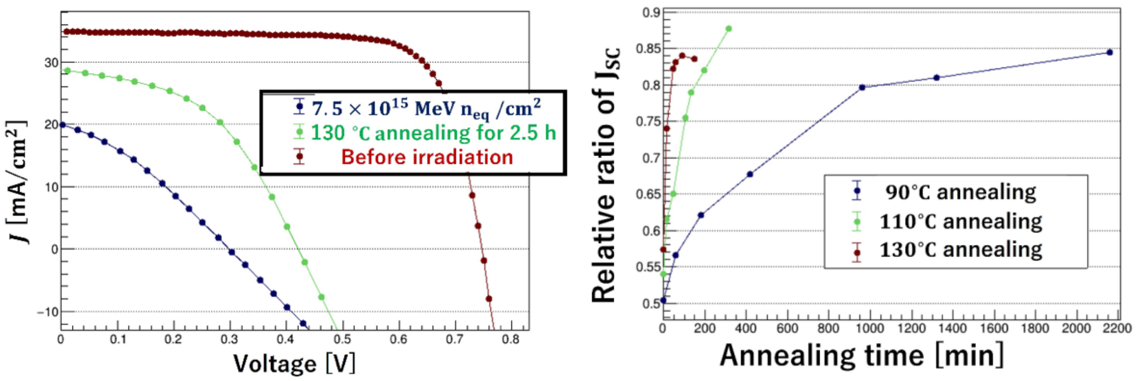


Fig. 4 (Left) J-V curve with an AM1.5 spectrum at 100 mWcm^{-2} at 25 °C. (Right) Annealing time dependence of J for 90, 110 and 130 °C.

radiation tolerance, recovery of radiation damage, and compensation of the defects by ions. To investigate the annealing temperature and time dependences of the recovery, we irradiated CIGS solar cells (2 μm active thickness) with a 70 MeV proton beam at CYRIC. Figure 4 (left) shows the current density as a function of voltage (J-V curve) before and after irradiation (7.5×10^{15} $MeV/n_{eq}/cm^2$) and also for annealing after irradiation. The J value decreased by radiation damage but recovered after dark annealing at 130 ℃ for 2.5 hours. Figure 4 (right) shows the relative ratio of J at 0 V as a function of annealing time for three temperatures. After one hour of dark annealing at 130 ℃, the J value recovered from 0.57 to 0.85, saturating at 0.87 after 90 minutes of dark annealing. Conversely, dark annealing at 90 ℃ required a longer period for JSC to recover to 0.85 than at 130 ℃. This result shows a strong temperature dependence between 90 – 130 ℃.

Following WPI committee's suggestion, we are trying to increase the strength and consistency within QUP regarding rad-hard devices. While demonstrating the rad-hard camera, which has been our target since QUP's original proposal, we are delving deeper into the physics of the devices we are developing to clarify the novelty of its measurement principle.

[Low Temperature Detectors (LTD)]

The low-temperature detector (LTD) research cluster seeks new measurement principles for precision measurements to search for new quantum fields. We focus on, but not limited to, adding novel functions to superconducting transition edge sensors (TES) read out with the superconducting quantum interference device (SQUID). We are also conducting R&D on fundamental techniques for operating superconducting sensors in low-noise environments.

SpaceTES for LiteBIRD: SpaceTES for LiteBIRD is QUP's flagship project. LiteBIRD is a space mission for primordial cosmology and fundamental physics. The Japan Aerospace Exploration Agency (JAXA) selected LiteBIRD as a strategic large-class (L-class) mission, with an expected launch in FY32. In FY23, LiteBIRD passed the mission definition review. It will enter the pre-project phase in FY24. The primary scientific objective of LiteBIRD is to search for the signal from cosmic inflation, either making a discovery or ruling out well-motivated inflationary models (Fig.5). The LiteBIRD will also provide insight into the quantum nature of gravity and other new physics beyond the standard models of particle physics and cosmology. QUP will develop the TES and its SQUID readout system, the quantum eyes of LiteBIRD, which will improve the sensitivity more than an order of magnitude than the current constraint. We have defined the scope of QUP's contribution and call it SpaceTES for LiteBIRD. It corresponds to one of the goals of the center "to lead the world in the grand challenges of cosmology and particle physics by developing and implementing new quantum field measurement systems in international projects such as the LiteBIRD satellite project and collider experiments," as written in QUP's Research Center Project. SpaceTES will be the first attempt to use the TES quantum sensor technology in space for microwave observations. One big challenge is to mitigate noise due to cosmic rays. The usual TES design used on the ground does not work in space

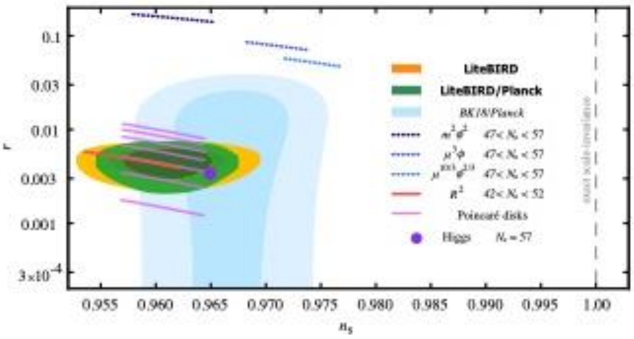


Fig. 5 LiteBIRD sensitivity on the tensor-to-scalar ratio r and the scalar spectral index n_s assuming Starobinsky's R^2 model for inflation (orange and green), which shows a clear discovery potential, significantly improving the current constraint (sky blue). From [*PTEP 2023 (2023) 4, 042F01*]).

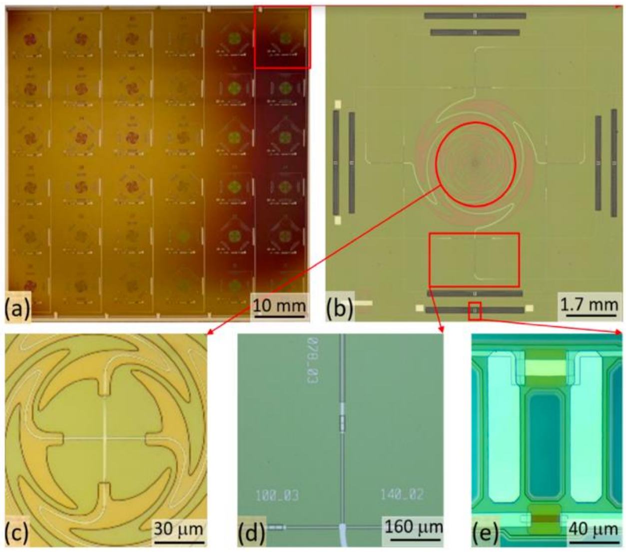


Fig. 6 Detector elements including (a) detector wafer, (b) trichroic pixel, (c) sinuous antenna, (d) band pass filters, and (e) TES bolometer (C. Raum, B. Westbrook, S. Beckman et al. - [*accepted for publication in JLTP*]).

because of the lack of a cosmic ray mitigation mechanism. At QUP, we invented a new design with palladium to efficiently absorb phonons by cosmic rays. In FY23, we had steady progress on the design of SpaceTES (by Dr. Tommaso Ghigna, QUP assistant professor) and fabricated the first prototype at the QUP Berkeley satellite (Fig.6). In the longer term, we need to develop microscopic descriptions of the cosmic-ray mitigation function based on phonon quantum field theory to elevate our invention to the level of new principle.

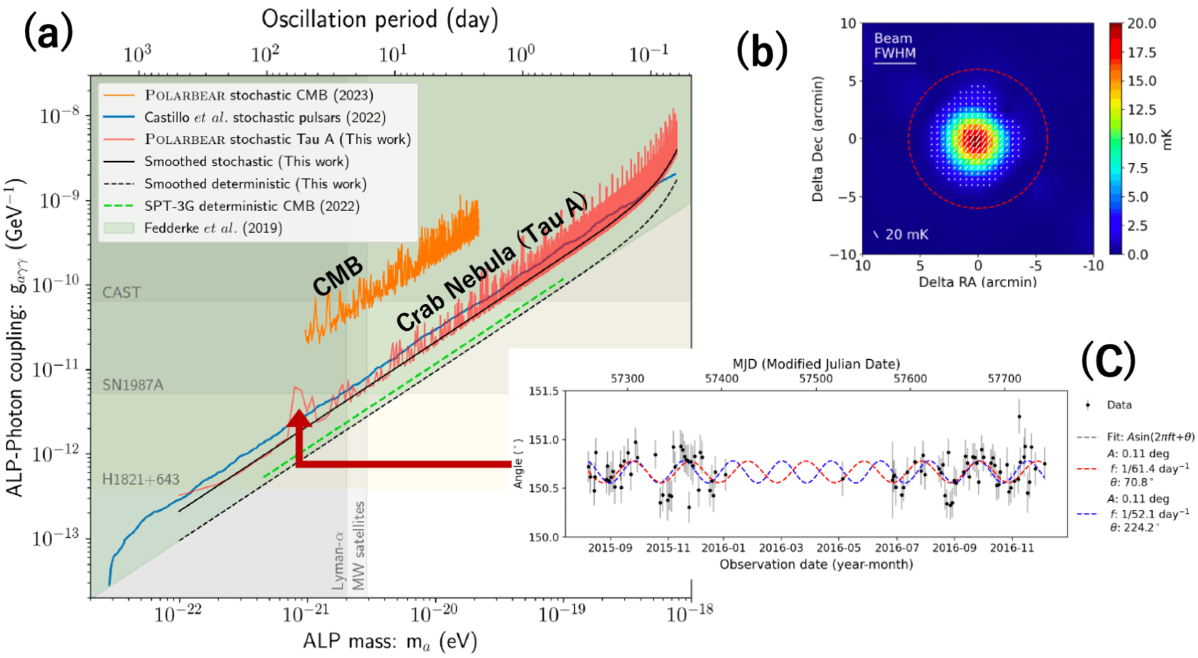


Fig. 7 (a) Upper bounds on the ALP-photon coupling at 95% C.L. (b) Polarization map of Tau A observed by POLARBEAR. (c) Measured oscillation of the polarization angle of CMB [*Phys. Rev. D, App1:6*] and Tau A [*arXiv:2403.02096*] by POLARBEAR.

CMB observations on ground related to SpaceTES for LiteBIRD: POLARBEAR is a ground-based telescope in Chile for CMB observations. It uses TESs that serve as a proof-of principle for SpaceTES. QUP PI Adrian Lee invented the design of TESs for POLARBEAR. In FY23, we searched for ultralight ALPs in POLARBEAR's observation data of the CMB [*Phys. Rev. D, App1:6*] and the Crab Nebula (Fig.7(b)) also known as Tau A [*arXiv:2403.02096*]. ALPs couple to photons through a Chern-Simons term, inducing a temporal oscillation in the polarization angle of linearly polarized sources such as CMB and Tau A. From our measurements, we set the tightest upper limit for the mass between 9.9 x 10^{-21} and 7.7 x 10^{-19} eV (Fig 7(a)). We find a hint of a polarization oscillation signal with a global significance level of 2.5σ at the frequency of 1/61 day^{-1}(Fig.7(c). We plan to confirm or reject the signal with more data from POLARBEAR2, a successor of POLARBEAR with the similar TES design features as SpaceTES but with no cosmic ray mitigation. Dr. Yuji Chinone, a QUP assistant professor, led the analysis with a student at the University of Tokyo.
QUP-Kamioka-DM project: Because of recent high-sensitive negative results of WIMP searches using two-phase noble gas detectors, astronomical searches, and collider experiments, lower-mass hidden sector dark matters are of great interest now. The Kamioka-DM project aims to search in the mass ranges lower than existing experiments in two phases. The first phase utilizes superfluid He (i.e. low-mass nucleon) as the scattering target to obtain higher energy deposition from dark matter particles, and QET (quasiparticle-trap-assisted electrothermal feedback transition-edge sensors) developed by the TESSERACT collaboration to detect the kinetic energy of He-atom quantum evaporation excited by phonons/rotons with a low energy threshold. In FY2023, we estimated the background level from detector components, cosmogenic and external gamma/neutron under various configurations using simulation (Fig.8 left). We confirmed that the background rate is < 10 d.r.u (differential rate unit = counts/day/keV/kg) when operated in Kamioka. With the present energy threshold of the QET, we can reach by a factor of two lower mass limits compared to the

present best results (Fig.8 right). Dilution fridge modification to accept the payload is now ongoing.

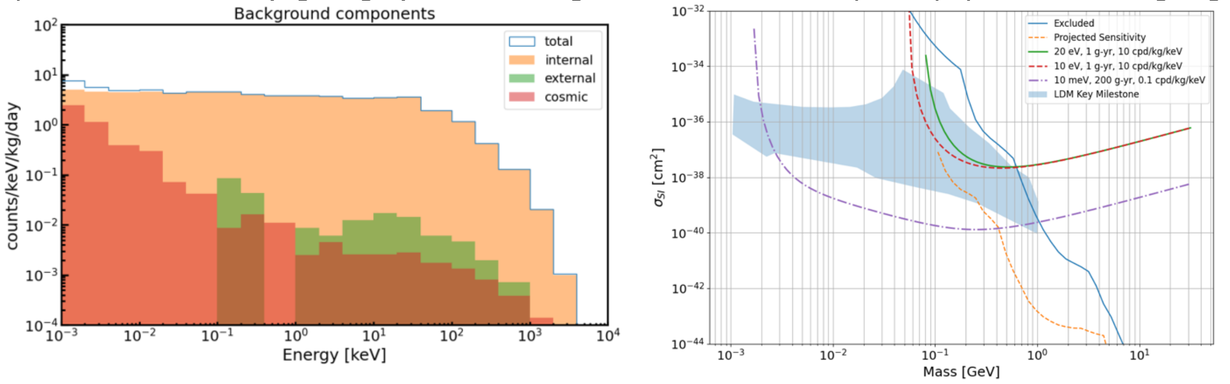


Fig. 8 Expected background level (Left) and projected sensitivity to light dark matter (Right). The background mainly comes from detector components, while the neutron background level will be estimated soon. The first payload of our experiment will be LHe with TES microcalorimeters developed by TESSERACT.

The phase 2 experiment utilizes electron scattering to reach an order of magnitude lower mass. When a dark matter particle kicks an electron in a superconductor, the scattered electron produces quasi-particles. If the superconductor is connected to a TES, the quasi-particles diffuse into the TES, and the energy can be measured with a low threshold to so explore an uncharted mass range, which is about factor ten smaller than the present constraint. Optimization of superconductor and TES materials and the operating temperature are keys to realizing such a device. We studied a plan to confirm experimentally the feasible configurations of the device.

Solar axion search: Axions must be produced in the central region of the Sun if they exist. Solar axions are expected to contain monochromatic lines arising from the photon and nuclear magnetic dipole moment coupling. The same nucleus on the Earth will absorb the axion and convert its energy to the forms of standard particles. With high energy resolution and high axion-to-heat conversion efficiencies, the TES microcalorimeter is one of the best sensors for solar-axion line searches. One drawback is the small amount of target material we can attach to TES. This problem can be

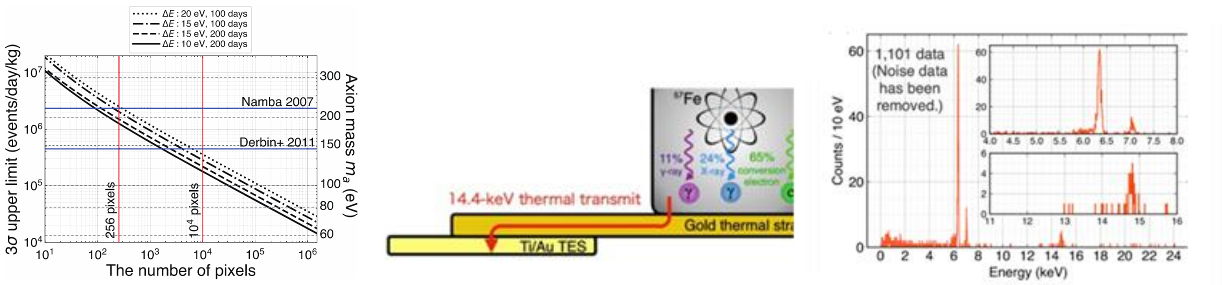


Fig. 9 (Left) Expected sensitivity of the solar axion search. Since QCD axion is assumed here, axion mass is shown instead of the coupling constant. (Middle) Schematic view of the detector. (Right) The energy spectrum obtained with a ^{57}Co calibration source.

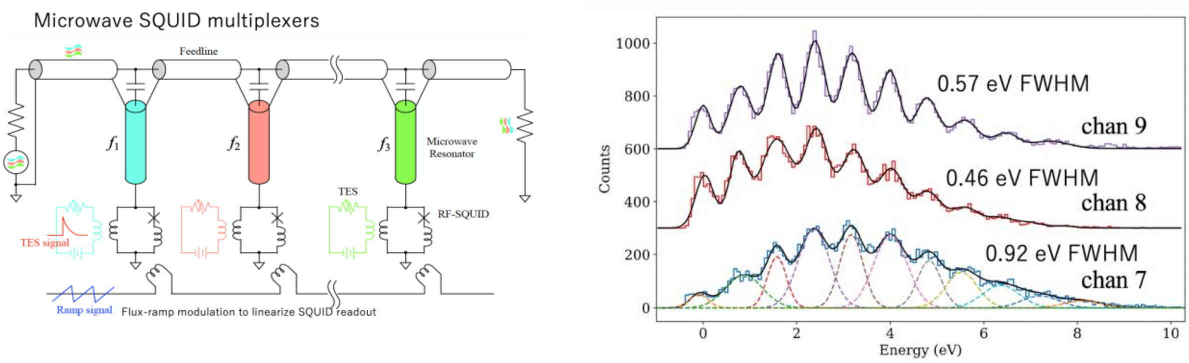


Fig. 10 (Left) Schematic diagram of the present microwave multiplexing. (Right) QUP's measurement of energy spectra for monochromatic photons of 1.55 mm wavelength (0.8 eV energy).

overcome using a large-scale multi-pixel readout using the microwave multiplexing technique (MWMUX). With ~1000 pixels, we can reach an unprecedented limit for the line search (Fig 9 left, [*App1:13,58*]). In FY23, we made a ^{57}Fe attached to TES array to search for Solar axions and started a test run. No axion signal has been detected so far. This is the first result in the world of running a TES with ferromagnetic material (Fe) attached as the energy converter (Fig 9. right).

Optical TES: We develop photon-counting TES sensors sensitive to visible light, aiming to apply them to various research fields, including bio-imaging and quantum computers. We have already achieved notable accomplishments, such as attaining the world's best energy resolution (67 meV) and shortest signal decay time (~70 ns). In FY23, we advanced the development of multiplexing and have successfully demonstrated the operation of a 40-channel multiplexed readout (Fig.10) [*App1:2*]. This is the first achievement in the world to multiplex TES calorimeter signals whose decay time is less than 1 μs. The degradation of energy resolution caused by the readout will be addressed by optimizing parameters in TESs and the readout system.

[Data acquisition & analysis for searches of new quantum fields]

The goal of the data acquisition and data analysis (DAQ&DA) research cluster is to "improve the eyesight" of various measurement systems. On the DA front, we focus on developing ML algorithms. New methodologies are applied to 1) new physics search beyond the Standard Model of particle physics, 2) measurements of the Higgs boson properties, 3) detector development (e.g., anomaly detections during inspections), 4) CMB data pipelines. On the DAQ front, our focus is on automation of ASIC design. The DAQ&DA research cluster also connects the QUP research clusters and contributes to community engagements on ML applications (Sec. 1-2). Among the published papers of the DAQ&DA research cluster in FY23, the following highlights our applications of new ML techniques.

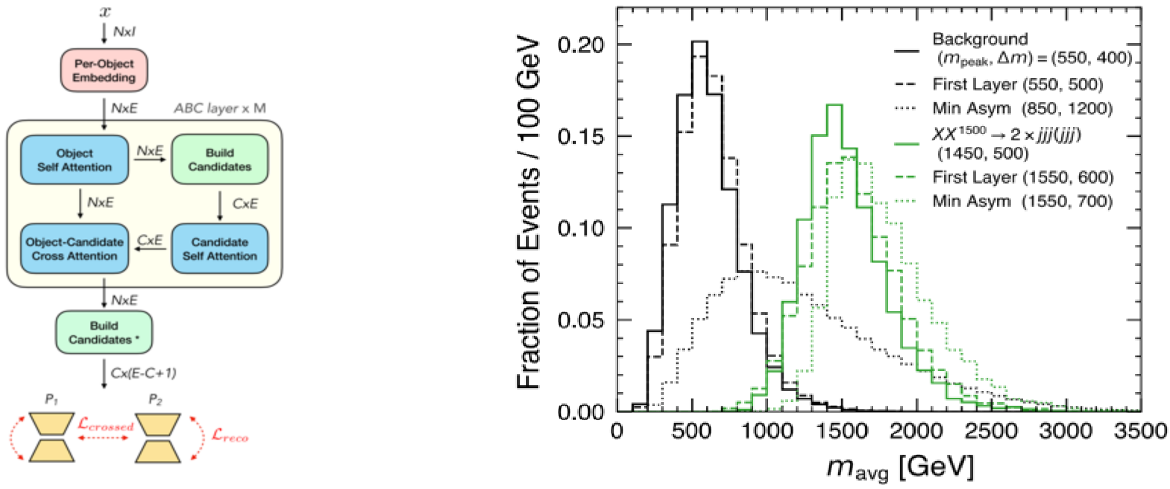


Fig. 11 (Left) Sketch of the Passwd-ABC model and components of the ABC layer. Multiple ABC layers are stacked followed by a final candidate-building operation. The first features encoding the category probability are swapped for the mass of the candidate. This final candidate building block is notated with an asterisk. Red lines indicate the terms that are used to build the reconstruction and similarity loss. (Right) Comparison of the average of the two reconstructed masses m_{avg} for the background (black) and an example signal (green) as reconstructed by Passwd-ABC in its last layer (solid line), intermediate layer (dotted line), and the mass reconstructed from the minimization of the mass asymmetry (dashed line).

ML application to new physics search beyond the Standard Model of particle physics: We developed a ML algorithm to extend resonance searches for beyond-the-standard-model (BSM) signals with pair-production in final states with high object multiplicity by introducing a novel neural network architecture, Passwd-ABC, which combines a custom layer based on attention mechanisms and dual autoencoders as shown in Fig. 11 (left). As shown in Fig. 11 (right), an improvement of the signal resolution is demonstrated after the first layer prediction is refined compared to classical methods. At the same time, the background distribution is strongly sculpted toward high masses when reconstructed by minimizing the mass asymmetry. The proposed methodology and the corresponding phenomenology studies in the context of RPV SUSY searches were published in *[Phys.*

Rev. D 109, L011702] and in [*JHEP, App1:25*], respectively.

We also developed an anomaly detection algorithm to extend model-independent searches for rare heavy resonances by introducing a novel ML model, GAN-AE, which combines an auto-encoder architecture coupled with a discriminant network where the two networks are trained adversarially in a GAN-like setting. The proposed strategy was tested on a test dataset composed of a background sample containing QCD multi-jet events and a benchmark BSM signal model, and it was demonstrated that a hidden signal could be correctly identified with up to 3σ significance. The proposed methodology and algorithm were published [*App1:77,282*].

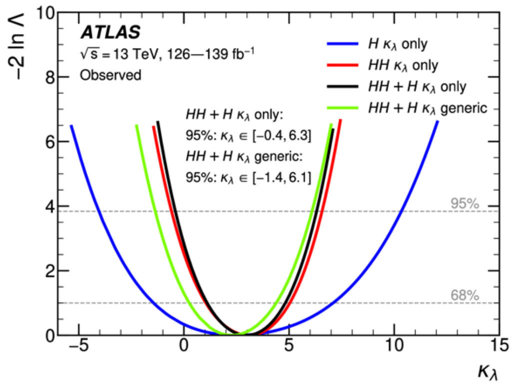


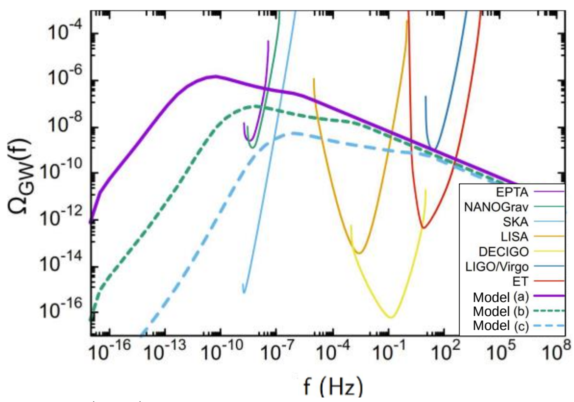
Fig. 12 Observed values of the test statistic (-2 lnΛ), as a function of the κ_λ parameter for the double-Higgs (red) and single-Higgs (blue) analyses, and their combination (black) derived from the combined single-Higgs and double-Higgs analyses, with all other coupling modifiers fixed to unity.

We conducted three kinds of ATLAS HH search using proton-proton collisions of 140 fb^{-1} in the LHC Run 2 period. We developed a fully data-driven estimation technique for the leading background QCD multi-jet events by introducing an artificial neural network. We also established the methodology to measure the self-coupling constant using the HH and single-Higgs processes and achieved the most stringent constraint on the Higgs self-coupling, λ, scaled to the Standard Model prediction and a less model-dependent interpretation. The results were published in [*Phys. Rev. D, App1:31*], [*ATLAS-CONF-2023-071*], and [*Phys. Lett. B, App1:28*], respectively (Fig.12).

[Theory Group]

Building on recent breakthroughs in quantum sensing and computing technology, QUP theorists invented new methods to detect new quantum fields that could comprise mysterious dark matter (DM) constituting ~85% of all matter in the Universe. An intriguing 2023 synergy work of QUP Director M. Hazumi and PI K. Nakayama, including affiliate Dr. S. Chigusa (UC Berkeley) as well as condensed matter experimentalists including affiliate Dr. N. Mizuochi (Kyoto U.), proposed using Nitrogen-Vacancy centers in diamonds as unique light sub-eV DM detectors [*arXiv:2302.12756*]. QUP experimentalists are now actively exploring concrete realizations of these ideas.

In complementary studies, a group at U. Tokyo led by QUP affiliate Dr. T. Moroi recently proposed using superconducting qubits [*Phys. Rev. Lett. App1:43*] as well as their quantum entanglement [*arXiv:2311.10413*] to look for light dark photon DM. Together with theorists at KEK Theory Center, QUP postdoc A. Ito proposed using ion trap techniques for axion DM detection [*JHEP 02, 124 (2024)*]. In 2020 Nakayama, Chigusa, Moroi proposed that magnon collective spin excitations in magnetic



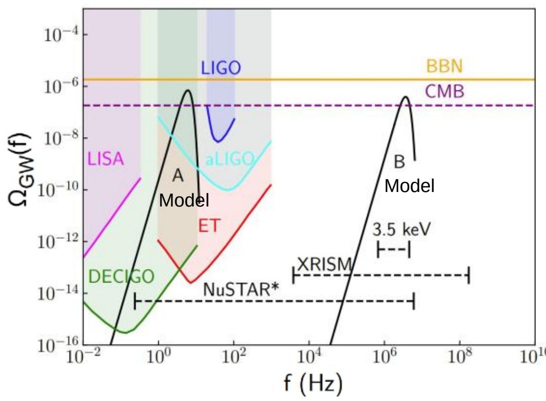


Fig. 13 (Left) Novel GW signatures from cosmic string scenario accompanying efficient production of very light (m << 1 eV) dark photon DM, for several benchmark models (a),(b),(c), from [*App1: 16*]. (Right) Novel coincidence GW and X-ray signatures from the scenario of decaying sterile neutrino DM produced by Hawking evaporation of early Universe black holes, shown for benchmark models A and B, from [*Phys. Lett. B 852 (2024) 138609*]. Sensitivities of existing and proposed experiments are also shown.

materials, including nuclear magnons, can be used as promising axion or dark photon DM detectors. Building on these results, a joint study of Nakayama, Ito, Chigusa and including QUP PI V. Takhistov showed that calculations of magnon excitation rates require significant modifications when the target material size is enlarged [*JHEP 01, 185 (2024)*].

How DM is produced cosmologically in the early Universe and with what parameters remains a major open research question. Only a few mechanisms for very light dark photon DM are known. Work led by PI Nakayama explored how dark photon DM can be efficiently produced from cosmic string topological defects, with observable gravitational wave (GW) signatures [*JHEP, App1:16*] (Fig. 13 left). Nakayama, with collaborators, constructed the first viable coherent oscillation scenario for dark photon DM [*JCAP, App1:17*].

PI Takhistov discovered novel potential manifestations of the immediate aftermath of the Big Bang [*Phys. Rev. Lett. App1:82*]. The study revealed that in various cosmological models, the fragmentation of the inflaton quantum field thought to drive rapid early Universe inflation expansion could lead to the new significant and observable production of gravitational waves (GWs). This offers complementary insights into the Universe's origins to other approaches like the detection of the CMB. The search for primordial GWs via the LiteBIRD space mission's polarized light observations of the CMB is a major project led by QUP.

PI Takhistov with an international team found that primordial black holes (PBHs) can uniquely probe unexplored dynamics of the fundamental quantum chromodynamics (QCD) strong force [*Phys. Rev. Lett. App1:20*]. The work suggests that PBH formation could indicate new QCD phase transitions at high temperatures in the early Universe, driven by new quantum fields. Such PBHs can contribute to DM, with hints possibly seen in astronomical surveys. Intriguingly, as shown by Takhistov and another international team [*Phys. Lett. B 852 (2024) 138609*] (Fig.13 right), Hawking evaporation of small PBHs can efficiently produce sterile neutrino DM. Novel X-ray signatures from sterile decays can be detected by the XRISM telescope, recently launched by JAXA and involving QUP members.

1-2. Generating Fused Disciplines

* Describe the content of measures taken by the center to advance research by fusing disciplines. For example, measures that facilitate doing joint research by researchers in differing fields. If any, describe the interdisciplinary research/fused discipline that have resulted from your efforts to generate fused disciplines. You may refer to the research results described concretely in "1-1. Advancing Research of the Highest Global Level."

[Systemology]

The Systemology Support Section (SSS) began its activities in earnest in FY2023 to support QUP projects with state-of-the-art, interdisciplinary systems engineering methods. That led to a new conceptual design of SpaceTES with an elaborate Faraday cage that shuts off the external electric field and an experimental concept for the QUP Kamioka Dark Matter Project.

(a) Success criteria of systemology: We have established the success criteria of systemology at QUP. See Sec. 5-2).

(b) Project support by SSS

(b-1) Systemology support of QUP-Kamioka-DM project: The objectives of the SSS concept study are to clarify QUP's research agenda and to establish realistic plans for QUP's research projects. The first phase of the support of the QUP-Kamioka-DM project was conducted from July 2023 to March 2024 using the Concurrent Research Design Facility (CRDF). We have completed the Concept Maturity Level 1 and 2 check list for the Phase 1 of the project. We show the science traceability matrix in Table 1 based on the checklist. This matrix shows the flow-down from the science goals to the instruments and data requirements. The SSS identified several technical, programmatic, and schedule risks of the project, e.g., problems in the energy-scale calibration, lack of a proper contact person to local industries, and delays in the fridge customizations. These results were reported to the QUP director and he started countermeasures for them.

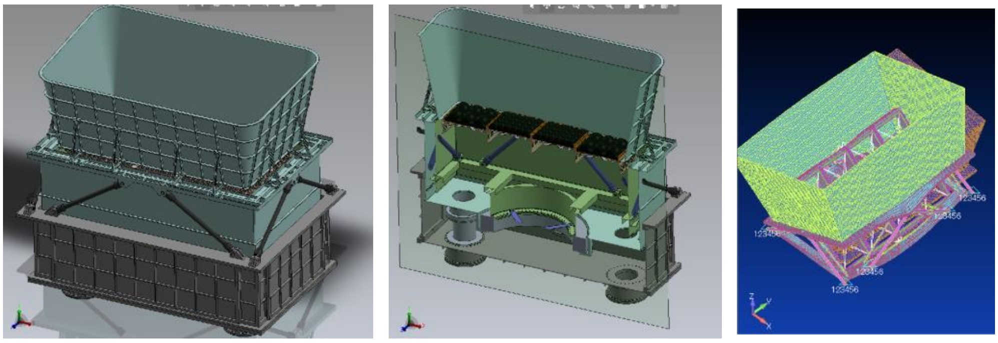
(b-2) Support of LiteBIRD SpaceTES

(b-2-1) Systems engineering support: SSS assisted preparing the Project Plan, Systems Engineering Management Plan, and Project Schedule.

(b-2-2) Multi-discipline engineering support: The thermal and mechanical design of the Focal Plane Unit were conducted (Fig. 14). We found two crucial problems in the design constructed by the University of California team; a large heat leak through the Faraday cage and buckling fractures of the 100 mK and 350 mK mechanical support structures. The SSS proposed new ideas to mitigate the problems and studied new NbTi films and new launch-lock mechanisms.

Science goals	Science objectives	Investigations		Instruments		Science data requirements
		Physical parameters	Observables	Design parameters	Requirements	
To understand what the dark matter is.	Step-1: To constrain the scattering cross-section of dark matter particles with nucleons down to 10^{-37} cm^2 when the dark matter particle mass is in the range from 300 MeV (100 MeV goal) to 600 MeV. If the dark matter particle is in this mass range and has a nucleon cross-section larger than the threshold, the dark matter particle will be detected.	Dark matter mass range to search	Amplitude of signal deposition by dark matter scattering with nucleons	1. Target nucleon 2. Detection threshold of energy deposition	1. ^{4}He (superfluid) 2. 40 eV (requirement), 10 eV (goal); Present value is 40 eV He atoms jump out from the surface of superfluid 4He by quantum evaporation excited by phonons/rotons after the deposition of energy to a 4He nucleon by a dark matter particle are detected with a quasiparticle-trap-assisted electrothermal feedback transition-edge sensors (QET). Superfluid He and QET are cooled down to 40 mK.	**Science data:** The data we obtain with this experiment is a counting histogram as a function of deposited energy, i.e. the energy spectrum of the deposited energy. If statistically significant events above the background are detected, we can estimate the mass of the incident particle, i.e. the dark matter particle, and its scattering cross-section with ^{4}He nucleon. If a significant number of events are not observed, the scattering cross section can be constrained as a function of the dark matter particle mass.
		Coupling strength of dark matter - nucleon scattering	Energy-deposition event rate of the target material in an energy range related to the assumed dark matter mass.	1. Background event rate 2. Target mass times data-taking duration	2. 10 counts/day/kg/keV Geant-4 simulation shows that this background rate is achievable when the instrument is operated in Kamioka with low radioactive shielding. 3. 1 g year	**Calibration data:** Calibration data are taken by turning on a TBD calibration source at a TBD rate. How frequently we take calibration data depends on the stability of the detector. **Data size:** 8channel x 1-3MHz x 16bit = 1.3-4TB/day
	Step-2 TBD					

Table 1. Science Traceability Matrix of QUP-Kamoka-DM project phase 1 (step 1) constructed by the SSS support.



(a) 3D-CAD outer view of LFT-FPU (Low-Frequency Telescope Focal-Plane Unit) designed by QUP SSS based on the initial concept by UCB.

(b) Cut-away view of LFT-FPU. We can see lenslets in front of detectors (black half spheres) and the Faraday cage structure.

(c) Example of the FEM (finite element method) analysis of the LFT-FPU vibration. In this analysis, outer shells except for the front hood are not included.

Fig. 14 Example figures of SpaceTES LFT FPU designed by SSS.

(c) Systemology study project: SSS's project support supports individual research projects, while the systemology study project conducts new studies combining activities in two or more research clusters in QUP. Presently, two studies are ongoing: (1) the development of MBSE (Model-Based Systems Engineering) and MBD (Model-Based Development) tools, which provide a better interface between the rad-hard detector and data-acquisition ASIC designs, and (2) the study of possible improvement teamwork structures in QUP. These studies are carried out under a contract with TOYOTA MOTOR CORPORATION.

[QUP Synergy Summit (QSS)]

The QUP Synergy Summit, a new pivotal platform for industry-academia collaboration, was launched in FY23. This unique initiative fosters a symbiotic relationship where the industry presents real-world problems and aims to solve them with KEK technology, a form of "deep tech" rooted in fundamental laws. The reverse pattern, where KEK's challenges are addressed with the industry's technology, is also under consideration, further enhancing the collaborative spirit of the QUP framework. The secretariat was set up at the QUP satellite at Toyota Central R&D Labs. The first theme was the soft error problem caused by cosmic rays.

[Systematic studies for new measurement principles]
In FY23, we published a few theoretical ideas to search for new quantum fields [*App1:1,14-17,20-24,43,79,82*]. To go one step further to conduct systematic studies to invent new measurement principles, the director formed a team of researchers from particle theory, astrophysical experiments, information science, nanotechnology/materials/applied physics, and measurement science.

[Connecting the QUP research clusters]
ML is a tool for connecting research clusters. For example, the SpaceTES team is exploring the possibility of using QUP's anomaly detection tool, which was developed for inspecting silicon pixel detectors for ATLAS. A researcher in the SpaceTES team (QUP Senior Scientist, Tijmen de Haan) has been developing a natural language assistant for cosmology using the GPU cluster. The methodology also applies to particle physics and systems engineering.

DAQ is another place of inter-research-cluster connections. Examples include a series of developments of readout electronics by QUP PI M. Miyahara, such as the development of design automation tools for analog ASICs in collaboration with the SSS. For the readout ASIC of the rad-hard sensor, Miyahara provided a pixel-type readout ASIC (Fig. 15) that will be directly deposited on CIGS for application to heavy ion detectors, which is a new concept. This ASIC has an ADC built into every 64-channel pixel, which will help investigate the electrical characteristics of CIGS.

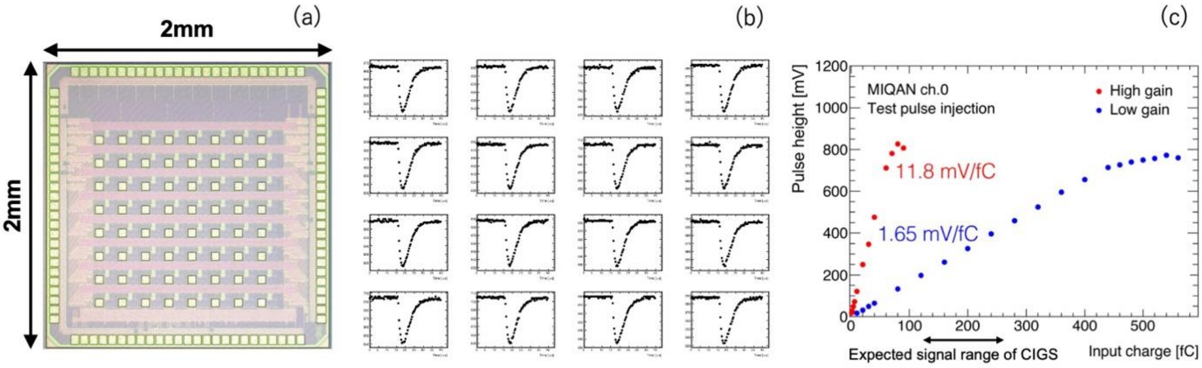


Fig. 15 (a) A prototype of pixel readout ASIC for the CIGS detector development in the rad-hard cluster (64ch/4mm^2). (b) Measured ADC waveforms of multiple channels by test pulse injection. Signal waveforms of all channels can be readout simultaneously. (c) Measured linearity of readout circuit. The linearity is maintained up to 400 fC, which can cover the expected signal range (180 fC) of CIGS.

[Community engagements concerning ML applications]
We are also active in engagements of our research in particle physics and cosmology to promote state-of-the-art ML technologies and applications. In 2023, we initiated a new series of international workshops, named “ML at High Energy Physics”. We successfully held the second annual "ML at HEP workshop" on 2024, January 9th-10th at KEK with over 110 participants from high energy physics and astrophysics. The workshop highlighted recent progresses in state-of-the-art ML applications to high energy physics and astrophysics through several talks by world-leading researchers. It also overviewed the related research progressing in Japan through 20 contribution talks by early-career researchers. We launched a new research consortium, “AI-Smart,” based on the JSPS core-to-core program for 2023-2028, with QUP as a host institute. The consortium aims to accelerate the implementation of AI technology and the development of "smart" research through international researcher exchanges and the training of young researchers. While most of the management members are QUP PIs (Nakahama, Taniguchi, Togawa) and a Senior Scientist (Chinone), the consortium defined four application targets in particle physics and cosmology experiments such as ATLAS, Belle II, and CMB experiments, namely, “physics analysis”, “accelerator control”, “detector development”, and “trigger and data acquisition”. The consortium has four partner countries: the United States, the United Kingdom, Switzerland, and Germany. The collaboration size has been extended to 60 members from Japan and 50 from abroad. The consortium hosted two events and supported one event focused on ML technologies for a breadth of purposes and targets as follows.

- "AI-Smart" kick-off workshop on 2023 September 25-26 at KEK, with 50 participants from in particle-collider experiments:
- "AI-Smart" school about "ML on FPGA" on 2024 February 28th to March 1st at the Kumamoto University Semiconductor and Digital Research and Education Organization, with 35 participants from various experiments on particle and nuclear physics (Fig. 16).
- The "ML application" session was part of the ATLAS Higgs workshop at the University of Tokyo in October 2023 with 120 participants.

Fig. 16 AI-Smart school group photo (Left), practical training (Middle), and a clean room tour (Right).

2. Global Research Environment and System Reform

2-1. Realizing an International Research Environment

* Describe what's been accomplished in the efforts to raise the center's recognition as a genuine globally visible research institute, along with innovative efforts proactively being taken in accordance with the development stage of the center, including the following points, for example:
- Efforts being developed based on the analysis of number and state of world-leading, frontline researchers (in Appendix 2); exchanges with overseas entities (in Appendix 4); number and state of visiting researchers (in Appendix 5)
- Proactive efforts to raise the level of the center's international recognition and to obtain diversity within the center including gender balance.
- Efforts to make the center into one that attracts excellent young researchers from around the world (such as efforts fostering young researchers and contributing to advancing their career paths)

The second QUP symposium, named QUPosium2023, was held on 11-13, Dec. 2023 at Tsukuba International Congress Center (Fig. 17). We invited 31 distinguished speakers, a Nobel-prize laureate Prof. Adam Riess (Johns Hopkins Univ.) and those from top-level institutions including Caltech, Fermilab, MIT, Oxford, Lawrence Berkeley National Lab and UCLA. 118 participants attended, and lively discussions were made. Nineteen early career researchers contributed to a poster session held at lunchtime.

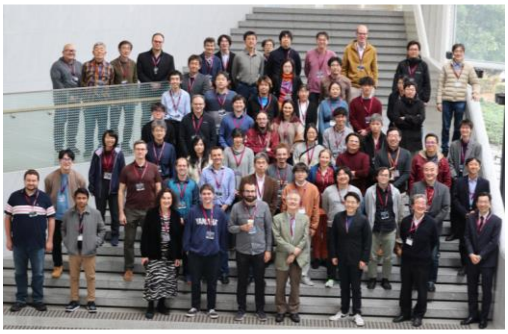


Fig. 17 Group photo of QUPosium2023.

A series of QUP seminars started in April 2022 and was held almost monthly. In total, 12 seminars were held in FY23 at KEK, accepting remote participants. The seminars were widely announced to the communities, and about 40 people joined each seminar on average.

Diversity is crucial to QUP, as clearly stated in its code of conduct. QUP has 14 PIs, five females and four non-Japanese. The fraction of foreign researchers at QUP increased steadily and reached 34% in 2023 (Fig. 18). The female fraction is 17%, which is twice as large as the KEK average (8%).

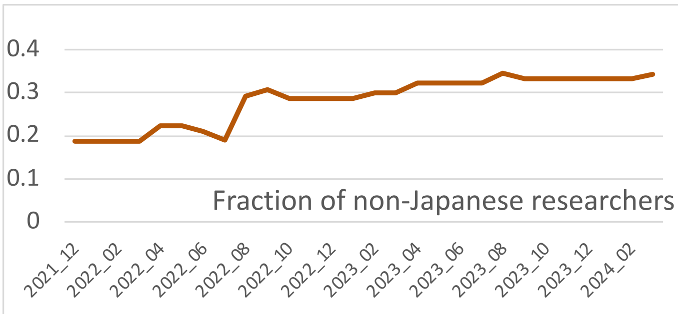


Fig. 18 QUP evolution of the fraction of foreign researchers.

After the COVID-19 restrictions were lifted, the director visited Univ. of Ferrara (Italy), the Polish Copernicus Academy (Poland), Tsinghua Univ. (China), T.D.Lee Institute (China), and Institute of High Energy Physics

(China) in 2023, contributing to QUP's recruitment and QUPIP's advertisement. As the world community is more recognizing QUP, we have received contacts from ARC Center of Excellence for Dark Matter Particle Physics (Australia) and National Research Council (Canada), and had online mini-workshop for each to discuss possible collaboration.

[QUP Internship Program (QUPIP)]
We have established a QUP internship program named QUPIP in FY23 that allows postdocs and students to stay at QUP institutes for 1-3 months and work with QUP's senior scientists. In FY23, 20 young researchers from top-level research institutions, including Harvard Univ., UC Berkeley, Ecole Normale Supérieure, Paris, Seoul NU., stayed with QUPIP, of which 70% came from abroad (Fig. 19). The program achieved the target number of interns. A visiting theory postdoc submitted a paper with the QUP supervisor during the stay. Some researchers continued to apply for FY24. One postdoc visited QUP again at their own expense. The program has also helped QUP's recruitment. One QUPIP applied for a position in the SSS of QUP after the experience and was hired starting in May 2024. Based on this achievement, QUPIP will accept interns for more than three months from FY24, and is working to provide generous support through employment rather than just a stipend for their stay.

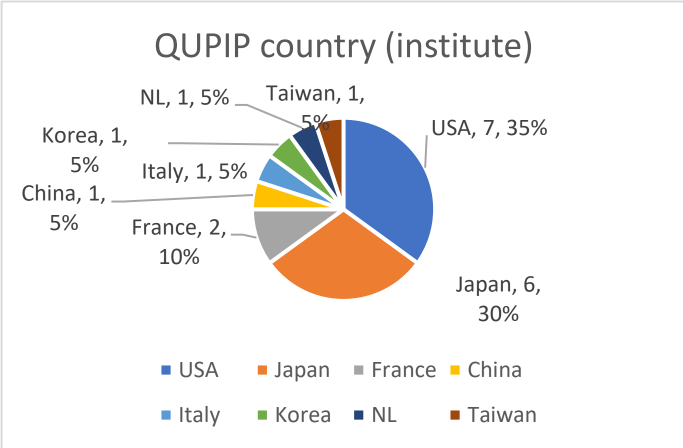


Fig. 19 QUPIP demography.

2-2. Making Organizational Reforms

* Describe the system reforms made to the center's research operation and administrative organization, along with their background and results.
* If innovated system reforms generated by the center have had a ripple effect on other departments of the host institutions or on other research institutions, clearly describe in what ways.
* Describe the center's operation and the host institution's commitment to the system reforms.

Unique recruitment/salary scheme: QUP's recruitment scheme enables quick decisions in the recruitment process. The QUP director negotiates with the individuals to determine their salary. The scheme is a significant factor that makes the QUP competitive with the world's top institutes in attracting excellent researchers. In FY23, we have set up a rule to update the annual salary with the evaluation, including one-on-one interviews with the QUP director, giving an incentive to the fixed-term researchers. The conditions of the fixed-term researchers at KEK are lower than those of the permanent researchers, but QUP is trying to close the gaps. The position of Principal Engineer was created at the end of FY22. It improves technical staff's labor conditions and helps attract excellent engineers to QUP. We hired the first Principal Engineer in May 2023.
Reform on the KEK rules on accepting graduate students: To further develop the QUPIP above, we are considering supporting graduate students by accepting and employing them long-term. Under the current KEK regulations, only domestic graduate students are accepted under the special researcher system, but the QUP has established bylaws to allow acceptance from overseas as well. In addition, since the hourly wage for students' employment is meager under the current KEK regulations and cannot be an attractive program, we are working with KEK to revise these regulations. If realized, the QUP will provide another example of reforming KEK's regulations**.**
KEK and QUP's operation: The new KEK director general, Dr. Shoji Asai, arrived on April 1, 2024. Dr. Kazunori Hanagaki became an executive director of KEK and resigned as the deputy director of QUP. We hired Dr. Kazuhisa Mitsuda as the new deputy director. He also serves as the leader of the SSS until we hire a new leader. Since its establishment on Dec. 16, 2021, QUP has been conducting research with 13 PIs. Following a suggestion by the WPI program committee, we searched for a new PI and hired Dr. Volodymyr Takhistov as the 14th PI on April 1, 2024. His role is to promote theoretical research and stimulate collaboration among QUP's research clusters. We completed hiring three deputy PIs, all non-Japanese, stationed at KEK to support three foreign PIs.

3. Values for the Future

3-1. Creating and Disseminating the Societal Value of Basic Research

* Describe the content of measures taken by the center to widely disseminate the results of its basic research to the general public.
* Describe what was accomplished in the center's outreach and other activities last year and how they have contributed to creating the Societal Value of Basic Research. In Appendix 6, describe concretely the contents of these outreach activities. In Appendix 7, describe media reports or coverage, if any, of the activities.

QUP focuses on disseminating information through public lectures, video presentations, and social media such as "X". While outreach activities should communicate QUP's ongoing research to the broad general public, they should also be targeted in each individual event.

Fig. 20 Science in Japan Forum in Washington DC.

Public lectures: The 26th "Science in Japan", sponsored by the Washington office of the Japan Society for the Promotion of Science, was held in June in Washington, DC (Fig. 20). The theme was "Quantum Taste of the Universe", with the full cooperation of QUP. The event provided an opportunity to introduce QUP's research to science attaches from around the world in Washington, D.C., as well as local researchers from universities and companies.

In March 2024, QUP organized a public lecture for high school students, "Making Tools to Look into the Universe!" in Tsukuba, attracting a young audience of about 100 participants, including 28 high school students. At the end of the event, we had tea time, when the participants had a chance to communicate directly with the Japanese and non-Japanese QUP researchers to learn about the various paths to becoming a researcher. It was a good opportunity for high school students to consider their future career paths. We will regularly hold this interactive type of public lecture in the future. The QUP researchers also gave various public talks at the culture centers and high schools. Junior high school students visited KEK/QUP and QUP researchers showed the labs and had an active Q&A time with them.

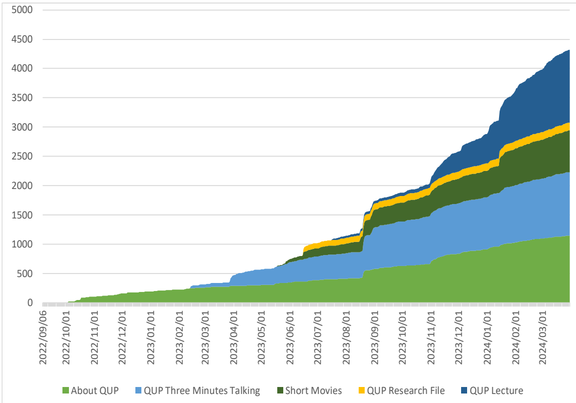


Fig. 21 Top: Accumulated QUP YouTube accesses.

Social Media: On social media X, we have been tweeting a variety of topics, from QUP's scientific results to everyday life. We have posted 106 topics in Japanese and 75 in English. Posting is in both languages, but Japanese is more prevalent due to the announcement of Japanese-language events. As shown in Fig. 19, the number of views has more than tripled from 2022, and the number of regular viewers has also increased.

QUP video: Two programs on QUP's research were broadcast on cable TV in Tsukuba, Japan, in FY23. QUP produces original videos with various audiences in mind. The "QUP three-minute talking" program, launched last year, is a high school-level program that introduces the research and personalities of QUP researchers. Four videos were distributed on YouTube in FY23. The videos are in Japanese, but we plan to introduce foreign researchers in English in FY24. Targeting undergraduate and graduate school students, we are producing the QUP Lecture Series. Currently, PI Iizuka is giving seven lectures on the Casimir effect. QUP also showed several videos related to explain the QUP's research deeper. The total number of views of QUP YouTube channels increased 10 times than FY22 (Fig. 21).

3-2. Human Resource Building: Higher Education and Career Development

* Describe the content of measures taken by the center to foster young researchers, including doctoral students, through their participation in a research system that creates new interdisciplinary domains within a rich international environment.

As discussed in Sec. 2-1, we have established the QUPIP program for accepting postdoctoral and graduate students. These early career scientists can stay for 1-3 months with the QUP researchers at the QUP main site at KEK, the Berkeley satellite, or the locations of QUP PIs such as Oxford and LBNL. In FY23, 20 QUPIP fellows stayed at QUP, including 8 PhD students and 5 master students. Seven students came from abroad. One Japanese PhD student visited the Berkeley satellite for 2 months. As discussed in Sec. 2-2, we have made an agreement with KEK that enables the QUP researchers to supervise the visiting domestic and foreign graduate students. One master's student from a Japanese university will come in April 2024. Based on an MOU held with SOKENDAI, most of the QUP's senior scientists have been affiliated with the graduate school since September 2023.

3-3. Self-sufficient and Sustainable Center Development

* Describe the state of implementation of the host institution's mid-to-long term measures for supporting the center toward becoming self-sufficient and sustainable after the 10-year funding period ends, such as reforming the host institution's organization, providing personnel with priority allocation of tenured posts to the center, providing fundamental financial support, and material support including land and buildings.

Fig. 22 Plan of QUP's new research building complex.

QUP and KEK continue extensive discussions on the support plans for making QUP a sustainable institute beyond the WPI funding period. QUP and KEK agreed to cooperate in creating a concrete financial plan for the permanent establishment of QUP. An estimated personnel costs of 400 million yen would be required to maintain current activities after the 10th year. This will require QUP to aggressively seek external funding of about 200 million yen for the programs it promotes, while KEK promises to cover at least 200 million yen. Following this discussion, the QUP acknowledged this support by updating the Research Center Project document submitted at the beginning of the project. By renovating the old KEK facilities, KEK offers a new research building complex for QUP (Fig. 22). The design work was completed in FY22, and the construction started. The new building will be completed by the end of FY24.

4. Others

* In addition to the above 1-3 points, if there is anything else that deserves mention regarding the center project's progress, please note it.

5. Center's Response to Results of Last Year's Follow-up

* Transcribe the item from the "Actions required and recommendations" section in the site visit report and the Follow-up report, then note how the center has responded to them.
* If you have already provided this information, indicate where in the report.

1) **There is very urgent need to establish a clear and credible research agenda that is coherent and systematic for achieving QUP's scientific vision, namely, to develop novel measurement principles for particle physics and cosmology with longer term societal impacts.**
   The SpaceTES for the LiteBIRD Project is more into the engineering phase than the basic research phase suited to WPI. To the extent that this project is to be pursued by QUP, it requires a clear internal and external interface definition, definitive plan for AIV (Assembly, Integration, Verification) with quality assurance and system engineering, and the necessary team staffing to deliver the flight TES system to JAXA. The funding to build the TES flight system must be clarified with KEK, JAXA and MEXT.
   The QUP-Kamioka-DM Project should develop a concrete plan for building the proposed facility at Kamioka and establish a strategy with a realistic plan and timeline for actual payloads (especially phase 2 and "plan B" for phase 2) to detect light dark matter. The novelty and superiority of this project among the multitude of DM projects has to be established.
   In addition to SpaceTES and QUP-Kamioka-DM, serious consideration has to be given to the PI-led projects including the Casimir force, rad-hard and collider physics projects to ensure their strength and coherency with QUP's objectives.

Our research agenda is shown on p.3 (Sec. 1-1), where we explain our cohesive, coherent and effective program to deliver QUP's scientific vision. Following the suggestion by the WPI committee and working group seriously, the director and PIs have discussed the objectives of the projects in our research agenda and visualized all milestones. The director and the deputy director maintain tighter communications with these PI-led projects through regular research cluster convenors' meetings and direct communications. The director has set the procedure for each project to become a flagship project through supports and evaluations by the SSS.

We have defined the scope of QUP's contribution to LiteBIRD, which we call SpaceTES. It corresponds to one of the goals of the center "to lead the world in the grand challenges of cosmology and particle physics by developing and implementing new quantum field measurement systems in international projects such as the LiteBIRD satellite project and collider experiments", as written in QUP's Research Center Project submitted at the beginning of the project. The SpaceTES project provides JAXA with LFT-FPU and related accessories and providing CNES (the French space

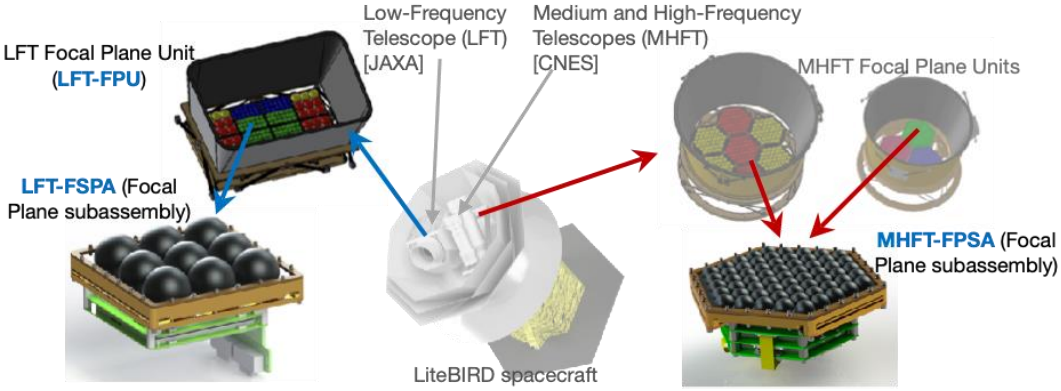


Fig. 23 QUP's contributions to LiteBIRD (a.k.a SpaceTES.)

organization) with MHFT-FPSAs (Fig. 23). The LFT-FPU can be divided into two parts: the LFT-FPSAs (see also Fig.5 in Sec. 1-1) and the mechanical and thermal structure of the LFT-FPU that supports the LFT-FPSAs from the 5K interface (see also Fig. 14 in Sec. 1-2). The LFT-FPSAs are mainly developed by the QUP Berkeley satellite, while the mechanical and thermal structure will be developed by a Japanese industry under the contract and control of QUP KEK. The external interface requirements of LFT-FPU with LFT were delivered from JAXA to QUP as the Interface Requirement Document. The internal interface specifications of LFT-FPSAs are described in the description document of the LFT-FPSAs. QUP contacted a company that supported JAXA's S&MA (System Safety and Mission Assurance) to ask for recommendations for QUP's MA, particularly on the quality control. In addition to the support by SSL of UCB, NASA agreed to form a team to support systems engineering and S&MA of the US activities. We already started talking with them. For the MHFT-FPSAs, the plan is not as concrete as that for the LFT-FPU. We have not received the interface requirements from CNES yet. As for the funding, we recognize that the funding is not secure yet, and that fallback plans must be developed.

The scientific goals and objectives of the QUP-Kamioka-DM project were clarified. We have confirmed that phase 1 can search for an unexplored region in the coupling and mass parameter space (Sec. 1-1). Phase 2 is expected to reach an unexplored region, although the background estimation has not been completed. The risks of the project plan were identified (see also the response to A/I 2 (Systemology) in Sec. 5). The QUP-Kamioka-DM team and the director are working hard to detect critical issues and build mitigation plans.

2) **The concept of systemology is not coming together. QUP should design much more concretely the application and extension of system engineering (aka systemology) to its research projects with fusion among disciplines in mind. QUP should also establish success criteria for the systemology section to gauge its effectiveness.**

One of QUP's goals is to establish quantum-field measurement systemology. We define it as the organized body of knowledge for practitioners developing quantum-field measurement instruments as a system by combining multiple technologies, rather than just developing individual technologies. While our methodologies themselves are advanced systems engineering, at QUP, we apply them to more infant and emerging research activities. Systems engineering methods help identify the science agenda in which the goals, objectives, and instrumentations are clearly connected. They are also helpful in identifying the risks and critical items of our research project plans. Under the auspices of the systemology support section (SSS), the QUP aims to advance research projects in this manner (Sec. 1-2). Thus, the success criteria of systemology consist of two parts. The first one is for the SSS.

Success criteria of systemology for SSS:

1. The SSS shall support concept studies of a plural number of research project candidates using the CRDF and ensure that at least one research project candidate reaches the exit level of the CRDF by the end of FY24.
2. The SSS should guide the concept study of the project candidates so that they can satisfy the QUP's goal, to invent new principles and measurement systems to search for theoretically predicted novel quantum fields and to propose and promote new projects based on new quantum field measurement systems, by the outcome of the research projects.

As the final goal, QUP members shall conduct their research in the systems engineering approach without the SSS support. Thus, the second part of the success criteria are for the entire QUP.

Success criteria of systemology for QUP:

1. To ensure a status in which most members of QUP understand the approach and methodology of systems engineering and utilize this knowledge to invent, propose/promote, and/or develop new quantum field measurements successfully.
2. (Extra success) To ensure a status in which the systems engineering approach and methodology are known in KEK, and the members have started utilizing them for their research and engineering.

3) Very strong efforts should be made by QUP's leadership to recruit foreign researchers and integrate them into QUP's activity. This includes additional foreign PIs residing on site and junior researchers including postdocs and graduate students. QUP should aim at levels higher than the WPI numerical target. Assuring the quality of personnel and promoting their long-term residence at QUP in Japan is also essential. To achieve this, QUP should examine what attractive features it can provide to foreign researchers.

We made strong effort in recruitment since September 2023. As of March 31, 2024, there are 35 researchers, as shown in Appendix 3-1a. Six more researchers have been appointed to arrive in early FY24, expecting to hit the target regarding the budget for personnel. We have a new foreign PI in particle theory, Volodymyr Takhistov, residing on-site. We continue our effort in FY24 to have another foreign PI on the experimental side. To establish attractive features for foreign researchers, we are receiving feedback from QUP researchers and improving our system.

4) QUP Internship Program (QUPIP) requires much more ideas and effort for it to exert a change in KEK's education system. The program should be made more attractive and better known to young researchers worldwide, along with having a relevant financial support scheme. QUP should dispatch young (Japanese) researchers to its Berkeley Satellite for extended periods to foster researchers with international perspectives, as stated in its proposal.

As noted in Sec. 2, the QUPIP program is working very well in FY23, achieving the target number of interns. On the other hand, as pointed out, a long-term educational program is needed, and we are working with KEK to develop the terms of reference to achieve extension of QUPIP's stay (more than three months is now possible), and to realize long-term stays under KEK's special researcher program and employment as a research assistant. Appendix 4-2 shows that the number of visitors to the Berkeley satellite increased from 6 in FY22 to 18 in FY23, including a QUP intern from a Japanese graduate school who stayed for two months. In the future, more young researchers will be sent to the satellite by synchronizing with the sensor development of the SpaceTES project.

5) QUP should make stronger, more persistent outreach efforts to promote public awareness of its societal value. Collaboration with diverse companies will be effective in disseminating the value of basic research to society.

As described in Sec. 3-1, our outreach activities in FY23 have increased significantly than FY22, including the public lectures in Japan and the US. We regularly updated QUP's various activities on

X and YouTube, resulting in a large increase in viewers. We are updating the web content and creating a new brochure to explain QUP's activities more clearly.

We have a strong connection with Toyota Central R&D Lab. Inc., but QUP is cooperating with various companies. For example, joint research projects are being conducted with other companies in the areas of SpaceTES and radiation-hard devices. As pointed out by the committee, we will keep relations with diverse companies to disseminate the value of basic research to society.

6) KEK Director-General should make KEK's support plan into an official statement so as to guarantee its execution of QUP's operation after WPI funding ends.

After discussion with PD/PO, we have updated the document "Research Center Project", including the KEK's support plan, as follows: "Following the strong recommendation from the program committee after the startup of the QUP, QUP and KEK extensively discussed support plans for making QUP a sustainable institute beyond the WPI funding period. KEK recognizes that the QUP is a key institute for KEK to explore a new direction for future research through the revolution of measurement science. In 2023, KEK agreed to cooperate in creating a concrete financial plan for the permanent establishment of QUP. We estimate that we need 400 million yen to maintain the proposed level of activities after the 10th year. Requesting QUP to aggressively seek external funding of about 200 million yen for the programs it promotes, KEK promises to cover the remaining 200 million yen to establish the permanent institute in KEK".

7) The new building to be built by 2025 should have enough space to truly house all PIs and researchers under-one-roof. It should have an attractive design, one that realizes the kind of open and international environment envisioned by WPI.

The plan for the new QUP building complex was made under government restrictions on renovation and refurbishment and the recent rise in construction costs. Nonetheless, we secured the office space (856 m^2) that would allow all PIs and researchers to gather under one roof, and large laboratories. The total area is 3,265 m^2. Specific features of the new building complex include: a large low-noise environment laboratory for advancing QUP's projects; a large anechoic chamber.; large offices for enhancing research exchange. To make the building attractive, we are setting up a new building committee inviting QUP researchers to discuss the best use of the new building and its preparatory fund we received from MEXT separately from the WPI grant.

8) As a WPI center, QUP is expected to develop a clear and unique identity, which is not an extension of KEK, in both its science, as a research organization, and its education. QUP and KEK should make clear and concrete statements on their views regarding this matter.

The new KEK directorate seriously acknowledges the recommendations from the WPI program committee and has started taking an action. The new KEK directorate will conduct a thorough review to ensure that QUP's research agenda aligns with the recommendations, and present a new proposal during the site visit in August 2024.

The heterogeneous presence of QUP at KEK as the Inter-University Research Institute Corporation provides a rationale for KEK to broaden its research and education beyond accelerator science.

As for research, the impacts of having QUP to KEK are two-fold as follows:

1) The QUP will enable KEK to reform its organization and introduce the new quantum frontier for particle physics and cosmology as the third research axis in addition to accelerator-based energy frontier and luminosity frontier.

2) We plan to introduce systems engineering strongly across KEK to have sufficient early studies for mitigating risks at later stages of the project. We will also change our recruitment system to hire highly skilled engineers. These are new initiatives at KEK and, thus, are the unique identity of QUP.

Regarding education, KEK already operates several good systems, including The Graduate University for Advanced Studies (SOKENDAI). However, KEK needs more organized student intake, dispatch to and from abroad, and financial support commensurate with international standards. QUP is preparing a new system for students' acceptance and dispatch in collaboration with foreign universities with adequate financial support schemes (e.g., special research assistant schemes allowing support at the international standard level.) The new system will allow resourced faculty members to accept and supervise graduate students on good terms, domestically and internationally. That will attract excellent graduate students to KEK and positively impact all researchers at KEK.

Appendix 1 FY 2023 List of Center's Research Results and Main Awards

1. Refereed Papers

- List only the Center's papers published in 2023. (Note: The list should be for the calendar year, not the fiscal year.)

(1) Divide the papers into two categories, A and B.

A. WPI papers

List papers whose author(s) can be identified as affiliated with the WPI program (e.g., that state "WPI" and the name of the WPI center (WPI-center name)). (Not including papers in which the names of persons affiliated with the WPI program are contained only in acknowledgements.)

B. WPI-related papers

List papers related to the WPI program but whose authors are not noted in the institutional affiliations as WPI affiliated. (Including papers whose acknowledgements contain the names of researchers affiliated with the WPI program.)

Note: On 14 December 2011, the Basic Research Promotion Division (the Basic and Generic Research Division at present) in MEXT's Research Promotion Bureau circulated an instruction requiring paper authors to include the name or abbreviation of their WPI center among their institutional affiliations. From 2012, the authors' affiliations must be clearly noted.

(2) Method of listing paper

- List only refereed papers. Divide them into categories (e.g., original articles, reviews, proceedings).
- For each, write the author name(s); year of publication; journal name, volume, page(s) (or DOI number), and article title. Any listing order may be used as long as format is consistent. (The names of the center researchers do not need to be underlined.)
- If a paper has many authors (say, more than 10), all of their names do not need to be listed.
- Assign a serial number to each paper to be used to identify it throughout the report.
- If the papers are written in languages other than English, underline their serial numbers.
- Order of Listing

A. WPI papers

1. Original articles
2. Review articles
3. Proceedings
4. Other English articles

B. WPI-related papers

1. Original articles
2. Review articles
3. Proceedings
4. Other English articles

(3) Submission of electronic data

- In addition to the above, provide a .csv file output from the Web of Science (e.g.) or other database giving the paper's raw data including Document ID. (Note: the Document ID is assigned by paper database.)
- The papers should be divided into A or B categories on separate sheets, not divided by paper categories.

(4) Use in assessments

- The lists of papers will be used in assessing the state of WPI project's progress.
- They will be used as reference in analyzing the trends and whole states of research in the said WPI center, not to evaluate individual researcher performance.
- The special characteristics of each research domain will be considered when conducting assessments.

(5) Additional documents

- After all documents, including these paper listings, showing the state of research progress have been submitted, additional documents may be requested.

A. WPI papers

1. Original Articles

[1] Y. Ema, M. Hazumi, H. Iizuka, K. Mukaida and K. Nakayama "Zero Casimir force in axion electrodynamics and the search for a new force" Physical Review D 108 (2023) 016009 DOI:10.1103/PhysRevD.108.016009

[2] Y. Mitsuya, T. Konno, S. Takasu, K. Hattori, M. Ohno, D. Fukuda and H. Takahashi "Photon Number Resolution with an Iridium Optical Transition Edge Sensor at a Telecommunication Wavelength" Journal of Low Temperature Physics 210 (2023) 498-505 DOI:10.1007/s10909-022-02928-0

[3] T. Ghigna et al. "Modeling TES Nonlinearity Induced by a Rotating HWP in a CMB Polarimeter" Journal of Low Temperature Physics 211 (2023) 357-365

DOI:10.1007/s10909-023-02939-5

[4] T. Fujino et al. "Characterization of a half-wave plate for cosmic microwave background circular polarization measurement with POLARBEAR" Review of Scientific Instruments 94 (2023) 064502 DOI:10.1063/5.0140088

[5] U. Fuskeland et al. "Tensor-to-scalar ratio forecasts for extended LiteBIRD frequency configurations" Astronomy and Astrophysics 676 (2023) A42 DOI:10.1051/0004-6361/202346155

[6] S. Adachi et al. (POLARBEAR collaboration) "Constraints on axionlike polarization oscillations in the cosmic microwave background with POLARBEAR" Physical Review D 108 (2023) 043017 DOI:10.1103/PhysRevD.108.043017

[7] Y. Inoue, M. Hasegawa, M. Hazumi, S. Takada, and T. Tomaru "Development of an epoxy-based millimeter absorber with expanded polystyrenes and carbon black for an astronomical telescope" Applied Optics 62 (2023) 1419-1427 DOI:10.1364/AO.480162

[8] S. Arai et al. "Cosmological gravity probes: Connecting recent theoretical developments to forthcoming observations" Progress of Theoretical and Experimental Physics (2023) 072E01 DOI:10.1093/ptep/ptad052

[9] T. Murokoshi, Y. Chinone, M. Nashimoto. K. Ichiki and M. Hattori "Mitigating Cosmic Microwave Background Shadow Degradation of Tensor-to-scalar Ratio Measurements through Map-based Studies" Astrophysical Journal Letters 949 (2023) L29 DOI:10.3847/2041-8213/acd37d

[10] H. Okumura et al. "Degradation of vertical GaN diodes during proton and xenon-ion irradiation" Japanese Journal of Applied Physics 62 (2023) 064001 DOI:10.35848/1347-4065/acddb4

[11] J. Nishinaga et al. "Annealing effects on Cu(In,Ga)Se2solar cells irradiated by high-fluence proton beam" Japanese Journal of Applied Physics 62 (2023) SK1014 DOI:10.35848/1347-4065/acc53b

[12] M. Miyahara, X. U. Zule, T, Ishii and N. Kimura "A Quick Startup Low-Power Hybrid Crystal Oscillator for IoT Applications" IEICE Transactions on Electronics E106.C (2023) 521-528 DOI:10.1587/transele.2022CTP0002

[13] Y. Yagi et al. "Fabrication of a 64-Pixel TES Microcalorimeter Array With Iron Absorbers Uniquely Designed for 14.4-keV Solar Axion Search" IEEE Transactions on Applied Superconductivity 33 (2023) 2100805 DOI:10.1109/TASC.2023.3254488

[14] S. Chigusa, T. Moroi, K. Nakayama, and T. Sichanugrist "Dark matter detection using nuclear magnetization in magnet with hyperfine interaction" Physical Review D 108 (2023) 095007 DOI:10.1103/PhysRevD.108.095007

[15] N. Kitajima and K. Nakayama "Nanohertz gravitational waves from cosmic strings and dark photon dark matter" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 846 (2023) 138213 DOI:10.1016/j.physletb.2023.138213

[16] N. Kitajima and K. Nakayama "Dark photon dark matter from cosmic strings and gravitational wave background" Journal of High Energy Physics (2023) 68 DOI:10.1007/JHEP08(2023)068

[17] N. Kitajima and K. Nakayama "Viable vector coherent oscillation dark matter" Journal of Cosmology and Astroparticle Physics (2023) 014 DOI:10.1088/1475-7516/2023/07/014

[18] M. Chen, G. B. Gelmini and V. Takhistov "Halo-independent dark matter electron scattering analysis with in-medium effects" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 841 (2023) 137922 DOI:10.1016/j.physletb.2023.137922

[19] M. Gerbino et al. "Synergy between cosmological and laboratory searches in neutrino physics" Physics of the Dark Universe 42 (2023) 101333 DOI:10.1016/j.dark.2023.101333

[20] P. Lu, V. Takhistov and G. M. Fuller "Signatures of a High Temperature QCD Transition in the Early Universe" Physical Review Letters 130 (2023) 221002 DOI:10.1103/PhysRevLett.130.221002

[21] M. Ogur, V. Takhistov and K. Kohri "Revealing dark matter dress of primordial black holes by cosmological lensing" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 847 (2023) 138276 DOI:10.1016/j.physletb.2023.138276

[22] V. Vardanyan, V. Takhistov, M. Ata and K. Murase "Revisiting tests of Lorentz invariance with gamma-ray bursts: Effects of intrinsic lags" Physical Review D 108 (2023) 123023 DOI:10.1103/PhysRevD.108.123023

[23] A. Ito and J. Soda "Exploring high-frequency gravitational waves with magnons" European Physical Journal C 83 (2023) 766 DOI:10.1140/epjc/s10052-023-11876-2

[24] A. Ito and T. Suyama "Superluminal propagation from IR physics" Physical Review D 107 (2023) 016011 DOI:10.1103/PhysRevD.107.016011

[25] H. K. Dreiner, Y. S. Koay, D. Köhler, V. M. Lozano, J. M. V. Berlingen, S. Nangia and N. Strobbe "The ABC of RPV: classification of R-parity violating signatures at the LHC for small couplings" Journal of High Energy Physics (2023) 215 DOI:10.1007/JHEP07(2023)215

[26] G. Aad et al. (ATLAS Collaboration) "Search for new phenomena in multi-body invariant masses in events with at least one isolated lepton and two jets using $\sqrt{s}$ = 13 TeV proton–proton collision data collected by the ATLAS detector" Journal of High Energy Physics (2023) 202 DOI:10.1007/JHEP07(2023)202

[27] G. Aad et al. (ATLAS Collaboration) "ATLAS flavour-tagging algorithms for the LHC Run 2 pp collision dataset" European Physical Journal C 83 (2023) 681 DOI:10.1140/epjc/s10052-023-11699-1

[28] G. Aad et al. (ATLAS Collaboration) "Constraints on the Higgs boson self-coupling from single- and double-Higgs production with the ATLAS detector using pp collisions at s=13 TeV" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 843 (2023) 137745 DOI:10.1016/j.physletb.2023.137745

[29] G. Aad et al. (ATLAS Collaboration) "Search for resonant and non-resonant Higgs boson pair production in the $b\bar{b}$ $\tau+\tau-$ decay channel using 13 TeV pp collision data from the ATLAS detector" Journal of High Energy Physics (2023) 40 DOI:10.1007/JHEP07(2023)040

[30] G. Aad et al. (ATLAS Collaboration) "Measurement of the Higgs boson mass in the H→ZZ∗→4ℓ decay channel using 139 fb−1 of s=13 TeV pp collisions recorded by the ATLAS detector at the LHC" Physics Letters, Section B: Nuclear, Elementary Particle and High-Energy Physics 843 (2023) 137880 DOI:10.1016/j.physletb.2023.137880

[31] G. Aad et al. (ATLAS Collaboration) "Search for nonresonant pair production of Higgs bosons in the bb¯bb¯ final state in pp collisions at √s = 13 TeV with the ATLAS detector " Physical Review D 108 (2023) 052003 DOI:10.1103/PhysRevD.108.052003

[32] Y. Zhou, N. Y. Yamasaki, S. Toriumi and K. Mitsuda "Geocoronal Solar Wind Charge Exchange Process Associated With the 2006-December-13 Coronal Mass Ejection Event" Journal of Geophysical Research: Space Physics 128 (2023) e2023JA032069 DOI:10.1029/2023JA032069

[33] J. C. Hood II et al. "Simultaneous Millimeter-wave, Gamma-Ray, and Optical Monitoring of the Blazar PKS 2326-502 during a Flaring State" Astrophysical Journal Letters 945 (2023) L23 DOI:10.3847/2041-8213/acbf45

[34] K. Abe et al. (Super-Kamiokande collaboration) "Search for Cosmic-Ray Boosted Sub-GeV Dark Matter Using Recoil Protons at Super-Kamiokande" Physical Review Letters 130 (2023) 031802 DOI:10.1103/PhysRevLett.130.031802

[35] J. Geng et al. "Dopant-assisted stabilization of negatively charged single nitrogen-vacancy centers in phosphorus-doped diamond at low temperatures" npj Quantum Information 9 (2023) 110 DOI:10.1038/s41534-023-00777-7

[36] H. Tabuchi et al. "Temperature sensing with RF-dressed states of nitrogen-vacancy centers in diamond" Journal of Applied Physics 133 (2023) 024401 DOI:10.1063/5.0129706

[37] Y. Ezoe et al. "GEOspace X-ray imager (GEO-X)" Primordial Black Hole Neutrinogenesis of Sterile Neutrino Dark Matter 9 (2023) 034006 DOI:10.1117/1.JATIS.9.3.034006

[38] Y. Sakai, S. Yamada, T. Sato, R. Hayakawa, R. Higurashi and N. Kominato "Richardson-Lucy Deconvolution with a Spatially Variant Point-spread Function of Chandra: Supernova Remnant Cassiopeia A as an Example" Astrophysical Journal 951 (2023) 59 DOI:10.3847/1538-4357/acd9b3

[39] C.-B. Chen and J. Soda "Implications of multi-axion dark matter on structure formation" Journal of Cosmology and Astroparticle Physics (2023) 049 DOI:10.1088/1475-7516/2023/06/049

[40] S. Kanno, A. Mukuno, J. Soda and K. Ueda "A peak in the power spectrum of primordial gravitational waves induced by primordial dark magnetic fields" Journal of Cosmology and Astroparticle Physics (2023) 052 DOI:10.1088/1475-7516/2023/05/052

[41] H. Omiya, K. Nomura and J. Soda "Hellings-Downs curve deformed by ultralight vector dark matter" Physical Review D 108 (2023) 104006 DOI:10.1103/PhysRevD.108.104006

[42] Y. Sugiyama , A. Matsumura and K.Yamamoto "Quantum uncertainty of gravitational field and entanglement in superposed massive particles" Physical Review D

108 (2023) 105019 DOI:10.1103/PhysRevD.108.105019

[43] S. Chen, H. Fukuda, T. Inada, T. Moroi, T. Nitta and T. Sichanugrist "Detecting Hidden Photon Dark Matter Using the Direct Excitation of Transmon Qubits" Physical Review Letters 131 (2023) 211001 DOI:10.1103/PhysRevLett.131.211001

[44] T. Harada, K. Kohri, M. Sasaki, T. Terada and C.-M. Yoo C.-M. "Threshold of primordial black hole formation against velocity dispersion in matter-dominated era" Journal of Cosmology and Astroparticle Physics (2023) 038 DOI:10.1088/1475-7516/2023/02/038

[45] M. He, K. Kohri, K. Mukaida and M. Yamada "Formation of hot spots around small primordial black holes" Journal of Cosmology and Astroparticle Physics (2023) 027 DOI:10.1088/1475-7516/2023/01/027

[46] D. Inman and K. Kohri "Enhanced small-scale structure in the cosmic dark ages" Physical Review D 107 (2023) 123513 DOI:10.1103/PhysRevD.107.123513

[47] N. Kawanaka and K. Kohri "Effects of Heat Conduction on Blocking off the Super-Eddington Growth of Black Holes at High Redshift" Astrophysical Journal 955 (2023) 67 DOI:10.3847/1538-4357/acee6d

[48] Li J.-P.; Wang S.; Zhao Z.-C.; Kohri K. "Primordial non-Gaussianity f NL and anisotropies in scalar-induced gravitational waves" Journal of Cosmology and Astroparticle Physics (2023) 056 DOI:10.1088/1475-7516/2023/10/056

[49] K. Fukushima, Y. Hidaka, T. Shimazaki and H. Taya "Chiral anomaly in a (1+1)-dimensional Floquet system under high-frequency electric fields" Annals of Physics 458 (2023) 169494 DOI:10.1016/j.aop.2023.169494

[50] T. Hayata and Y. Hidaka "String-net formulation of Hamiltonian lattice Yang-Mills theories and quantum many-body scars in a nonabelian gauge theory" Journal of High Energy Physics (2023) 126 DOI:10.1007/JHEP09(2023)126

[51] T. Hayata and Y. Hidaka "q deformed formulation of Hamiltonian SU(3) Yang-Mills theory" Journal of High Energy Physics (2023) 123 DOI:10.1007/JHEP09(2023)123

[52] T. Hasada, K. Homma and Y. Kirita "Design and Construction of a Variable-Angle Three-Beam Stimulated Resonant Photon Collider toward eV-Scale ALP Search" Universe 9 (2023) 355 DOI:10.3390/universe9080355

2. Review Articles

[53] M. Garcia-Sciveres "Hybrid pixel readout integrated circuits" Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1057 (2023) 168725 DOI:10.1016/j.nima.2023.168725

[54] H. Akamatsu and J. van der Kuur "Transition Edge Sensors X-ray Spectrometers: Applications for X-ray Astronomy" in Book "High-Resolution X-ray Spectroscopy: Instrumentation, Data Analysis, and Science" (2023) 71-91 DOI:10.1007/978-981-99-4409-5_4

B. WPI-related papers

This section lists papers published in 2024 with significant contributions by the QUP scientists.

1. Original Articles

[55] R. Takaku et al. "Performance of a 200 mm Diameter Achromatic HWP with Laser-Ablated Sub-Wavelength Structures" Journal of Low Temperature Physics 211 (2023) 346-356 DOI:10.1007/s10909-022-02922-6

[56] A. Natochii et al. "Measured and projected beam backgrounds in the Belle II experiment at the SuperKEKB collider" Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1055 (2023) 168550 DOI:10.1016/j.nima.2023.168550

[57] H. Sugiyama et al. "The soft X-ray background with Suzaku. II. Supervirial temperature bubbles?" Publications of the Astronomical Society of Japan 75 (2023) 1324-1336 DOI:10.1093/pasj/psad073

[58] Y. Yagi et al. "Performance of TES X-Ray Microcalorimeters Designed for 14.4-keV Solar Axion Search" Journal of Low Temperature Physics 211 (2023) 255-264 DOI:10.1007/s10909-023-02942-w

[59] T. Tsuruta et al. "Two-Dimensional Position-Sensitive Transition-Edge Sensor Microcalorimeters for Gamma Rays" IEEE Transactions on Applied Superconductivity 33 (2023) 2101904 DOI:10.1109/TASC.2023.3263135

[60] H. Fukushima et al. "Development of differential amplifier circuits based on radiation hardened H-diamond MOSFET (RADDFET)" Diamond and Related Materials 134 (2023) 109758 DOI:10.1016/j.diamond.2023.109758

[61] M. Kholili et al. "A low-power and high-gain frontend for GHz application using trans-impedance amplifier for fast particle detection" Journal of Instrumentation 18 (2023) P11010 DOI:10.1088/1748-0221/18/11/P11010

[62] D.V. Berlea et al. "Radiation Hardness of MALTA2, a Monolithic Active Pixel Sensor for Tracking Applications" IEEE Transactions on Nuclear Science 70 (2023) 2303-2309 DOI:10.1109/TNS.2023.3313721

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[280] H. Sakai et al. "Conceptual design of the high-power electron beam irradiator using niobium-tin superconducting cavity" Journal of Physics: Conference Series 2687 (2024) 092013 DOI:10.1088/1742-6596/2687/9/092013

[281] J. Tamura et al. "Fabrication progress of the prototype spoke cavity for the JAEA-ADS linac" Journal of Physics: Conference Series 2687 (2024) 052008 DOI:10.1088/1742-6596/2687/5/052008

4. Other English articles

[282] L. Vaslin, S. Calvet, V. Barra and J. Donini "pyBumpHunter: A model independent bump hunting tool in Python for High Energy Physics analyses" SciPost Phys. Codebases (2023) 15-DOI:10.21468/scipostphyscodeb.15

2. Invited Lectures, Plenary Addresses (etc.) at International Conferences and International Research Meetings

- List up to 10 main presentations during FY 2023 in order from most recent.
- For each, write the date(s), lecturer/presenter's name, presentation title, and conference name.

Date(s)	Lecturer/Presenter's name	Presentation title	Conference name
Mar 18 - 22, 2024	Volodymyr Takhistov	Black Holes: Marvelous Manifestations and New Dark Matter	IBS CTPU-CGA International Workshop on (Primordial) Black Holes and Gravitational Waves
Mar 4-7, 2024	Louis Vaslin	Anomaly Detection algorithms applied to the Quality Control of detector components	AISSAI Anomaly Detection Workshop
Dec 4-8, 2023	Kaori Hattori	Characterization of optical transition-edge sensors	Japan-the Netherlands exchange meeting for joint development of microcalorimeter system for future space/ground missions
Nov 27 - Dec 1, 2023	Daniela Bortoletto	Detector R&D: tracking detectors and particle ID	The 13th ICFA seminar on "Future Perspectives in High Energy Physics"
Jul 23-28, 2023	Tommaso Ghigna	Design and optimization of the lowest frequency pixels of LiteBIRD Low-Frequency Telescope	The 20th International Conference on Low Temperature Detectors
Jul 23-28, 2023	Suerfu Burkhant	The TESSERACT project and progress toward light dark matter direct detection using superfluid helium-4	The 20th International Conference on Low Temperature Detectors
Jul 20-21, 2023	Kazuhisa Mitsuda	Observations of WHIM and Implications	Detecting Missing Baryons in the Universe
Jul 17-21, 2023	Yu Nakahama	Probing the nature of electroweak symmetry breaking with Higgs boson pairs in ATLAS	The 31st Lepton Photon conference
Jun 25-29, 2023	Manabu Togawa	The CIGS semiconductor detector for particle physics	24th International Workshop On Radiation Imaging Detectors
Jun 12-16, 2023	Masashi Hazumi	Primordial cosmology and fundamental physics with LiteBIRD	From the Galaxy to the Big-Bang

3. Major Awards

- List up to 10 main awards received during FY 2023 in order from the most recent.
- For each, write the date issued, the recipient's name, and the name of award.
- In case of multiple recipients, underline those affiliated with the center.

Date	Recipient's name	Name of award
2024,1,1	Daniela Bortoletto	OBE -Officer of the Order of the British Empire

Appendix 2 FY 2023 List of Principal Investigators

NOTE:
*Underline names of principal investigators who belong to an overseas research institution.
*In the case of researcher(s) not listed in the in the latest report, attach a "Biographical Sketch of a New Principal Investigator"(Appendix 2a).
*Enter the host institution name and the center name in the footer.

<Results at the end of FY2023> **Principal Investigators Total: 13**

Name	Age	Affiliation (Position title, department, organization)	Academic degree, specialty	Effort (%)*	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Center director Masashi Hazumi	59	High Energy Accelerator Research Organization(KEK), Institute of Particle and Nuclear Studies(IPNS), and International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles(QUP), Professor	PhD, Physics	80	2021/10/1	Stays at the center. Several visits to the satellites	
<u>Daniela Bortoletto</u>	65	University of Oxford, Professor, Head of Particle Physics	PhD, Physics	20	2021/10/1	Mainly at Oxford University and joins videoconference meetings (PI meeting/colloquium (every week)) and occasional meetings with the director (once a month)) . Stays in the center for 1 week each in August and December.	Regular Contributions via videoconference.
<u>Mauricio A. Garcia-Sciveres</u>	57	Lawrence Berkeley National Laboratory, Senior Scientist	PhD, Physics	20	2021/10/1	Mainly stays at LBNL and joins videoconference meetings (PI meeting/colloqium (every week) and occasional meetings with the director (once a month)). Stays in the center for 3 times (23 days in total).	Regular Contributions via videoconference. Sent two postdocs to the center for the internship program (QUPIP) for 2x2 months.

Masaya Hasegawa	45	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Stays at the center.	
Kaori Hattori	42	National Institute of Advanced Industrial Science and Technology (AIST), Research Institute for Physical Measurement, Senior Researcher and KEK,QUP, Associate Professor	PhD, Physics	40	2021/10/1	Stays at the center for 40% to participates in the Center's activities as PI. Joins videoconference meetings from another institution.	
Hideo Iizuka	51	Toyota Central R&D Labs., Inc., Senior Fellow and KEK,QUP, Professor	Doctor of Engineering	40	2021/10/1	Stays at the Center for ~40% to participate in the Center's activities. Stays at the Toyota Satellite time-to-time for the QUP research activities.	
Adrian Tae-Jin Lee	59	University of California, Berkeley, Professor	PhD, Physics	50	2021/10/1	Stays at the Berkeley satellite. Joins videoconference meetings (PI meeting/Colloquium (every week), steering committee meeting (every month), Flagship project meeting (every week) and occasional meetings with the director (every week)) from the satellite. One week stay in December.	Regular Contributions via videoconference. Accepted an internship Phd student (QUPIP) to the Berkeley satellite for 2 months. Sent a PhD student to the center for the internship program (QUPIP) for 2 months.
Masaya Miyahara	43	KEK,IPNS, Associate Professor	Doctor of Engineering, ASIC design	70	2021/10/1	Stays at the center.	
Yu Nakahama	42	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Stays at the center.	

Kazunori Nakayama	41	Tohoku University, Graduate School of Science and Faculty of Science, Associate Professor	PhD, Physics	30	2021/10/1	Stays in Tohoku university and joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (a few in a month)) . Came to the center several times for research discussions and workshops.	
Nanae Taniguchi	44	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Stays at the center.	
Manabu Togawa	45	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Stays at the center.	
Noriko Yamasaki	57	Japan Aerospace Exploration Agency (JAXA), Institute of Space and Astronautical Science (ISAS), Professor	PhD, Physics	20	2021/10/1	Stays at the ISAS satellite and joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)). Several visits to the center.	

Principal investigators unable to participate in project in FY 2023

Name	Affiliation (Position title, department, organization)	Starting date of project participation	Reasons	Measures taken

Appendix 3-1 FY 2023 Records of Center Activities

1. Researchers and center staff, satellites, partner institutions
1-1. Number of researchers in the "core" established within the host institution

- Regarding the number of researchers at the Center, fill in the table in Appendix 3-1a.

Special mention

- Enter matters warranting special mention, such as concrete plans for achieving the Center's goals, established schedules for employing main researchers, particularly principal investigators.
- As background to how the Center is working on the global circulation of world's best brains, give good examples, if any, of how career paths are being established for the Center's researchers; that is, from which top-world research institutions do researchers come to the Center and to which research institutions do the Center's researchers go, and how long are their stays at those institutions.

The headquarters of the International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP) has remained unchanged since the start of the center and throughout FY2023. Masashi Hazumi is the Director, and Kazunori Hanagaki is the Deputy. Katsuo Tokushuku is the Administrative Director.

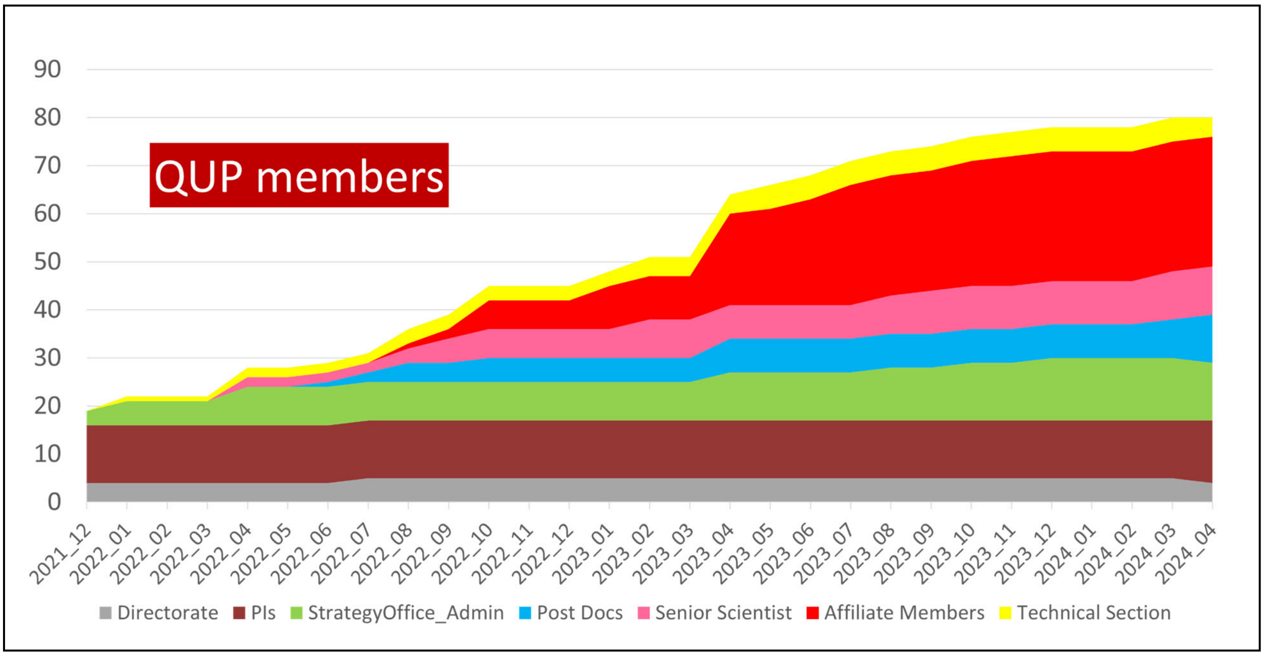
However, a major change in QUP and KEK occurred in April 2024, related to the change of the director general of KEK. Dr. Shoji Asai has taken over from Dr. Masanori Yamauchi in FY2024. The former QUP deputy director, Prof. Kazunori Hanagai, has been appointed as an executive director of KEK. With this move, the QUP director Masashi Hazumi has appointed Prof. Kazuhisa Mitsuda as his deputy.

All thirteen initial PIs have been officially appointed by February 2022. Aiming to have closer contacts, some outside PI's started being partially hired by the QUP. PI Kaori Hattori of AIST has been an associate professor at QUP at a cross-appointment since April 2022. PI Hideo Iizuka has been a professor at QUP at a cross-appointment since May 2023. Following the recommendation from the program committee, we called for new PIs to strengthen the QUP research. Since April 1, An associate Professor. Volodymyr Takhistov joined as a new PI in the theory sector.

The QUP's plan is to have a deputy PI for each non-resident overseas PI. By September 2023, all three overseas PIs appointed their deputies.

In FY2023, there are

The number of QUP researchers grew during FY2023, as shown in the plot.



1-2. Satellites and partner institutions

- List the satellite and partner institutions in the table below.
- Indicate newly added and deleted institutions in the "Notes" column.
- If satellite institutions have been established overseas, describe by satellite the Center's achievements in coauthored papers and researcher exchanges in Appendix 4.

<Satellite institutions>

Institution name	Principal Investigator(s), if any	Notes
QUP Space and Astronautical Science Satellite	Noriko Yamazaki	
QUP Satellite in Toyota Central R&D Labs., Inc.	Hideo Iizuka	
QUP Berkeley Satellite	Adrian Lee	

< Partner institutions>

Institution name	Principal Investigator(s), if any	Notes
Kavli IPMU	None	
SOKENDAI	KEK's PIs (M. Hazumi, M. Hasegawa, Y. Nakahama, N. Taniguchi and M. Togawa, K. Hattori)	MOU on the education of graduate students.
Nicolaus Copernicus Academy, Poland	None	MOU on the collaboration related to SpaceTES project

2. Holding international research meetings

- Indicate the number of international research conferences or symposiums held in FY2023 and give up to three examples of the most representative ones using the table below.

FY 2023: 5 meetings

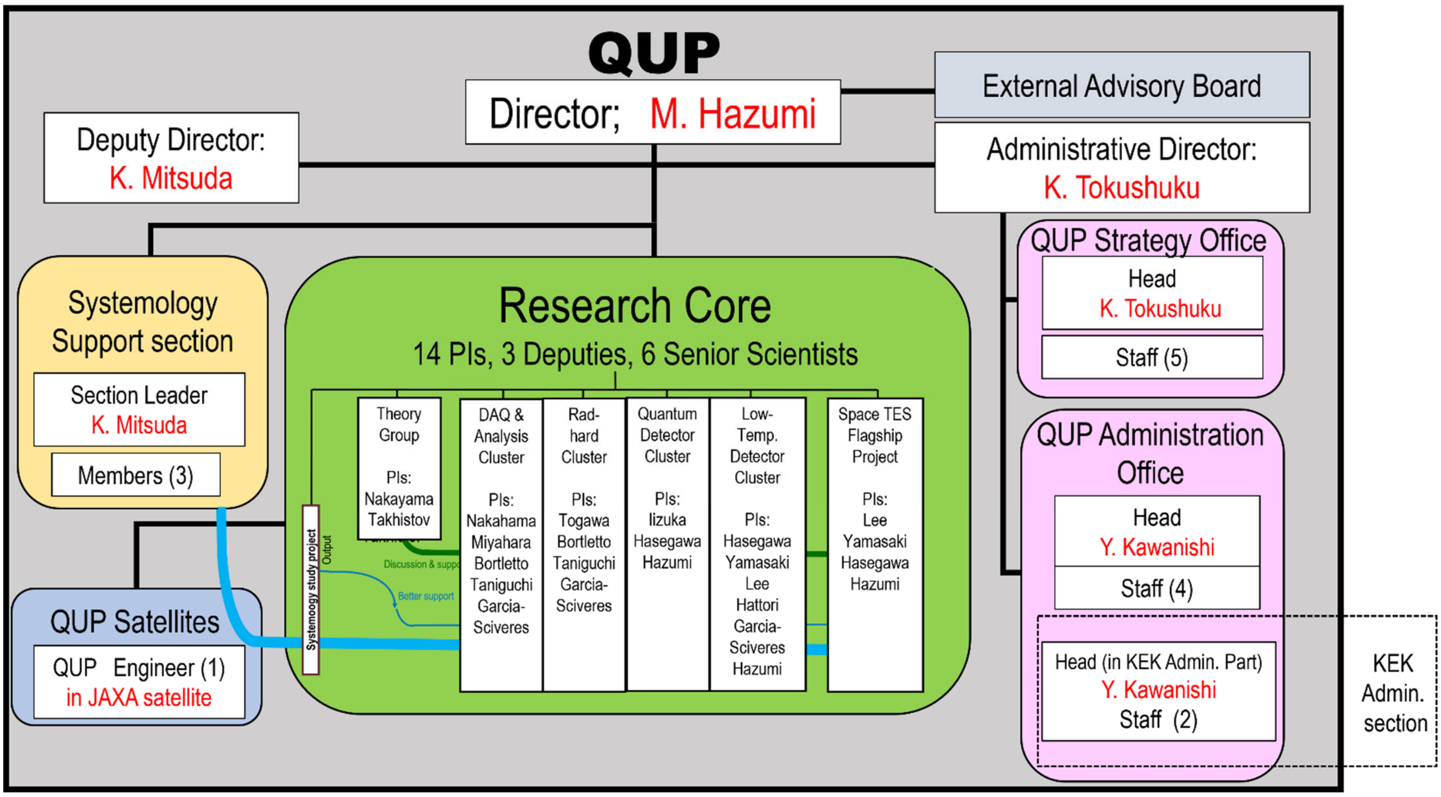
Major examples (meeting titles and places held)	Number of participants
QUPosium2023 (December 11-13, 2023, Epochal Tsukuba, Japan)	From domestic institutions: 101 From overseas institutions: 17
"AI-Smart" JSPS Core-to-Core Program: AI-Smart x Trigger KickOff Workshop (September 25-26, 2023, KEK, Tsukuba, Japan)	From domestic institutions: 42 From overseas institutions: 9
"International hands-on workshop of LiteBIRD simulation" (July 3-7, 2023, KEK, Tsukuba, Japan)	From domestic institutions: 21 From overseas institutions: 29

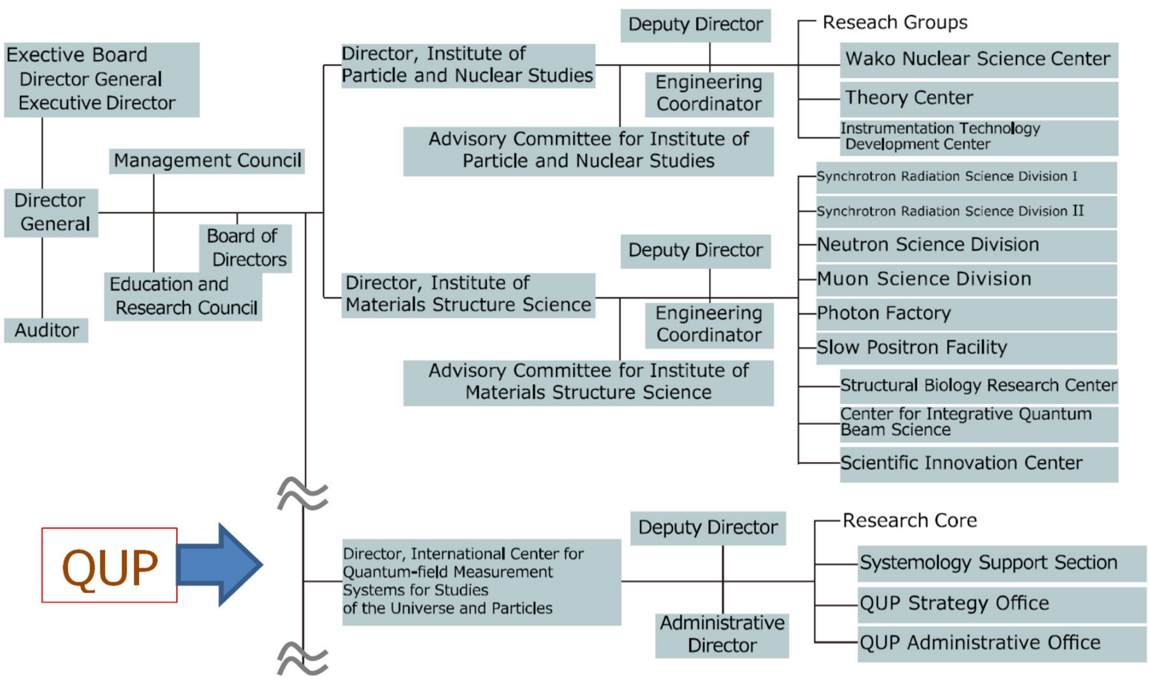
3. Diagram of management system

- Diagram the center's management system and its position within the host institution in an easily understood manner.
- If any new changes have been made in the management system from that in the latest "center project" last year, describe them. Especially describe any important changes made in such as the center director, administrative director, head of host institution, and officer(s) in charge at the host institution (e.g., executive vice president for research).

The structure of the research core has changed as described in sections 1-1 of this appendix. The diagram of the QUP organization and its position at KEK is shown below. The full chart of the KEK is accessible from https://www.kek.jp/en/about-en/organization-en/chart-en/.

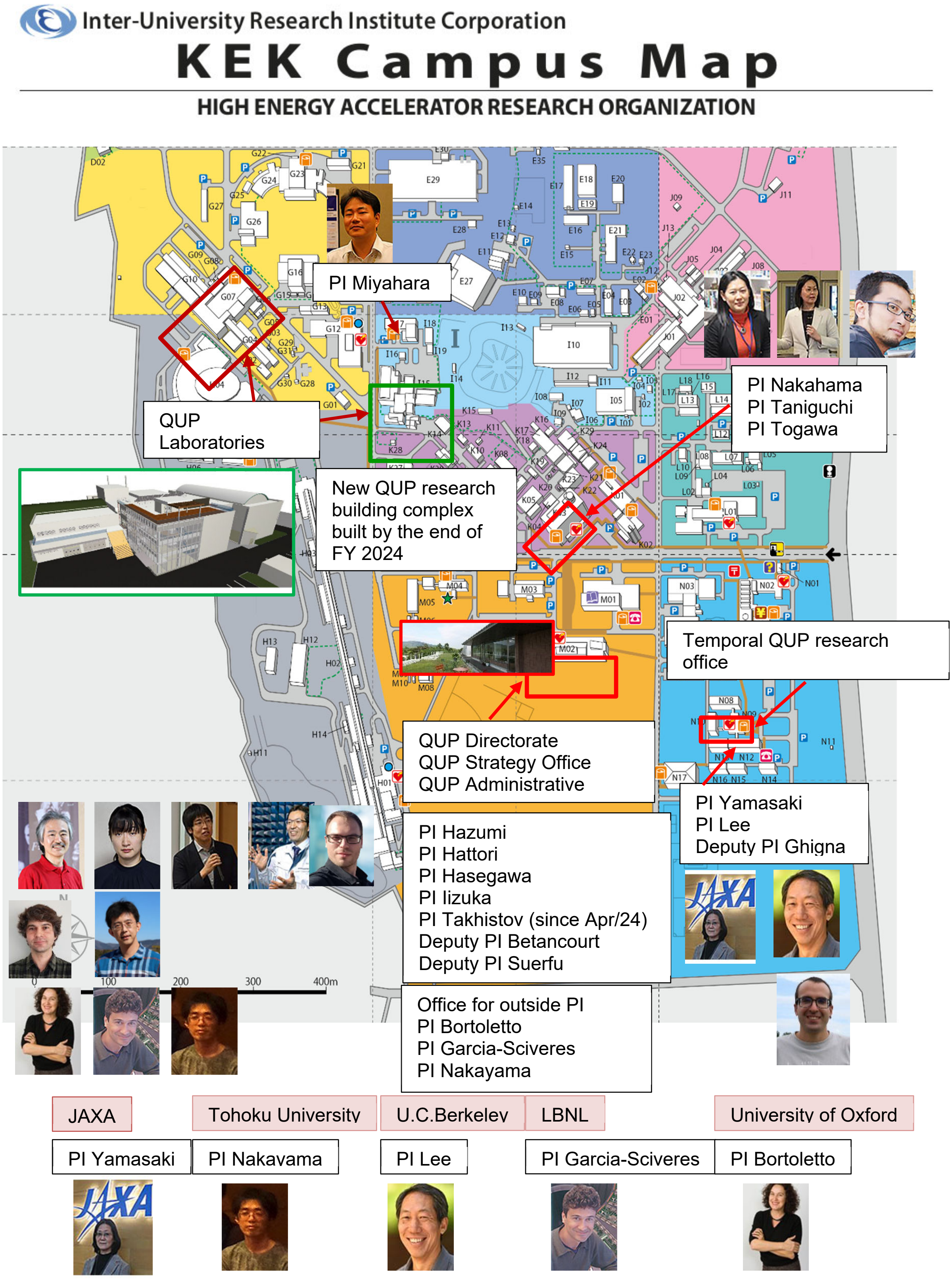
QUP Organization as of April 2024





4. Campus Map

- Draw a simple map of the campus showing where the main office and principal investigator(s) are located.



5. Securing external research funding*

External research funding secured in FY2023

Total: 491,315,386 yen

- Describe external funding warranting special mention. Include the name and total amount of each grant.

* External research funding includes "KAKENHI," funding for "commissioned research projects," "joint research projects," and for others (donations, etc.) as listed under "Research projects" in Appendix 3-2, Project Expenditures.

Appendix 3-1a FY 2023 Records of Center Activities

Researchers and other center staff

Number of researchers and other center staff

* Fill in the number of researchers and other center staff in the table blow.
* Describe the final goals for achieving these numbers and dates when they will be achieved described in the last "center project."

a) Principal Investigators

（full professors, associate professors or other researchers of comparable standing)

(number of persons)

	At the beginning of project	At the end of FY 2023	Final goal (Date: March, 2025)
Researchers from within the host institution	6	8	8
Researchers invited from overseas	3	3	3
Researchers invited from other Japanese institutions	4	2	2
Total principal investigators	13	13	13

b) Total members

	At the beginning of project		At the end of FY 2023		Final goal (Date: March, 2025)	
	Number of persons	%	Number of persons	%	Number of persons	%
Researchers	15		35		67	
Overseas researchers	3	20	12	34	27	40
Female researchers	5	33	6	17	24	36
Principal investigators	13		13		13	
Overseas PIs	3	23	3	23	3	23
Female PIs	5	38	5	38	5	38
Other researchers	2		14		14	
Overseas researchers	0	0	5	36	4	29
Female researchers	0	0	0	0	4	29
Postdocs	0		8		40	
Overseas postdocs	0	0	4	50	20	50
Female postdocs	0	0	1	13	15	38
Research support staffs	0		10		20	
Administrative staffs	3		25		25	
Total number of people who form the "core" of the research center	18		70		112	

	At the beginning of project		At the end of FY 2023		Final goal (Date: March, 2025)	
	Number of persons	%	Number of persons	%	Number of persons	%
Doctoral students	0		11		15	
Employed	0	-	9	81.8	15	100.0

※b) The number of doctoral students in the lower table can be duplicated in the upper table of overall composition.

Appendix 3-2 Project Expenditures

1) Overall project funding

* In the "Total costs" column, enter the total amount of funding required to implement the project, without dividing it into funding sources.

* In the "Amount covered by WPI funding" column, enter the amount covered by WPI within the total amount.

* In the "Personnel," "Project activities," "Travel," and "Equipment" blocks, the items of the "Details" column may be changed to coincide with the project's actual content.

(Million yens)

Cost items	Details (For Personnel - Equipment please fill in the breakdown of fiscal expenditure, and the income breakdown for Research projects.)	Total costs	Amount covered by WPI funding
Personnel	Center director and administrative director	26	24
	Principal investigators (no. of persons):12	47	9
	Other researchers (no. of persons):21	145	117
	Research support staff (no. of persons):10	62	62
	Administrative staff (no. of persons):25	67	53
	RA for university students (no. of persons):7	3	0
	Subtotal	350	265
Project activities	Research startup cost (no. of persons):15	19	15
	Cost of outreach	5	5
	Gratuities and honoraria paid to resaearchers (no. of persons):1	3	3
	Cost of satellite organizations (no. of satellite organizations):3	31	23
	Cost of international symposiums (no. of symposiums):2	5	4
	Rental fees for facilities	52	0
	Other costs (Space charge, equipment relocation cost, etc.)	567	23
	Subtotal	682	73
Travel	Domestic travel costs	6	6
	Overseas travel costs	31	30
	Travel and accommodations cost for invited scientists (no. of domestic scientists):39 (no. of overseas scientists):37	22	21
	Travel cost for scientists on transfer (no. of domestic scientists):1 (no. of overseas scientists):1	2	2
	Subtotal	61	59
Equipment	Facility improvement costs	14	10
	Facility / equipment procuement cost	154	153
	Establishing new facility	473	0
	Subtotal	641	163
Research projects (Detail items must be fixed)	Project supported by other government subsidies, etc. *1	36	0
	KAKENHI	160	0
	Commissioned research projects, etc.	317	0
	Joint research projects	15	0
	Ohers (donations, etc.)	0	0
	Subtotal	528	0
Total		2262	560

Costs (Million yens)

WPI grant in FY 2023	560
Costs of establishing and maintaining facilities	487
Establishing new facility (Number of facilities: 1, 3,230 m²)	473
Repairing facilities (Number of facilities:2, 2,074 m²)	14
Others	0
Costs of equipment procured	154
Pulse Tube Refrigeration System (Number of units:4)	49
Cryostat (Number of units:1)	15
Laser (Number of units:1)	10
Others	80

*1. Management Expenses Grants (including Management Enhancements Promotion Expenses (機能強化経費)), subsidies including National university reform reinforcement promotion subsidy (国立大学改革強化推進補助金) etc., indirect funding, and allocations from the university's own resources.

*2 When personnel, travel, equipment (etc.) expenses are covered by KAKENHI or under commissioned research projects or joint research projects, the amounts should be entered in the "Research projects" block.

*1 運営費交付金（機能強化経費を含む）、国立大学改革強化推進補助金等の補助金、間接経費、その他大学独自の取組による学内リソースの配分等による財源
*2 科研費、受託研究費、共同研究費等によって人件費、旅費、設備備品等費を支出している場合も、その額は「研究プロジェクト費」として計上すること

2) Costs of satellites

(Million yens)

Cost items	Details	Total costs	Amount covered by WPI funding
Personnel	Principal investigators (no. of persons):0		
	Other researchers (no. of persons):0		
	Research support staff (no. of persons):0		
	Administrative staff (no. of persons):0		
	Subtotal	0	0
Project activities	Subtotal	31	23
Travel	Subtotal	0	0
Equipment	Subtotal	0	0
Research projects	Subtotal	0	0
Total		31	23

Appendix 4 FY 2023 Status of Collaboration with Overseas Satellites

1. Coauthored Papers

- List the refereed papers published in FY 2023 that were coauthored between the center's researcher(s) in domestic institution(s) (include satellite institutions) and overseas satellite institution(s). List them by overseas satellite institution in the below blocks.
- Transcribe data in same format as in Appendix 1. Italicize the names of authors affiliated with overseas satellite institutions.
- For reference write the Appendix 1 item number in parentheses after the item number in the blocks below. Let it free, if the paper is published in between Jan.-Mar. 2024 and not described in Appendix 1.

Overseas Satellite 1 QUP Berkeley Satellite (University of California, Berkeley)

(Total: 2 papers)

1) (6) S. Adachi, *A. T. Lee* et al. (POLARBEAR collaboration) "Constraints on axionlike polarization oscillations in the cosmic microwave background with POLARBEAR" Physical Review D 108 (2023) 043017 DOI:10.1103/PhysRevD.108.043017
2) (33) J. C. Hood II, , *A. T. Lee* et al. "Simultaneous Millimeter-wave, Gamma-Ray, and Optical Monitoring of the Blazar PKS 2326-502 during a Flaring State" Astrophysical Journal Letters 945 (2023) L23 DOI:10.3847/2041-8213/acbf45

2. Status of Researcher Exchanges

- Using the below tables, indicate the number and length of researcher exchanges in FY 2023. Enter by institution and length of exchange.
- Write the number of principal investigator visits in the top of each space and the number of other researchers in the bottom.

Overseas Satellite 1: QUP Berkeley Satellite (University of California, Berkeley)

<To satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2023	3	0	0	0	3
	10	1	4	0	15

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2023	1	0	0	0	1
	2	0	2	0	4

Appendix 5 FY 2023 Visit Records of Researchers from Abroad

* If researchers have visited/ stayed at the Center, provide information on them in the below table.
* Enter the host institution name and the center name in the footer.

Total: 72

	Name	Age	Affiliation		Academic degree, specialty	Record of research activities (Awards record, etc.)	Time, duration	Summary of activities during stay at center (e.g., participation as principal investigator; short-term stay for joint research; participation in symposium)
			Position title, department, organization	Country				
1	Christopher Betancourt	36	Senior Scientist, Universität Zürich, Switzerland	Switzeland	Ph.D. in physics	Particle physics experiment	2023/04/18 ～ 2023/04/28	Discussion on the QUP radhard cluster activities
2	Tien-Tien Yu	33	Professor, University of Oregon	USA	Ph.D. in physics	Particle physics theory	2023/05/12 ～ 2023/05/12	Speaker of the QUPseminar
3	Andrey Dushkin	65	Engineer, Tufts University, U.S.A.	USA	MS, Design and Mechanical Engineering	Mechanical Engineering	2023/05/12 ～ 2023/05/18	Paticipation at QUP collaboration meeting and discussion on the Kamioka light dark matter project
4	John Ellis	77	Professor, King's College London & CERN	UK	Ph.D. in physics	Particle Physics Theory 1982 Maxwell Medal and Prize 2005 Paul Dirac Medal and Prize	2023/06/12 ～ 2023/06/12	Speaker of the QUPseminar
5	Alessandro Carones	29	Postdoc, Tor Vergata University	Italy	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
6	Carlo Baccigalupi	53	Faculty, SISSA, Trieste	Italy	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
7	Giuseppe Pugilisi	34	Faculty, INFN	Italy	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
8	Guillaume Patanchon	47	Faculty, APC	France	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
9	Louise Mousset	30	Postdoc, IRAP	France	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
10	Luca Pagano	40	Faculty, Ferrara University	Italy	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
11	Mathew Galloway	32	Postdoc, Universitetet i Oslo	Norway	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
12	Nicoletta Krachmalnicoff	39	Faculty, SISSA, Trieste	Italy	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
13	Paolo Campeti	32	Researcher, INFN Ferrara	Italy	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation

14	Thejs Brinckmann	36	Faculty, Ferrara University	Italy	Ph.D. in physics	Astroparticle physics	2023/06/26 ～ 2023/07/07	Participation to the International hands-on workshop of LiteBIRD simulation
15	Mathis Maurice	24	Master student, Institut National Polytechnique(INP).	France	Ph.D. in physics	Particle physics exeperiment	2023/07/01 ～ 2023/08/26	QUP internship program (QUPIP)
16	Louise Mousset	31	Postdoctoral resaearcher, IRAP	France	Ph.D. in physics	Astrophysics and cosmology	2023/07/03 ~ 2023/07/07	Speaker of the International hands-on workshop of LiteBIRD simulation
17	Luca Pagano	40	Assistant Professor, University of Ferrara	Italy	Ph.D. in physics	Astrophysics and cosmology	2023/07/03 ~ 2023/07/07	Speaker of the International hands-on workshop of LiteBIRD simulation
18	Mathew Galloway	34	Postdoctoral resaearcher, Institute for Theoretical Astrophysics, University of	Norway	Ph.D. in physics	Astrophysics and cosmology	2023/07/03 ~ 2023/07/07	Speaker of the International hands-on workshop of LiteBIRD simulation
19	Nicoletta Krachmalnicoff	36	Assistant Professor, Italy	Italy	Ph.D. in physics	Astrophysics and cosmology	2023/07/03 ~ 2023/07/07	Speaker of the International hands-on workshop of LiteBIRD simulation
20	Paolo Campeti	33	Researcher, INFN	Italy	Ph.D. in physics	Astrophysics and cosmology	2023/07/03 ~ 2023/07/07	Speaker of the International hands-on workshop of LiteBIRD simulation
21	Miaochen Jin	22	PhD students, Harvard University	USA	Ph.D student	Particle physics exeperiment	2023/07/07 ～ 2023/08/16	QUP internship program (QUPIP)
22	Jason Arakawa	27	Postdoc, University of Delaware	USA	Ph.D. in physics	Particle physics theory	2023/07/08 ～ 2023/08/08	QUP internship program (QUPIP)
23	Philip Lu	29	Postdoc, Seoul National University	South Korea	Ph.D. in physics	Particle physics theory	2023/07/08 ～ 2023/08/09	QUP internship program (QUPIP)
24	Davide Vaccaro	32	Researcher, NWO-I/SRON	Netherlands	Ph.D. in physics	Astroparticle physics	2023/07/15 ～ 2023/07/22	Paticipation as a speaker at QUP Cryo Cluster Mini Workshop
25	Matteo d'Andrea	34	Researcher, Instituto Nazionale di Astrofisica(INAF) ITALY	Italy	Ph.D. in physics	Astroparticle physics	2023/07/16 ～ 2023/07/21	Paticipation as a speaker at QUP Cryo Cluster Mini Workshop
26	Simone Lotti	38	Postdoc, Instituto Nazionale di Astrofisica（INAF）Italy	Italy	Ph.D. in physics	Astroparticle physics	2023/07/16 ～ 2023/07/21	Paticipation as a speaker at QUP Cryo Cluster Mini Workshop
27	Jan van der Kuur	54	Instrument Scientist, NWO-I/SRON	Netherlands	Ph.D. in physics	Astroparticle physics	2023/07/18 ～ 2023/07/23	Paticipation as a speaker at QUP Cryo Cluster Mini Workshop
28	Benjamin Westbrook	38	Postdoc, University of California, Berkeley	USA	Ph.D. in physics	Particle physics exeperiment	2023/07/30 ～ 2023/08/03	Paticipation as a speaker at QUP collaboration meeting
29	Christopher Raum	57	Engineer, University of California, Berkeley	USA	Ph.D. in electrical engineering	Silicon photonics and silicon micromachining	2023/07/31 ～ 2023/08/04	Paticipation as a speaker at QUP collaboration meeting

30	Marianna Safronova	50	Professor, University of Delaware	USA	Ph.D. in physics	Partcle physics theory APS fellow 2012 the American Physical Society's Woman Physicist of the	2023/08/01 ～ 2023/08/03	Speaker of the QUPseminar
31	Xinran Li	29	Postdoctoral Researcher, Lawrence Berkeley National Laboratory (LBNL)	USA	Ph.D. in physics	Particle physics exeperiment	2023/08/02 ～ 2023/09/30	QUP internship program (QUPIP)
32	Michael Doser	63	Senior research physicist, CERN	Switzeland	Ph.D. in physics	Particle physics exeperiment	2023/08/08 ～ 2023/08/08	Speaker of the QUPseminar
33	Harigaya Kesuke	36	Assistant professor, Univ. of Chicago	USA	Ph.D. in physics	Particle physics theory	2023/08/10 ～ 2023/08/10	Speaker of the QUPseminar
34	Thomas Schwemberger	27	PhD students, University of Oregon	USA	Ph.D student	Particle physics theory	2023/08/17 ～ 2023/09/27	QUP internship program (QUPIP)
35	Remy Kriboo	32	Engineer, SRON	Netherlands	Mechanical Engineering, BSc	Particle physics exeperiment	2023/09/01 ～ 2023/10/27	QUP internship program (QUPIP)
36	Graciela Gelmini	63	Professor, University of California, Los Angeles	USA	Ph.D. in physics	Particle physics theory	2023/09/16 ～ 2023/09/25	Speaker of the QUPseminar
37	So Chigusa	31	Researcher, Lawrence Berkeley National Laboratory	USA	Ph.D. in physics	Particle physics theory	2023/09/19 ～ 2023/09/22	Discussion on the QUP darkmatter searches
38	Brian Petersen	52	Secior researcher, CERN	Switzerland	Ph.D. in physics	Particle physics exeperiment	2023/09/25 ～ 2023/09/26	AI－Smart JSPS Core-to-Core Program:AI-Smart Kick Off Workshop
39	Catrin Bernius	41	Researcher, SLAC	USA	Ph.D. in physics	Particle physics exeperiment	2023/09/25 ～ 2023/09/26	AI－Smart JSPS Core-to-Core Program:AI-Smart Kick Off Workshop
40	Rainer Bartoldus	56	Senior Scientist, SLAC	USA	Ph.D. in physics	Particle physics exeperiment	2023/09/25 ～ 2023/09/26	AI－Smart JSPS Core-to-Core Program:AI-Smart Kick Off Workshop
41	Stephanie Majewski	42	Faculty, University of Orego	USA	Ph.D. in physics	Particle physics exeperiment	2023/09/25 ～ 2023/09/26	AI－Smart JSPS Core-to-Core Program:AI-Smart Kick Off Workshop
42	Yannik Buch	28	PhD student, Georg-August-University, Goettingen	Germany	Ph.D student	Particle physics exeperiment	2023/09/25 ～ 2023/09/26	AI－Smart JSPS Core-to-Core Program:AI-Smart Kick Off Workshop
43	Nils Halverson	56	Professor, University of Colorado Boulder	USA	Ph.D. in physics	Astroparticle physics	2023/09/26 ～ 2024/3/31	Discussion on the LiteBIRD/QUP-SpaceTES project
44	Tylor Adikns	26	PhD students, University of California, Barkeley	USA	Ph.D student	Particle physics exeperiment	2023/10/01 ～ 2023/11/13	QUP internship program (QUPIP)
45	William Derocco	29	Postdoctoral researcher, Santa Cruz Institute for Particle Physics	USA	Ph.D. in physics	Particle physics theory	2023/10/13 ～ 2023/11/19	QUP internship program (QUPIP)
46	Silvia Micheli	27	Graduate student, Sapienza Universita di Roma	Italy	Ph.D student	Astroparticle physics	2023/10/16 ~ 2023/12/29	Visitor with an EU-RISE program (CMB-Inflate)
47	Serena Giardiello	27	Graduate student, Cardiff University	UK	Ph.D student	Astroparticle physics	2023/10/2 ~ 2023/11/30	Visitor with an EU-RISE program (CMB-Inflate)

48	Maarif Miftahul	28	Ph.D. Student, National Central University, Taiwan	Taiwan	Ph.D student	Particle physics exeperiment	2023/11/09 ～ 2023/12/09	QUP internship program (QUPIP)
49	Joseph Silk	81	Professor Johns Hopkins U. & Oxford U. & IAP, Sorbonne U.	USA	Ph.D. in physics	Astroparticle Physics 2007 Royal Society Bakerian Medal 2011 Balzan Prize 2019 Gruber Prize in Cosmology	2023/11/10 ～ 2023/11/10	Speaker of the QUPseminar
50	Giovanni de Lellis	50	Professor, University of Naples	Italy	Ph.D. in physics	Particle physics theory	2023/12/05 ～ 2023/12/07	Paticipation as a speaker at QUPosium2023
51	Fujiwara Makoto	55	Senior Scientist and Head, TRIUMF CANADA Particle and Nuclear Physics	Canada	Ph.D. in physics	Particle physics exeperiment	2023/12/08 ～ 2023/12/19	Paticipation as a speaker at QUPosium2023
52	Tracy Slatyer	39	Professor, Massachusetts Institute of Technology	USA	Ph.D. in physics	Particle physics theory	2023/12/09 ～ 2023/12/13	Paticipation as a speaker at QUPosium2023
53	Joseph Eimer	42	Associate Research Scientist, Johns Hopkins University	USA	Ph.D. in physics	Astroparticle physics	2023/12/09 ～ 2023/12/14	Paticipation as a speaker at QUPosium2023
54	Gordan Krnjaic	40	Assistant Professor, University of Chicago	USA	Ph.D. in physics	Particle physics theory	2023/12/09 ～ 2023/12/17	Paticipation as a speaker at QUPosium2023
55	Henry Grasshorn Gebhardt	38	Postdoc, California Institute of Technology(Caltech)	USA	Ph.D. in physics	Astroparticle physics	2023/12/09 ～ 2023/12/18	Paticipation as a speaker at QUPosium2023
56	Stefano Profumo	45	Professor, Univ. of California(UC) U.S.A. Santa Cruz	USA	Ph.D. in physics	Particle physics theory	2023/12/10 ～ 2023/12/13	Paticipation as a speaker at QUPosium2023
57	Roni Harnik	48	Scientist , Fermi National Accelerator Laboratory	USA	Ph.D. in physics	Particle physics exeperiment	2023/12/10 ～ 2023/12/15	Paticipation as a speaker at QUPosium2023
58	Alexander Kusenko	57	Professor, Univ. of California(UC) U.S.A. Los Angeles	USA	Ph.D. in physics	Particle physics theory	2023/12/11 ～ 2023/12/13	Paticipation as a speaker at QUPosium2023
59	Yuki Inoue	37	Associate Professor, National Central University	Republic of china (Taiwan)	Ph.D. in physics	Astroparticle physics	2023/12/11 ～ 2023/12/13	Paticipation at QUPosium2023
60	Adam Riess	54	Johns Hopkins University and the Space Telescope Science Institute	USA	Ph.D. in physics	Astroparticle physics 2011 Nobel Prize in Physics 2006 Shaw Prize in Astronomy 2011 Albert Einstein Medal 2015 Breakthrough Prize in Fundamental Physics	2023/12/12 ～ 2023/12/12	Paticipation as a speaker at QUPosium2023 (remote)
61	Huilin Qu	32	Senior Scientist, CERN	Switzeland	Ph.D. in physics	Particle physics exeperiment	2024/01/06 ～ 2024/01/12	Paticipation as a speaker at ML at HEP workshop
62	Vinicius Mikuni	30	Researcher, Lawrence Berkeley National Laboratory	USA	Ph.D. in physics	Particle physics exeperiment	2024/01/07 ～ 2024/01/14	Paticipation as a speaker at ML at HEP workshop
63	Darius Faroughy	32	Faculty, Rutgers University	USA	Ph.D. in physics	Particle physics theory	2024/01/09 ～ 2024/01/10	Paticipation as a speaker at ML at HEP workshop

64	Gregor Kasieczka	39	Faculty, Universitat Hamburg	Germany	Ph.D. in physics	Particle physics exeperiment	2024/01/09 ～ 2024/01/10	Paticipation as a speaker at ML at HEP workshop
65	Myeonghun Park	41	Faculty, Seoul National University of Science and Technology	Korea	Ph.D. in physics	Particle physics theory	2024/01/09 ～ 2024/01/10	Paticipation as a speaker at ML at HEP workshop
66	Sung Hak Lim	34	Postdoc, Rutgers University	USA	Ph.D. in physics	Particle physics theory	2024/01/09 ～ 2024/01/10	Paticipation as a speaker at ML at HEP workshop
67	Jianing Wang	26	Ph.D. Student, Chinese Academy of Sciences(CAS) CHINA Institute of	China	Ph.D student	Particle physics theory	2024/01/10 ～ 2024/03/12	QUP internship program (QUPIP)
68	Junsong Lin	34	Assistant Project Scientist, University of California Berkeley	USA	Ph.D. in physics	Particle physics exeperiment	2024/01/20 ～ 2024/03/02	QUP internship program (QUPIP)
69	Chuan Liao	30	Ph.D graduate, Universität Hamburg	Germany	Ph.D. in physics	Particle physics experiment	2024/01/21 ～ 2024/01/27	Discussion on radiation hard detectors
70	Clément Walter	29	Ph.D graduate, Ecole Normale Supérieure	France	Ph.D student	Astroparticle physics	2024/01/30 ～ 2024/03/31	QUP internship program (QUPIP)
71	Surjeet Rajendran	40	Associate professor, Johns Hopkins U.	USA	Ph.D. in physics	Astroparticle physics	2024/02/21 ～ 2024/02/22	Speaker of the QUPseminar
72	Eugenia di Giorgi	29	Ph.D. Student, Trento Univ. ITALY Dept. of Physics	Italy	Ph.D student	Astroparticle physics	2024/03/02 ～ 2024/03/31	QUP internship program (QUPIP)

Appendix 6 FY2023 State of Outreach Activities

* Fill in the numbers of activities and times held during FY2023 by each activity.
* Describe the outreach activities in the "3-1. Societal Value of Basic Research" of Progress Report, including those stated below that warrant special mention.

Activities	FY2023 (number of activities, times held)
PR brochure, pamphlet	QUP general brochure minor update (English 1, Japanese 1)
Lectures, seminars for general public	QUP public lecture (1), Science Lecture to the public (3),
Teaching, experiments, training for elementary, secondary and high school students	QUP Site visits by junior high school students (1), high school students (2)
Science café	On the occasion of the KEK Open House (1)
Open houses	In Collaboration with KEK Open House (2)
Participating, exhibiting in events	WPI Symposium (1), Science Agora (1)
Press releases	Web news posting in Japanese (23), in English(19)
Publications of the popular science books	YouTube video release: QUP introduction (1), QUP three minute talk (4: Japanese), QUP lecture (9)
Others（　　　　　　）	

*If there are any rows on activities the center didn't implement, delete that (those) row(s). If you have any activities other than the items stated above, fill in the space between parentheses after "Others" on the bottom with the name of those activities and state the numbers of activities and times held in the space on the right. A row of "Others" can be added, if needed.

Outreach Activities and Their Results

List up to three of the Center's outreach activities carried out in FY 2023 that have contributed to enhancing the brand or recognition of your Center and/or the brand of the overall WPI program, and describe its concrete contents and effect in narrative style. (Where possible, indicate the results in concrete numbers.)

Examples:
- As a result of using a new OO press-release method, a OO% increase in media coverage was obtained over the previous year.
- By holding seminars for the public that include people from industry, requests for joint research were received from companies.
- We changed our public relations media. As a resulting of using OO to disseminate information, a OO% increase in inquiries from researchers was obtained over the previous year.
- As a result of vigorously carrying out OO outreach activity, ¥OO in external funding was acquired.

As already shown in section 3-1 of the main document, QUP's YouTube channel and official Twitter have opened.

- In the YouTube channel, the view counts increased by a factor 10.
- On Twitter, we posted 106 (75) Japanese (English) tweets and got 170k (20k) reactions.

The first lecture for the general public was held on March 24, 2024. We targeted high school students, and they comprised 30% of the participants. We set an opportunity for the attendants to talk with QUP researchers, including foreign researchers. The survey shows that this attempt was strongly supported, so we will organize this type of event regularly in the future.

Appendix 7 FY 2023 List of Project’s Media Coverage

* List and describe media coverage (e.g., articles published, programs aired) in FY2023.

* Enter the host institution name and the center name in the footer.

	Date	Types of Media (e.g., newspaper, magazine, television)	Description
1	May 2023	Cable TV in Tsukuba city (ACCS) and YouTube	14 minute program to introduce research insitutes in Tsukuba city title as "Tsukuba de Kagaku (Sicence in Tsukuba) No.24. QUP senior scientist, Prof. Hiroki Akamatsu gave a pulic lecture on the low temperature detector. (https://www.youtube.com/watch?v=SfRKnQoAIVk)
2	June 2023	Cable TV in Tsukuba city (ACCS) and YouTube	14 minute program to introduce research insitutes in Tsukuba city title as "Tsukuba de Kagaku (Sicence in Tsukuba) QUP researchers and facility were introduced. (https://www.youtube.com/watch?v=0bLFSntTclA&t=91s)
3	January, 7, 2024	Newspaper (Nihon Keizai Shinbun)	QUP-PI's acticities on the Casimir force
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