QUP Overview and “Project Q”

Masashi Hazumi
(QUP, KEK)

What is QUP?

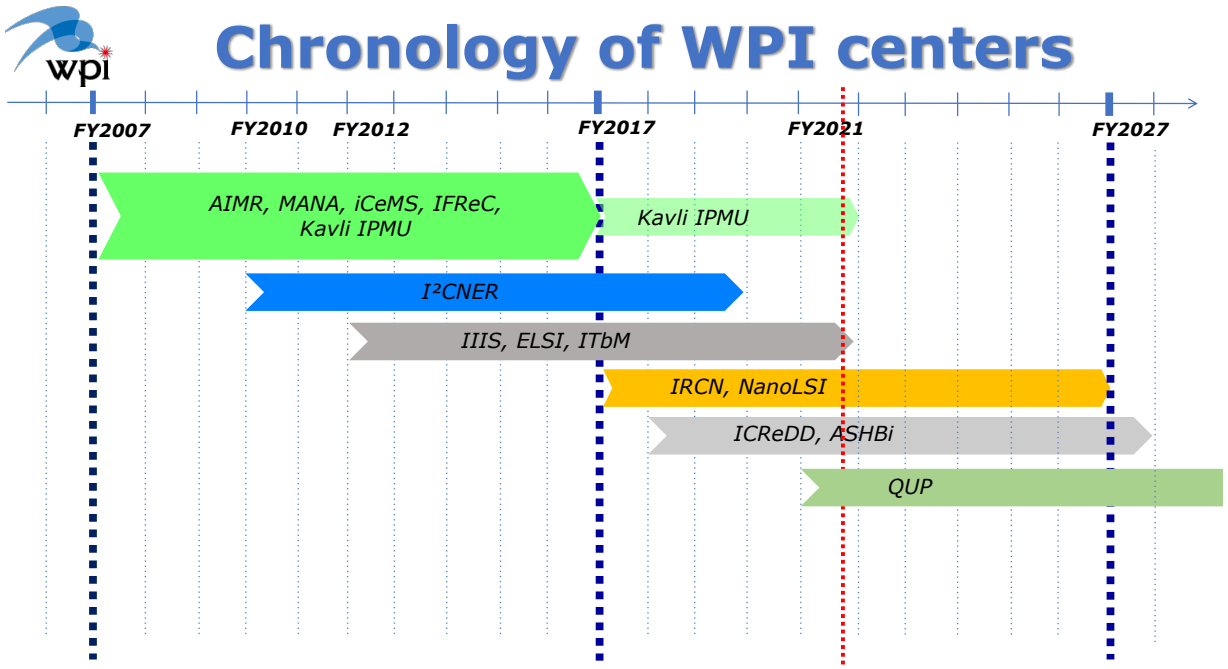

International Center for
Quantum-field Measurement Systems for
Studies of the Universe and Particles (QUP)
New WPI Center at KEK established on Dec. 16, 2021

What is WPI?

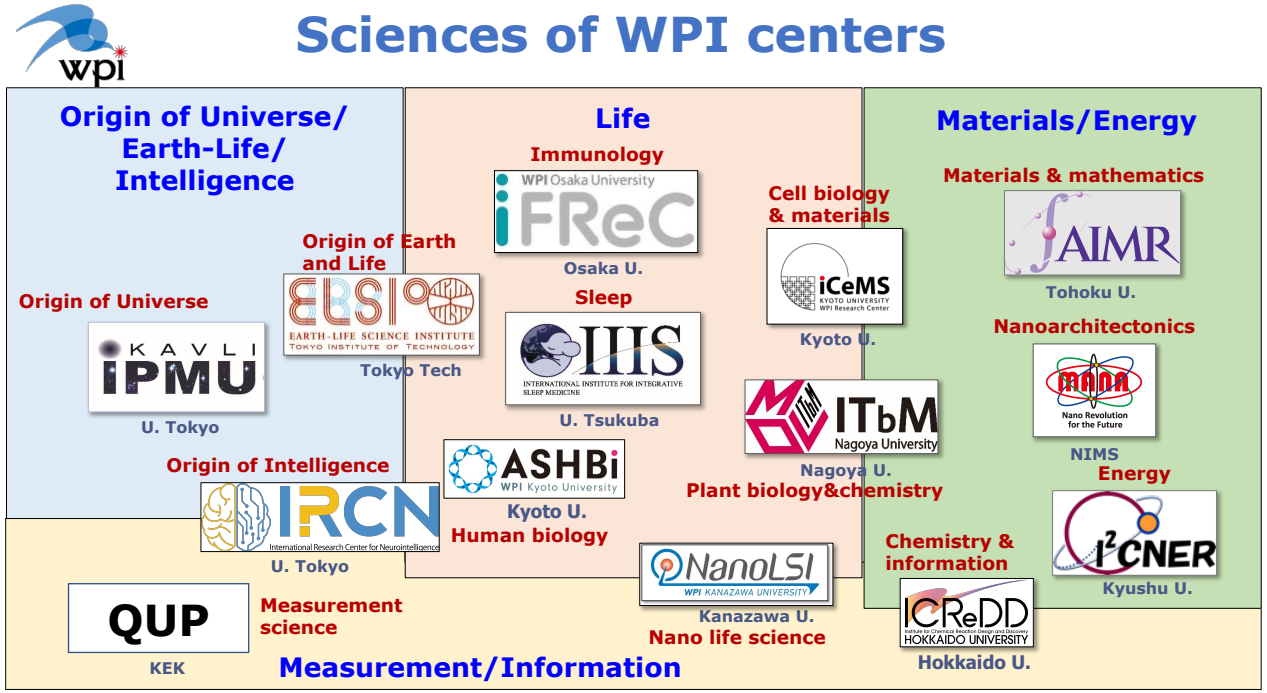
World Premier International Research Center Initiative

- **Japan's flagship program to establish internationally-opened and globally-visible research centers**
- **Started in 2007, have launched 14 centers, and continuing to the future**
- **10-year support phase (total ~70M USD) to establish self-reliant operation**

Chronology of WPI centers



Sciences of WPI centers



WPI Missions

- **World-Leading Scientific Excellence and Recognition**
  - **Highest Level of Research Impact**
  - **Interdisciplinarity and Diversity**

- **Global Research Environment and System Reform**
  - **Global Brain Circulation**
  - **Capacity Building beyond Disciplinary/Organizational Boundaries**
  - **Effective, Proactive and Agile Management**

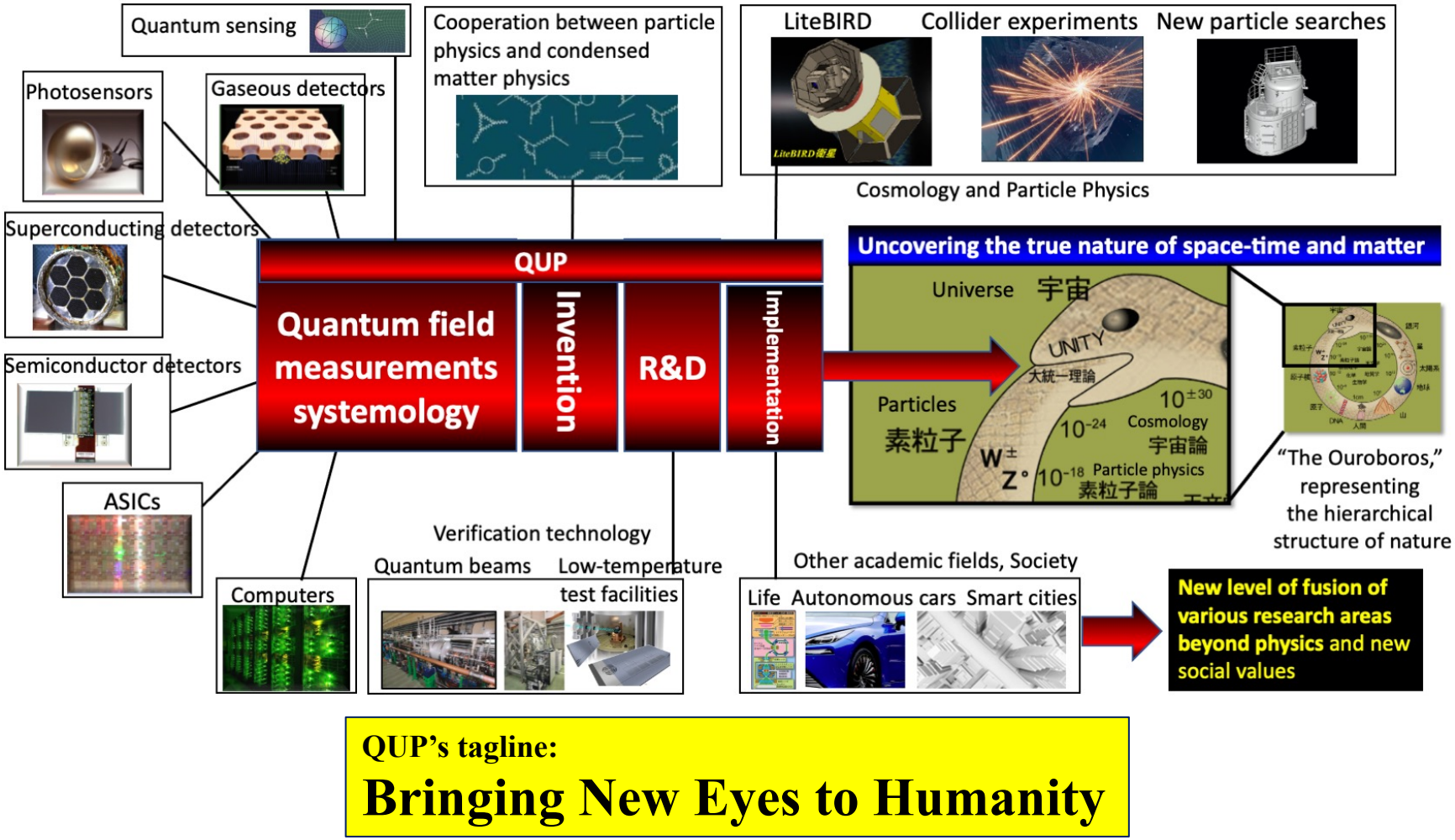
- **Values for the Future**
  - **Societal Value of Basic Research**
  - **Human Resource Building**
  - **Self-sufficient and Sustainable Center Development**

QUP's Missions

Five Missions

1. Integrate particle physics, astrophysics, condensed matter physics, measurement science, and systems science.
2. Invent and develop new systems for measuring quantum fields (space-time with particles and quasiparticles created and annihilated, and associated physical quantities).
3. Bring innovation to measurements in cosmological observations and particle experiments, and elucidate the true nature of space-time and matter.
4. Establish a new measurement science, quantum field measurement systemology, as a science of means through the above practices.
5. Last but not least, we will create a new level of fusion of various research areas beyond physics and new social values through application to other fields and social implementation.

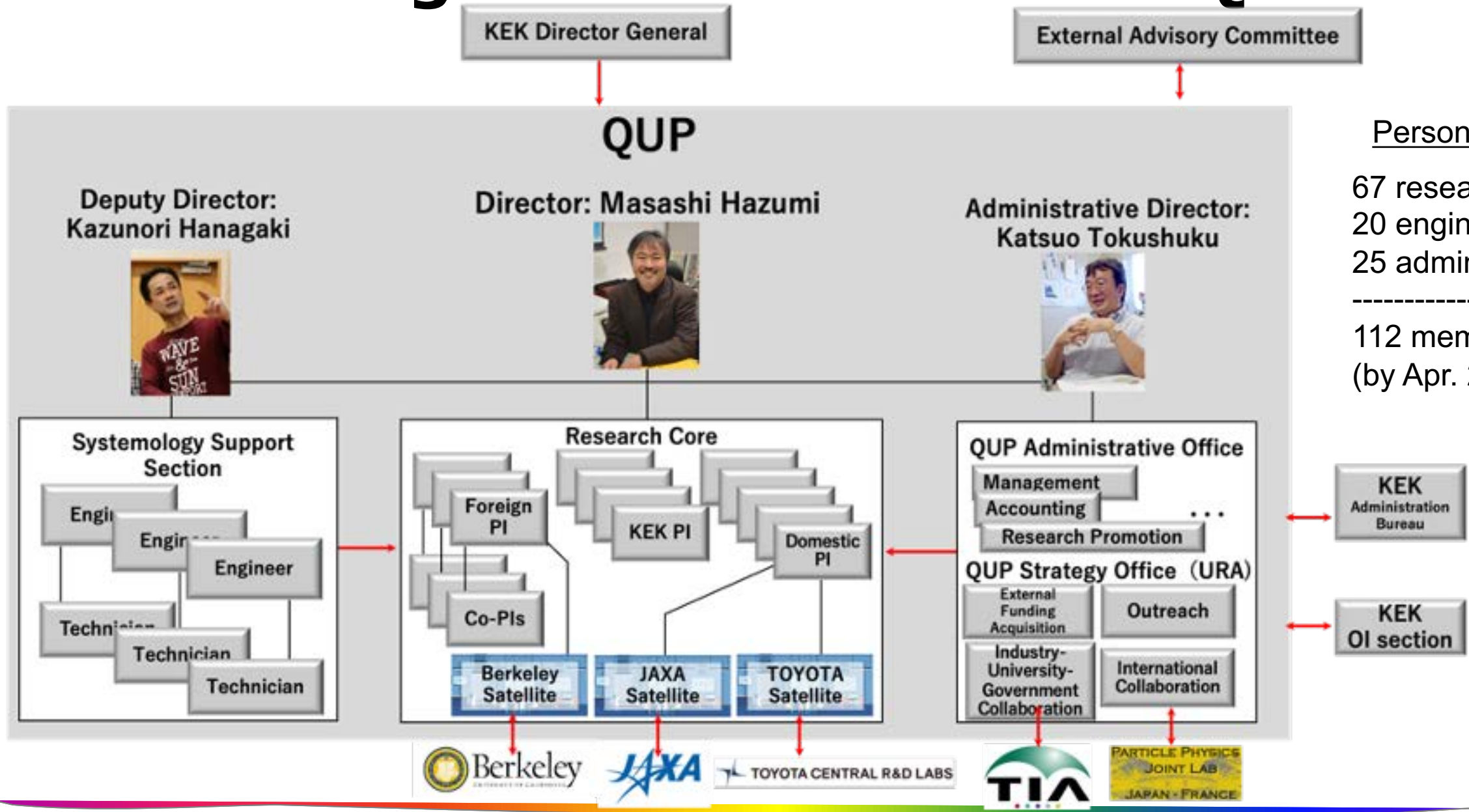
Overall Framework with Key Words



QUP's tagline:

Bringing New Eyes to Humanity

Organizational chart of QUP



Personnel

67 researchers
20 engineers
25 admin. Staff

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112 members
(by Apr. 2023)

QUP is international

- >30% of QUP researchers (total ~70 members) will be non-Japanese.
- PIs from Univ. Oxford, UC Berkeley and LBNL.
- PIs are leading scientific international collaborations (LiteBIRD, ATLAS, Belle2, ATHENA, etc.)

Daniela Bortoletto
University of Oxford
Professor

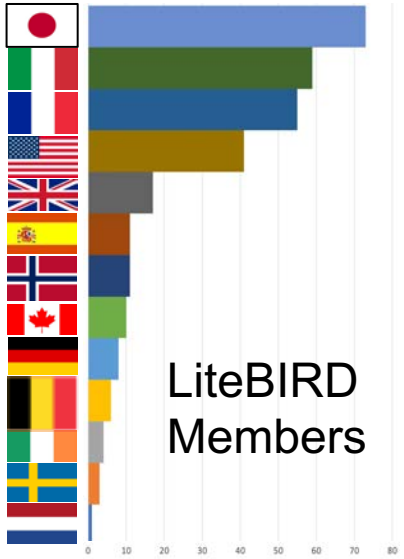
Adrian T. Lee
UC Berkeley
Professor

Maurice Garcia-Sciveres
LBNL
Senior Scientist

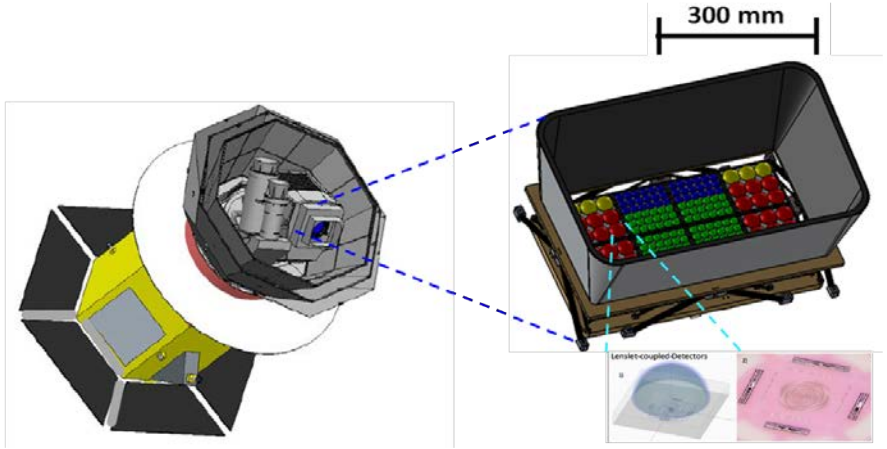
Example: LiteBIRD – selected as a JAXA's strategic L-class mission for launch in 2020s

The director of QUP is the founder and the world PI of LiteBIRD.

More than 300 members from 13 countries



QUP will invent, develop and provide superconducting detector system for LiteBIRD as a QUP flagship project.



Initial PIs

- Low-temperature (superconducting) sensor systems L
- Radiation-hard semiconductor detectors R
- New device/firmware/algorithms/theory N

Principal Investigators

1 L

Masashi Hazumi
KEK
Professor

2 R

Manabu Togawa
KEK
Associate Professor

3 L

Masaya Hasegawa
KEK
Lecturer

4 N

Masaya Miyahara
KEK
Associate Professor

5 R

Nanae Taniguchi
KEK
Assistant Professor

6 L

Adrian T. Lee
UC Berkeley
Professor

7 R

Daniela Bortoletto
University of Oxford
Professor

8 L R

Maurice Garcia-Sciveres
LBNL
Senior Scientist

9 L

Kaori Hattori
AIST
Senior Researcher

10 L

Noriko Y. Yamasaki
JAXA
Professor

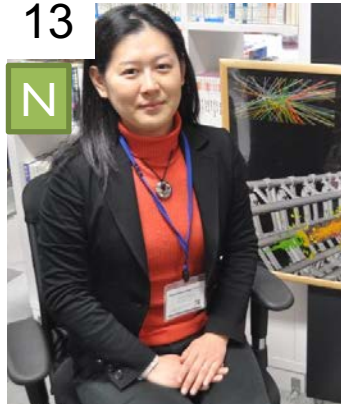
11 N

Kazunori Nakayama
U. Tokyo
Assistant Professor

12 N

Hideo Iizuka
Toyota Central R&D Lab.
Senior Fellow

13 N



Yu Nakahama
KEK
Associate Professor

Job opening!

- ~20 postdocs (or assistant professors) working with initial PIs
- Applications by Feb. 28 for full consideration
- See more details at AcademicJobsOnline

AcademicJobsOnline.org

List | Search |

KEK, QUP

Position ID:	KEK-QUP-POSTDOC [#21028, KEK-QUP-PD2022-1]
Position Title:	QUP Postdoctoral Fellow
Position Type:	Postdoctoral
Position Location:	Tsukuba, Ibaraki 305-0801, Japan [map]
Subject Areas:	Astrophysics & Cosmology High Energy Physics Particle Physics Data Science Electronic Materials and Devices (more...)
Appl Deadline:	2022/02/28 11:59PM (posted 2022/01/26, updated 2022/01/25, listed until 2022/06/30)
Position Description:	

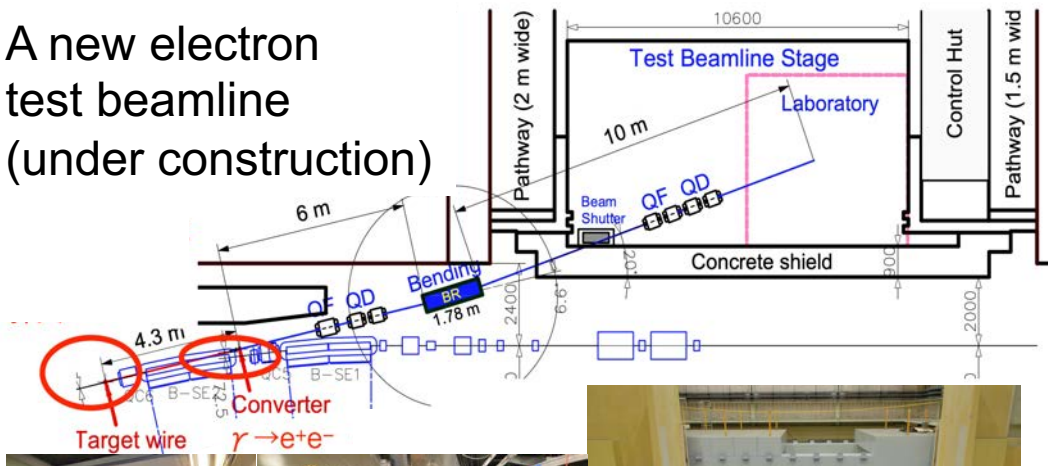
KEK's research infrastructure

"Fuji experimental hall" (2000m^2)

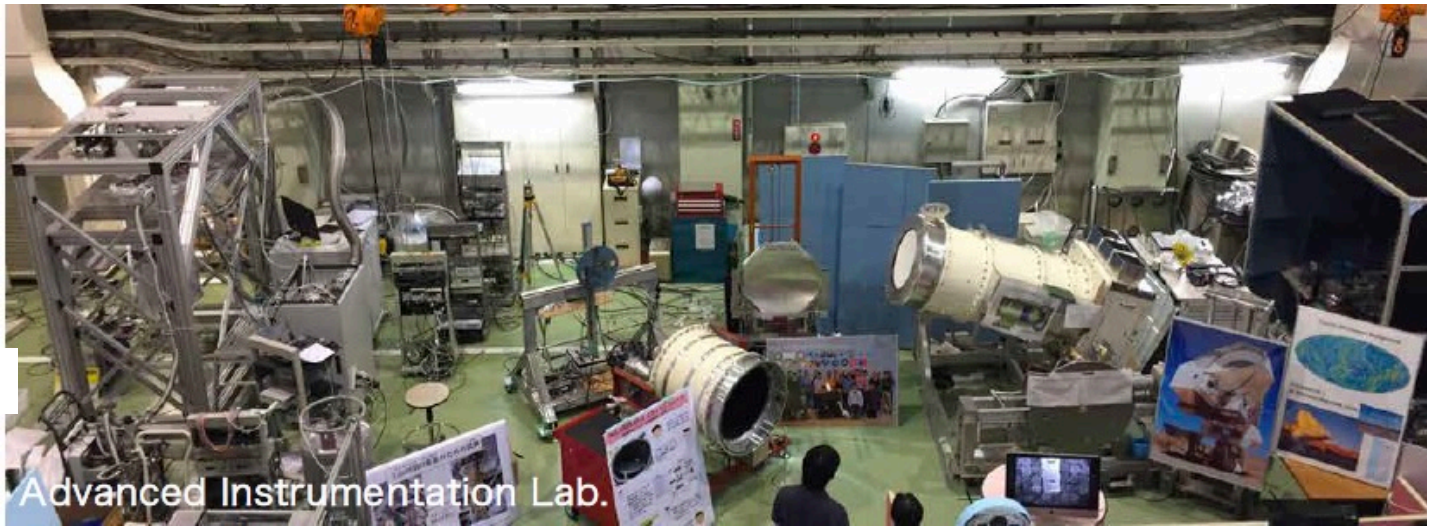
Entrance

KEK's research infrastructure (cont.)

A new electron test beamline (under construction)



Advanced Instrumentation Lab. for Cryogenic Detector R&D



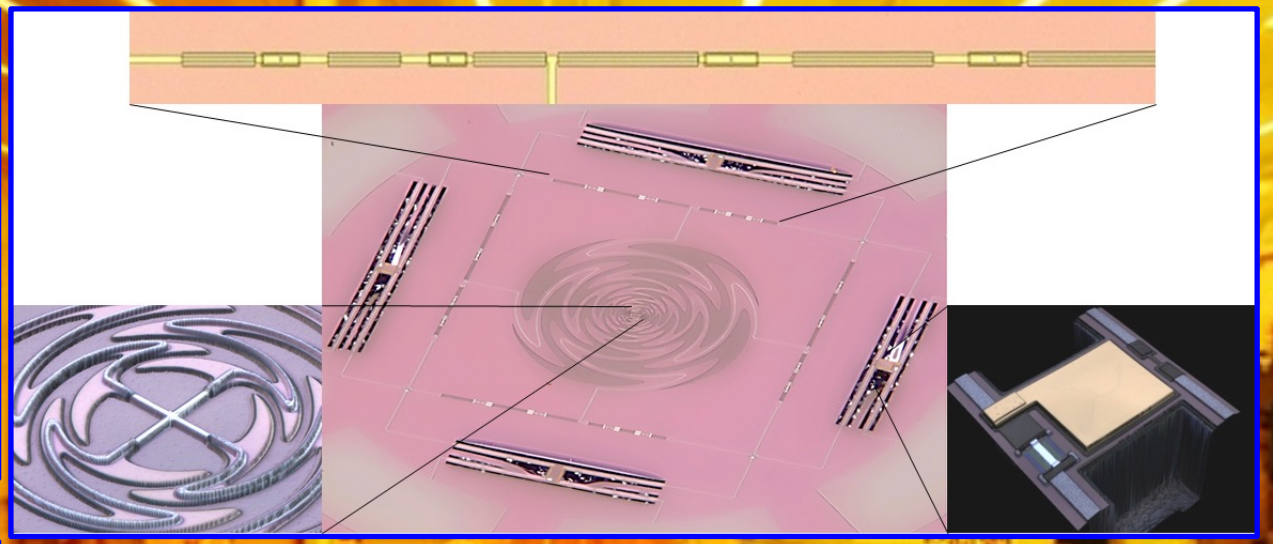
Neutron and Muon beamlines

X-ray microscopy beamline

Semiconductor detector R&D Lab.

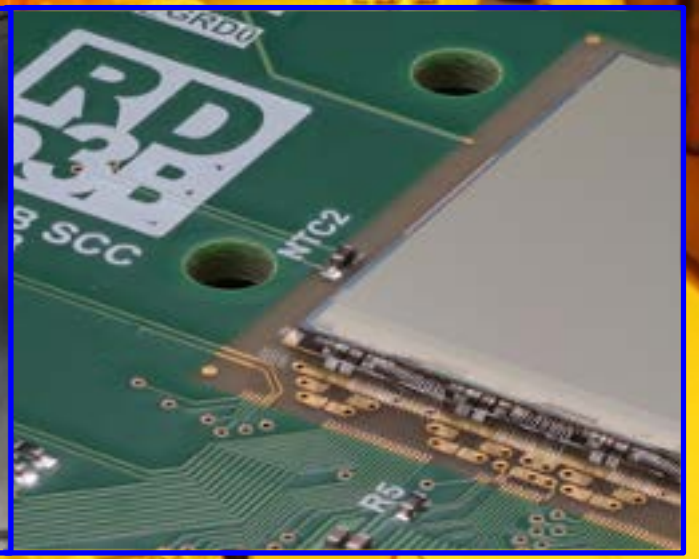
QUP Satellite in UC Berkeley

- Satellite includes Berkeley Physics Department and LBNL Physics Division
- World-leaders in Quantum Sensors
- **CMB:** Berkeley pioneered many TES technologies
- **HEP:** Most complex integrated circuits (RD53)
- **Dark Matter:** World-record athermal noise for low-mass DM search



Roles of the QUP satellite in Berkeley

- Fabrication and characterization of new TES bolometers for LiteBIRD
- Readout ASICs for future collider experiments and for novel quantum sensors
- New target materials and new quantum sensors for dark matter and photon detection



QUP Satellite in Toyota Central R&D Labs.

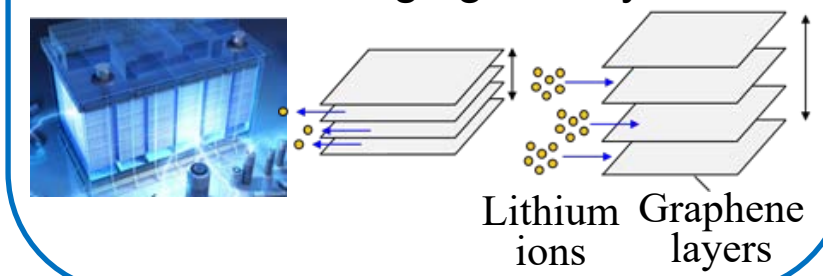
Roles of the QUP Satellite
in Toyota Central R&D Labs.

- Development of quantum sensors
- Social-implementation experiments

Casimir devices

Non-contact shaft-bearing motor

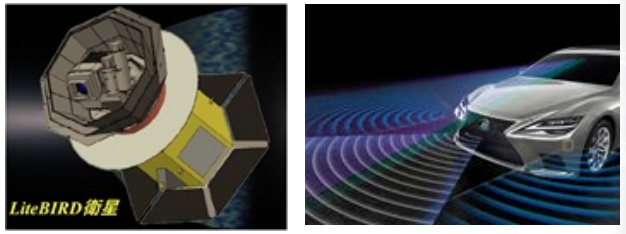
Fast-charging battery



Quantum-field measurement technology creates new social values & enriched society.

Technology exchange

Radars



Six project categories at QUP

1. QUP flagship projects

   - Highest priority at QUP
   - Two projects are identified
     1. Superconducting detector system for LiteBIRD
     2. **Project Q**

2. QUP PI-led projects
3. Interdisciplinary/Challenging/Exploratory mini-projects
4. Projects for human resource development and brain circulation
5. Projects toward implementation to society
6. Quantum-field Measurement Systemology

What is Project Q?

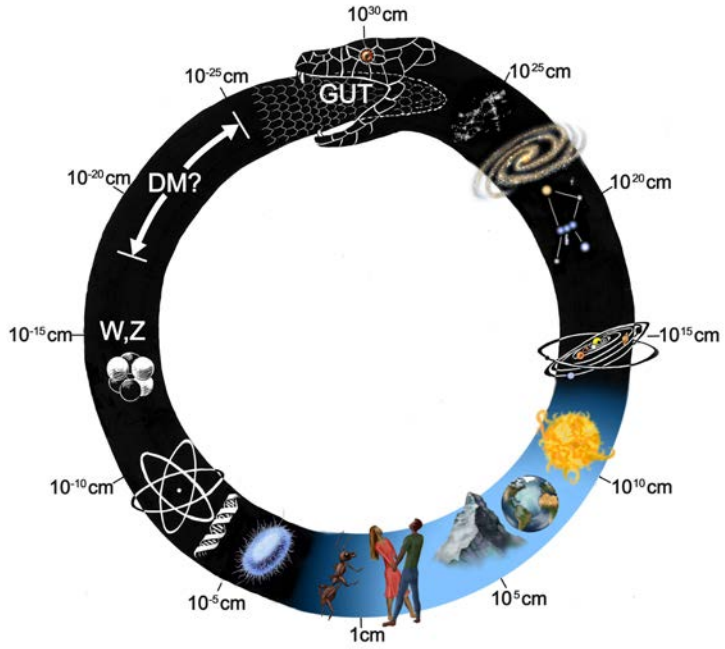
A new QUP flagship project with a new method to search for a new quantum field

- Widely solicit new ideas from domestic and international communities (QUP-PI ideas are also welcome)
- Any of space observation, accelerator or non-accelerator, any!
- Any new quantum field, axions, gravitons, light DM, any!
- Workshops and other opportunities for discussion, and finish the first stage of selection by the end of March 2023 (exact timing is TBD.)
  - This workshop is the kick-off!
- After a year of project review, the content of Project Q will be decided by the end of March 2024 (exact timing is TBD.)
- Bold, new ideas are welcome!
  - Example 1: New methods using quasiparticles in solids
  - Example 2: New methods using new quantum sensors (e.g. diamond quantum sensors)

Related talks at this workshop!

From QUP,
- Kazunori Nakayama (next talk)
- Maurice Garcia-Schiveres (this morning)

Our cute logo!



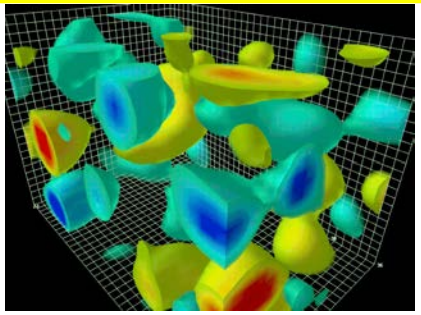
http://new-universe.org/zenphoto/Chapter2/Illustrations/Abrams22.jpg.php

Backup Slides

QUP brings “new eyes" to humanity.

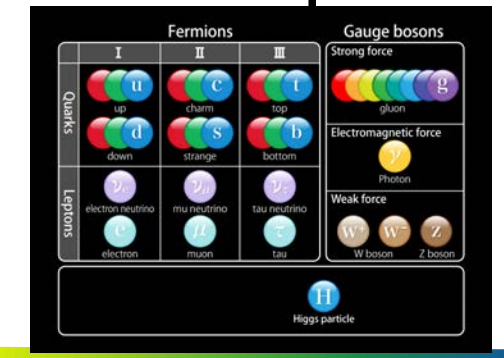
Quantum-field measurement systems

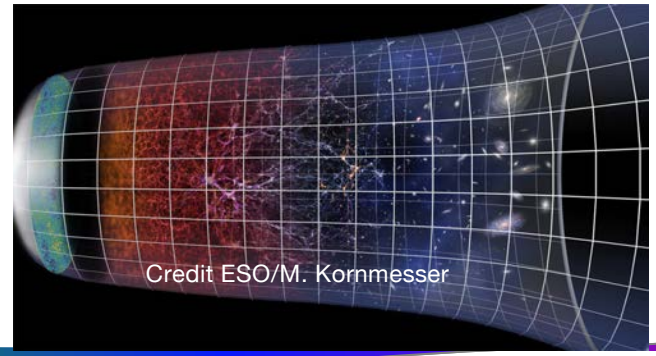
Quantum fields



By Prof. D. B. Leinweber (Univ. Adelaide)

= the backbone of reality from particles to cosmos





“The only real voyage of discovery consists not in seeking new landscapes, but in having new eyes.”

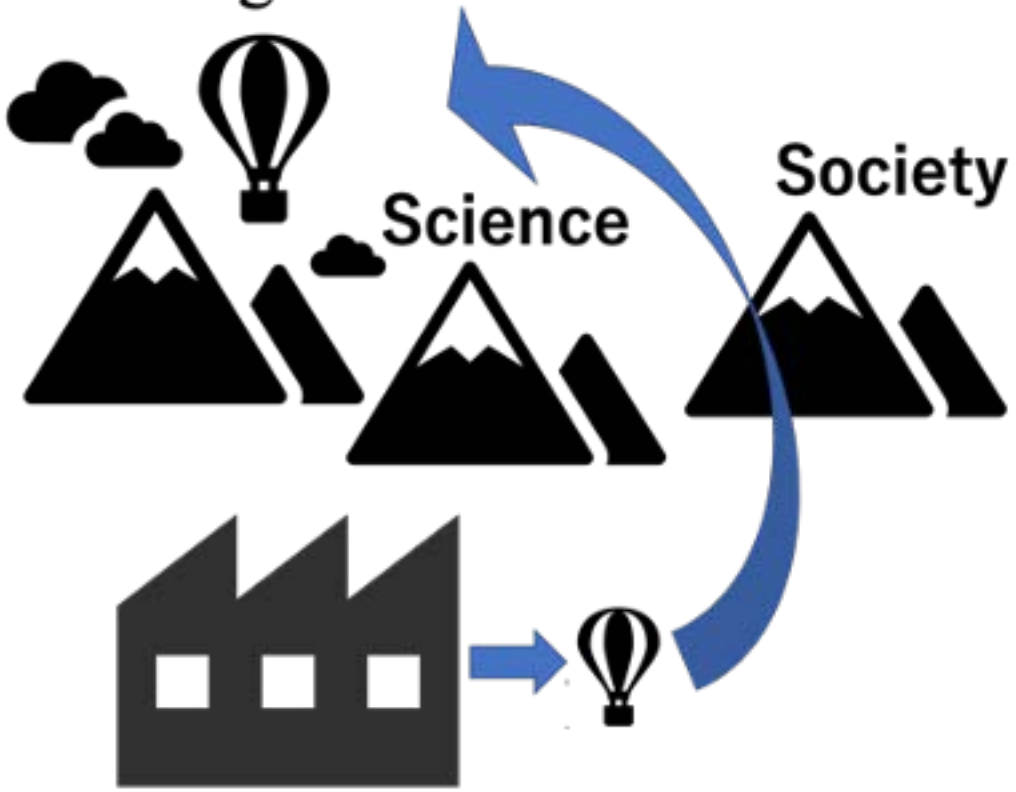
Marcel Proust

What is different from other WPI centers? - Uniqueness of QUP

Image of existing WPI centers

International expedition aiming for the summit

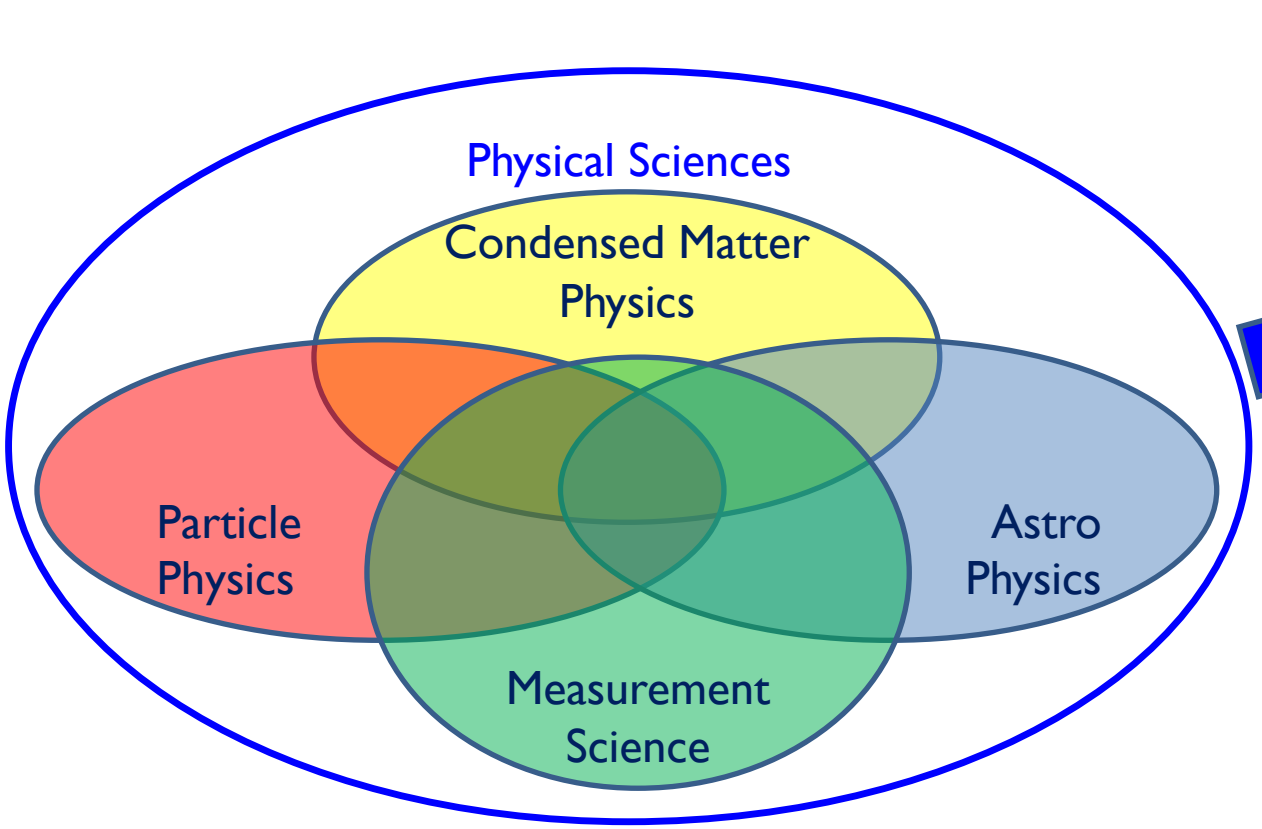
Image of this WPI center



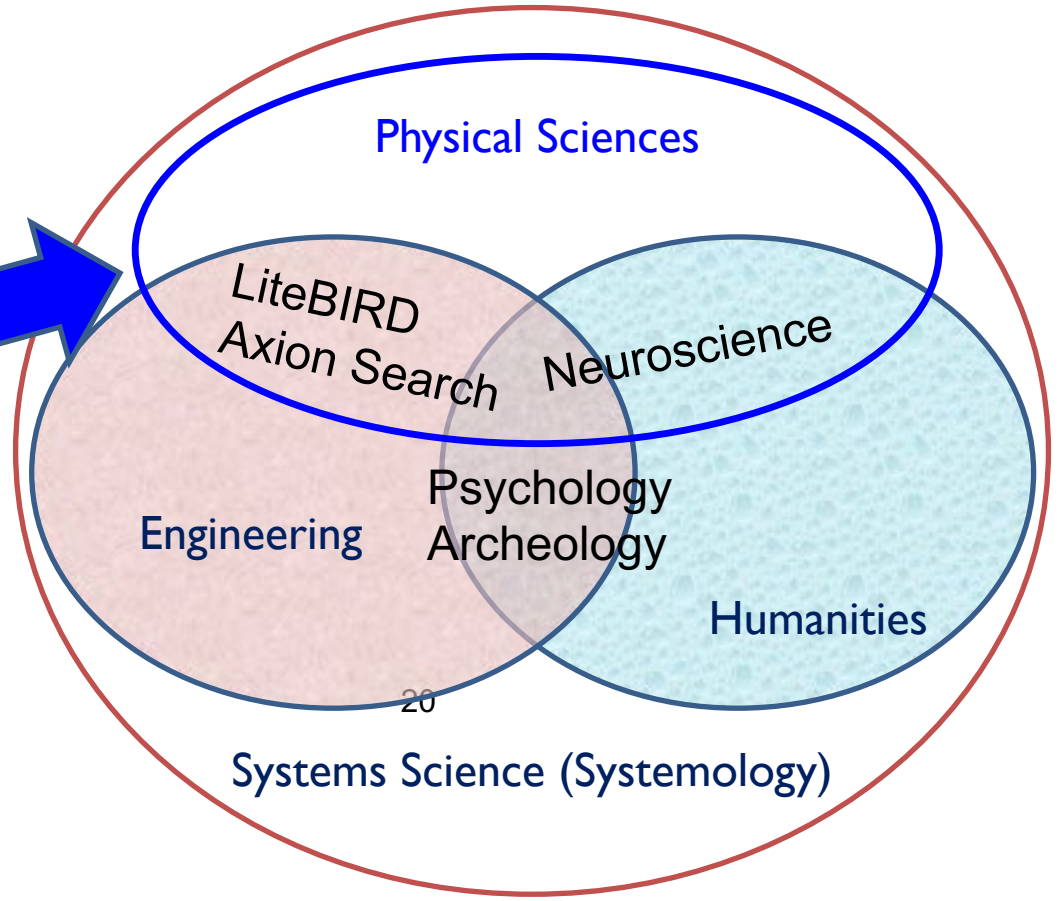
Lab to develop a vehicle that can fly anywhere

Meta-level interdisciplinary fusion for means, not for a single goal, to produce academic and social values

Two levels of interdisciplinary research at QUP



Level-1 Interdisciplinary Research in Physical Sciences



Level-2 Interdisciplinary Research

Systems Engineering and Systems Science (Systemology) at QUP

Motivation

- We want/need to be faster and more accurate in doing big and complex science projects.
- We want to accumulate our know-hows efficiently, before our tacit knowledge disappears.
- We want to make our knowledge explicit (not tacit) so that others can learn it.

Approach

Systemology Studio

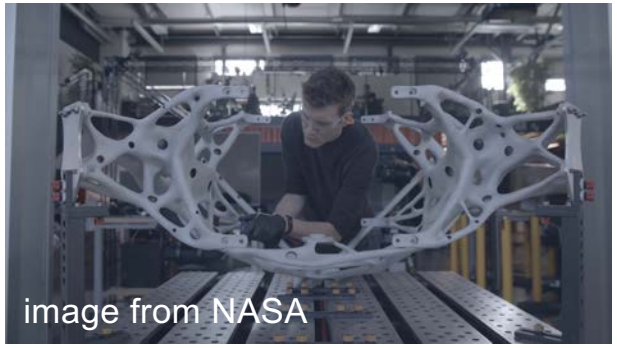
- Software developed by QUP's Systemology Support Section
- Aggregating existing tools (particle interaction simulators, 3D CAD software, MBSE software, etc.)
- Implementing database of technical (and even human) attributes

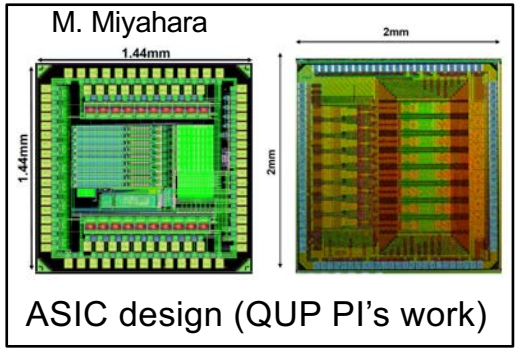
Systems Theory

Feedback from our practice

Concurrent design work

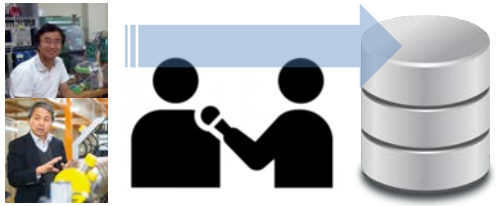
Automated design from a requirements flow





ASIC design (QUP PI's work)

From tacit knowledge to explicit knowledge



e.g. Detailed interviews to researchers with excellent development capability

MBSE Database

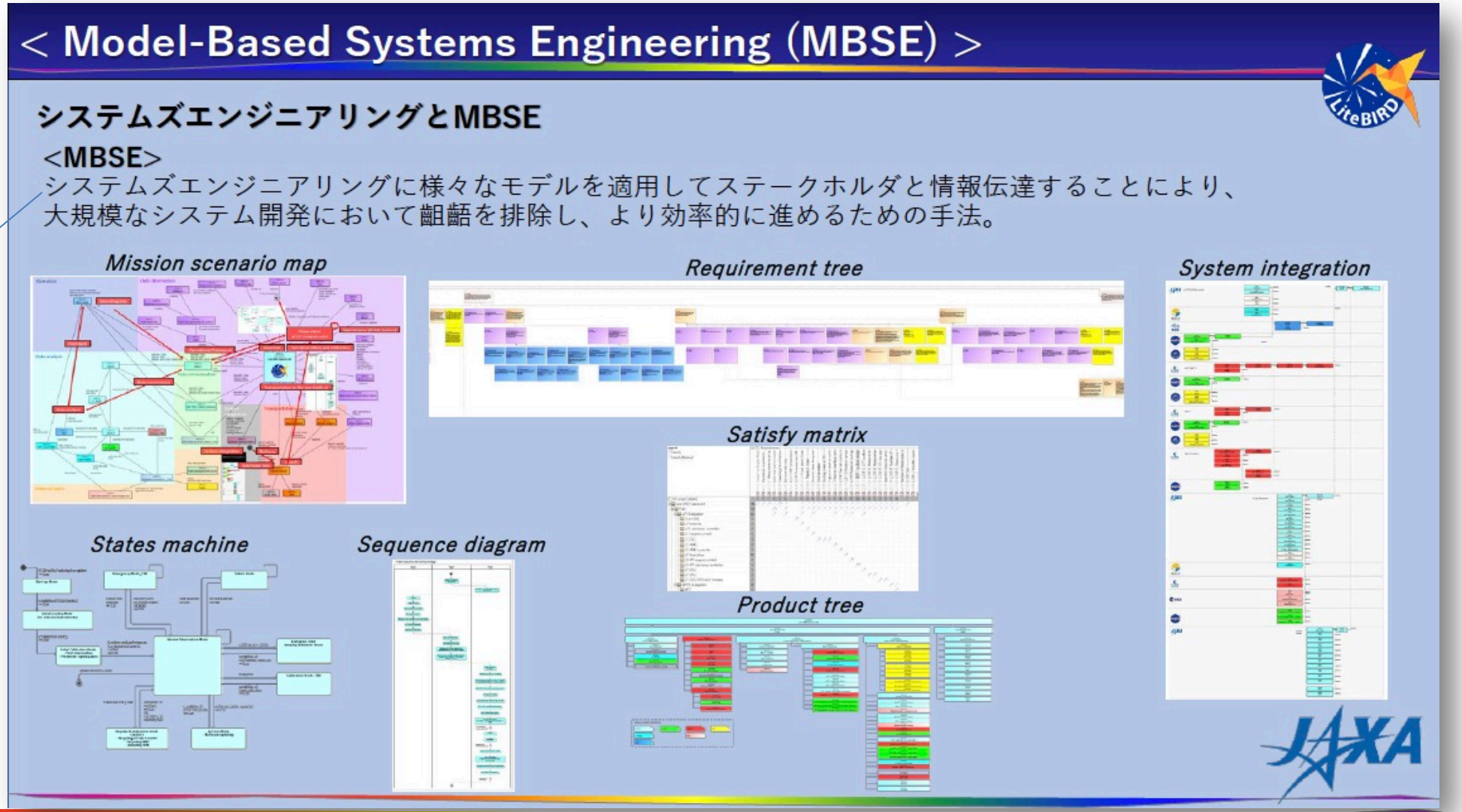
Systemology is our "research booster."

Model-Based Systems Engineering（MBSE

Example at LiteBIRD

K. Watanuki（JAXA）

A method to eliminate discrepancies and proceed more efficiently in large-scale system development by applying various models to systems engineering and communicating information with stakeholders.



QUP at KEK: Executive Summary

- QUP will invent novel quantum-field measurement systems and achieve major discoveries in particle physics and cosmology
  → The Highest Level of Research Impact
- Systemology and two levels of interdisciplinary research
  → Expanding Knowledge Frontiers
- Truly international science team with Berkeley Satellite and Univ. Oxford, and large scientific international collaborations → Brain Circulation
- Advancing internationalization and triggering system reforms of KEK
  → Effective, Proactive and Agile Management
- Huge impacts on social implementation with the Toyota Satellite
  → Societal Value of Basic Research
- Systemology-conscious education
  → Unique contribution to higher education
- Strong support by KEK → Self-sufficient development

スーパーラドハード検出器に向けて

Manabu Togawa

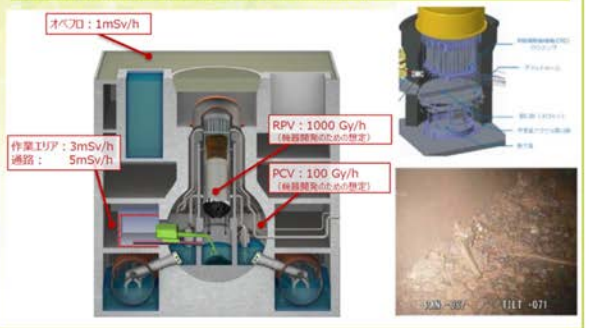
熱・光処理による機能回復！

RCPV Research Center for Photovoltaics

陽子線照射によるCIGS太陽電池の劣化および回復

西永 慈郎[1]、外川 学[2]、石塚 尚吾[1]
[1]産業技術総合研究所、[2]高エネルギー加速器研究機構

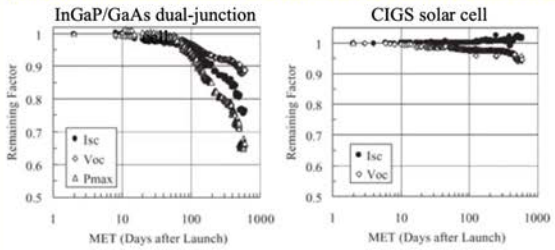
研究背景（福島第一原子力発電所）[1]

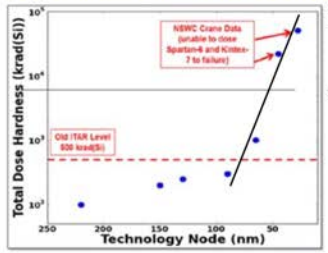


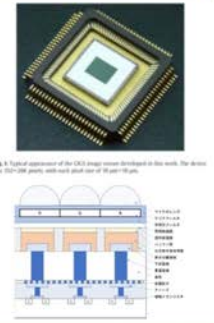
耐放射線カメラ（撮像管、固体撮像素子）[2]

	光導電型撮像管 ビジコン、トリニコン	固体撮像素子 CCD, CMOS
原理	光電面に光が照射されて電荷が生じる位置を電子線走査することで信号に変換	フォトダイオードによって信号に変換し、CCDもしくは直接読み出しが可能
サイズ	大きな真空管	小型
消費電力	大きい	小さい
蓄積線量	2×10^4 Gy	1000 Gy

CIGS太陽電池の放射線耐性[3]、CMOS回路の放射線耐性[4]、CIGSイメージセンサの構造図[5]

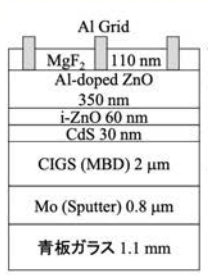




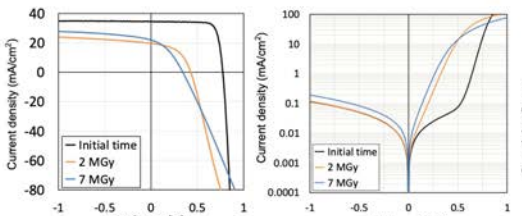


- CIGS太陽電池の高い放射線耐性は、MSD-1(“Tsubasa”)などによって検証済みである。（劣化を回復させる機構を有する）
- 最新のCMOS回路は放射線耐性が飛躍的に向上している。

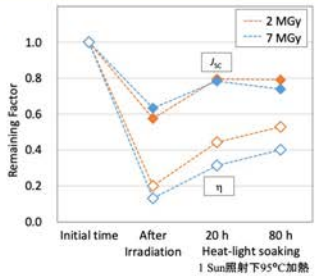
実験方法・結果（CIGS太陽電池への陽子線照射および熱・光処理）

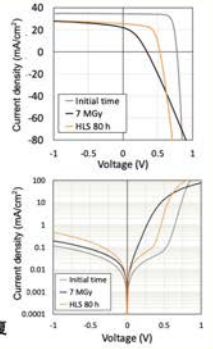


70 MeV 陽子線, -15°C冷却下
エネルギー損失(TID, Si 150 μm厚換算)
2 Mgy, 7 MGy



	Eff. (%)	V_{oc} (V)	J_{sc} (mA/cm²)	FF	$R_{sh,dark}$ (Ωcm²)	$R_{ser,dark}$ (Ωcm²)	$N_{ov,0V}$ (cm⁻³)	n_{dark}
初期値	21.4	0.774	34.7	0.795	3×10^3	0.5	5×10^{16}	1.3
2 MGy	4.1	0.429	19.6	0.493	4×10^3	3.1	3×10^{16}	1.9
7 MGy	2.8	0.34	22.0	0.373	1×10^3	7.0	1×10^{16}	2.0





- 短絡電流がイメージセンサにとって重要
- 短絡電流が短時間で保存率 0.8 まで回復

結論

- 高放射線耐性イメージセンサ実現に向けて
  - CIGS太陽電池の放射線耐性は高い
  - 最新のCMOS集積回路は放射線耐性が飛躍的に向上
- CIGS太陽電池の放射線耐性
  - 陽子線照射(7 MGy)後も、太陽電池動作を確認
  - 熱・光処理によって、変換効率、光電流の回復を確認
  - CIGS層内の再結合中心の消失が起こり、機能が回復

参考文献・謝辞

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[5] K. Miyazaki *et al.*, Thin Solid Films, 517, 2392 (2009).

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https://unit.aist.go.jp/rpd-envene/PV/ja/results/2019/poster/P34.pdf

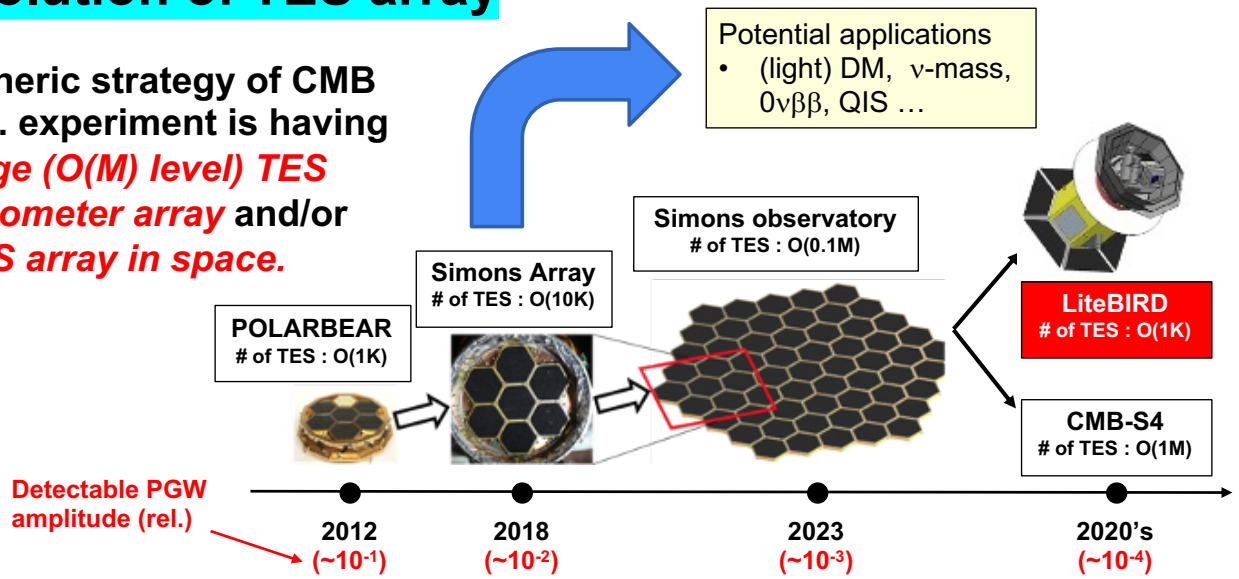
Advancing photon detection sensitivity of TES array

Masaya Hasegawa

Establishment of key technologies for realizing ultra low-noise and large superconducting detector arrays

Evolution of TES array

Generic strategy of CMB pol. experiment is having *large (O(M) level) TES bolometer array* and/or *TES array in space.*



Key challenges towards 1M TES array

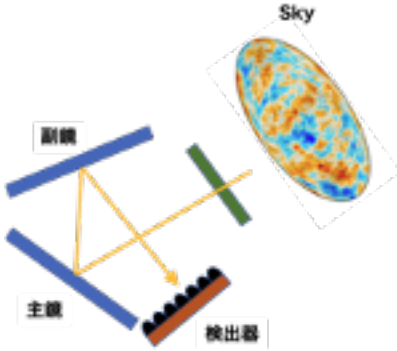
Project ①	Detector development and Fabrication
Project ②	Multiplexing readout
Project ③	Mitigating Excess Noise
Project ④	Processing large array data
Project ⑤	Characterization and QC

Adrian (+Masashi, Noriko & Kaori) lead

My target in QUP

Mitigating Excess Noise

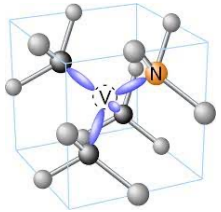
Mirror temperature (as an example)



- Additional polarization is induced at reflecting off the mirror
- If mirror temperature is fluctuated by ~10mK√s, the pol. amplitude is varied by ~5uK√s, leading it to the additional noise.

We need to monitor the warm equipment at the level of 1mK√s. ** Refined TOD process is also indispensable.*

Diamond censor (w/ NV center) is a promising candidate.

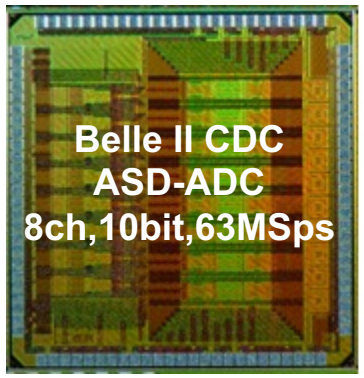


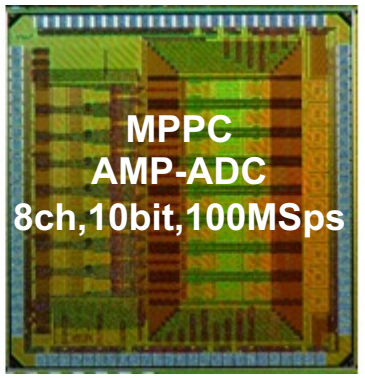
© Mizuochi lab. (Kyoto U)

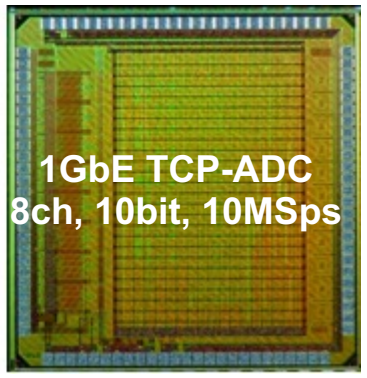
*Beating excess noise is one of biggest challenges for next gen. CMB experiment, and we will realize it by applying **control engineering technique** and ultrahigh sensitive **(quantum) sensors**.*

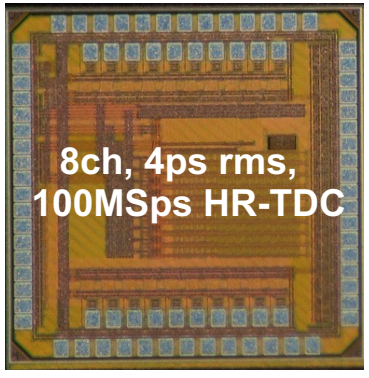
Masaya Miyahara（Age. 41）
2017～ Associate Professor in IPNS, KEK
Research area：Analog Mixed signal LSI and its applications

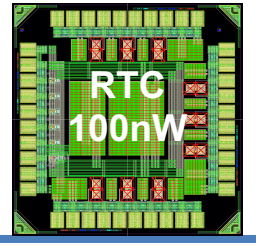
Collaboration with Industry

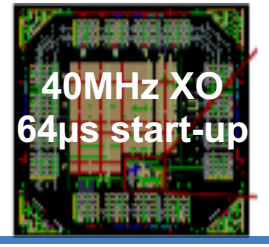




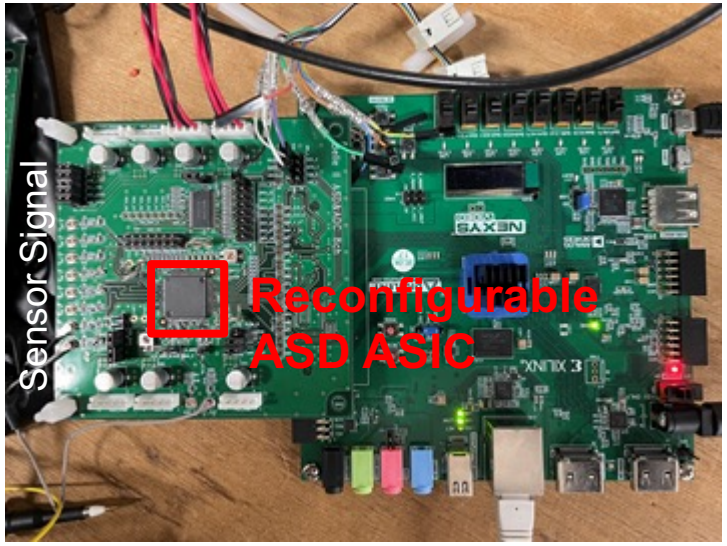


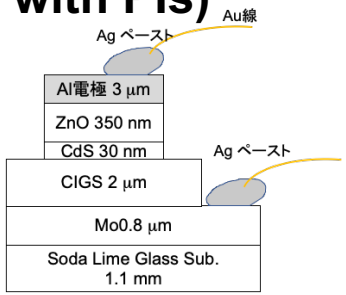




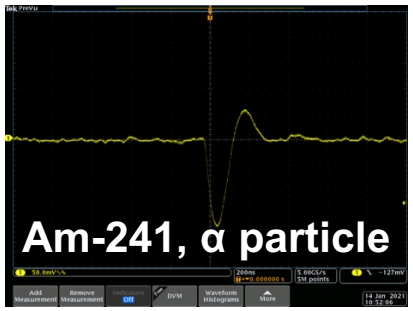


Activity 1. Read-out ASIC (collaborate with PIs)
Ex. Rad-hard detector read-out ASIC





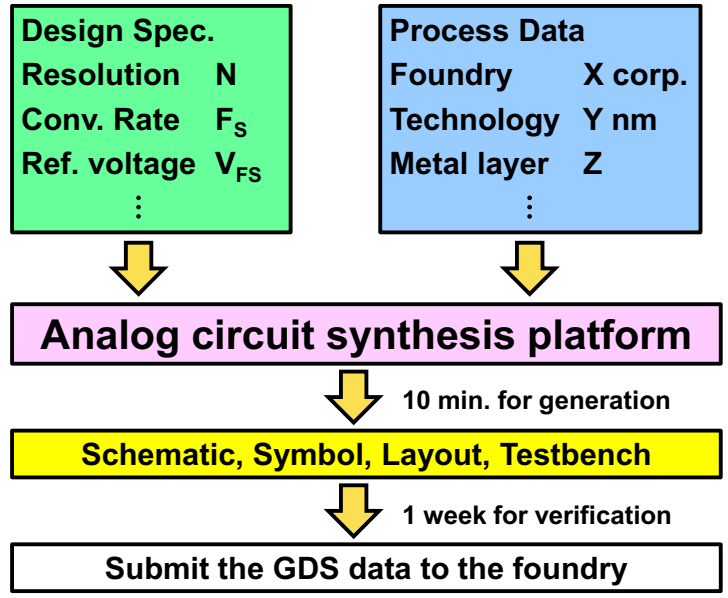
CIGS detector



Activity 2. Design automation for Analog LSI

ASIC development issue
- Long TAT
- Difficult to fix the bug
- Engineer Education
（Analog 10 years）

Concepts
- Performance scalable
- Process scalable
- Effective use of past works (know-how)



Radiation hardness and high rate tolerance new device and applications

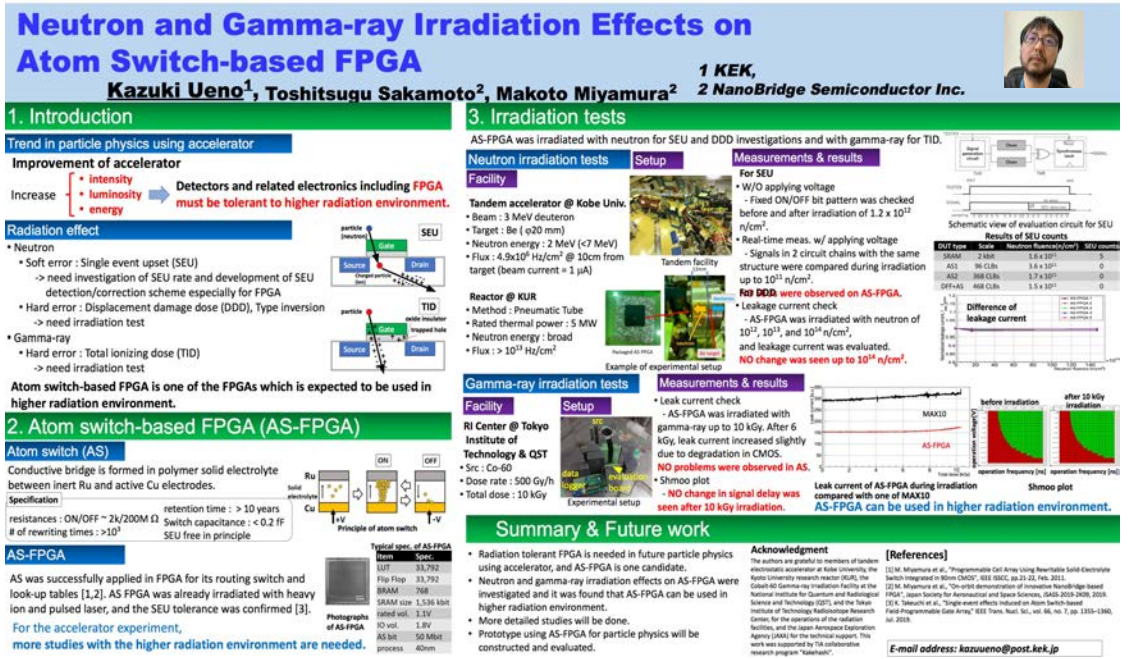
w/ K. Ueno (KEK IPNS)
Electronics experts will join.

radiation hardness of electric devices is challenge for high energy physics experiments

- Achieve practical use of new device

  new FPGA with atomic switch technology

  - promising radiation hardness
  - R&D for application to practical use in higher energy experiments is about to start
  - development tools for users is desired
  - implementation of high speed optical link in near future

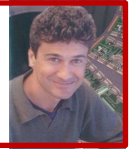


Kazuki Ueno, IEEE 2021

- Create new application by combining existing ideas

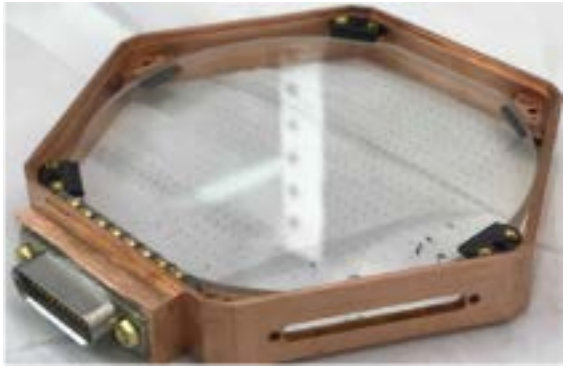
Garcia-Sciveres QUP program

Maurice Garcia-Sciveres



Quantum Sensing for Low Mass Particle Dark Matter Searches

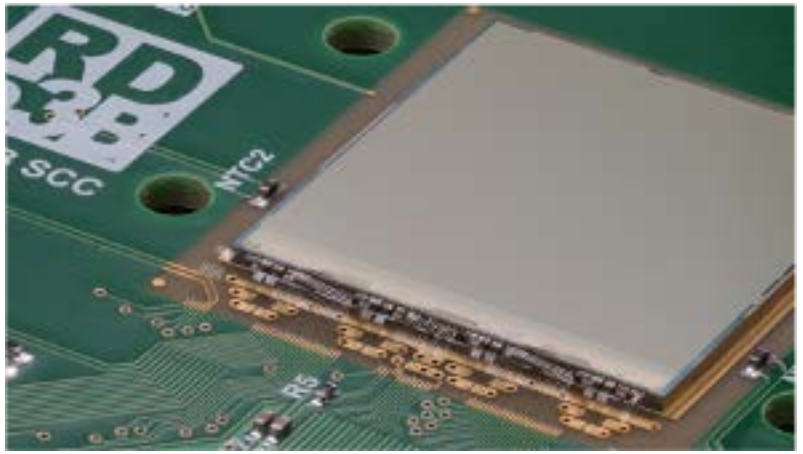
- Establish cryogenic (sub-Kelvin) underground research lab in Japan.
  - Kamioka is a possible location
- Deploy demonstrator DM searches using novel sensors to push limits of low threshold
  - Needed to extend DM search mass range well below the protong mass
  - Collaboration with SPICE-HeRALD experiments under development to achieve first science results in a few years
- Basic QIS measurements also. For example decoherence mechanisms studies thanks to ultra-low background



Next Generation Pixel Readout for Colliders

Jointly with Daniela Bortoletto

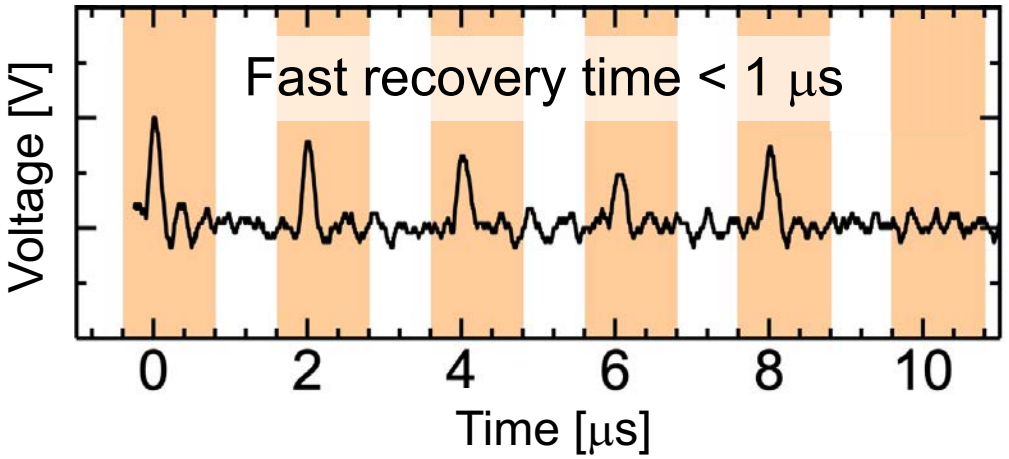
- Open a new chapter for RD53 collaboration
- Move to 28nm CMOS technology
  - Enable <100ps per pixel timing
  - Enable higher bandwidth readout (needed to readout out timing data in addition to what is done today)
- Interface to novel sensors
  - Collaborate with sensor development efforts

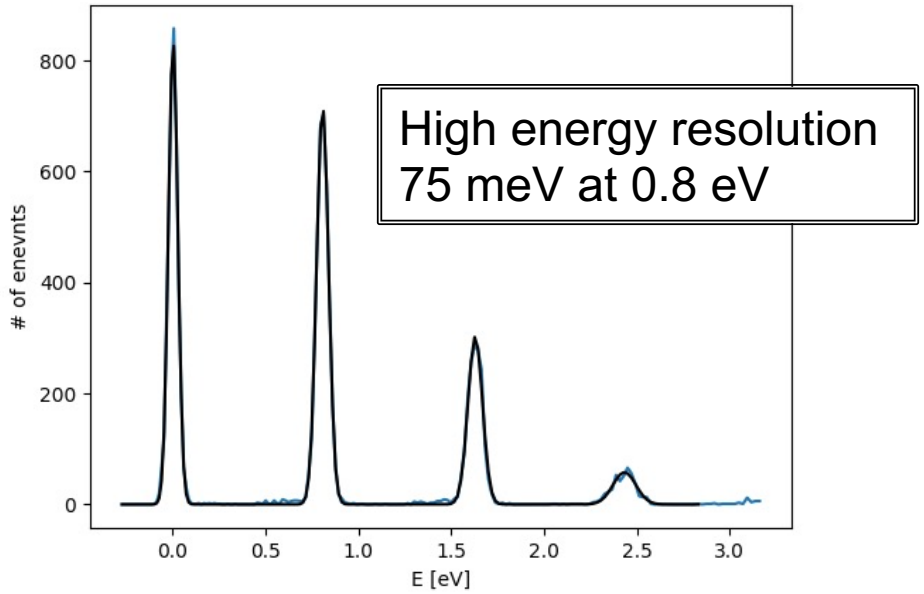


Optical transition-edge sensors (TES)

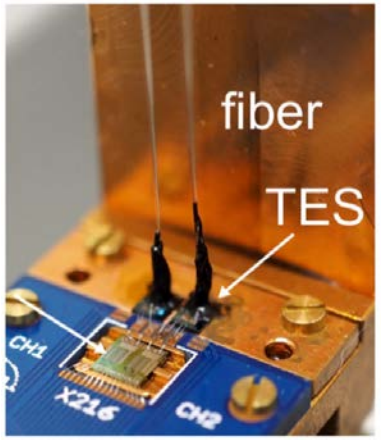
Kaori Hattori

Repetition rate of pulsed laser : 500 kHz



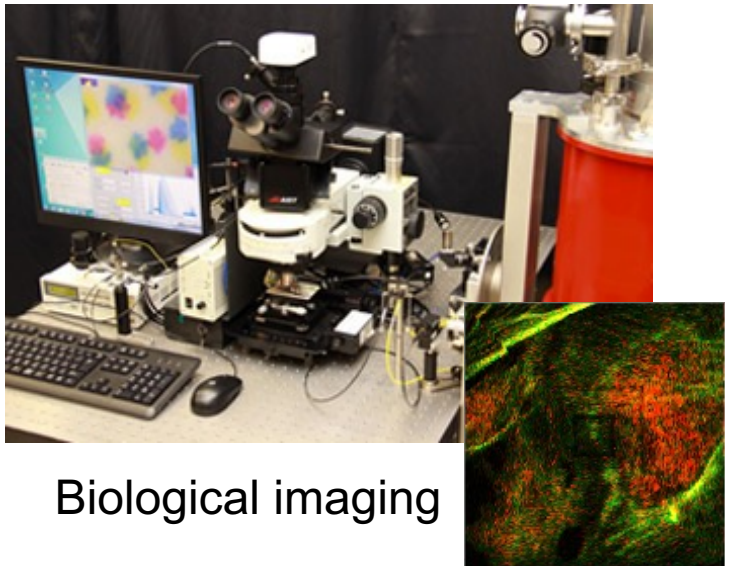


High energy resolution
75 meV at 0.8 eV



Optical TESs

Scanning microscope with a TES



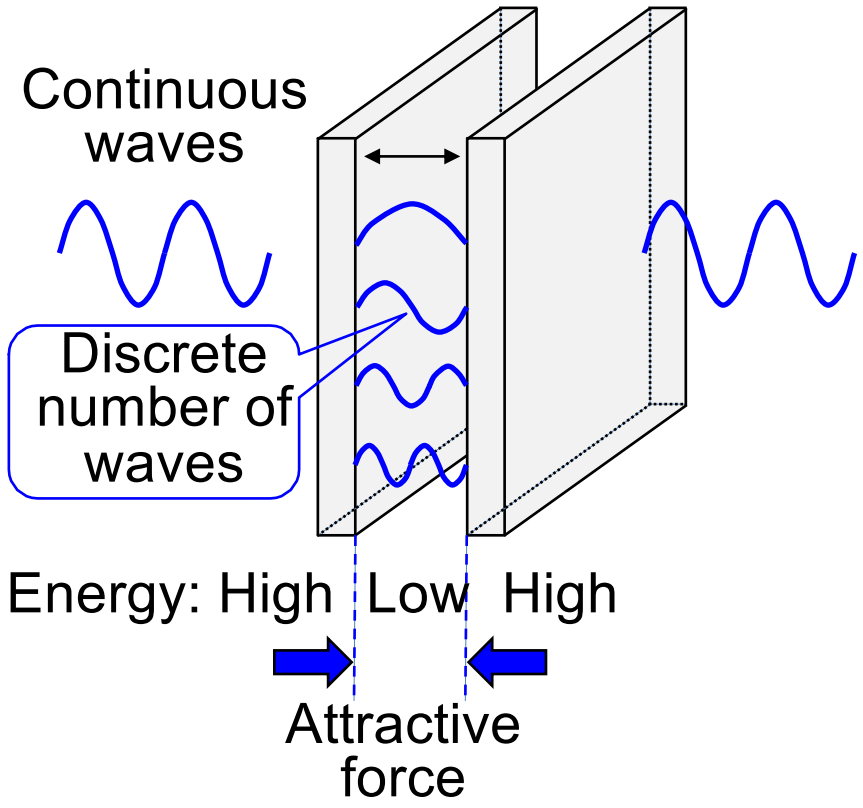
Biological imaging

Ultra-low dark counts
→Proved biological imaging using a faint light source
Fast detector response
→Suitable for quantum computing

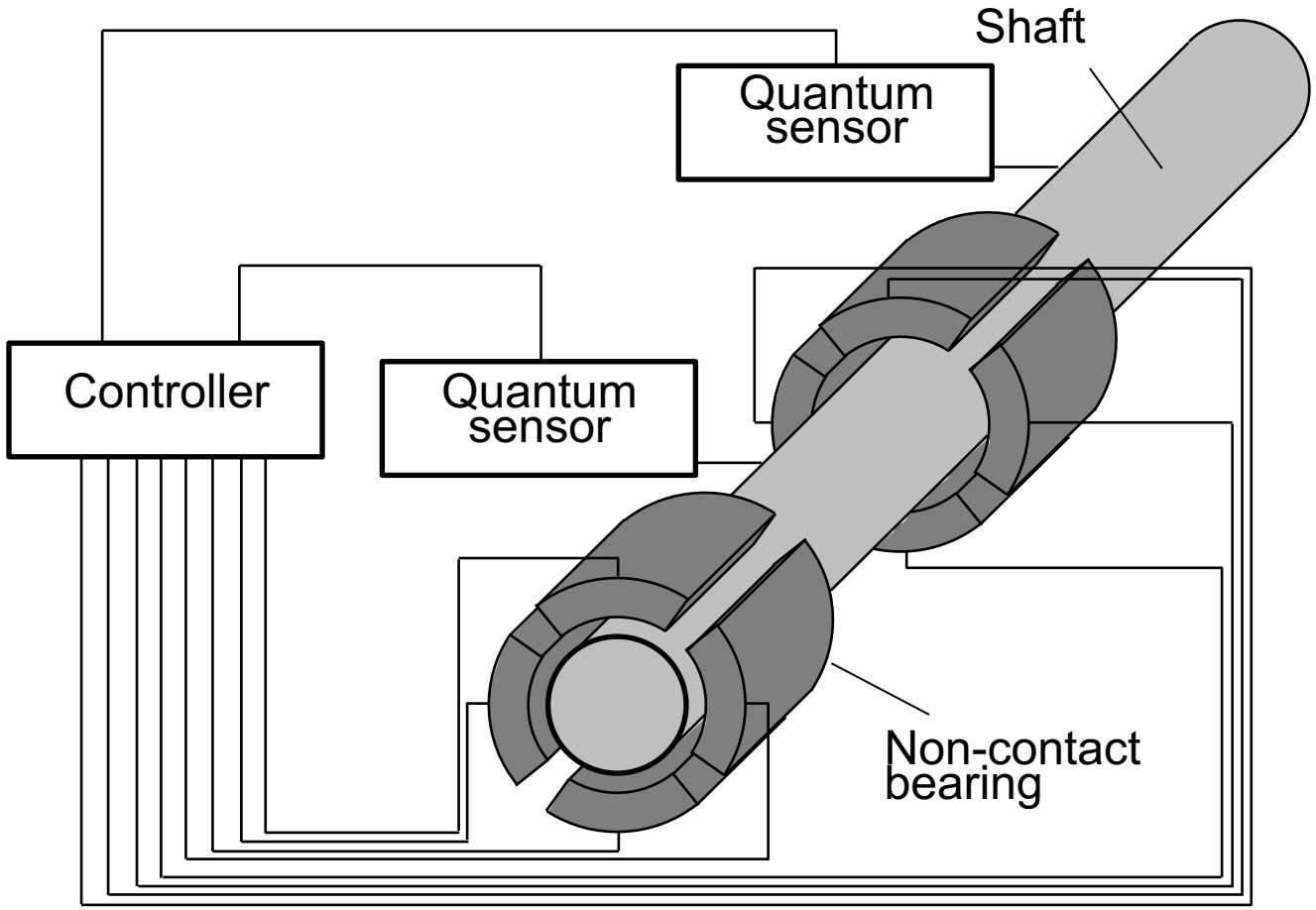
We will start new projects using optical TESs at QUP!

Casimir Force Device

What is Casimir force?



Non-contact shaft-bearing system



Advanced Physics-Analysis Techniques

Yu Nakahama

- Developments of advanced analysis techniques,
  e.g. with Machine Learning, and Real-Time analyses “Triggers”

- Applications to Data Analyses in colliders → Brand-new physics-outputs