World Premier International Research Center Initiative (WPI)
FY2022 WPI Project Progress Report

Host Institution	High Energy Accelerator Research Organization (KEK)	Host Institution Head	Masanori Yamauchi
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 2023) 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**)

The main objective of QUP is to invent and develop a measurement system with higher sensitivity using known quantum fields in order to explore and discover new quantum fields. While many previous attempts have used photons and electrons as probes, QUP will open up many possibilities, including quasiparticles such as phonons. Once the basic R&D has been completed and matured, the goal is to implement it in cutting-edge experiments for studies of the Universe and particles. The discovery of even one new quantum field would be a major achievement that would pioneer new physics. We will also promote social implementation and innovation using our inventions.

In FY2022, the following progress and results have been obtained.

- Achievements in the development of low-temperature detectors, especially the Superconducting Transition Edge Sensor (TES).
- Narrowing down the candidate search for new quantum fields.
- Development of radiation hard detector.

QUP has 13 PIs. Six of them are TES experts and are advancing applications in the cosmic microwave background (CMB) experiment, the dark matter search experiment, and the axion search experiment. A TES detector in the near-infrared region with the world's highest energy resolution of less than 100 meV was developed by PI Hattori and published as a paper. For the axion search and dark matter search, we have been evaluating the key backgrounds of the search. A paper describing the basic concept of the LiteBIRD project to measure CMB polarization in space was published, and the development goal of a focal plane detector applying TES, the SpaceTES project as a flagship project, was clarified.

To support these activities in a coordinated manner, four dilution refrigerators were installed as a common QUP facility; all were delivered in March 2023 and successfully tested for cooling to below 10 mK; two were used to search for dark matter, and two began to be used to develop focal plane detectors for CMB observations.

Frequent discussions on the search for unknown quantum fields, both theoretical and experimental, were carried out. As a result, we showed that it is possible to conduct an axion search using a diamond detector with an NV center, which has recently been in highlight as a high-precision magnetic field measuring instrument. We also discussed a search method using interference with the Casimir force. We submitted these results in a paper. These results were obtained from the fusion of particle research, condensed matter research, and social implementation research in the

QUP. These new ideas will be pursued further and, based on the growth of the research, they may be potential candidates for future flagship projects at QUP.

We carried out the selection of Project Q which is worth to be the QUP flagship project, in line with the main objective of QUP, which is to search for new quantum fields from known quantum fields. Nine proposals were received from both inside and outside of QUP. We have recognized that the proposal by a QUP PI M. Garcia-Sciveres to capture phonons from the recoil of dark matter-matter interactions is excellent as it will open a wide new window for light dark matter searches, although we did not choose it as a new flagship project at this stage since it requires further R&D to demonstrate low noise. Another merit of the proposal is that three PIs work jointly, which emerged through the Project Q process. We will promote the R&D for this proposal as an integral part of QUP toward the future flagship project.

In the development of radiation-resistant detectors, CIGS semiconductors ($Cu(In,Ga)Se_2$) were shown to have the ability to recover from radiation damage and to be promising as particle detectors. Development of thicker devices for use in particle experiments and demonstration of the long-term sustainability of the recovery function are underway.

There were many decisions made with KEK on the organizational governance of QUP at KEK. The QUP director has the primary responsibility for the QUP researcher appointments and supporting staff, as written in the previous report. This year, specific bylaws were set up for the QUP director to negotiate with the individuals to determine their salary. QUP and KEK have made a sustainable financial plan beyond the WPI funding period.

As a new common research facility, it was approved to renovate and refurbish the QUP building to integrate the experimental and research areas, in line with the WPI's "one roof" concept. The construction is scheduled to be completed by the end of FY2024.

QUP established the organization structure and mid-term plan of the systemology support section to breed and foster brand-new excellent research concepts from a fusion of ideas of QUP individual researchers with the help of systemology approach. In addition, QUP has established a new position for an engineer: Principal Engineer. With this position and by making the above-mentioned salary negotiation system, it has become possible to attract skilled engineers. The first Principal Engineer will come to the Systemology Support Section of QUP in May 2023.

The establishment of all three satellite offices has been completed. The last remaining QUP Berkeley Satellite at the University of California, Berkeley became operational in December 2022.

The QUP webpage provides specialized research results and research-related news, and in September 2022, a Twitter and YouTube channel were established for publicity to reach a wider public, with an audience of high school students in mind.

A new education program called "QUP Internship Program (QUPIP)" is set up, which will give young researchers the opportunity to stay at QUP and work with QUP researchers. Applications for the program will open in April 2023 for domestic and foreign graduate students and post-doctoral fellows, and acceptance will begin in July 2023.

* 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 2022.
* 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.

[Research Objectives]

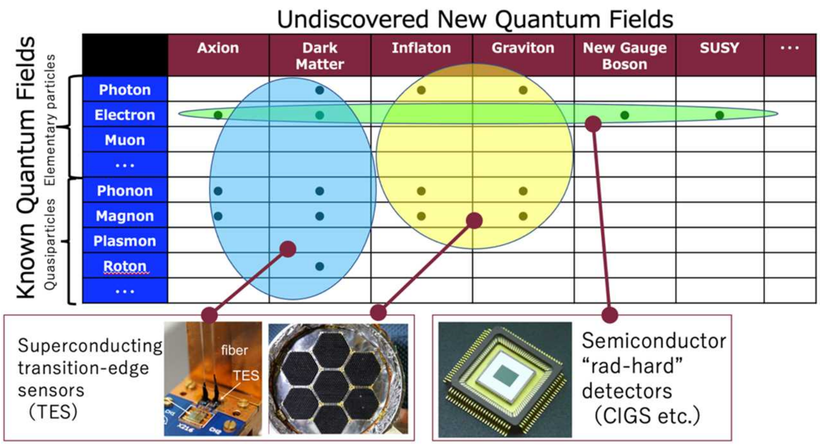

Fig. 1. QUP invents new measurement systems more sensitive than ever at intersections of new and existing quantum fields. QUP primarily covers intersections with "●" and will go beyond.

In a nutshell, the activity of QUP is to invent measurement systems with unprecedented sensitivity to discover new quantum fields, taking full advantage of the quantum properties of well-known quantum fields. This vision is shown schematically in Fig. 1. Many previous attempts are with photons and electrons as the probe. At QUP, our inventions are expanding to other quantum fields, including quasiparticles such as phonons. Also, many previous attempts rely on particle pictures of the probe. At QUP, we are keen on quantum enhancements due to coherence and entanglement to invent our new measurement systems.

QUP is home to many PIs who are experts in detector development, particularly for the low-temperature detectors such as transition-edge sensors (TES) illustrated in (blue/yellow) and the rad-hard detectors in green in Fig. 1. The development of low-temperature detectors has two use cases: ground-based experiments (blue) and space-based observations (yellow). The latter, the newly named SpaceTES project, is the flagship project of QUP with the LiteBIRD satellite. In addition to these groups, we have a cluster of PIs developing new quantum detectors and a cluster for improving analyzing methods to increase sensitivity, which is, so to speak, "giving a better sight."

The interaction with the theory group is critical to defining which unknown quantum fields to explore with these detectors, and enhance our interdisciplinary research. The systemology group also supports concept studies of research. These two elements create synergy among QUP's research clusters (Fig. 13.)

Once basic R&D is completed and our inventions reach a higher level of maturity, we aim to implement them into state-of-the-art experimental studies on the Universe and particles. The discovery of any one of the new quantum fields shown in the columns of Fig. 1 will pioneer new physics and is sure to win the Nobel Prize in Physics. QUP's inventions for studies of the Universe and particles will lead to applications to society. QUP's strong tie to the Toyota Central R&D Labs., Inc. is a window to this direction.

[Research achievements: Introduction]
One year after QUP's establishment, we have had various developments and achievements. This section presents these in a categorized manner in close connection to the QUP's research structure.

- Targeting the search candidates of the new quantum field with the new methods.
- Advancement on low-temperature detectors, especially on TES in various applications and in the collaborative activities at QUP.
- Focusing on the rad-hard device development.

[The new quantum field searches]
Frequent discussions on the search for unknown quantum fields were carried out with many theorists and experimentalists, under the initiative of the QUP director. It has resulted in two proposals for new measurement methods with quantum sensors, as shown below. The other activities, such as the searches in the collider experiments and discussion in connection to the project Q selection are also highlights of the year.

Light dark matter search with nitrogen-vacancy centers in diamond
The nitrogen-vacancy center consists of a nitrogen atom substituting a carbon atom adjacent to a vacancy in the diamond. The NV diamonds have been in the spotlight as a high-precision magnetic field measurement device in recent years, in the area of condensed matter physics and applications. The PI. K. Nakayama and his QUP collaborators have proposed new ideas to directly search for light dark matter, such as the axion or the dark photon, by using magnetometry with nitrogen-vacancy centers in diamonds (https://arxiv.org/abs/2302.12756). They gave several concrete examples to estimate the sensitivity of dark matter couplings. As an illustration, the expected sensitivity on the axion-electron coupling constant as a function of the axion mass is obtained through a magnetometry method (Fig. 2). This brand-new interdisciplinary study demonstrates how recent developments in engineering and industrial science are instrumental in solving fundamental physics problems.

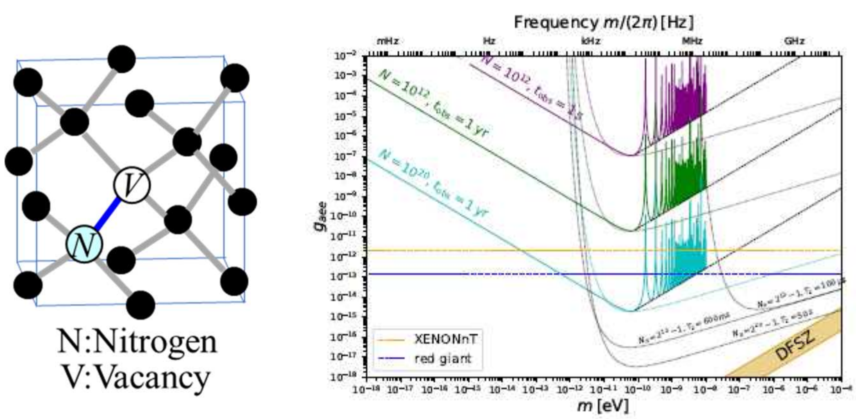

Fig. 2. The reach of diamond NV-center magnetometry on the axion dark matter model. The labels of the vertical and horizontal axes represent the axion-electron coupling constant and the axion mass.

Zero Casimir force for new force search

New force search is of great importance since it is mediated by new particles that often appear in models of physics beyond the standard model. Depending on the new particle mass, measurements of a short-range force at the micrometer scale have so far provided the best sensitivity for new force search. To probe such new force, the Casimir force is an obstacle, which we want to remove. PI. K. Nakayama, H. Iizuka, and their collaborators point out that there is a stable configuration of metal plates where the Casimir force is vanishing, by introducing non-reciprocal materials (https://arxiv.org/abs/2302.14676). They consider a concrete setup involving Weyl semimetals (Fig. 3) for practical experiments. Remarkably, their setup realizes zero Casimir force between metals, by selecting a proper choice of the vacuum gap. The result may be useful for the search for new force mediated by light particles at the micrometer scale.

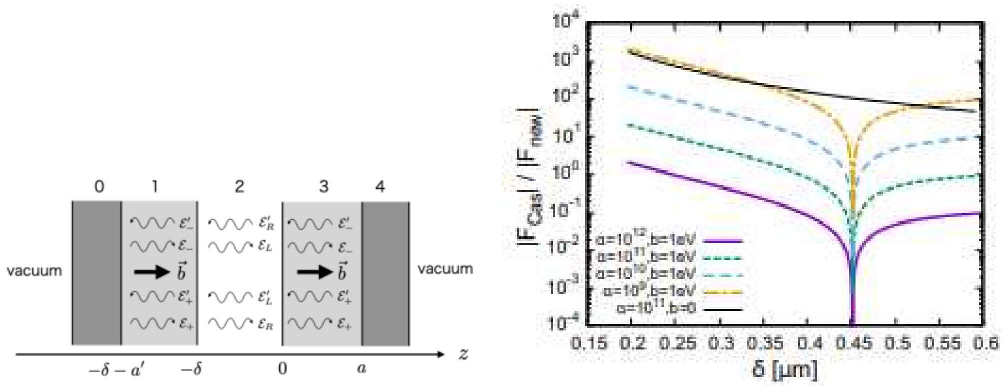

Fig. 3. The ratio between the Casimir force |FCas| and new force |Fnew| for various choice of new force strength.

New Field searches at the collider experiments

The search with the already taken collider data are also in progress. It is our QUP mission to improve the search capability with the new technique of machine learning. New particle searches at LHC, CERN, have also been improving with the development of new methods. Usually, there is a problem that the background becomes a similar distribution to the new particles after selections to increase the signal sensitivity. QUP Senior Scientist J. Montejo-Berlingen has been developing model-independent methods with invariant mass to search for new particles. As shown in Fig. 4., even complex events with a single muon and 15 jets can be included in a search for SUSY particles with R-parity violation, demonstrated in 2021. Events are simpler, but this analytical method was also applied this year to W' and Z' searches. (https://arxiv.org/abs/2211.08945).

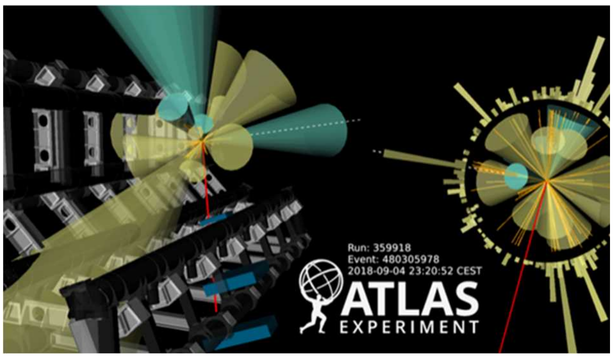

Fig. 4. SUSY candidate event with 15 jets.

Spin off from the project Q discussion

An international workshop for Project Q was held in November 2022 in order to discuss new ideas for using quantum devices as tools for the discovery of new quantum fields in terrestrial laboratories as well as space missions. Nine proposals from inside or outside QUP were received. We reaffirmed that the low-temperature detector technology we are advancing, such as TES, will further expand

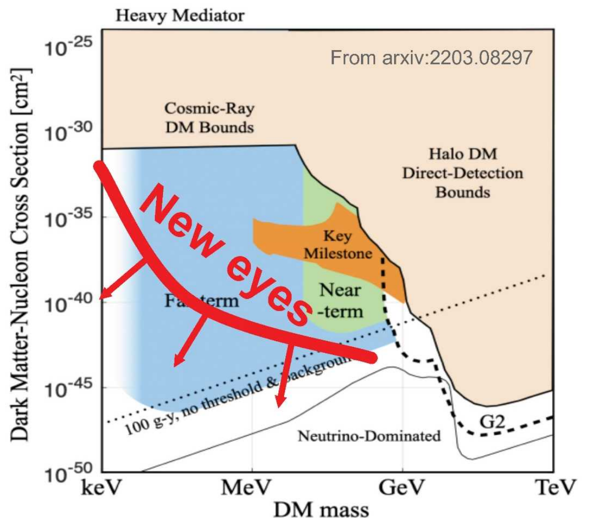

Fig. 5. Dark Matter sensitivity with "New eyes" with phonon detection.

the possibilities for a wider range of new particle searches.

Among the proposals, the experimental plan presented by QUP PI M. Garcia-Sciveres to capture phonons from the recoil of dark matter-matter interactions shows that we can widely perform the search for dark matter in lower mass regions than before as illustrated in Fig. 5. There is a common goal with PIs Hattori and Hasegawa in the development of the low-noise environment for phonon detection. It can be promoted as an integral part of QUP. We decided to promote this project, although not yet as the flagship project Q, by making good use of the low-temperature facility as described in section 1-2 and with an extension of the facility to its low background environment.

Searches for the new fields in space

QUP theorists have significantly contributed to the wider range of ways to search for the new quantum fields which govern our universe. PI. K. Nakayama discussed the implication of the anomaly in the cosmic optical background [12] (in the reference listed in Appendix 1-1). QUP Senior Scientists V. Takhistov proposed various observables to test the case that primordial black holes are the origin of dark matter [14].

Measurement theory in the relativistic quantum field

The recent developments in quantum technologies and quantum sensors enable new types of experiments for discovering various candidates of dark matter particles by utilizing the entanglement of matter and its decoherence. Many studies were based on non-relativistic theory. QUP Senior Scientist S. Iso and his colleagues analyzed entanglement generation by relativistic quantum field theories and showed a trade-off relation between the visibility of the interference pattern and the distinguishability of quantum measurement [15].

[Low-temperature Detector]

There are six PIs at QUP, who are experts in TES. They are working on applications in the CMB experiment, dark matter, and axion search experiments. To support these activities in a coordinated manner, four dilution refrigerators were installed in March 2023 at the Fuji laboratory as a common facility of QUP. This will be described in section 1-2.

World records in the high-resolution one-photon detector using TES

As already mentioned as a preliminary result in last year's report, PI Hattori developed a TES detector in the near-infrared region with a world-record energy resolution of 67 meV and published it in a

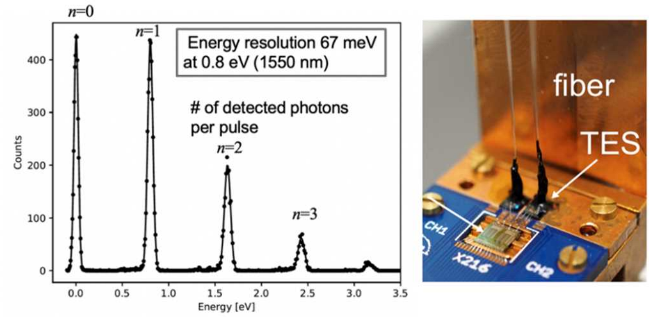

Fig. 6. World record on energy resolution on the single photon paper, in September 2022 [2]. (Fig. 6)

Origin of the noise for detecting phonons with TES

PI. Garcia-Sciveres has been working on the performance of the device against noise, which is the key to the search for dark matter as discussed in the project Q. In a new report published in August; "A Stress Induced Source of Phonon Bursts and Quasiparticle Poisoning" [149], it is shown that material stress is a major source of low energy backgrounds, and we are working on methods to reduce and discriminate stress backgrounds, in a systematic approach.

Design documents of the LiteBIRD

The paper on the LiteBIRD project, which was reported in the previous report as the first QUP submitted paper, was published in November [1]. The paper defines the scope of the main development in the QUP's flagship project, SpaceTES, as it provides the basic concept of the LiteBIRD project to measure CMB polarization in space, including scientific objectives, mission and system requirements, operation concept, spacecraft and payload module design, expected scientific outcomes, potential design extensions, and synergies with other projects.

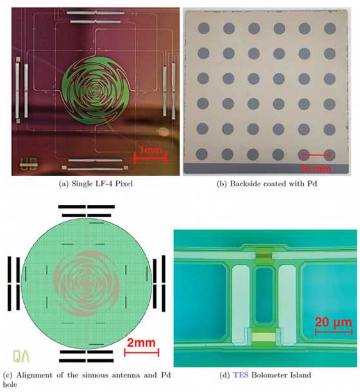

Fig. 7. Design of TES detector for LiteBIRD

The development of a superconducting TES detector system for the SpaceTES project is being carried out as a flagship project at QUP. The group demonstrated a low noise level of the TES detector that meets performance requirements for millimeter waves [1] and established a new design that minimizes phonon noise from cosmic rays by applying palladium to the back surface of the detector [17].

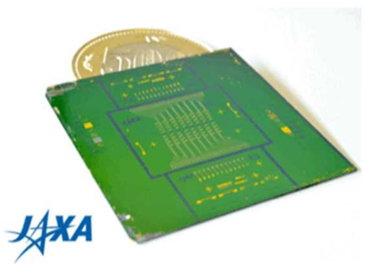

Fig. 8. TES array with iron absorber.

TES array with iron absorbers

PI. N. Yamasaki and her group developed a TES detector array utilizing iron absorbers for Solar axion search. Thanks to the micro-machining facility at the ISAS satellite, they updated and optimized the design of this dedicated TES array. This year, they tuned the electroplating process and fabricated a 64-pixel array with normal ^{56}Fe absorbers which are connected to TES by gold thermal transfer straps. The thickness and estimated thermal conductivity satisfy the requirements. (The results were submitted in April 2023 (https://arxiv.org/abs/2304.09539).

[Development of rad-hard detector]

The PIs in the rad-hard cluster work for every aspect of the detector system to work in the high-radiation environment. Following the QUP's mission of integrating components from front-end to back-end, the system includes not only the new detectors but also the readout electronics; ASICs and FPGAs.

Annealing effects of CIGS semiconductor

In the development of radiation-hard detectors, PI. M. Togawa and his group have demonstrated that CIGS semiconductors ($Cu(In,Ga)Se_2$) have a recovery function from radiation damage and are promising as particle detectors. They are developing a thicker device for use in particle physics experiments and also demonstrating whether the recovery function is sustainable over the long term. The first results on the annealing effect shown in Fig. 9 (in the application to solar cells) is being published in the Japanese Journal of Applied Physics (2023) 62 and awarded as Spotlights 2023 of the journal. Further beam test was performed by 400 MeV/u $^{132}Xe^{54+}$ ions at HIMAC in Nov. 2022, to study the single particle response of the device. Various annealing conditions were tested.

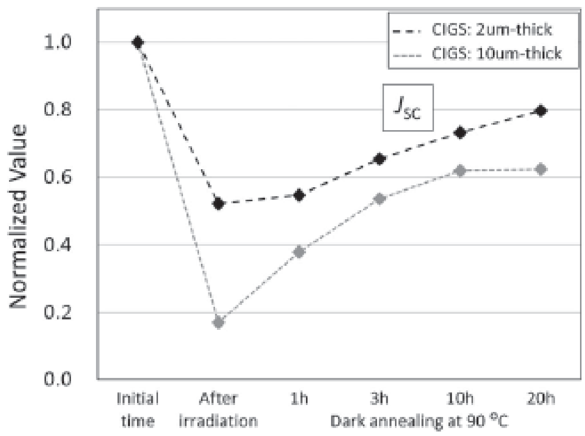

Fig. 9. Change in the short-circuit current density of the CIGS solar cells after proton irradiation with 1 × 10^{16} MeVneq cm^{-2} and dark annealing at 90 °C.

Gallium Nitride Detector

At the HIMAC experiment, the GaN strip sensor was also irradiated. The analog signals from the sensors for 32 channels were successfully converted to digital data using the ADC built into the ASIC, developed by PI. M. Miyahara. The group succeeded in demonstrating that the GaN can be used for strip sensors shown in Fig. 10. This is the first step and further optimization is ongoing.

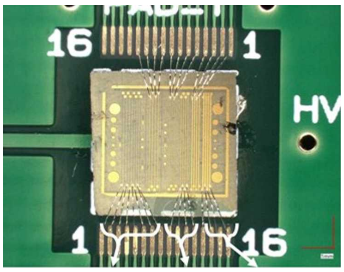

Fig. 10. The GaN strip detector

Rad-hard Silicon Detector

In terms of radiation tolerance of silicon semiconductor detectors, PI. D. Bortoletto and her group have focused on the Low Gain Avalanche Detector (LGAD) and the MALTA Depleted Monolithic Active Pixel Sensors (DMAPS). The production of LGADs with T-e2v focused on 50 μm thick devices with 8 different combinations of gain layer (GL) implant dose and energy [29,32]. The devices were irradiated with neutrons up to 1x10^{16} 1 MeV $n_{eq}cm^{-2}$ and initial measurements were completed. The effects of neutron irradiation on MALTA2 on Epitaxial (Epi) and Czochralski (CZ) substrates were obtained using a pion beam at the CERN North Area. Sensor efficiencies as a function of applied bias were compared pre- and post-neutron irradiation to the fluence of 2x10^{15} 1 MeV $\mathrm{n_{eq}cm^{-2}}$[34]. The measurements show that the MALTA-Cz outperform MALTA-Epi, reaching an efficiency of over 95% after irradiation. The MALTA2 sensors are fabricated using the Tower Semiconductor 180 nm CMOS imaging process

Rad-hard readout for High Luminosity LHC

As the silicon device is the only solution for the near-term application, PI M. Garcia-Sciveres continues his role as a co-spokesperson of the RD53 Collaboration at CERN, producing the pixel readout chips for the ATLAS and CMS experiments at the HL-LHC. In April 2023, the group finally submitted for fabrication of the final production chip for ATLAS. These chips will also be used for the above-mentioned CIGS sensor development.

Novel device development

PI N. Taniguchi is developing future read out device. The group has performed irradiation tests of atom-switch FPGA at the hadron beam line in J-PARC. Leak current has been monitored and recorded during accelerator operation. Data analysis is ongoing and we may try a similar test at the next chance during beam operation.

Automation of Analog ASIC design

Generally, ASICs used in physics experiments require analog circuits to read out signals. Analog ASIC development is not automated so far, it takes months to years. In addition, expert engineers are required for development, and it takes more than 10 years to train expert engineers. So, securing human resources is one of the challenges. To address these issues, PI. M. Miyahara is trying to create a platform that automatically synthesizes analog circuits from ASIC target specifications and process data. Operational amplifiers (OPAMP), comparators, DACs, and ADCs are commonly used in analog ASICs. In 2022, he completed an automatic synthesis environment for OPAMP, comparators, and DAC. Fig. 11 shows a part of the program used to generate the OPAMP and a layout diagram of the generated one. The work is extended to combine the systemology research described in the next section.

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."

[Scientific results from the fused activities]

Researchers in different fields have been meeting at QUP, resulting in two theoretical proposals of new usages of quantum detectors. As presented in the previous section, a new QUP preprint submitted in February 2023 shows that the NV-diamond sensor, which is been rapidly developed in

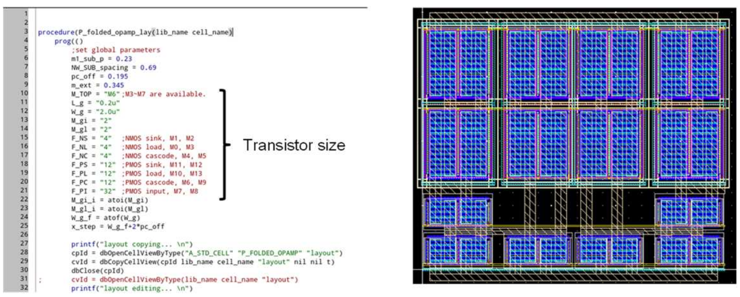

Fig.11. Program code to generate operational amplifiers and the generated one.

the application field, can open a new window in dark matter searches. The Casimir force, on which QUP PI, Dr. H. Iizuka and his group in the QUP Satellite in Toyota Central R&D Labs., Inc. are working, also impacts the axion searches and new force searches to solve fundamental questions in physics.

[Fused action toward the society]

After forming a QUP satellite in Toyota Central R&D Labs., Inc. on April 1, 2022, intensive discussions were made to define the roles of the satellite. As for projects for society, several areas of common interest are identified. Therefore, we are also launching a new consortium, led by the satellite, to further discuss these topics and to plan and promote collaborative research with industrial partners. One of them is to deepen the understanding of the single event upset, which was caused by environmental irradiation, such as cosmic rays, and can result in the malfunction of a programmable controller. The effect may generate big problems in smart cities, where a huge number of programmable controllers are operational. As a regular event of the consortium, a forum called "QUP Synergy Summit (QSS)" is being created by the initiative of the QUP satellite in Toyota Central R&D Labs., Inc., where the researchers in QUP, other labs in KEK, and various companies in interest gather together. A kickoff meeting is planned in July 2023.

[QUP facilities for the fused research]

Since the beginning of the QUP foundation, we have noticed the importance of having common QUP facilities QUP researchers are able to use. The first such facility identified is for low-temperature detectors, which was actualized with the FY2021 and FY2022 budgets. In March 2023, we started the operation of four dilution refrigerators in the Fuji experimental hall at KEK (Fig. 12). We completed the initial operation tests, demonstrating the capability to reach below 10mK. The system is used for developing quantum detectors at low temperatures, as reported in the previous sections. Two of them will be used mainly by K. Hattori and M. Garcia-Sciveres for the detectors of dark matter searches and the other two for the SpaceTES project, i.e. the development of focal plane detectors for the LiteBIRD space mission. KEK has implemented a new test beam facility in the electron accumulator ring. The first beam was successfully extracted in March 2022, and studies to optimize the beam parameters took place. The facility will also be an excellent experimental platform for QUP.

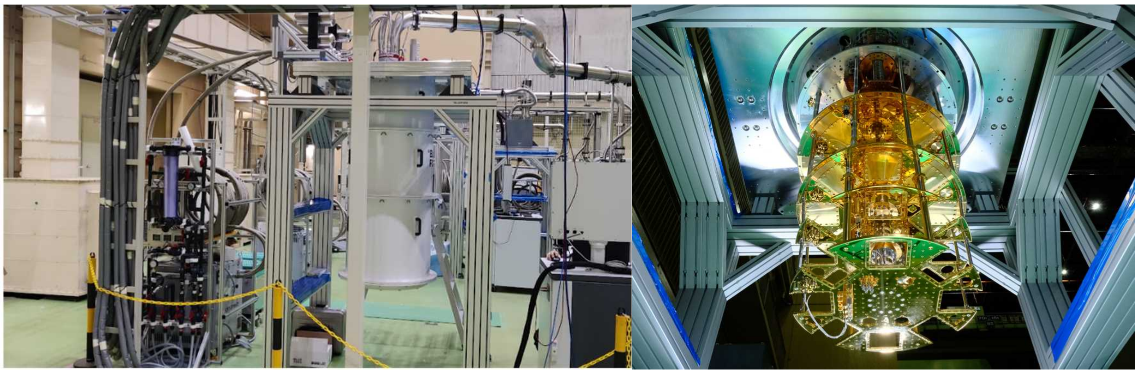

Fig. 12. Dilution refrigerators installed in Fuji experimental hall.

The next plans to facilitate the fused research among QUP researchers are to set up a large-volume clean environment for pursuing reliable measurements. In connection to the building of a new/renovated building complex, a large-volume anechoic room against a wide range of radio wave and a large-volume cold room with ~4K degrees are planned. Design works for the rooms were almost completed in FY2022. The basic performance test will be held in FY2023, and then finally, they will be placed in FY2024 in the experimental area of the building complex.

[QUP structure for better researcher interaction and planning]

One year passed since the foundation of QUP, and we clarified the QUP research structure as shown in Fig. 13.

- Flagship Project
  The SpaceTES project is the QUP flagship project. It was renamed from the LiteBIRD project to avoid confusion with the LiteBIRD satellite itself. The primary role of the project is to design, fabricate, and validate the TES detector subsystem of its Low-Frequency Telescope (LFT) and to deliver the flight model for the LiteBIRD satellite. LiteBIRD is a mission to explore the universe before the hot Big Bang proposed by the QUP director and selected as JAXA's mission.
- Research Clusters
  It became clear that the cluster structure of the research is more suitable. In the report in the previous year, the cluster was defined as "Weakly-bound formation of the PI-led projects". But now, this is the central structure of the QUP. We have formed 3 clusters for detector/device development and one for the backend of the measurement.
  - Low-temperature detector cluster
  - Quantum detector cluster
  - Rad-hard device cluster
  - Data acquisition and analysis cluster

In addition to these instrument development research clusters, the Theory Group and Systemology study group are related to all of these clusters and will enhance synergy among them.

As for Systemology, Prof. Kazuhisa Mitsuda, Senior Scientist of QUP, is the leader of the Systemology Support Section since April 1, 2023. The section supports not only the SpaceTES project but also any research project at QUP. The methodology to support research projects is being investigated based on the systems engineering approach. In addition, studies of Systemology itself have also started as a separate project outside the Systemology Support Section.

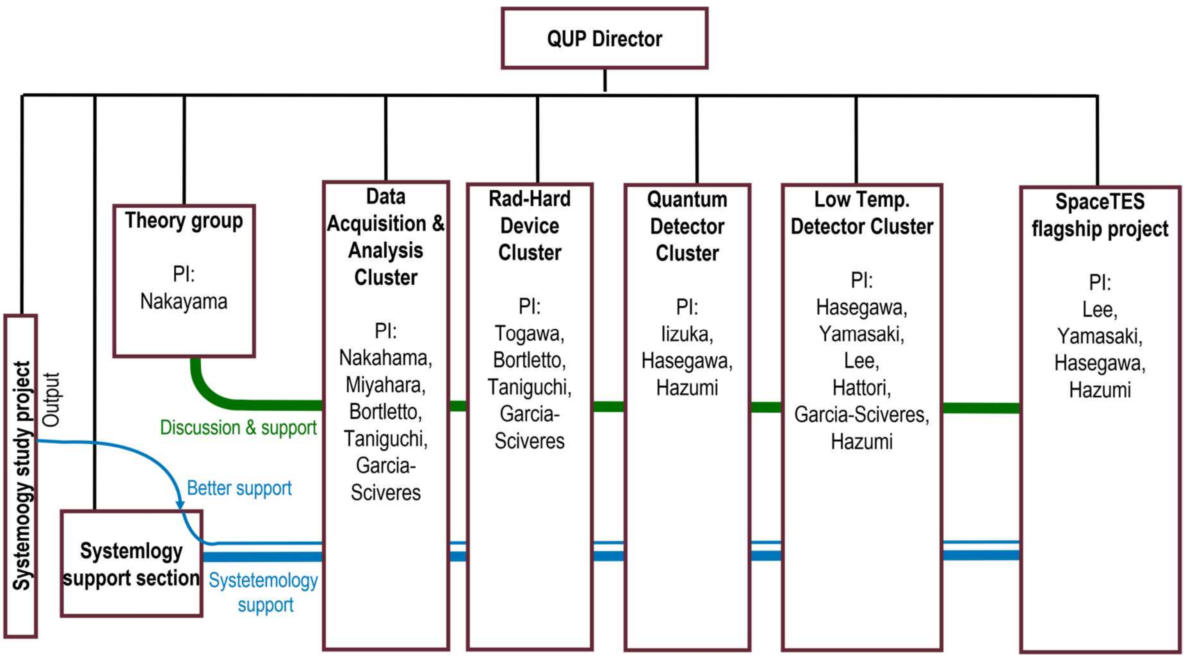

Fig. 13. The structure of the QUP research core and the interaction with the Systemology Support Section.

[Systemology support of research projects]
Systemology is an interdisciplinary field that deals with many different types of systems. Among them, systems engineering (SE) is a field that deals with engineered systems. Systemology at QUP focuses on SE but extends the scope of SE from engineered systems to research projects. Since there are lots of similarities in the concept studies of engineered systems and those for research projects, we consider concept studies of research projects can be improved by bringing systemology approach (thick blue line in Figure 13). We consider such fusion of research and systemology will bring brand-new excellent research concepts with much-improved research objectives and methods. However, since there is a difference between engineered systems and research projects, we need to tailor the SE processes before adopting them to research projects. Our short-term (a few years) goal is to establish a Concurrent Design Facility (CDF) for research projects and to use it for research-project support. In FY2022, we concentrated on establishing the Concept Maturity Level (CML) for research projects, which will be used as guidance for concept study. We conducted this activity with one of the QUP research projects and we had an interview with the PI, to create CML for relevant attributes. The figure below shows the conceptual goal image of the CDF for research projects.

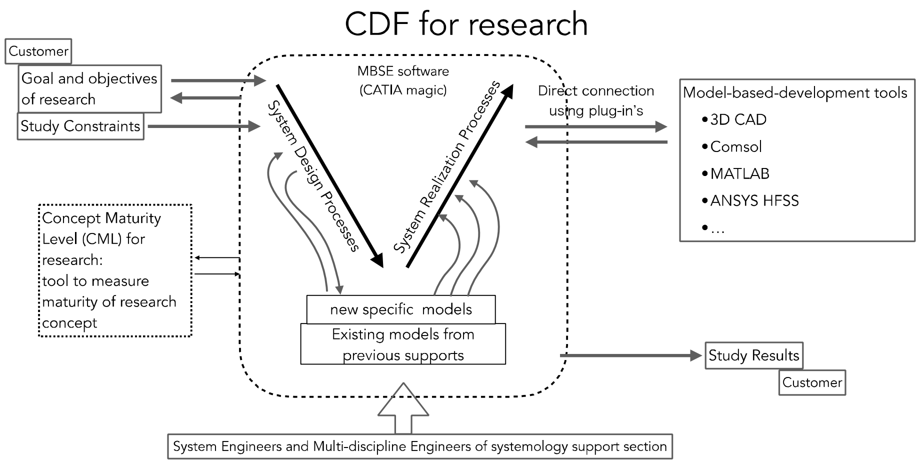

Fig. 14. the conceptual goal image of the CDF for research

[Systemology support of SpaceTES project]
We supported the SpaceTES project team to execute all necessary SE processes in concept study (Pre-Phase A) of the LiteBIRD Low Frequency Telescope's Detector Subsystem (LFT-DS). The SE processes started from requirement analysis and completed with the risk analysis to establish the technology development plan. Products from this activity form the main part of the input package for the JAXA's Mission Definition Review.

[Studies to further expand systemology support]
As described above , we are trying to expand the scope of SE from engineered systems to research projects. We also noticed other possible expansions of SE. If we set a research project as a system of interest, it is possible to take team members ("human factors") as elements of the system. Such an expansion seems to have the potential to bring "new eyes on researchers themselves." We formed an interdisciplinary study team to this end. The outcome of the study will potentially improve future systemology support, which is denoted with a thin blue line in Figure 13.
The study team has initiated two subprojects as the first step to understand the "human factors" of the research project better. In the first subproject, we try to remove human factors in the development of analog ASICs and then observe the merits and demerits. In the other subproject,

we try to model the team members or human factors using SE tools.

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)

With the requirement to contain the COVID-19 pandemic gradually relaxed toward the end of the fiscal year, the real move of researchers is getting possible. The first QUP symposium, named QUPosium, was held on 12-15/December at Tsukuba International Congress Center (Epochal). About 20 distinguished speakers were invited, with two joining online. As it was held almost one year after the foundation of QUP, the inauguration ceremony was also held.

Fig. 15. QUPosium2022

Four workshops are organized by QUP in FY2022. Two hybrid international workshops were one related to project Q, "toward Project Q" on November 7-8, and another related to machine learning named "ML at HEP" on February 23-24. A hybrid domestic workshop on radiation hard electronics was held on August 12. A purely online international workshop on Hubble Tension was co-organized by the KEK IPNS theory center on February 21-22.

A series of QUP seminars started in April 2022 and is held almost every month in total, 10 seminars were held in FY2022, mostly online. It was announced widely to the communities, and about 40 people joined each seminar on average.

The Berkeley satellite was officially inaugurated in December 2022 after the signing of the MOU. Post-doctoral and senior research fellows have been sent to advance the development of detectors at Berkeley's Marvell Nanofabrication Laboratory.

Diversity is a crucial part of QUP, as clearly stated in its code of conduct. QUP has 13 PIs with five females and three non-Japanese. The fraction of foreign researchers at QUP jumped to 30% in 2022

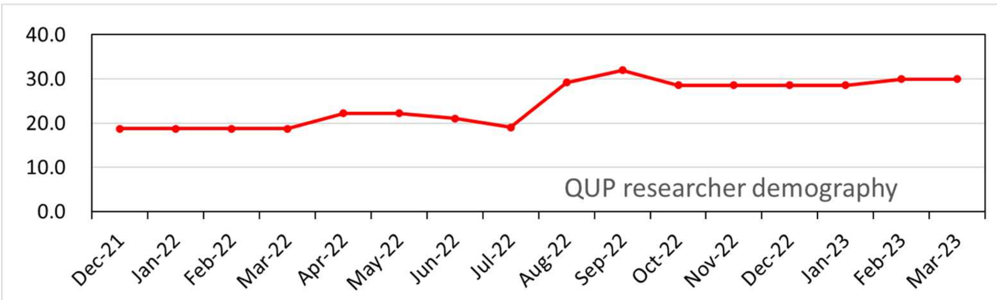

Fig. 16. QUP evolution of the fraction of foreign researchers (in %).

(Fig. 16). The female fractions are kept above 20%. The ratios are far more extensive than the KEK average.

To support the activities of a diverse group of researchers, the QUP has established a room that can be used when children are brought with researchers. A new utility toilet for women has been installed in the experimental area of the Fuji laboratory, which had a toilet on the ground floor, only.

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.

At the foundation of QUP, there were many discussions with KEK on how to harmonize the organization structure of QUP, which is a top-down institute, with the rules of KEK which is one of the inter-university research institute corporations where the opinions of the user community are strongly reflected in the lab operation. An agreement was made at the start of QUP so that the QUP director takes the primary responsibility for the QUP researcher appointments and supporting staff. This ensures the leadership of the QUP director, as already reported in last year's report.

This year, specific bylaws were set up for the QUP director to negotiate with the individuals to determine their salary. The system of reporting individual cases to the KEK Director's Meeting will lead to the spread of this system to KEK as a whole in the future.

By establishing Principal Engineer as a new QUP position, and by making the above-mentioned salary negotiation system, it has become possible to improve the labor conditions of technical staff, which helps to attract good engineers. The first Principal Engineer will come to QUP in May, 2023. In line with this, changes to the 5-year term for highly skilled technical staff are under consideration.

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.

The QUP web page (https://www2.kek.jp/qup/en/) is the place to show the QUP's scientific activities. For more casual information, and for the wider audience, we started utilizing social media. Since September 2022, QUP's YouTube channel and official Twitter have opened. With an international nature of QUP, Twitter messages are posted both in Japanese and English. In

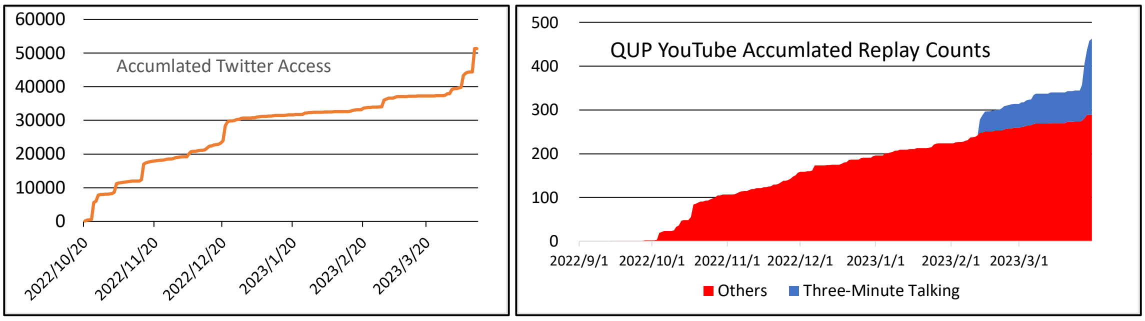

Fig. 17. History of Twitter (left) and YouTube (right) accesses.

the YouTube channel, we started introducing the researcher's interviews titled "Three minute talkings" in February 2023. The target audience is high school students, so we started with the Japanese version. Fig. 17 shows the access records to Twitter messages and YouTube videos. As for Twitter, we posted 38 (31) Japanese (English) tweets and got 45,762 (8,825) reactions. We are not yet at the stage of big influencers but will continue to send out our messages.

QUP joined the collaborative activities among the WPI institutes. In the WPI symposium organized by IRCN in November, the QUP displayed our activities in a dedicated booth. Dr. Iizuka, QUP PIs served as the moderator in the panel discussion in the symposium.

We also showed the idea of our science concepts and our goal in the various media. The director Masashi Hazumi got an interview from the CERN Courier, the widely distributed magazine of CERN in December. He was appointed as a member of the Copernican Academy in Poland in February and in the occasion of the inauguration, a video interview was taken together with the Polish minister of education and science.

The QUP researchers also gave various public talks in 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.

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.

We have established a program for accepting post-doctoral and graduate students. These early carrier scientists are able to stay for a short term (1-3 months) with the QUP researchers, at the QUP main site at KEK and also at the Berkeley satellite and the locations of QUP PIs such as Oxford and LBNL as well. The program is open for a call, and the first selection for about 15 researchers will start in May 2023. Initially, the program was considered as a program for post-doctoral fellows, but following the recommendation from the WPI program committee, it was decided that graduate students would also be eligible.

In parallel, based on an MOU held with SOKENDAI, we will apply several QUP senior scientists to be affiliated in the graduate school so that the QUP researchers are entitled to supervise their graduate students.

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.

QUP and KEK extensively discussed 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 in 10 years' time. Estimated personnel costs of 400 million yen would be required to maintain current 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 200 million yen. In order to get the resource, KEK will urgently create a general budget package for promoting new research as shown in Fig 18.

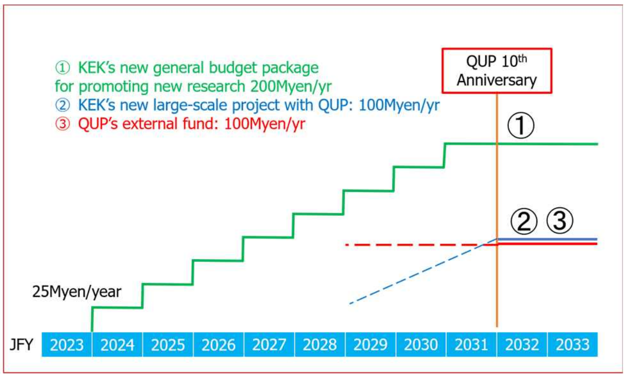

Fig. 18. KEK and QUP financial plan after 10 years.

As stated in the proposal of the WPI application, KEK's support during the WPI grant period will include the provision of facilities including office and laboratory space, cooperation in obtaining research funds, and the gradual promotion of some of QUP researchers and technicians to permanent positions after the fifth year.

Specifically, the following support has been initiated.

- An idea has emerged of having a new research building complex for QUP by renovating the old KEK facilities. The budget is now secured, and it will be completed by the end of FY2024.

Fig. 19. Plan of a new research building complex for QUP

- Before the complex is usable, KEK offered QUP to use an old KEK dormitory building as office space for increasing QUP researchers. The renovation started on January 2023 and it will be handed out to the QUP by the summer in 2023.
- The LiteBIRD project, which has an important connection with the QUP activities as the actual application for SpaceTES, the flagship project of the QUP, is included in KEK's roadmap as an important future plan. KEK has decided to list LiteBIRD in a prioritized implementation plan, referred as the project implementation plan (PIP), and to obtain budgets according to its priority.

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.

As described in QUP's proposal, we established an External Advisory Board with 5 board members. We had an in-person meeting in December and obtained useful suggestions on how to improve the organization and research implementation at QUP.

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.

Among the two reports, we will quote the items in the follow-up report in this section, as the recommendations from the two reports are almost identical. We will explicitly refer to the site visit report for some items which is specific to the report.

<u>1) Concrete identification of the actual Project Q should be done immediately. This effort should be led by QUP leadership and with the full participation of all the PIs. This will be critically important for interconnecting individual PIs and sharing QUP's vision, while alleviating the danger of devolving into an ongoing development of detectors and sensors.</u>

We started the selection of Project Q which is worth to be the QUP flagship project, in line with the main objective of QUP, which is to search for new quantum fields from known quantum fields, for example, the axion search using magnons and the dark matter search using phonons.

In response to points raised at the August 2022 site visit, we presented a more accelerated plan at the Program Committee meeting on November 2; the new plan was to set it up by the summer of 2023. After the meeting, we further shortened the process.

The call of Project Q was publicized both inside and outside of QUP. Nine proposals were received, and the selection was made with critical eyes by using the full power of QUP in March. We have recognized that the proposal presented by a QUP PI M. Garcia-Sciveres to capture phonons from the recoil of dark matter-matter interactions is excellent as it will open a wide new window for light dark matter searches, although we did not choose it yet as a new flagship project at this stage, since it requires further R&D to demontrate low noise (see section 1.1 (p.7) about new findings about excess noise.) The proposal was also highly rated because it is a joint effort with PIs Hattori and Hasegawa sharing a common goal. PI Garcia-Sciveres will conduct a phase-I measurement with the measurement system he brings, PI Hattori will conduct a phase-II measurement with her optical TES, and PI Hasegawa takes care of the cryogenic system optimization. Such synergy did not exist at the beginning of QUP but emerged thanks to the Project Q framework. We have, therefore, decided to promote the R&D for this proposal as an integral part of QUP toward the future flagship project. With this conclusion, QUP's research implementation has become clear.

In addition, some other proposals also require the development of new TES detectors. We will collaborate with such groups in the QUP low-temperature detector cluster.

<u>2) PI-led projects are a mere collection of each PI's research projects. To support them as QUP projects, they will need to be evaluated according to their significance and novelty in line with QUP's vision. Those with sufficient merit should be promoted to Flagship Projects and be provided with personnel and funding resources</u>.

QUP PIs were selected among the experts of various sensors in line with our goal to "bring new eyes to humanity." Their works were already in the direction of QUP. We further improved the coherency among the PIs through the discussions of Project Q and the tighter connection in the research clusters.

The accelerated process for the project Q selection, following the recommendation from the committees, helped to increase the collaborations among the QUP PIs. As described above, a project led by PI M. Garcia-Sciveres, which is in line with QUP's vision and with PIs' collaborative effort, can be promoted to a flagship project after a successful R&D phase to demonstrate low noise.

To improve the communication among PIs further, after discussion with the researchers in QUP, we have redefined the clusters in the research core so that more coordinated research can be initiated among the PIs. Four research clusters (low-temperature detectors, quantum detectors, rad-hard devices, and data acquisition and analysis) have been formed as described in section 1-2, which are essential to carry out QUP's mission.

This created more opportunities for PIs in the cluster to discuss issues with a common QUP vision, thereby generating new ideas. Two workshops (rad-hard and machine learning) were organized in FY2022 by the cluster initiative. The studies on the uses of NV diamond sensors and Casimir force for the new quantum field searches are good examples from the quantum sensor cluster and theory group. These details are described in section 1-1. These new ideas will be pursued further and, based on the growth of the research, they may be potential candidates for future flagship projects.

We also noticed the importance of the common facilities where various PIs work together for their individual research activities. By the end of FY2022, we have started the operation of the QUP facility with four dilution refrigerators, as reported in section 1-2 ([QUP facilities for the fused research].) More common facilities are planned in the new building complex, which will be constructed by the end of FY2024.

Related to comment 4) of the site visit report which is read "Success of QUP depends on all its members to know each other and share its vision and goal. To achieve this, establish a detailed plan of (frequent) meetings, workshops, co-locations involving all QUP groups and projects (individually and jointly), and staff exchanges, to maximize interactions and joint results, and provide visibility of this plan to all members involved.", we have made the following actions.

In order to maximize the interactions, we started the coffee chat time every Tuesday and Thursday at the QUP director room at the beginning and then at a communication space. This has helped communication among QUP researchers. The monthly QUP all-hands meeting started in September 2022. We suffered a lot from COVID-19, with difficulty meeting in person. QUPosium described in section 2-2 was a good opportunity to meet QUP members scattered in various institutes for the first time. Since FY2023, we will have QUP week twice or three times a year when all QUP researchers will gather in one place and show their activities to the QUP members.

3) The scope of the Flagship Project to develop a TES detector for the LiteBIRD mission should be clarified in terms of the demarcation point of responsibility between the basic development of the TES detector system and the delivery of the flight TES detector system to JAXA.

The primary role of QUP for LiteBIRD is to design, fabricate, and validate the TES detector subsystem of its Low-Frequency Telescope (LFT). QUP has a responsibility from the basic development of the TES detector system to the delivery of the flight TES detector system to JAXA. In addition, QUP will also deliver TES detector subassemblies to the French space agency (CNES) who is in charge of the Middle and High Frequency Telescope (MHFT.) QUP works on the key part as it develops new eyes to investigate the quantum field which governed the start of our Universe. We refer the QUP's flagship project as the SpaceTES project, to avoid confusion with the entire LiteBIRD project.

The human resources required for the SpaceTES project are about 30% of the total number of QUP researchers, which is appropriate for a flagship project. The SpaceTES project will not put a strain on the WPI budget because the project's budget will be provided separately (see section 3-3).

As described in section 1-2 and the answer to recommendation 4), the QUP systemology support section helps the SpaceTES team make the clear demarcation point of responsibility and come up with development and management plans, which are to be evaluated in JAXA's mission definition review. The Systemology Support Section will work for Systems Engineering (SE) and Safety & Mission Assurance (S&MA) throughout the whole SpaceTES project.

4) The Systemology project must be concrete in its design and schedule. The buildup of the Systemology Support Section, including the appointment of the section leader and staffs, must be expedited.

Fig. 20. shows the present organization structure of the Systemology Support Section. Prof. Kazuhisa Mitsuda, Senior Scientist of QUP, is the leader of the Systemology Support Section since April 1, 2023. He has extensive experience in space projects and has held several leading systems engineering positions at JAXA, including Chief Engineer and Director of the Systems Engineering Promotion Office. Two members in the systems engineering unit, Principal Engineer and S&MA personnel, are assigned to work for SpaceTES LiteBIRD project using 100% of their time. Two members from Mechanical Engineering Center or other organizations of KEK will participate in the unit on demand base, namely when their expertise is needed, they will participate in the systemology support of research. All other members work both on systemology support of research and systemology support of SpaceTES project. The percentage share depends on person and is 50% on average.

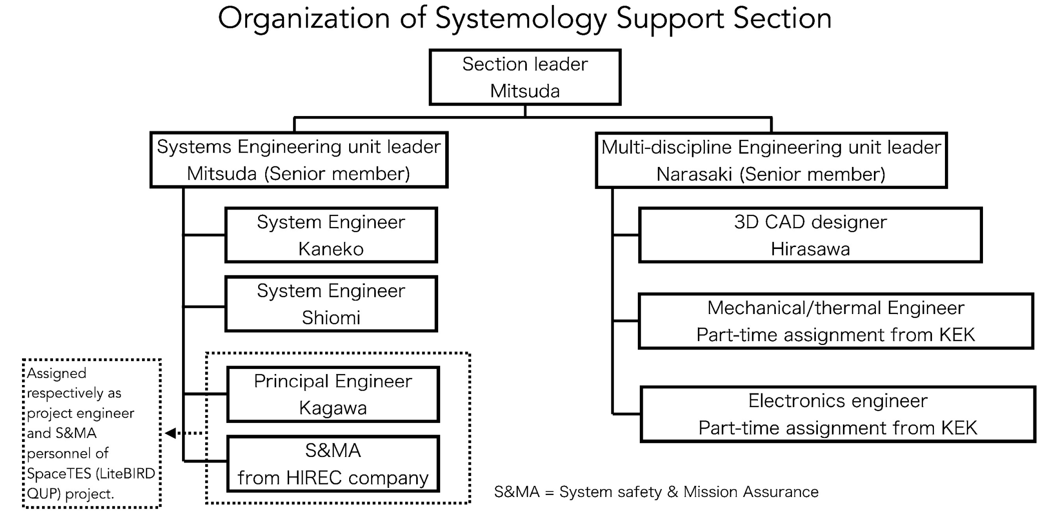

Fig. 20. Present organization of the Systemology Support Section

Fig. 21 shows the plans for the first five years. For systemology support of research projects as described in section 1-2, the first two years are devoted to design and to build the support system. Then after the first trial of a research support, the system will be brushed up. Thereafter, we hope to conduct research support stably. For systemology support of SpaceTES, we follow the standard SE processes. The detailed contents of the support will change when the project phase proceeds.

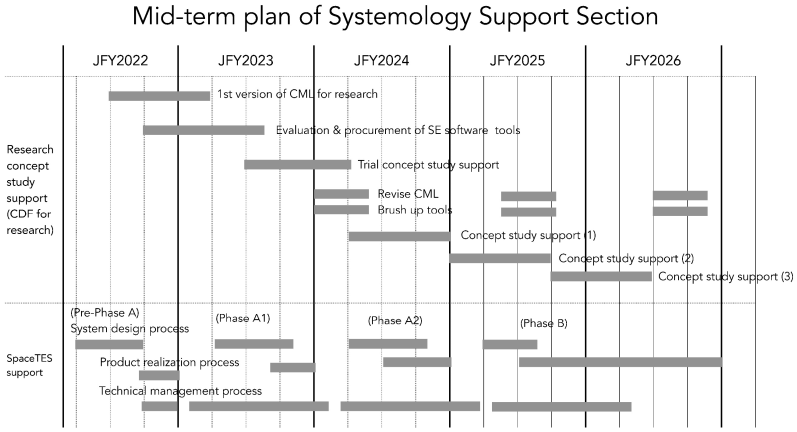

Fig. 21. Mid-term plan of Systemology Support section. Only the top-level items are shown.

<u>5) The "Beauty in Physics" project is unlikely to generate the highest quality-level of scientific results in its present form.</u>

We will not treat this project as a core activity of QUP.

<u>6) Formal establishment of the Berkeley satellite should be done immediately to attract young students and postdocs.</u>

As described in section 2-1, the Berkeley satellite opened in December 2022.

<u>7) Efforts should be made to recruit additional PIs from abroad who can always stay at QUP.</u>

To recruit additional PIs, we are contacting candidates from abroad, prioritizing a new PI in the quantum detector research cluster to build a real measurement system based on QUP's new ideas described in section 1.1.

In addition to recruiting PIs, we hired a deputy PI, who stays at QUP KEK, from abroad for PI M. Garcia-Sciveres. Another deputy PI for PI D. Bortoletto has also been appointed from abroad to start in August 2023. Deputy PIs always staying at QUP enhance the activity of the remote PIs who stay outside Japan.

<u>8) An aggressive plan is urgently needed for reaching out to graduate students as well as postdocs.</u>

As described in section 3-2, a program for accepting post-doctoral and graduate students called "QUP Internship Program (QUPIP)" is set up and under the call for application.

<u>9) KEK Director General should clarify KEK's policy and support plan for making QUP a sustainable institute beyond the WPI funding period. The support plan should include the provision of PI positions and a new building that is well designed for QUP researchers to gather under one roof.</u>

As described in section 3-3, intensive discussion was made between KEK and QUP, and the support of KEK beyond the WPI funding period has become clear for making QUP a sustainable institute.

Appendix 1 FY 2022 List of Center's Research Results and Main Awards

1. Refereed Papers

- List only the Center's papers published in 2022. (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] E. Allys et al. (LiteBIRD Collaboration) "Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey" Progress of Theoretical and Experimental Physics 150 (2022) DOI:10.1093/ptep/ptac150

[2] K. Hattori et al. "An optical transition-edge sensor with high energy resolution" Superconductor Science and Technology 35 (2022) 95002 DOI:10.1088/1361-6668/ac7e7b

[3] B. Westbrook et al. "Development of the low frequency telescope focal plane detector modules for LiteBIRD" Proceedings of SPIE - The International Society for Optical Engineering 12190 (2022) 121900I DOI:10.1117/12.2630574

[4] J. Hubmayr et al. "Optical Characterization of OMT-Coupled TES Bolometers for LiteBIRD" Journal of Low Temperature Physics 209 (2022) 396-408 DOI:10.1007/s10909-022-02808-7

[5] P. Vielva et al. "Polarization angle requirements for CMB B-mode experiments. Application to the LiteBIRD satellite" Journal of Cosmology and Astroparticle Physics 2022 (2022) 29 DOI:10.1088/1475-7516/2022/04/029

[6] D. Paoletti, F. Finelli, J. Valiviita and M. Hazumi "Planck and BICEP/Keck Array 2018 constraints on primordial gravitational waves and perspectives for future B -mode polarization measurements" Physical Review D 106 (2022) 83528 DOI:10.1103/PhysRevD.106.083528

[7] S. Adachi et al. "Improved Upper Limit on Degree-scale CMB B-mode Polarization Power from the 670 Square-degree POLARBEAR Survey" Astrophysical Journal 931 (2022) 101 DOI:10.3847/1538-4357/ac6809

[8] S. Mori et al. "Simulation of TES X-ray Microcalorimeters Designed for 14.4 keV Solar Axion Search" Journal of Low Temperature Physics 209 (2022) 518-524 DOI:10.1007/s10909-022-02902-w

[9] M. Imura et al. "Highly tolerant diamond Schottky barrier photodiodes for deep-ultraviolet xenon excimer lamp and protons detection" Functioal Diamond 2 (2022) 167-174 DOI:10.1080/26941112.2022.2150526

[10] Yohei Ema, Kyohei Mukaida, and Kazunori Nakayama "Scalar field couplings to quadratic curvature and decay into gravitons" Journal of High Energy Physics 2022 (2022) 87 DOI:10.1007/JHEP05(2022)087

[11] Q. Li et al. "Instability of the electroweak vacuum in Starobinsky inflation" Journal of High Energy Physics 2022 (2022) 102 DOI:10.1007/JHEP09(2022)102

[12] Kazunori Nakayama and Wen Yin "Anisotropic cosmic optical background bound for decaying dark matter in light of the LORRI anomaly" Physical Review D 106 (2022) 103505 DOI:10.1103/PhysRevD.106.103505

[13] C. Chichiri, G. B. Gelmini, P. Lu, and V. Takhistov "Cosmological dependence of sterile neutrino dark matter with self-interacting neutrinos" Journal of Cosmology and Astroparticle Physics 2022 (2022) 36 DOI:10.1088/1475-7516/2022/09/036

[14] V. Takhistov et al. "Impacts of Jets and winds from primordial black holes" Mon.Not.Roy.Astron.Soc. 517 (2022) 1 DOI:10.1093/mnrasl/slac097

[15] Yoshimasa Hidaka, Satoshi Iso, and Kengo Shimada "Complementarity and causal propagation of decoherence by measurement in relativistic quantum field theories" Physical Review D 106 (2022) 76018 DOI:10.1103/PhysRevD.106.076018

[16] Sai Wang, Valeri Vardanyan and Kazunori Kohri "Probing primordial black holes with anisotropies in stochastic gravitational-wave background" Physical Review D 106 (2022) 123511 DOI:10.1103/PhysRevD.106.123511

B. WPI-related papers

In this section, papers published in 2022 with the significant contribution by the QUP scientists are listed. These are categorized as [17]-[133]: Original articles, [134]: a Review article, [135]-[148]: Proceedings, and [149]: Other English article.

1. Original Articles

[17] N. Krachmalnicoff et al. "In-flight polarization angle calibration for LiteBIRD: Blind challenge and cosmological implications" Journal of Cosmology and Astroparticle Physics 2022 (2022) 39 DOI:10.1088/1475-7516/2022/01/039

[18] K. D. Crowley et al. "The Simons Observatory: A large-diameter truss for a refracting telescope cooled to 1 K" Review of Scientific Instruments 93 (2022) 55106 DOI:10.1063/5.0093857

[19] T. Tsuruta et al. "Thermal Conductance of Thick-Membrane TES Microcalorimeters for Several-MeV Gamma Rays" Journal of Low Temperature Physics 209 (2022) 449-456 DOI:10.1007/s10909-022-02776-y

[20] T. Hasebe et al. "Sensitivity Modeling for LiteBIRD" Journal of Low Temperature Physics (2022) DOI:10.1007/s10909-022-02921-7

[21] R. Takaku et al. "Performance of a 200 mm Diameter Achromatic HWP with Laser-Ablated Sub-Wavelength Structures" Journal of Low Temperature Physics (2022) DOI:10.1007/s10909-022-02922-6

[22] K. Sakaguri et al. "Broadband Multi-layer Anti-reflection Coatings with Mullite and Duroid for Half-wave Plates and Alumina Filters for CMB Polarimetry" Journal of Low Temperature Physics 209 (2022) 1264-1271 DOI:10.1007/s10909-022-02847-0

[23] T. Ghigna et al. "Testing magnetic interference between TES detectors and the telescope environment for future CMB satellite missions" Proceedings of SPIE - The International Society for Optical Engineering 12190 (2022) 121902N DOI:10.1117/12.2630091

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3. Proceedings

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[136] A Sharma et al. "Latest developments and characterisation results of the MALTA sensors in TowerJazz 180nm for High Luminosity LHC" PoS EPS-HEP2021 (2022) 818 (2022) DOI:10.22323/1.398.0818

[137] S. Iso et al. "Proceedings of the East Asia Joint Symposium on Fields and Strings 2021" Proceedings (2022) DOI:10.1142/13004

[138] T. Gogami et al. "High accuracy spectroscopy of 3- and 4-body Λhypernuclei at Jefferson Lab" EPJ Web Conf. 271 (2022) 01001 (2022) DOI:10.1051/epjconf/202227101001

[139] P. Eckert et al. "Commissioning of the hypertriton binding energy measurement at MAMI" EPJ Web Conf. 271 (2022) 01006 (2022) DOI:10.1051/epjconf/202227101006

[140] T. Gogami et al. "Cross-section measurement of virtual photoproduction of iso-triplet three-body hypernucleus, Λnn" EPJ Web Conf. 271 (2022) 02002 (2022)

DOI:10.1051/epjconf/202227102002

[141] K. Okuyama et al. "Study of the Λ/Σ0 electroproduction in the low-Q2 region at JLab" EPJ Web Conf. 271 (2022) 02003 (2022) DOI:10.1051/epjconf/202227102003

[142] K. Itabashi et al. "Study of ¥Lamda n FSI with Λ quasi-free productions on the 3H(e, e′K+)X reaction at JLab" EPJ Web Conf. 271 (2022) 02006 (2022) DOI:10.1051/epjconf/202227102006

[143] P. Eckert et al. "Preparation of the hypertriton binding energy measurement at MAMI" PoS PANIC2021 (2022) 201 (2022) DOI:10.22323/1.380.0201

[144] P. Eckert et al. "Systematic treatment of hypernuclear data and application to the hypertriton" Rev.Mex.Fis.Suppl. 3 (2022) 3, 0308069 (2022) DOI:10.31349/SuplRevMexFis.3.0308069

[145] Y. Takeuchi et al. "Fabrication and Low-Power Test of Disk-and-Washer Cavity for Muon Acceleration" JACoW IPAC2022 (2022) 1534-1537 (2022) DOI:10.18429/JACoW-IPAC2022-TUPOMS046

[146] Y. Nakazawa et al. "High-Power Test of an APF IH-DTL Prototype for the Muon Linac" JACoW LINAC2022 (2022) 275-278 (2022) DOI:10.18429/JACoW-LINAC2022-MOPORI22

[147] Y. Takeuchi et al. "End-to-End Simulations and Error Studies of the J-PARC Muon Linac" JACoW LINAC2022 (2022) 562-564 (2022) DOI:10.18429/JACoW-LINAC2022-TUPORI08

[148] Y. Kondo et al. "The Muon Linac Project at J-PARC" JACoW LINAC2022 (2022) 636-641 (2022) DOI:10.18429/JACoW-LINAC2022-WE1AA05

4. Other English article

[149] R. Anthony-Petersen et al. "A Stress Induced Source of Phonon Bursts and Quasiparticle Poisoning" 2208.02790 [physics.ins-det] (2022) DOI:10.48550/arxiv.2208.02790

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

- List up to 10 main presentations during FY 2022 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 27-30, 2023	Masaya Hasegawa	Simons array and Simons Observatory; probing cosmic inflation and particle physics from Chile	International Conference on the Physics of the Two Infinities
Mar 13-17, 2023	Volodymyr Takhistov	Fundamental Physics with Atmospheric Collisions	CERN Neutrino Platform Pheno Week 2023
Mar 6-9, 2023	Yu Nakahama	Application of Artificial Intelligence in High Energy Physics	The 2nd Japanese-Canadian Frontiers of Science (JCFoS) Symposium
Feb 22-24, 2023	Maurice Garcia-Sciveres	HEP and QIS	P5 Town Hall at LBNL
Feb 22-24, 2023	Masashi Hazumi	LiteBIRD	P5 Town Hall at LBNL
Dec 12-15, 2022	Adrian Lee	TES focal plane detector subsystem for LiteBIRD	QUPosium2022
Dec 12-15, 2022	Hiedo Iizuka	Quantum Sensor development at QUP and industrial applications in general	QUPosium2022
Nov 14-18, 2022	Yuji Chinone	The past, present, and future of the search for primordial gravitational waves from cosmic inflation with CMB experiments in the Atacama desert and space	The 9th Korea- Japan Workshop on Dark Energy
Nov 14-18, 2022	Satoshi Iso	Relativistic quantum measurements and Decoherence	East Asia Joint Workshop on Field and String 2022
Oct 31 - Nov 4, 2022	Kaori Hattori	An optical transition-edge sensor with high energy resolution	Single Photon Workshop 2022

3. Major Awards

- List up to 10 main awards received during FY 2022 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
Feb 2023	Nanae Taniguchi	JPS Fumiko Yonezawa Memorial Award
Feb 2023	Masashi Hazumi	Member of the Copernican Academy in Poland

Appendix 2   FY 2022 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 proposal for newly selected centers in FY2021, 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 FY2022> **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	58	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	Mostly stays at the center. Several visits to satellites	
<u>Daniela Bortoletto</u>	64	University of Oxford, Professor, Head of Particle Physics	PhD, Physics	20	2021/10/1	joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	Regular Contributions via videoconference. Stay in the center for 1 week in December.
<u>Mauricio A. Garcia-Sciveres</u>	56	Lawrence Berkeley National Laboratory, Senior Scientist	PhD, Physics	20	2021/10/1	joins videoconference meetings (PI meeting (every week), and occasional meetings with the director and other PIs (~ every week)) from another institution.	Regular Contributions via videoconference. Stay in the center for 1 week in December.
Masaya Hasegawa	44	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	

Kaori Hattori	41	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% and joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	
Hideo Iizuka	50	Toyota Central R&D Labs., Inc., Senior Fellow	Doctor of Engineering	40	2021/10/1	comes to the center every other week. joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) remotely when he is inToyota Central R&D Labs., Inc..	
Adrian Tae-Jin Lee	58	University of California, Berkeley, Professor	PhD, Physics	50	2021/10/1	joins videoconference meetings (PI meeting (every week), steering committee meeting (every month), Flagship project meeting (every week) and occasional meetings with the director (once a month)) from another institution. One week stay in December.	Regular Contributions via videoconference. Stay in the center for 1 week in December.
Masaya Miyahara	42	KEK,IPNS, Associate Professor	Doctor of Engineering, ASIC design	70	2021/10/1	Mostly stays at the center.	
Yu Nakahama	41	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	
Kazunori Nakayama	40	Tohoku University, Graduate School of Science and Faculty of Science, Associate Professor	PhD, Physics	30	2021/10/1	joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution. Comes to the center several times for workshops.	

Nanae Taniguchi	43	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	
Manabu Togawa	44	KEK,IPNS, Associate Professor	PhD, Physics	70	2021/10/1	Mostly stays at the center.	
Noriko Yamasaki	56	Japan Aerospace Exploration Agency (JAXA), Institute of Space and Astronautical Science (ISAS), Professor	PhD, Physics	20	2021/10/1	joins videoconference meetings (PI meeting (every week) and occasional meetings with the director (once a month)) from another institution.	

*Percentage of time that the principal investigator devotes to working for the center vis-à-vis his/her total working hours.

Principal investigators unable to participate in project in FY 2022

Name	Affiliation (Position title, department, organization)	Starting date of project participation	Reasons	Measures taken
None				

Appendix 2a Biographical Sketch of a New Principal Investigator

(within 3 pages per person)

Name (Age)

Affiliation and position (Position title, department, organization, etc.)

Academic degree and specialty

Effort **%**

* Percentage of time that the principal investigator devote to working for the center vis-à-vis his/her total working hours.

Research and education history

Achievements and highlights of past research activities

Achievements

(1) International influence * Describe the kind of attributes listed below.

a) Recipient of international awards

b) Member of a scholarly academy in a major country

c) Guest speaker or chair of related international conference and/or director or honorary member of a major international academic society in the subject field

d) Editor of an international academic journal

e) Peer reviewer for an overseas competitive research program (etc.)

(2) Receipt of major large-scale competitive funds (over the past 5 years)

(3) Major publications (Titles of major publications, year of publication, journal name, number of citations)

(4) Others (Other achievements indicative of the PI's qualification as a top-world researcher, if any.)

Appendix 3-1 FY 2022 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 headquarter 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. Masashi Hazumi is the Director and Kazunori Hanagaki is the Deputy. Katsuo Tokushuku is the Administrative Director.

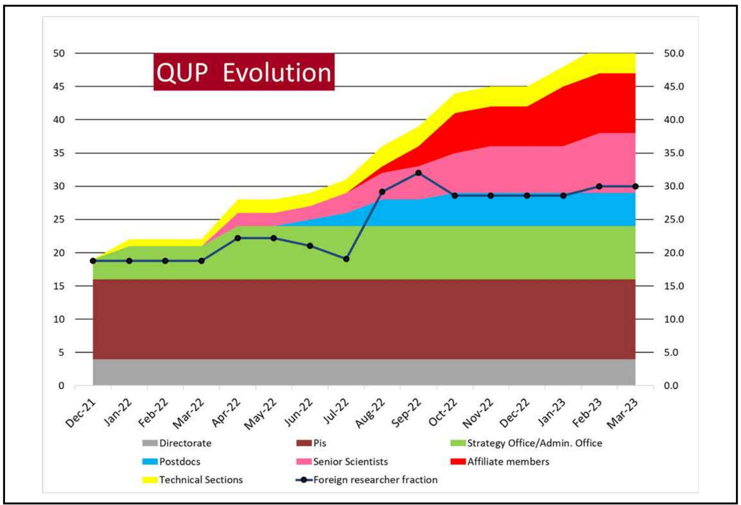
All thirteen initial PIs have been officially appointed by February 2022. Aiming to have closer contacts, some outside PI's started being partially hired by the QUP. PI Kaori Hattori of AIST has been an associate professor at QUP at a cross-appointment since April 2022.

The QUP's plan is to have a deputy PI for each non-resident oversea PI. One deputy, Suerfu for PI M. Garcia-Sciveres has been QUP assistant professor since February 2023. The deputy of D. Bortoletto has been appointed as QUP associate professor and will arrive on August 1, 2023. The last one for Adrian Lee is under the open call.

We planned to have one or two new PIs related to the quantum sensor or low-temperature sensor, in FY2023.

Open recruitment of new researchers began in January 2022. Excellent post-doctoral applicants were hired as assistant professors. By the end of March 2023, eight post-doctoral fellows, four assistant professors, and two associate professors had been selected for employment. Three of these post-doctoral fellows and one associate professor will be positioned after April 2023.

The role of the Systemology Support Section was clarified. The research part of the systemology is moved to the research core, and the section serves on the systems engineering for the QUP projects. Kazuhisa Mitsuda has been appointed as the leader of the section. Two engineers were newly hired in FY2022. Since May 2023, a principal engineer will take office as the leader of the system engineering for the SpaceTES project. A few more engineers are planned in place in FY2023.



In FY2022, the number of staff in the QUP administration office increased from 3 to 6 in April 2022. The QUP strategy office, which is managed by the QUP administrative director, has 2 persons for outreach and web activities. Since April 2023, two Research Administrators (URAs) have joined to promote applications for external funds. The set up of the basic function of the two offices has been completed.

Numbers of QUP researchers were growing during FY2022 as shown in the plot, aiming for the planned stable point by the end of FY2023.

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	MOU was signed with Toyota Central R&D Labs., Inc. on April 1,2022
QUP Berkeley Satellite	Adrian Lee	MOU was signed with UC Berkeley and on effect since December 1, 2022.

< 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)	MOU on education of graduate students.

2. Holding international research meetings

- Indicate the number of international research conferences or symposiums held in FY2022 and give up to three examples of the most representative ones using the table below.

FY 2022: 4 meetings

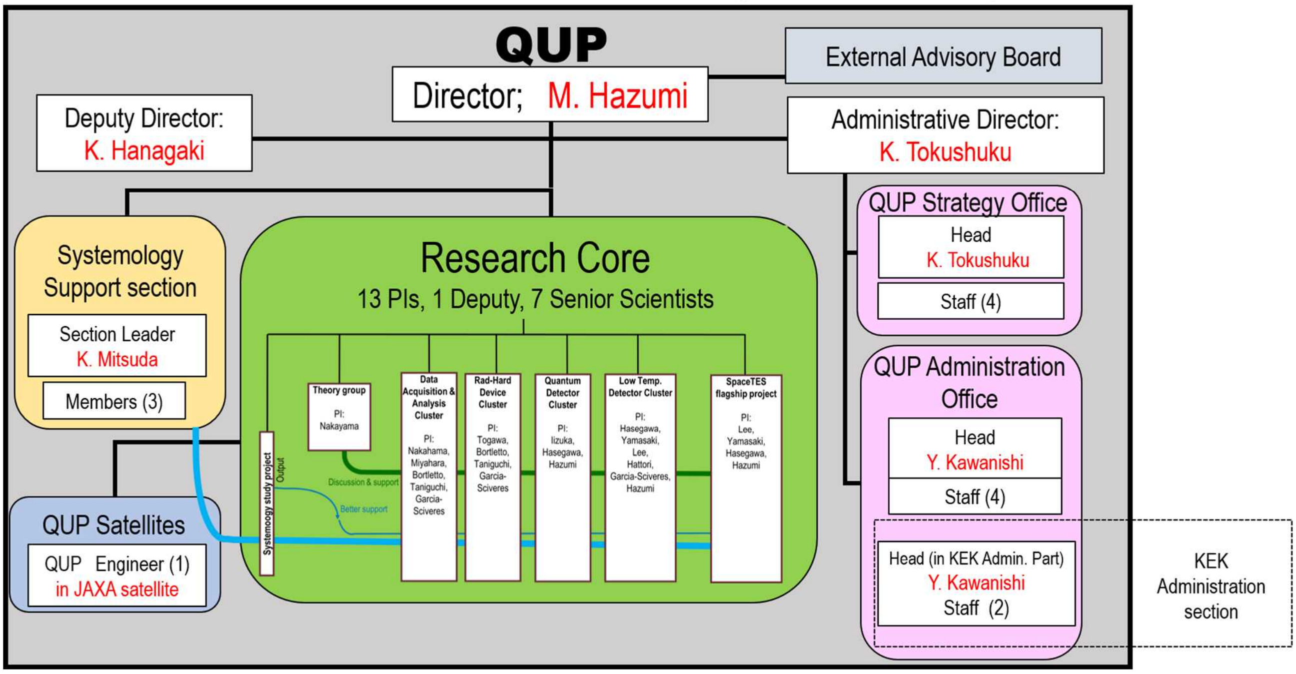
Major examples (meeting titles and places held)	Number of participants
QUPosium2022 (December 12-15, 2022, Epochal Tsukuba, Japan)	From domestic institutions: 117 From overseas institutions: 38
QUP workshop: toward Project Q (November 7-8, 2022, QUP/KEK, Japan)	From domestic institutions: 82 From overseas institutions: 9
ML at HEP workshop (February 23-24, 2023, QUP/KEK, Japan)	From domestic institutions: 101 From overseas institutions: 18

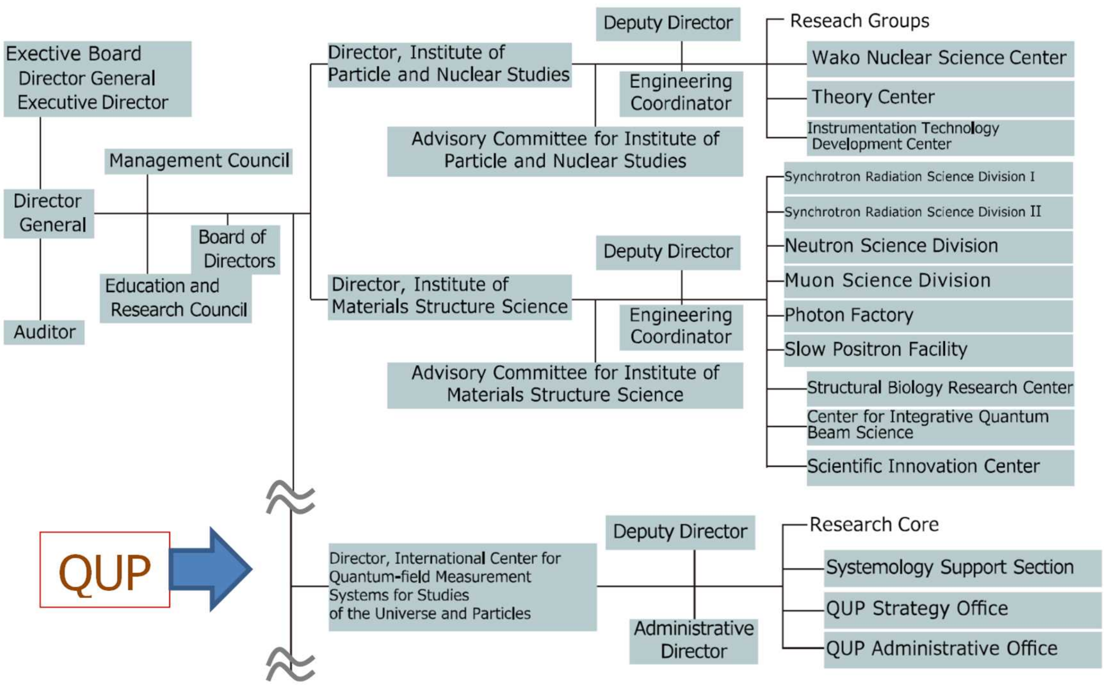
3. Diagram of management system

- 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).

There is no change in the management system of QUP or KEK. The structure of the research core has changed as described in section 1-2 of the main document. 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/.

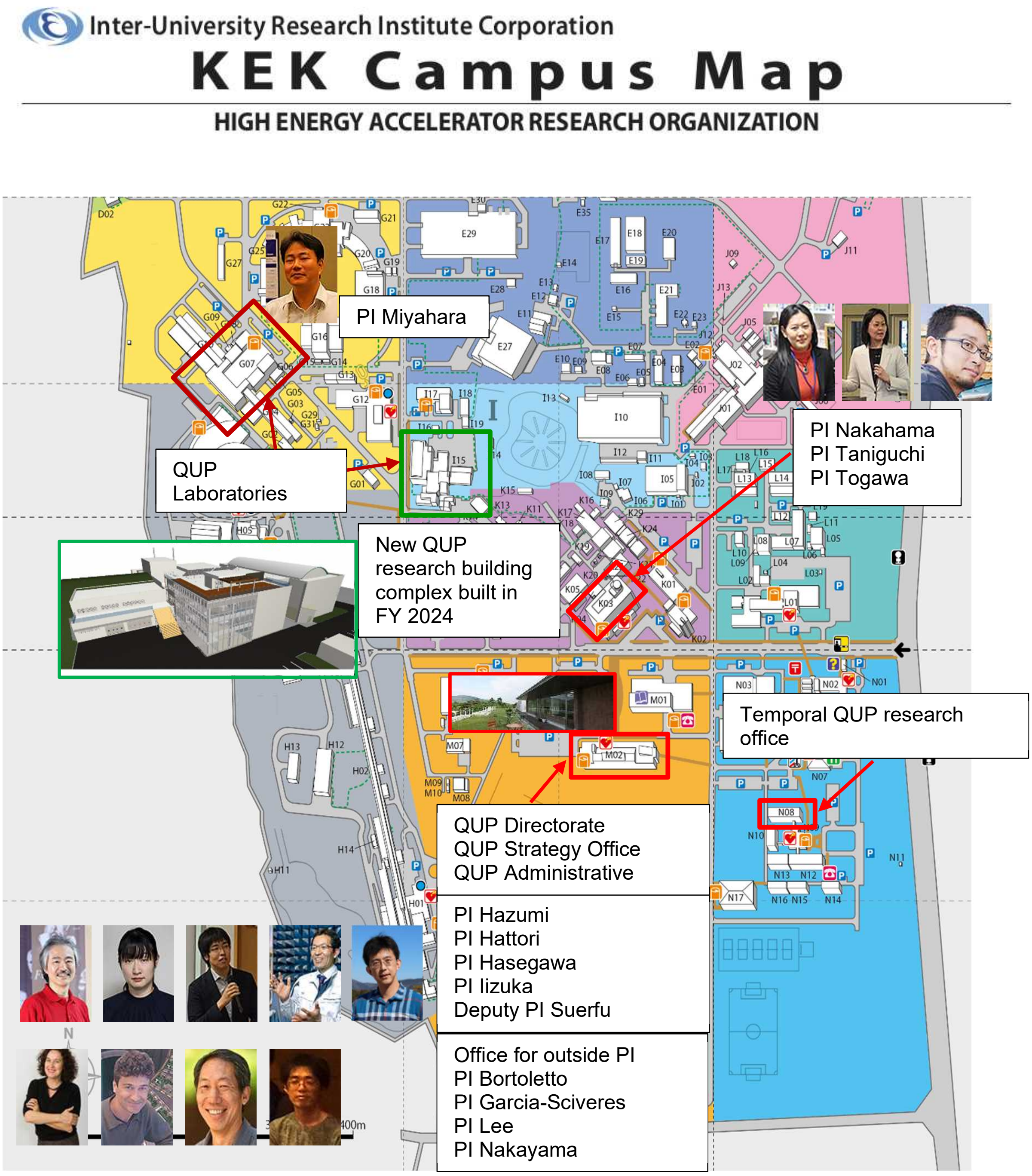
QUP Organization as of April, 2023





4. Campus Map

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



JAXA	Tohoku University	U.C.Berkeley	LBNL	University of Oxford
PI Yamasaki	PI Nakayama	PI Lee	PI Garcia-Sciveres	PI Bortoletto

5. Securing external research funding*

External research funding secured in FY2022

Total: 376,334,616 yen, which includes
81,700,000 yen from Kakenhi,
5,384,616 yen from Collaboration with the private sector, and
289,250,000 yen from the other resources.

- 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 2022 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 2022	Final goal (Date: March, 2025)
Researchers from within the host institution	6	7	8
Researchers invited from overseas	3	3	3
Researchers invited from other Japanese institutions	4	3	2
Total principal investigators	13	13	13

b) Total members

	At the beginning of project		At the end of FY 2022		Final goal (Date: March, 2025)	
	Number of persons	%	Number of persons	%	Number of persons	%
Researchers	15		30		67	
Overseas researchers	3	20	9	30	27	40
Female researchers	5	33	6	20	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		12		14	
Overseas researchers	0	0	4	33	4	29
Female researchers	0	0	0	0	4	29
Postdocs	0		5		40	
Overseas postdocs	0	0	2	40	20	50
Female postdocs	0	0	1	20	15	38
Research support staffs	0		6		20	
Administrative staffs	3		8		25	
Total number of people who form the "core" of the research center	18		44		112	

	At the beginning of project		At the end of FY 2022		Final goal (Date: March, 2025)	
	Number of persons	%	Number of persons	%	Number of persons	%
Doctoral students	0		0		15	
Employed	0	-	0	-	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	27	23
	Principal investigators (no. of persons):12	40	3
	Other researchers (no. of persons):15	78	50
	Research support staff (no. of persons):6	33	33
	Administrative staff (no. of persons):23	105	47
	Subtotal	283	156
Project activities	Research startup cost (no. of persons):10	54	29
	Cost of international symposiums (no. of symposiums):1	3	3
	Cost of outreach	6	6
	Cost of satellite organizations (no. of satellite organizations):1	4	0
	Gratuities and honoraria paid to invited principal investigators	2	2
	Rental fees for facilities	55	0
	Cost of utilities	0	0
	Other costs	449	4
	Subtotal	573	44
Travel	Domestic travel costs	3	3
	Overseas travel costs	10	6
	Travel and accommodations cost for invited scientists (no. of domestic scientists):13 (no. of overseas scientists):12	5	5
	Travel cost for scientists on transfer (no. of domestic scientists):1 (no. of overseas scientists):3	1	1
	Subtotal	19	15
Equipment	Cost of facility maintenance (repair work etc.)	102	50
	Cost of research equipipemts	312	305
	Subtotal	414	355
Research projects (Detail items must be fixed)	Project supported by other government subsidies, etc. *1	99	0
	KAKENHI	82	0
	Commissioned research projects, etc.	289	0
	Joint research projects	5	0
	Ohers (donations, etc.)	0	0
	Subtotal	475	0
Total		1764	570

Costs (Million yens)

WPI grant in FY 2022	570
Costs of establishing and maintaining facilities	102
Advanced Instrumentation Lab. Renovation (Number of facilities: 1, 1,500m2)	48
Fuji Experimental Facility Equipment Renovation (Number of facilities: 1, 1,150m2)	12
Others	42
Costs of equipment procured	313
Dilution Refrigerator: 2	204
Oscilloscope: 1	15
Others	94

*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	4	0
Travel	Subtotal	0	0
Equipment	Subtotal	0	0
Research projects	Subtotal	0	0
Total		4	0

Appendix 4 FY 2022 Status of Collaboration with Overseas Satellites

1. Coauthored Papers

- List the refereed papers published in FY 2022 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. 2023 and not described in Appendix 1.

Overseas Satellite 1 QUP Berkeley Satellite (University of California, Berkeley)
(Total: 7 papers)

1) (1) E. Allys, *A. T. Lee* et al. (LiteBIRD Collaboration) "Probing Cosmic Inflation with the LiteBIRD Cosmic Microwave Background Polarization Survey" Progress of Theoretical and Experimental Physics 150 (2022) DOI:10.1093/ptep/ptac150

2) (3) B. Westbrook, *A. T. Lee* et al. "Development of the low frequency telescope focal plane detector modules for LiteBIRD" Proceedings of SPIE - The International Society for Optical Engineering 12190 (2022) 121900I DOI:10.1117/12.2630574

3) (4) J. Hubmayr, *A. T. Lee* et al. "Optical Characterization of OMT-Coupled TES Bolometers for LiteBIRD" Journal of Low Temperature Physics 209 (2022) 396-408 DOI:10.1007/s10909-022-02808-7

4) (7) S. Adachi, *A. T. Lee* et al. "Improved Upper Limit on Degree-scale CMB B-mode Polarization Power from the 670 Square-degree POLARBEAR Survey" Astrophysical Journal 931 (2022) 101 DOI:10.3847/1538-4357/ac6809

5) (18) K. D. Crowley, *A. T. Lee* et al. "The Simons Observatory: A large-diameter truss for a refracting telescope cooled to 1 K" Review of Scientific Instruments 93 (2022) 55106 DOI:10.1063/5.0093857

6) (20) T. Hasebe, *A. T. Lee* et al. "Sensitivity Modeling for LiteBIRD" Journal of Low Temperature Physics (2022) DOI:10.1007/s10909-022-02921-7

7) (23) T. Ghigna, *A. T. Lee* et al. "Testing magnetic interference between TES detectors and the telescope environment for future CMB satellite missions" Proceedings of SPIE - The International Society for Optical Engineering 12190 (2022) 121902N DOI:10.1117/12.2630091

2. Status of Researcher Exchanges

- Using the below tables, indicate the number and length of researcher exchanges in FY 2022. 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
FY2022	2	0	0	0	2
	2	1	1	0	4

<From satellite>

	Under 1 week	From 1 week to 1 month	From 1 month to 3 months	3 months or longer	Total
FY2022	0	1	0	0	1
	0	0	0	0	0

Appendix 5 FY 2021 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: 12

	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	Trangsrud Amy	40	Systems Engineer, NASA Jet Propulsion Laboratory	U.S.A.	PhD Physics	Systems Engineering on various NASA projects	2022/12/4～12/16	Speaker of QUPosium2022
2	Rocca Jennifer Marie	46	Systems Engineer, NASA Jet Propulsion Laboratory	U.S.A.	PhD Physics	Systems Engineering on various NASA projects	2022/12/4～12/16	Speaker of QUPosium2022
3	Zeki Semir	82	Professor, Division of Biosciences/Cell and Developmental Biology, Uni College London	U.K.	PhD Biology	the Chair of Neuroesthetics at University College London, Fellow of the Royal Society,	2022/12/8～12/18	Speaker of QUPosium2022
4	Egami Eiichi	59	Professor, Dept. of Astronomy/Steward Observatory, Uni Arizona	U.S.A.	PhD Physics	Astronomy	2022/12/10～12/20	Speaker of QUPosium2022
5	Staggs Suzanne	57	Professor, Dept. of Physics, Uni Princeton	U.S.A.	PhD Physics	Dark Matter Searches, Particle physiccs	2022/12/10～12/17	Speaker of QUPosium2022/EAB
6	Gershon Timothy John	48	Professor, Dept. of Physics, Uni Warwick	U.K.	PhD Physics	Particle physics with colliders	2022/12/11～12/15	Speaker of QUPosium2022
7	Hoecker Andreas	55	Senior scientist, CERN	Switzerland	PhD Physics	Spokesperson of the ATLAS collaboration, particle physics	2022/12/11～12/15	Speaker of QUPosium2022
8	Budker Dmitry	59	Professor, Institute of Physics, THEP	Germany	PhD Physics	Quantom detctors	2022/12/11～12/17	Speaker of QUPosium2022
9	Vaslin Louis	28	Postdoc, Laboratoire de Physique de Clermont	France	PhD Physics	Particle physics with colliders	2023/2/19～2/26	Speaker of "ML at HEP" workshop
10	Roussel Joshua Ryan	30	Researcher, SLAC	U.S.A.	PhD Physics	Particle physics with colliders	2023/2/21～2/26	Speaker of "ML at HEP" workshop
11	Heinrich Lukas	36	Assistant professor, Dept. of Physics, Technical University Munich	Germany	PhD Physics	Particle physics with colliders	2023/2/22～2/25	Speaker of "ML at HEP" workshop
12	CUI Wei Kevin	57	Professor, School of Sciences, Tsinghua University	China	PhD Physics	Astroparticle Physics	2023/3/22～3/25	Research, Discussion

Appendix 6 FY2022 State of Outreach Activities

* Fill in the numbers of activities and times held during FY2022 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	FY2022 (number of activities, times held)
PR brochure, pamphlet	QUP general brochure (English 1, Japanese 1)
Lectures, seminars for general public	Science Lecture to the public (4)
Teaching, experiments, training for elementary, secondary and high school students	Lecture for high school students (1), High school visit by QUP postdoc (1), a Site visit by junior high school students (1)
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),
Others（ Twitter ）	Japnese posting (38), English posting (31)
Others（ YouTube channel ）	https://www.youtube.com/channel/UCs_wVvmdCLMtQjD_J9J1nIQ QUP facility in English (1), QUP introduction (1: Japanese), QUP three minute talk (4: Japanese)

*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 2022 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, since September 2022, QUP's YouTube channel and official Twitter have opened.

- In the YouTube channel, we started introducing the researcher's interviews titled "Three minute talkings" in February 2023. The target audience is set high school students, so we started with the Japanese version.
- On Twitter, we posted 38 (31) Japanese (English) tweets and got 45,762 (8,825) reactions.

In either case, we are not yet at the stage of big influencers but will continue to send out our messages and there is a sign of gaining new viewers. The quantitative monitoring of the reactions is set, as some plots shown in the main document.

Appendix 7 FY 2022 List of Project's Media Coverage

* List and describe media coverage (e.g., articles published, programs aired) in FY2022.

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

	Date	Types of Media (e.g., newspaper, magazine, television)	Description
1	None		
2			
3			
4			
5			
6			
7			
8			
9			
10			