Cosmic Background Neutrino Decay Search
– COBAND Experiment –

Shinhong Kim (University of Tsukuba, CiRfSE)

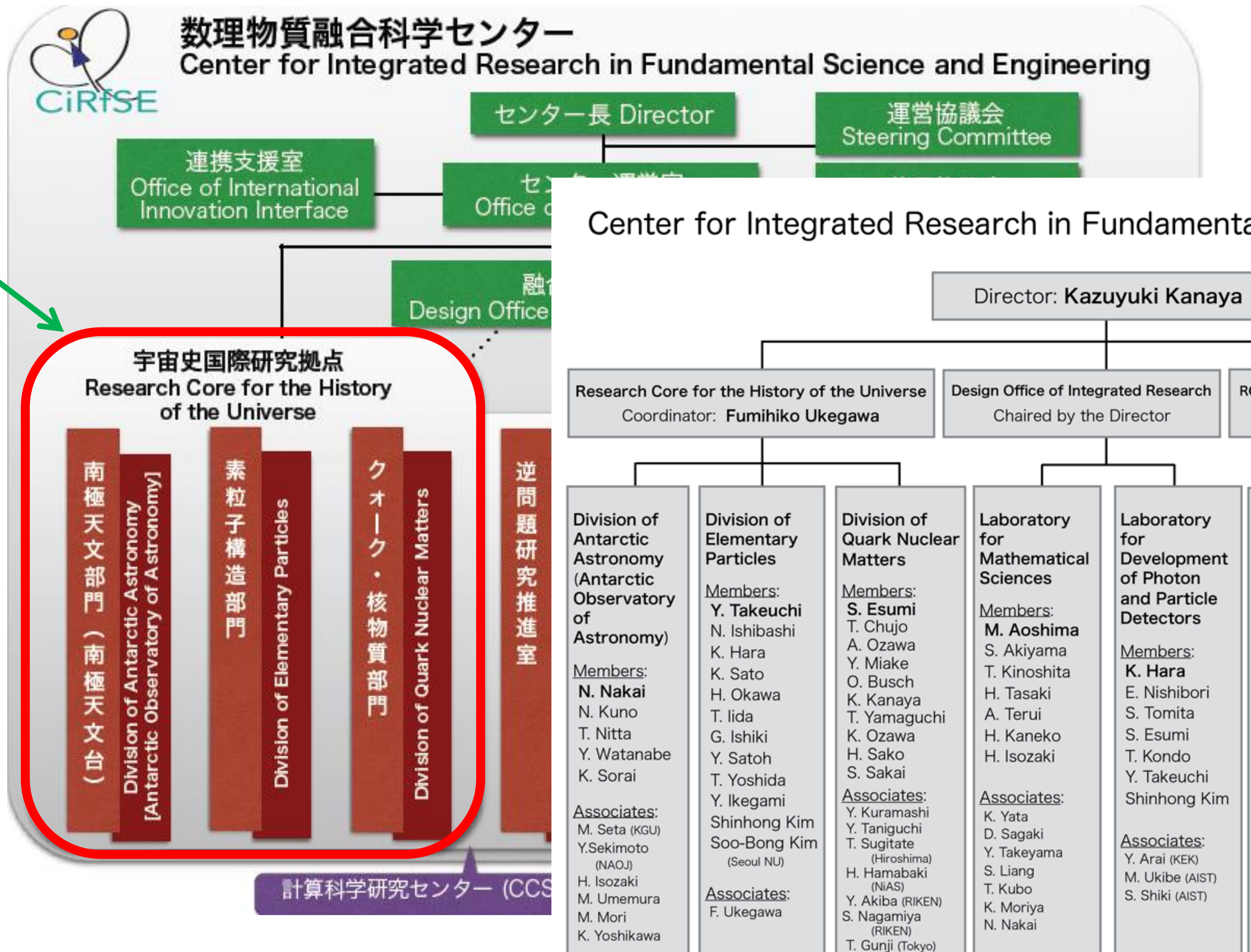
at Seoul National University
April 28, 2017

宇宙史国際研究拠点
Research Core for the History of the Universe
数理物質融合科学センター
Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba

CiRfSE

ν_3 γ ν_2
COBAND

Research Core for the History of the Universe



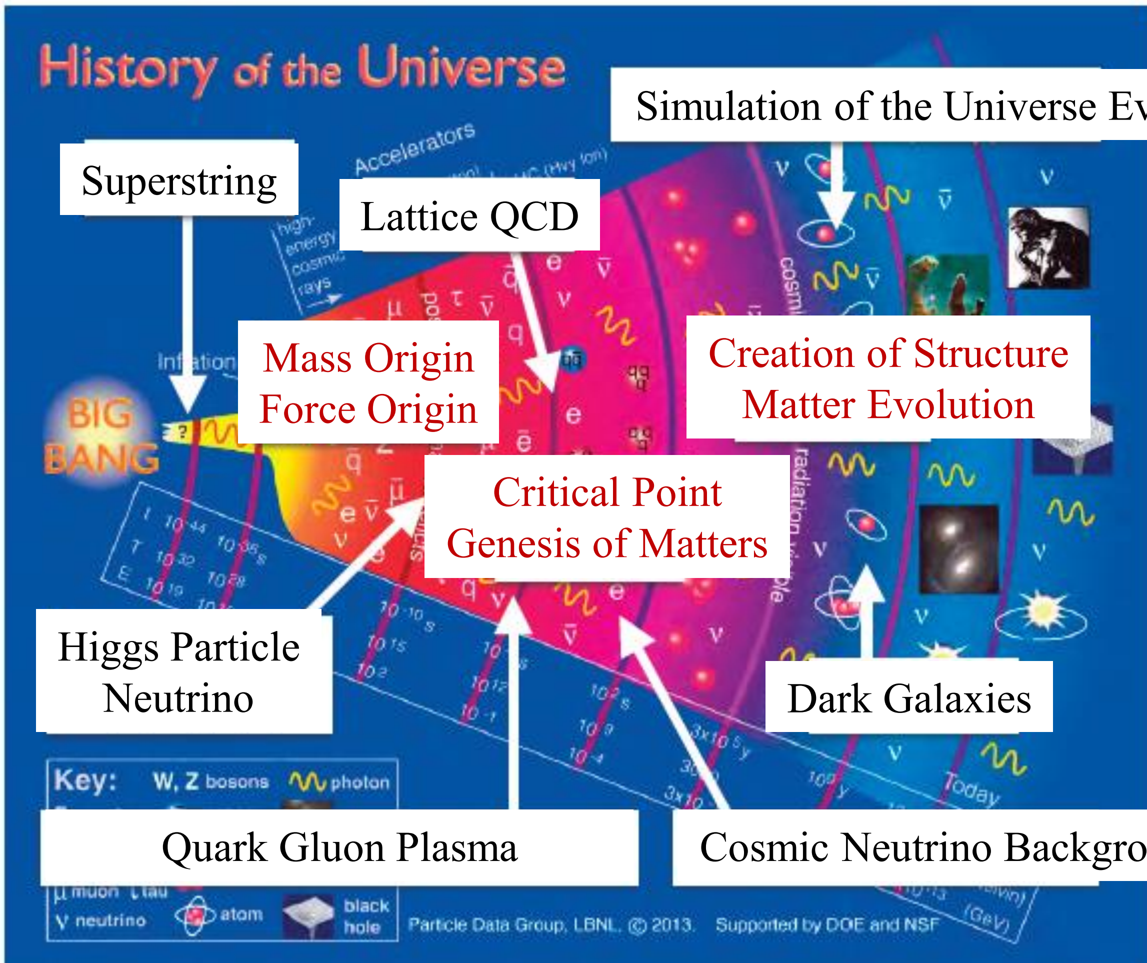
Three Divisions:

- Antarctic Astronomy
- Elementary Particles
- Quark and Nuclear matters

Research Core for the History of the Universe

under Center for integrated Research in Fundamental Science and Engineering, University of Tsukuba (founded on Sep. 1, 2014)

Mission: coordinate the studies in elementary particles, quark nuclear matters and astrophysics to construct an integrated view of the History of the Universe.



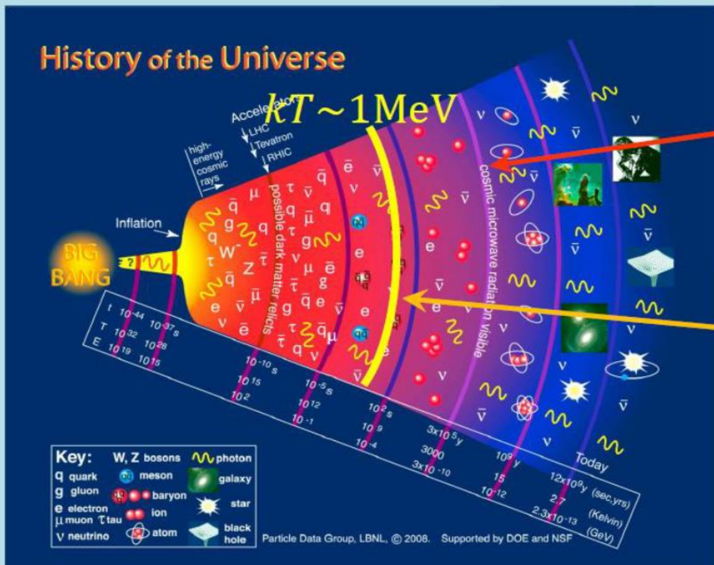
Illuminate the "Darkness":
=>Dark matter, Dark energy , Dark galaxies
=>Genesis of matters, creation of structure and their evolution

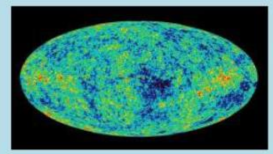
COsmic BAckground Neutrino Decay (COBAND) Experiment

宇宙背景ニュートリノ崩壊探索

COBAND

Cosmic Background Neutrino Decay Search





CMB

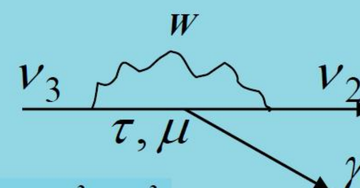
$n_\gamma = 411/\text{cm}^3$

$T_\gamma = 2.73\ \text{K}$

CνB

$$n_\nu = n_{\bar{\nu}} = \frac{3}{4}\left(\frac{T_\nu}{T_\gamma}\right)^3 \frac{n_\gamma}{2} = 56/\text{cm}^3$$

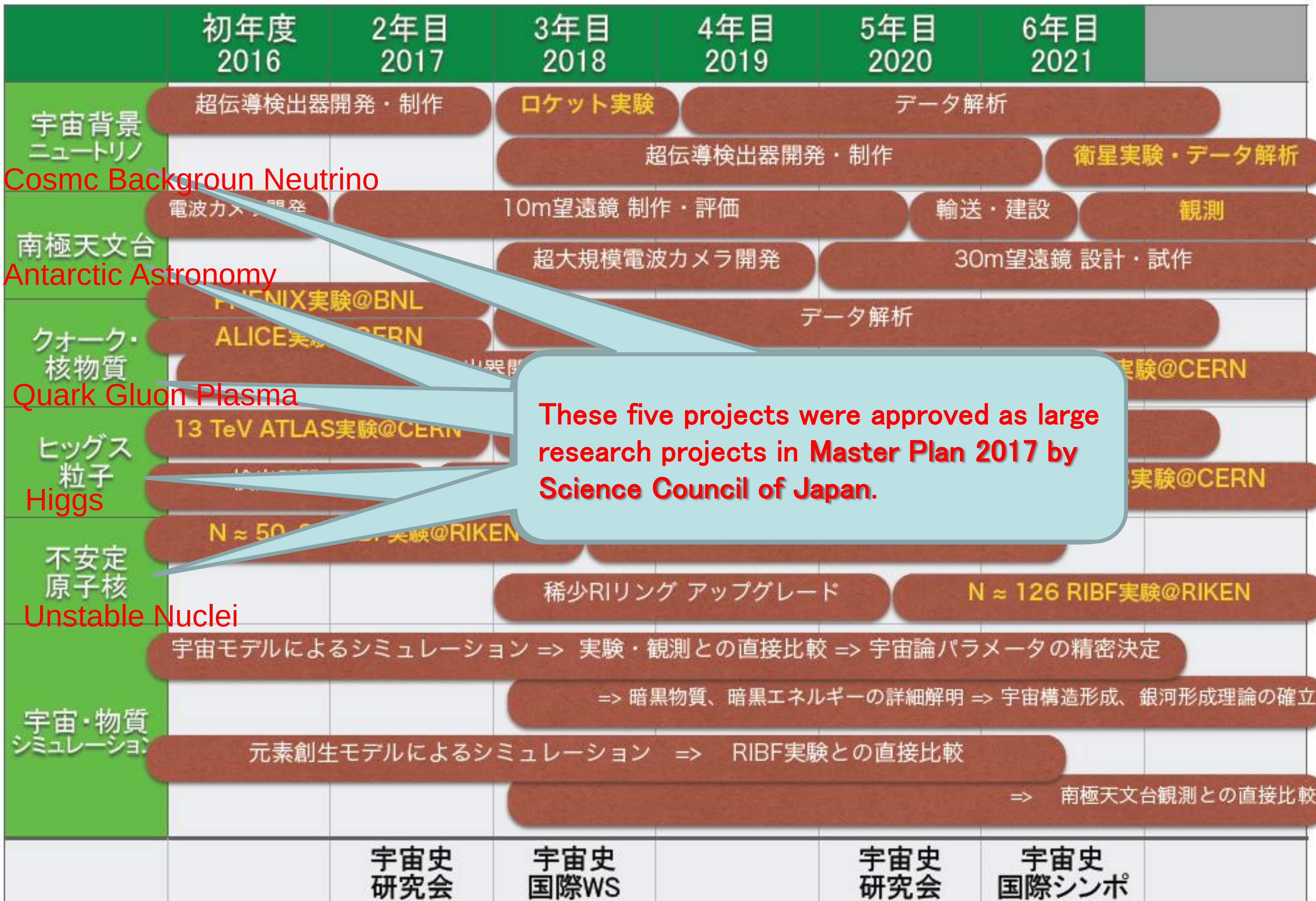
$$T_\nu = \left(\frac{4}{11}\right)^{\frac{1}{3}} T_\gamma = 1.95\text{K}$$



$$E_\gamma = \frac{m_3^2 - m_2^2}{2m_3}$$

http://hep.px.tsukuba.ac.jp/coband/

Schedule of Research Core for the History of the Universe

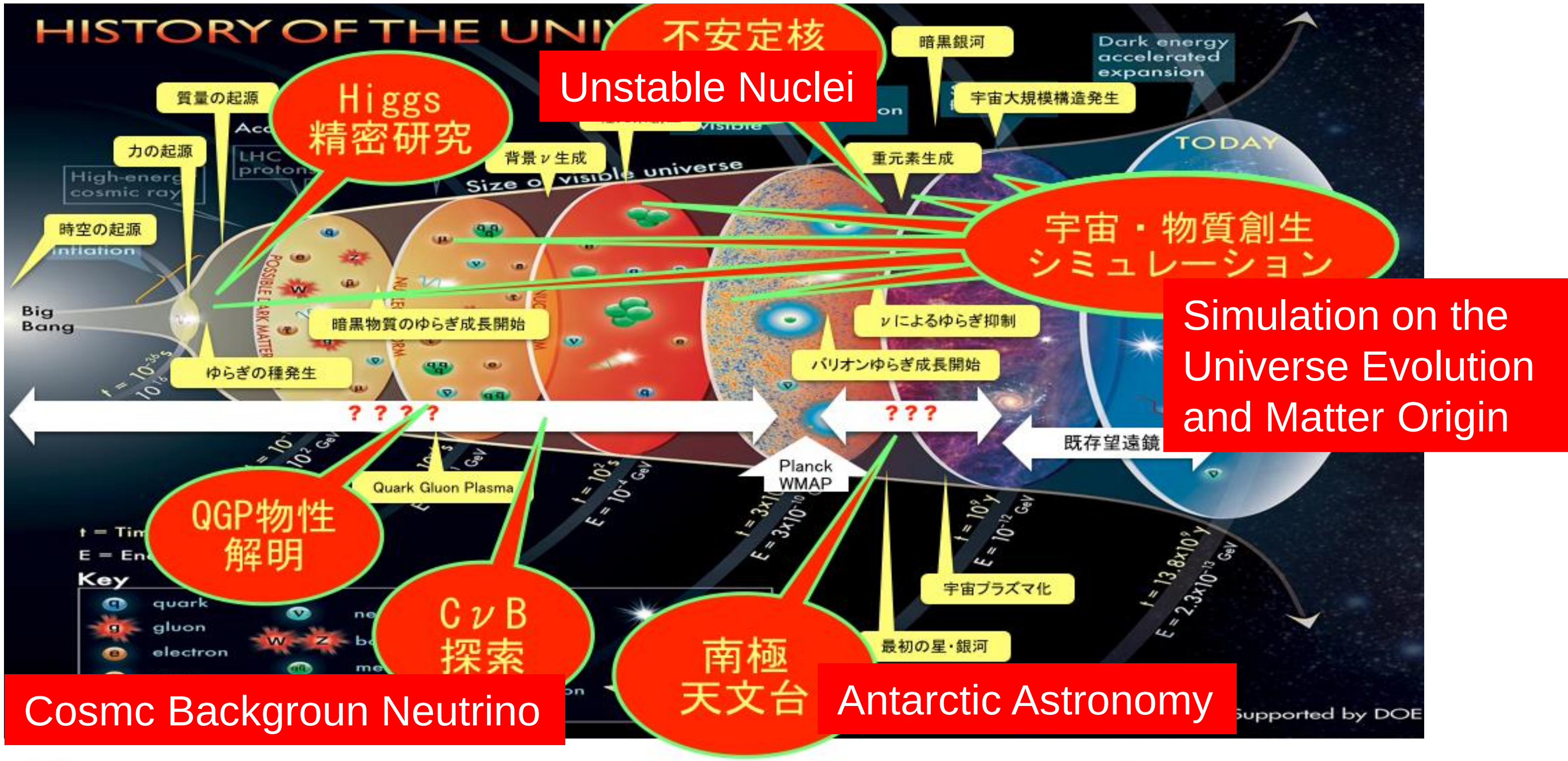


概算要求： 宇宙史の暗黒を照らす国際研究拠点形成

Budget Request to MEXT:

International Research Center to illuminate the Darkness in the History of the Universe

Aiming at illuminating the Darkness in the History of the Universe



- ☑ 生命につながる元素の起源？
- ☑ 宇宙の構造の起源？　力・物質・時空の起源？
- ☑ 実験的に未解明の領域（暗黒）が多く残されている。

- 最先端の宇宙観測、素粒子・原子核実験プロジェクトを有機的に融合
- 現象とメカニズムの同時解明
- 物質と生命の起源に迫る新領域の国際的研究ネットワークを形成

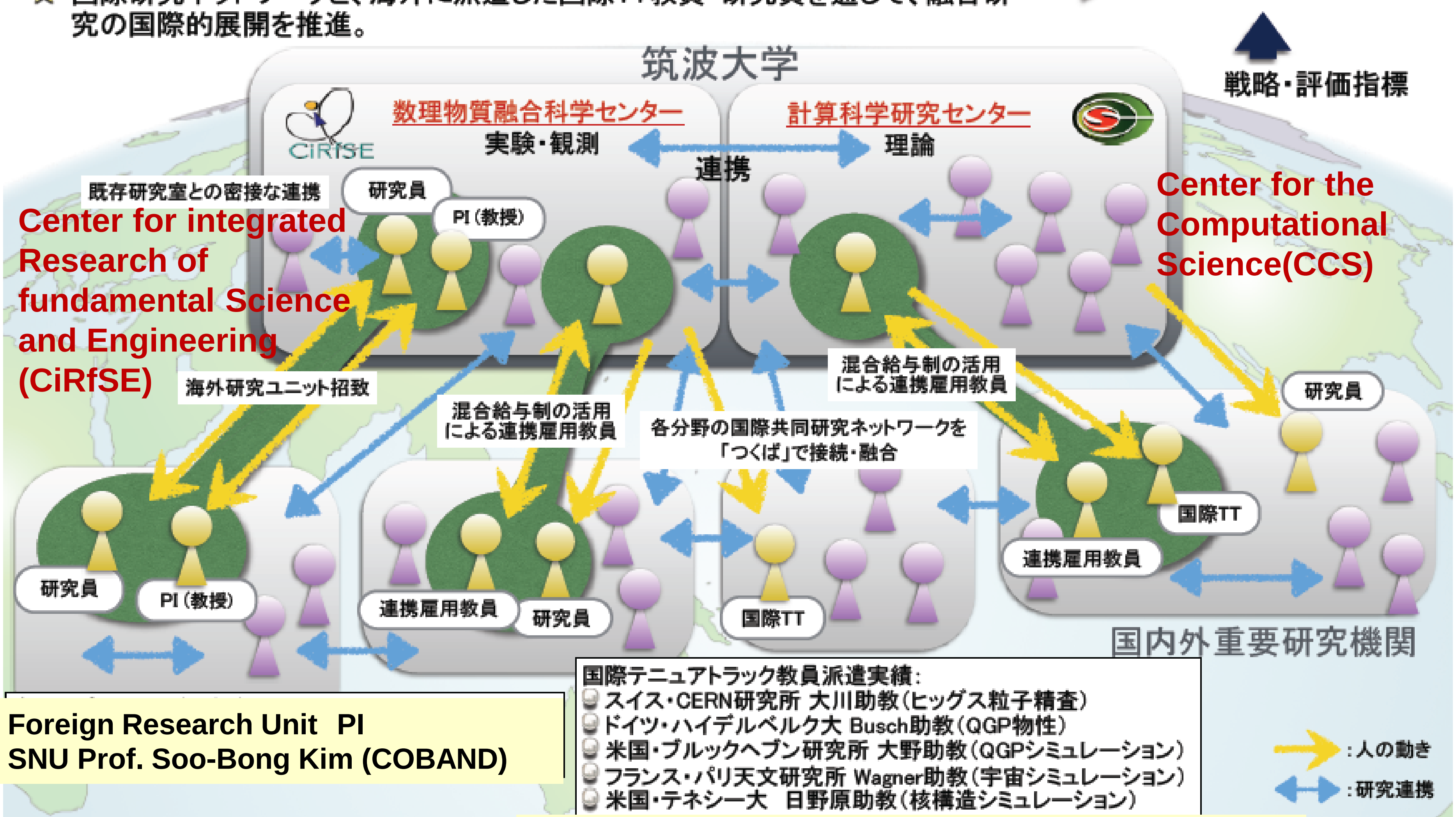
Five experiment projects and simulation studies which led by University of Tsukuba group are integrated and developed to illuminate the darkness such as dark galaxies, dark matter and dark energy in the History of the Universe.

Approved for April 2016 to March 2022 (24,800kYen/year).
Budget for Researchers of Research Unit, Crossover Appointment and Postdocs.

Collaboration System with Research Units and Cross-Appointment Researchers

☆ 海外研究ユニット招致（副PIつくば常駐、混合給与なども活用）と、国際テニュアトラック教員の活用・研究員の交換により、国際共同研究体制を強化。
☆ 国際研究ネットワークと、海外に派遣した国際TT教員・研究員を通じて、融合研究の国際的展開を推進。

国内外の人材交流・共同研究のハブとなる。



Foreign Research Unit PI
SNU Prof. Soo-Bong Kim (COBAND)

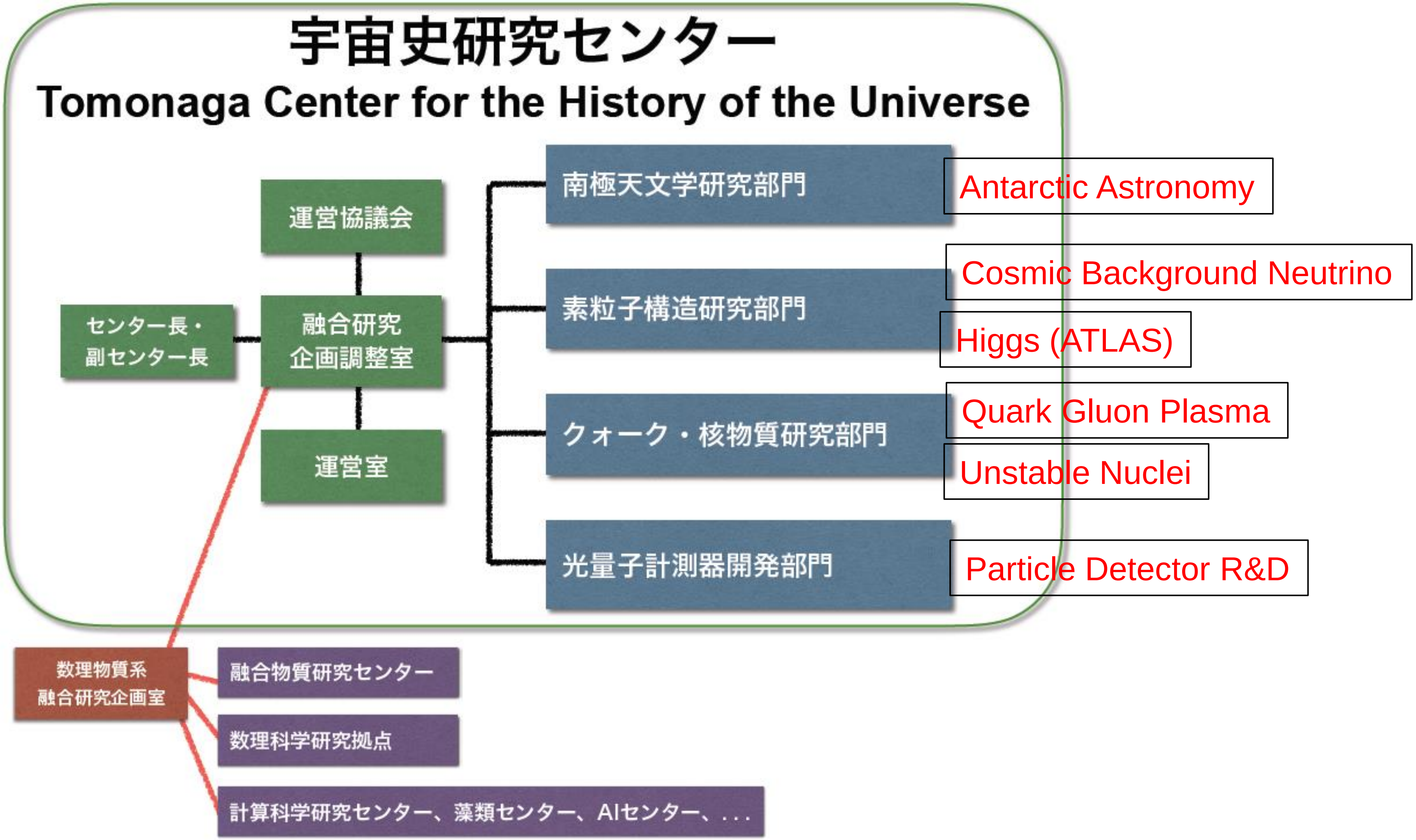
1 Assistant Professor and 1 postdoc (COBAND)

Research Core for the History of the Universe

→ **Tomonaga Center for the History of the Universe**

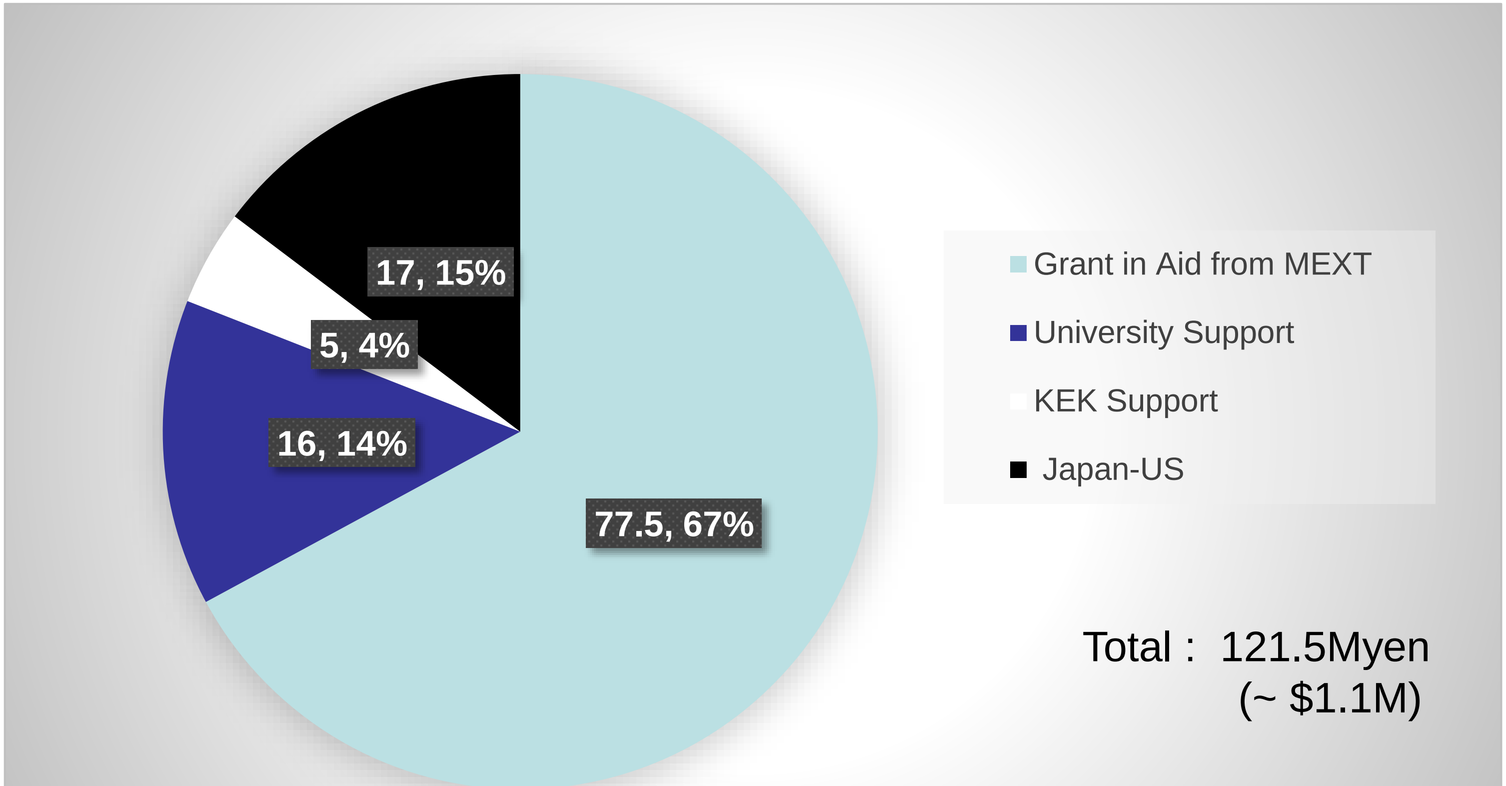
Re-Organization

From Oct. 2017



Approved for October 2017 to March 2022 (10,500kYen/year).
Budget for Postdocs, Detector R&D and travel expenses.

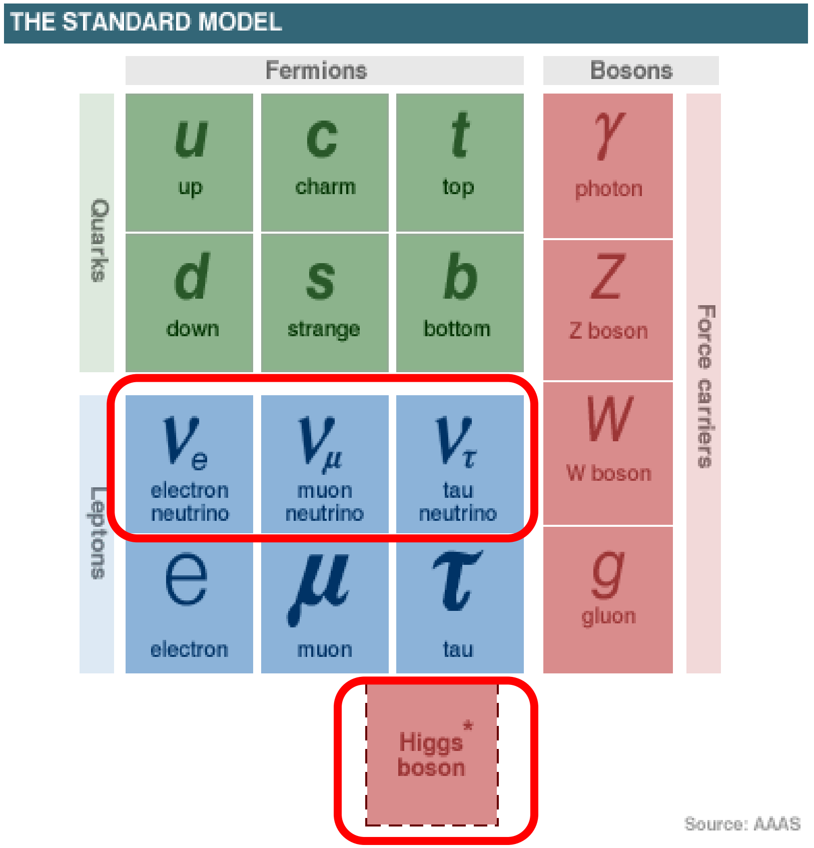
R&D Budgets for the COBAND in the period of JFY2013-2017



Grant in Aid “Neutrino” from MEXT	R&D of Superconducting Infrared Detector for Neutrino Decay Experiment	JFY2013—2017	77.5 MYen
University Support	He3 Sorption Refrigerator	JFY2013, 2016	21.0 MYen
KEK Support	Cooperative Project of University of Tsukuba and KEK	JFY2013–2016	5.0 MYen
Japan-US Project	Neutrino Decay Search Experiment Cooperative	JFY2012–2014	17.0 MYen

Cosmic Background Neutrino Decay Search (COBAND)

Division of Elementary Particles ：Higgs and Neutrino



The origin of the mass and matter

↑

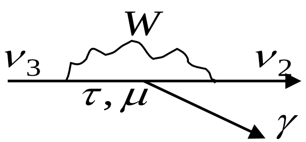
Studies on Neutrinos and Higgs.

Neutrino：
- Neutrino masses
- Cosmic background neutrino

Higgs：
- Coupling to bosons and fermions
- Search for other Higgs such as heavy neutral Higgs and charged Higgs

Motivation of Search for Cosmic Background Neutrino Decay

- Only neutrino mass is unknown in elementary particles. Detection of neutrino decay enables us to measure an independent quantity of Δm^2 measured by neutrino oscillation experiments. Thus we can obtain neutrino mass itself from these two independent measurements.



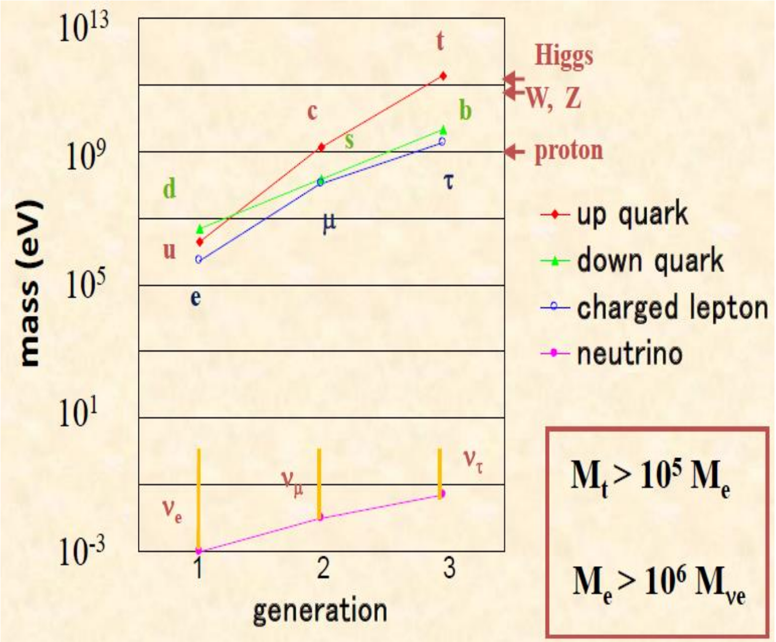
$$\nu_3 \rightarrow \nu_2 + \gamma$$

$$E_\gamma = \frac{m_3^2 - m_2^2}{2m_3} = \frac{\Delta m_{23}^2}{2m_3}$$

Using $\Delta m_{23}^2 = (2.43 \pm 0.09) \times 10^{-3}\,\mathrm{eV}^2$

$E_\gamma = 10 \sim 25$ meV at ν_3 rest frame.

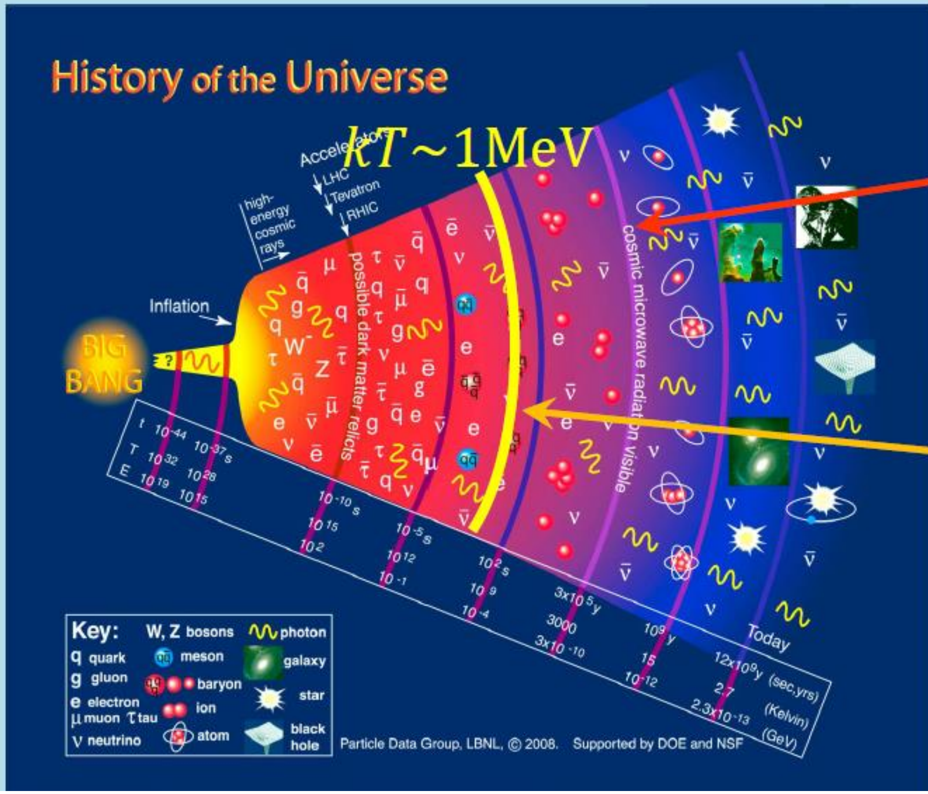
(Far-Infrared region $\lambda = 50 \sim 125\ \mu$)

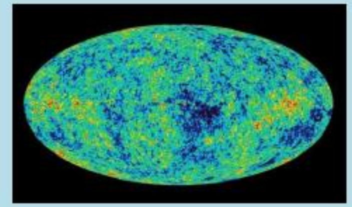


- As the neutrino lifetime is very long, we need use cosmic background neutrino to observe the neutrino decay. To observe this decay of the cosmic background neutrino means a discovery of the cosmic background neutrino predicted by cosmology.

- Left-Right symmetric model predicts the neutrino lifetime larger than 10^{17} year while the standard model predicts 2 x 10^{43} year. Measured neutrino lifetime limit $\tau > 3 \times 10^{12}$ year.

Big-Bang Cosmology and Cosmic Background Neutrino (CνB)





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CνB

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$$= 56/\mathrm{cm}^3$$
$$T_\nu = \left(\frac{4}{11}\right)^{\frac{1}{3}} T_\gamma = 1.95\mathrm{K}$$

- A few seconds after Big Bang → Cosmic Background Neutrino (CνB) became free.
- 300,000 years after Big Bang → Cosmic Microwave Background (CMB) became free.

Cosmic Background Neutrino

Fermi and Bose Distribution Function $F(E) = \dfrac{1}{e^{(E-\mu)/kT} \pm 1}$

where + for fermions and - for bosons, and E is energy and μ is a chemical potential.

For $\mu \ll T$ *and* $m \ll T$,

Energy density $\rho = g \int \frac{d^3p}{(2\pi)^3} EF(E) = g\,(\frac{7}{8})^F \frac{\pi^2}{30} T^4$

Number density $n = g \int \frac{d^3p}{(2\pi)^3} F(E) = g(\frac{3}{4})^F \frac{\zeta(3)}{\pi^2} T^3$

Entropy $s = \frac{4\rho}{3T} = g(\frac{7}{8})^F \frac{2\pi^2}{45} T^3$

Temperature:

Below 3MeV, ν is decoupled from other particles because the weak interaction cross section becomes too small.

Below 1MeV, $e^+e^- \rightarrow \gamma\gamma$ is possible, but $\gamma\gamma \rightarrow e^+e^-$ is impossible. so photons are reheated by this process. The entropies before and after this time are equal to each other:

Entropy $s \propto g\,(\frac{7}{8})^F T^3$ *g*=2(for γ), 2(for e^- or e^+), 1(for ν or anti-ν)

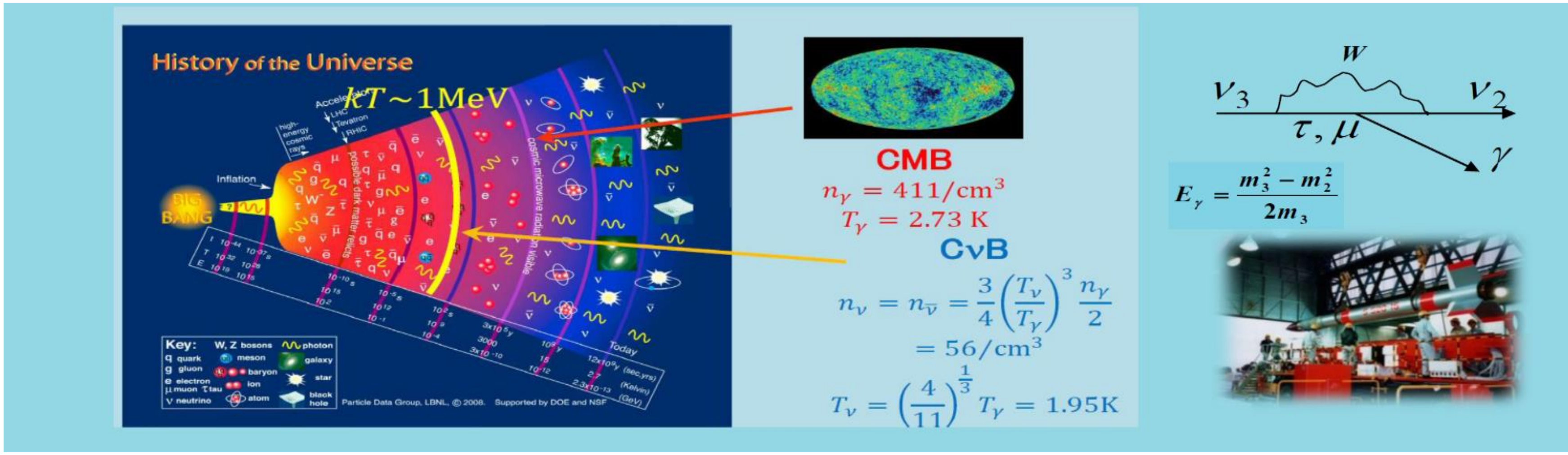
where *g* is the spin degree of freedom, and *F* = 1(for fermions) and 0 (for bosons).

$s_{\gamma 0} = a^3\left(s_\gamma + s_{e^-+e^+}\right)$, $s_{\nu 0} = a^3 s_\nu$ *where a is a scale factor.*

$$\rightarrow \quad \frac{s_{\nu 0}}{s_{\gamma 0}} = \frac{s_\nu}{s_\gamma + s_{e^-+e^+}} = \frac{2\times\frac{7}{8}}{2+4\times\frac{7}{8}} = \frac{7}{22} \qquad \therefore\ s_{\nu 0} = \frac{7}{22} s_{\gamma 0}$$

$$2 \times \frac{7}{8} T_\nu^3 = \frac{7}{22} \times 2T_\gamma^3 \quad \rightarrow \quad T_\nu = (\frac{4}{11})^{\frac{1}{3}} T_\gamma \qquad As\ \ T_\gamma = 2.73K, \qquad \therefore\ T_\nu = 1.95\text{K}$$

Cosmic Background Neutrino



Temperature:

T_ν= 1.95K

Number density:

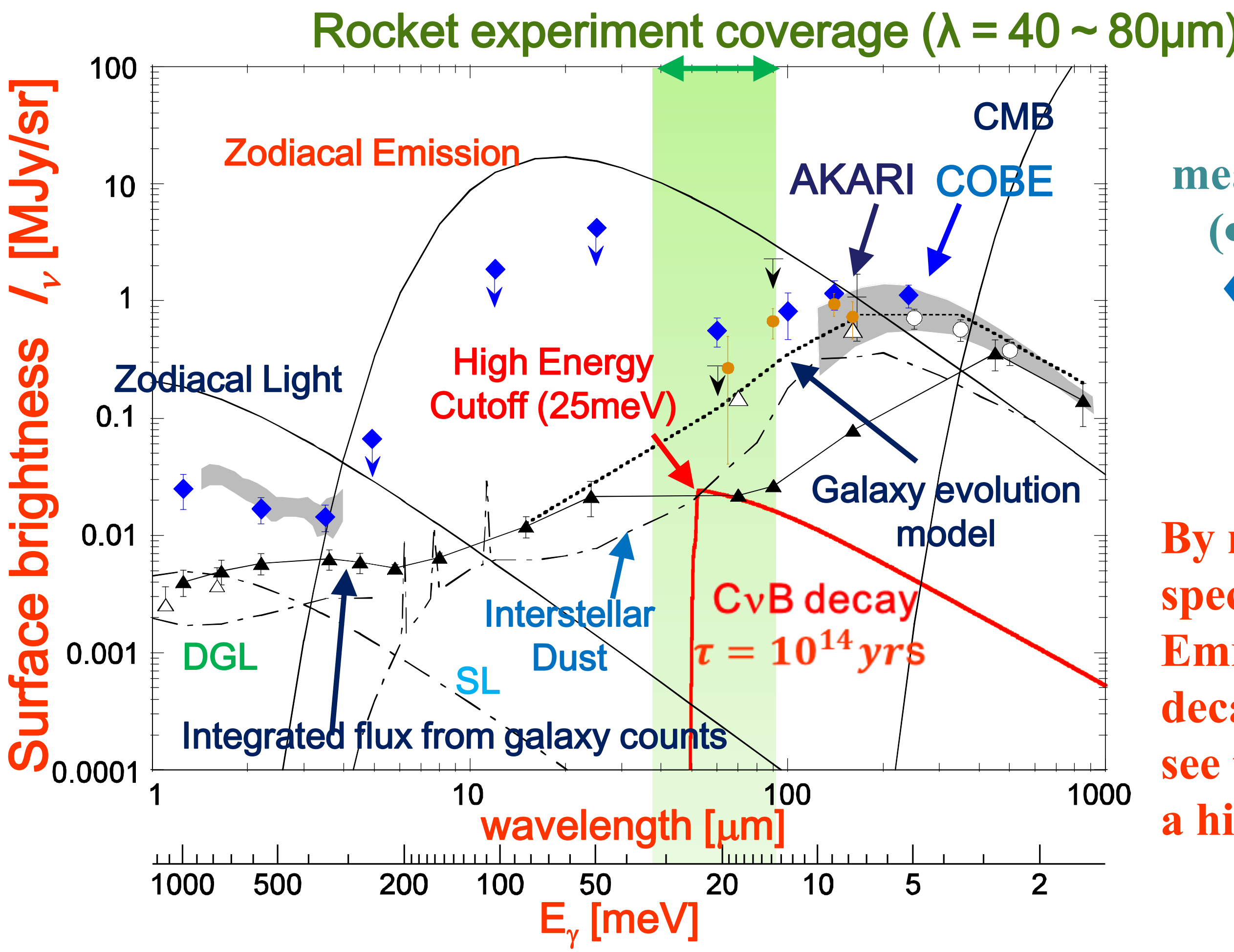
As μ/T $\ll$1, $n \propto g\ (\frac{3}{4})^F T^3$

where *g* is the spin degree of freedom, and *F* = 1(for fermions) and 0 (for bosons).

$$\rightarrow \quad n_\nu = \frac{3}{4}\left(\frac{T_\nu}{T_\gamma}\right)^3 \frac{n_\gamma}{2}$$

$$\therefore n_{\nu_\alpha} \approx n_{\bar{\nu}_\alpha} \approx 56\text{cm}^{-3} \quad (\alpha = e, \mu, \tau)$$

Signal of Cosmic Background Neutrino Decay and its Backgrounds



CIB measurements (● AKARI, ◆ COBE)

By measuring the energy spectrum of the Zodiacal Emission with the CνB decay continuously, we can see the CνB decay signal as a high energy cutoff.

Requirements for the detector

- Continuous spectrum of photon energy around $E_\gamma \sim 25\ \mathrm{meV} (\lambda = 50\mu\mathrm{m})$
- Energy measurement for single photon with better than 2% resolution for $E_\gamma = 25\mathrm{meV}$ to identify the sharp edge in the spectrum
- Rocket and/or satellite experiment with this detector

JAXA Rocket Experiment for Neutrino Decay Search

Plan: 5minutes data acquisition at 200 km height in **2019.**

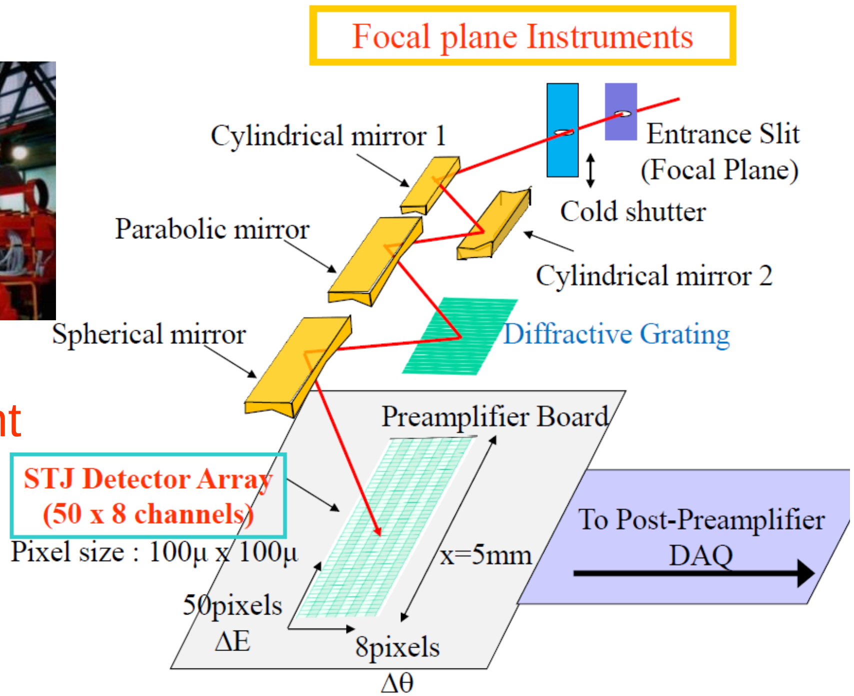
Improve the current limit of lifetime $\tau(\nu_3)$ by two orders of magnitude ($\sim 10^{14}$years).

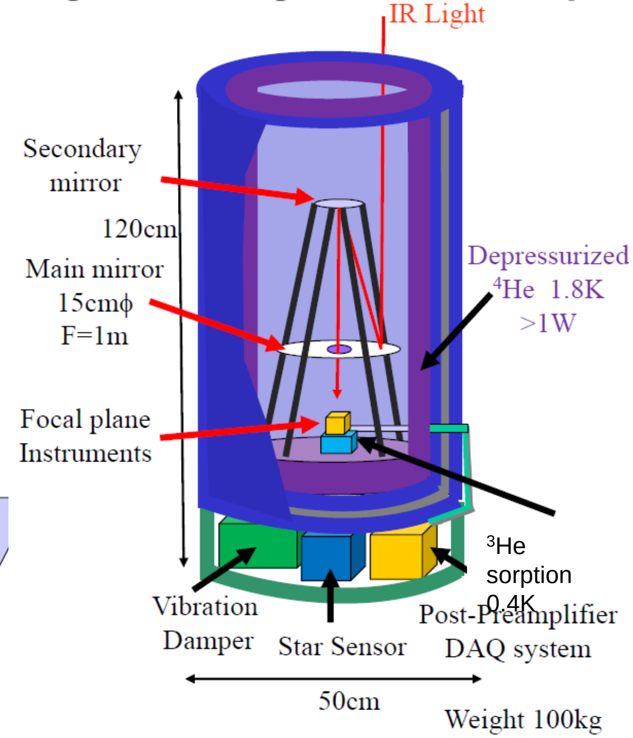
»Superconducting Tunneling Junction (STJ) detectors in development

> Array of 50 Nb/Al-STJ pixels with diffraction grating covering $\lambda = 40 - 80\mu m$

JAXA Rocket CIB Experiment

（Feb 2, 1992）





Satellite experiment after 2020 → sensitivity of $\tau(\nu_3) \sim 10^{17}$year

> STJ using Hafnium: Hf-STJ for satellite experiment (S. H. Kim et al. JPSJ 81,024101 (2012))

- $\Delta = 20\mu eV$: Superconducting gap energy for Hafnium
- $N_{q.p.} = 25meV/1.7\Delta = 735$ for 25meV photon: $\Delta E/E < 2\%$ if Fano-factor is less than 0.3

Zodiacal Emission

Thermal emission from the interplanetary dust cloud

$$I_\nu = \frac{2h\nu^3}{c^2}\frac{1}{\exp(h\nu/kT)-1}$$

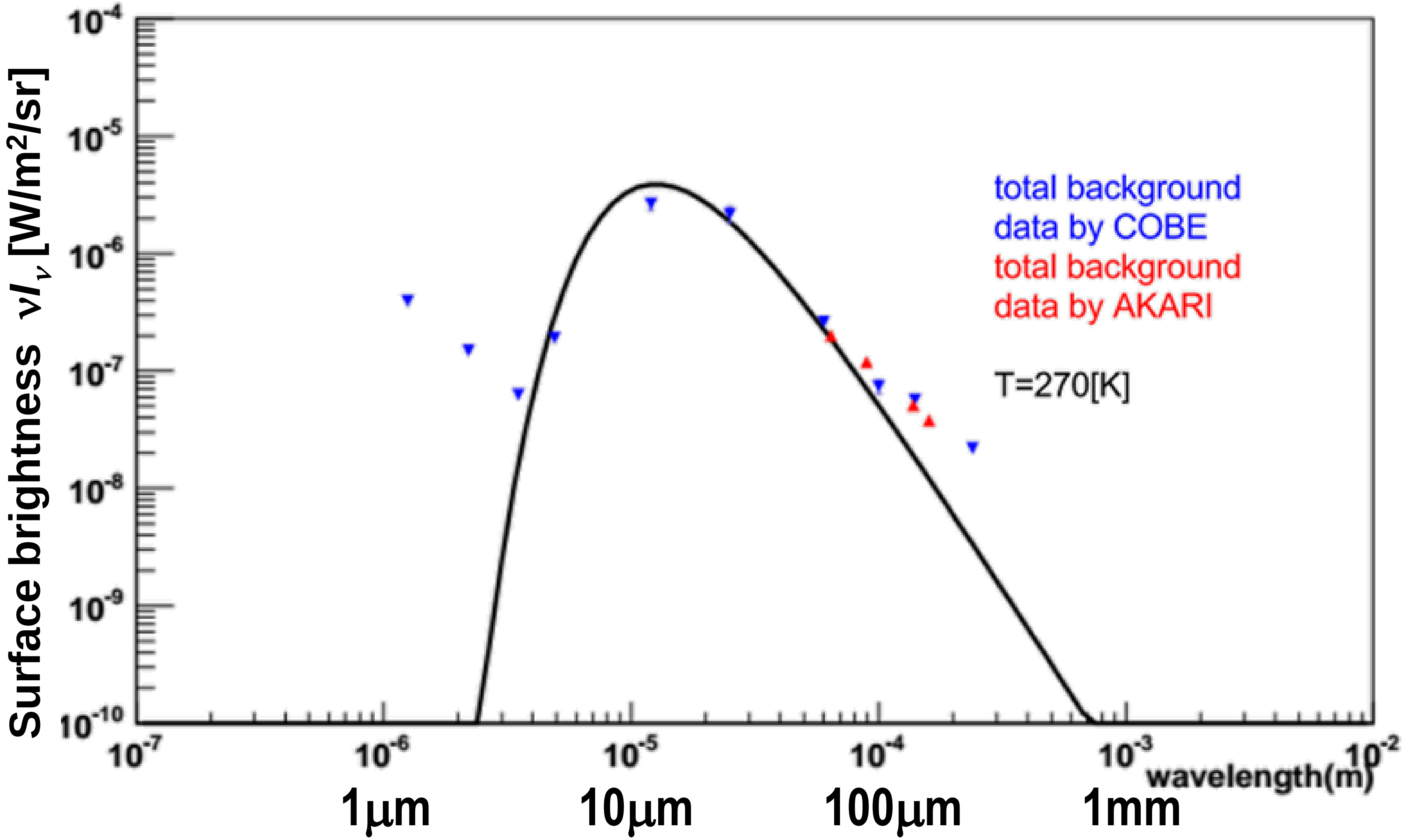
$$\times A\left(\frac{\nu}{c}\times 10^{-5}\right)^B \ \mathrm{Wm^{-2}sr^{-1}}$$

$T = 270K,\ A = 6\times 10^{-8},\ B = 0.3$

h [Js], c [m/s], λ [m]

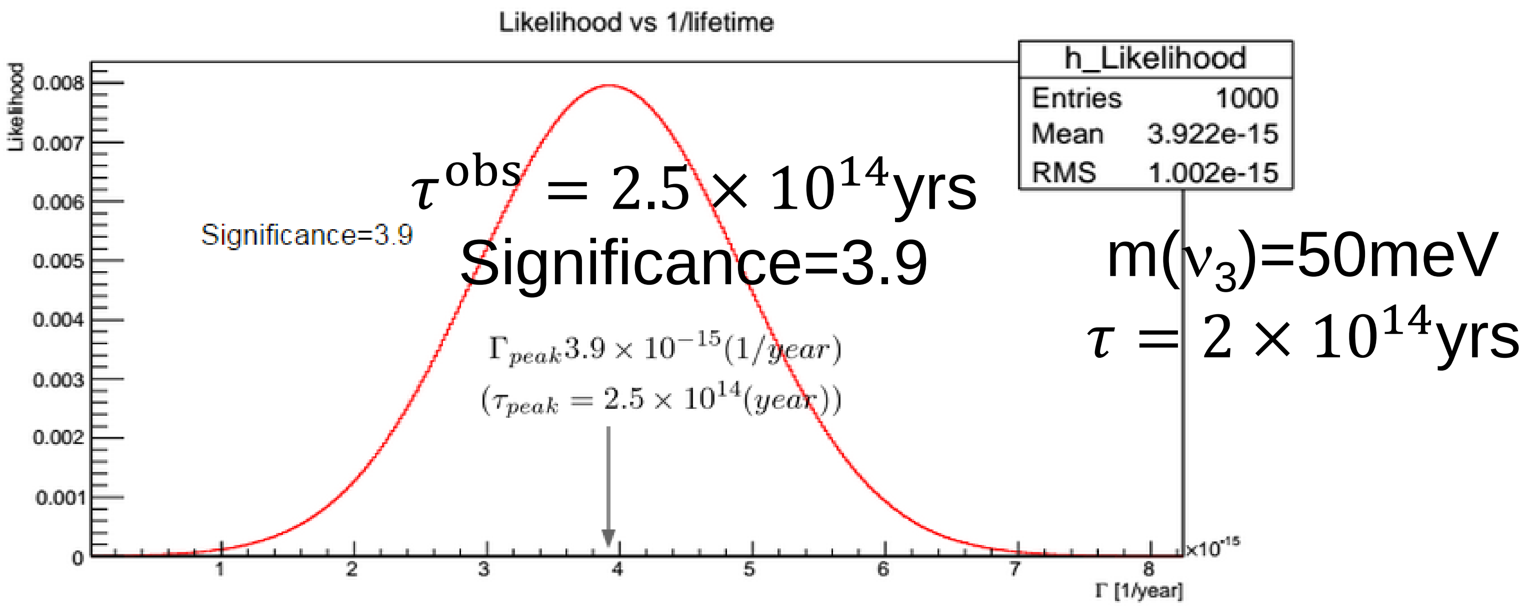
Zodiacal Emission(ZE) is overwhelmingly dominating. Here we consider only ZE as the background.

Zodiacal Emission



Discovery potential for neutrino decay

1. Create a pseudo-data for ND and ZE expectation on assumption of ν_3 mass and lifetime: $N_{obs}(m^{true}, \Gamma^{true})$
2. Calculate expected distribution of ND+ZE on assumption of ν_3 mass and lifetime: $N_{exp}(m, \Gamma)$
3. Calculate likelihood of the pseudo-data as a function of the decay width for each neutrino mass
4. Obtain the most probable decay width and its significance



Sensitivity to neutrino decay

Parameters in the rocket experiment simulation

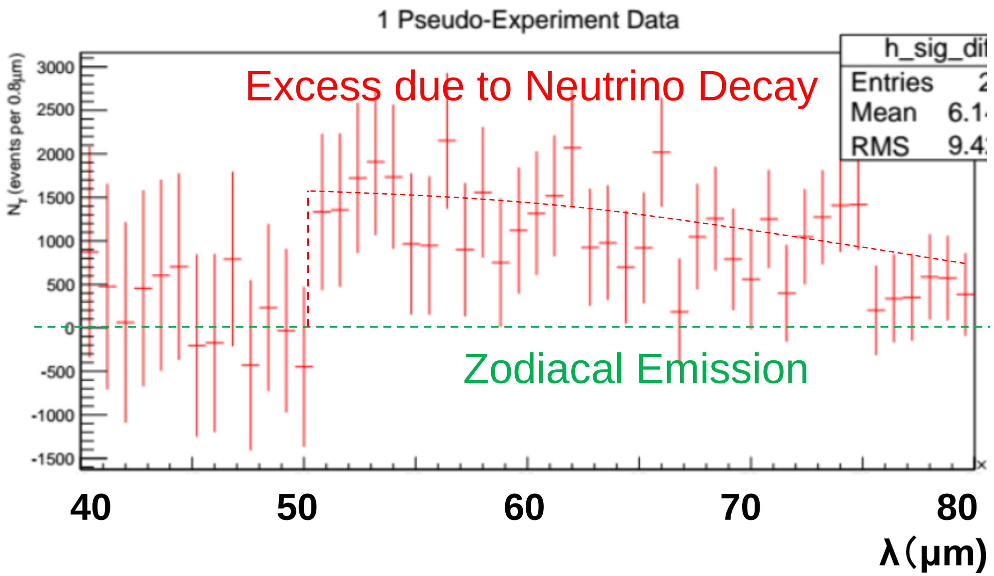
telescope dia.: 15cm

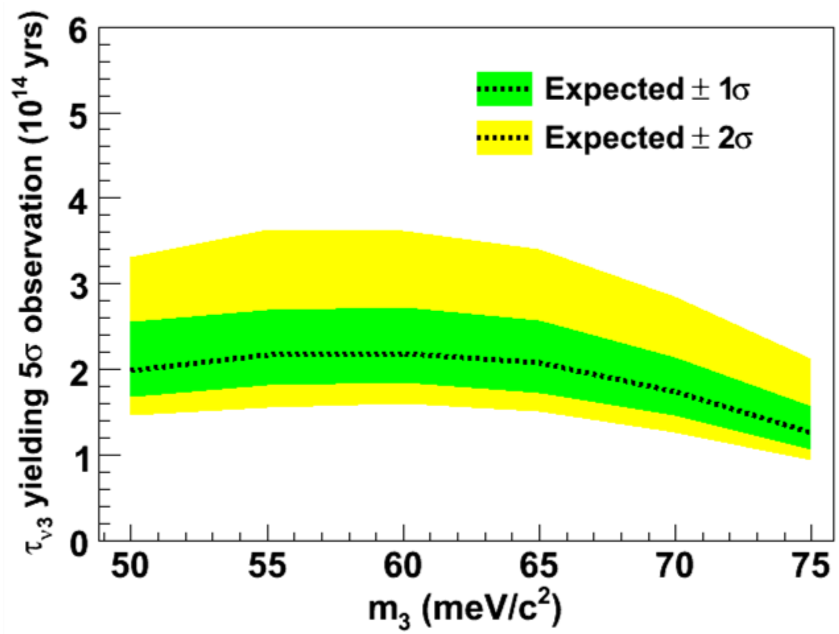
50-column (λ: 40μm – 80 μm) $\times$ 8-row array

Viewing angle per single pixel: 100μrad $\times$ 100μrad

Measurement time: 200 sec.

Photon detection efficiency: 100%



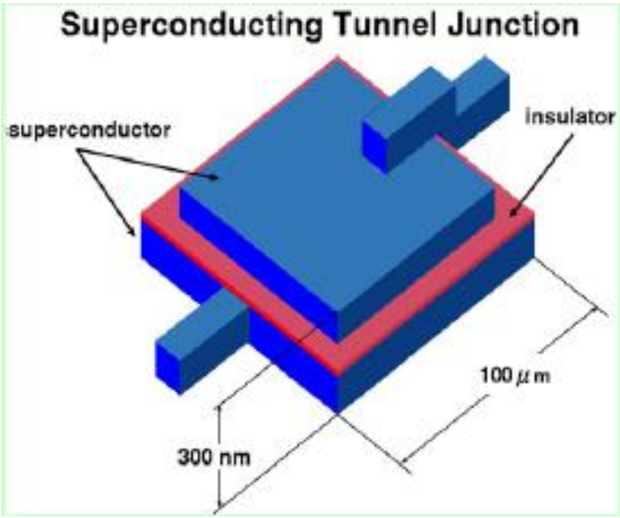


- If ν_3 lifetime were 2×10^{14} yrs, the signal significance is at 5σ level

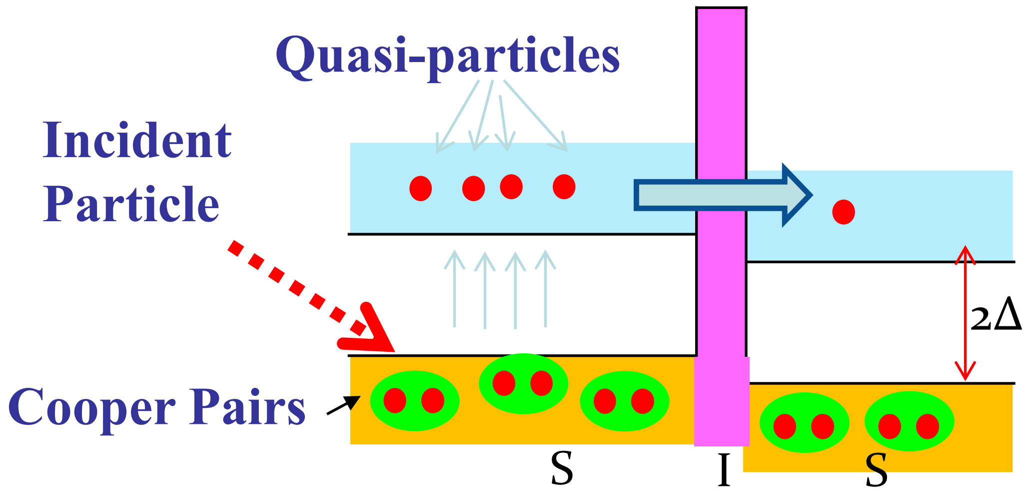
R&D Status of Superconducting Tunnel Junction Detector for COBAND experiment

STJ (Superconducting Tunnel Junction) Detector

Superconductor / Insulator / Superconductor Josephson Junction

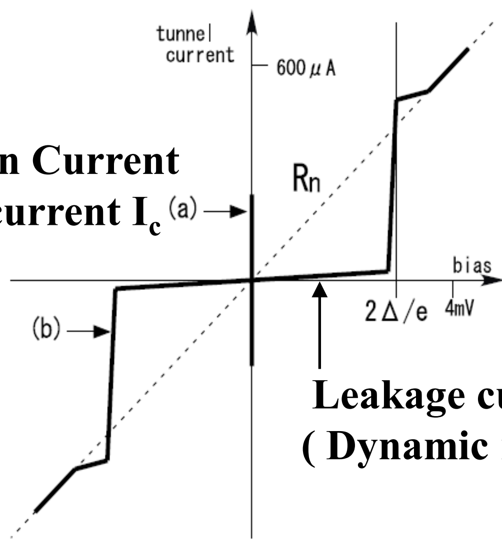


At the superconducting junction, quasi-particles over their energy gap go through tunnel barrier by a tunnel effect. By measuring the tunnel current of quasi-particles excited by an incident particle, we measure the energy of the particle.



Energy gap Δ

current-voltage (I-V) curve for STJ



Josephson Current
Critical current I_c

Leakage current
(Dynamic resistance R_d in $|V| < 2\Delta/e$)

Material	$T_c(K)$	Δ(meV)
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

STJ Energy Resolution

STJ Energy Resolution

$$\sigma_E = \sqrt{1.7\Delta(FE)}$$

Using Hf as a superconductor,

$$\sigma_E / E = 1.7\% \quad \text{at } E = 25\text{meV}$$

Δ: Band gap energy
F: Fano factor (= 0.2)
E: Incident particle energy

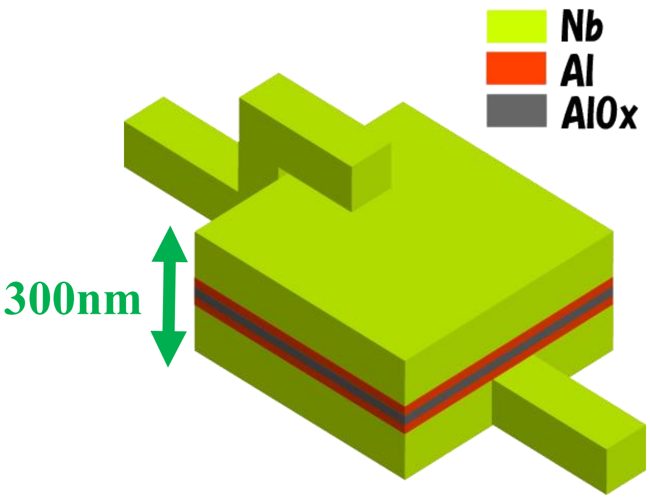
Material	$T_c(K)$	$\Delta(\text{meV})$
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

Tc : Critical Temperature

Operation is done at a temperature around 1/10 of Tc

We reported that Hf-STJ worked as a STJ in 2011.

Nb/Al-STJ Photon Detector



Number of Quasi-particles in Nb/Al-STJ

$$N_q = G_{Al} \, {}^{E_0}/_{1.7\Delta}$$

G_{Al} : Trapping Gain In Al(~10)
E_0 : Photon Energy
Δ : E-Gap in superconductor

For 25meV single photon

$$N_q = 10 \frac{25\ meV}{1.7 * 1.550\ meV} = 95\ e$$

Back tunneling Effect → Trapping Gain

Quasi-particles near the barrier can mediate Cooper pairs, resulting in true signal gain

- Bi-layer fabricated with superconductors of different gaps $\Delta_{Nb} > \Delta_{Al}$ to enhance quasi-particle density near the barrier
- Nb/Al-STJ Nb(200nm)/Al(10nm)/AlOx/Al(10nm)/Nb(100nm)

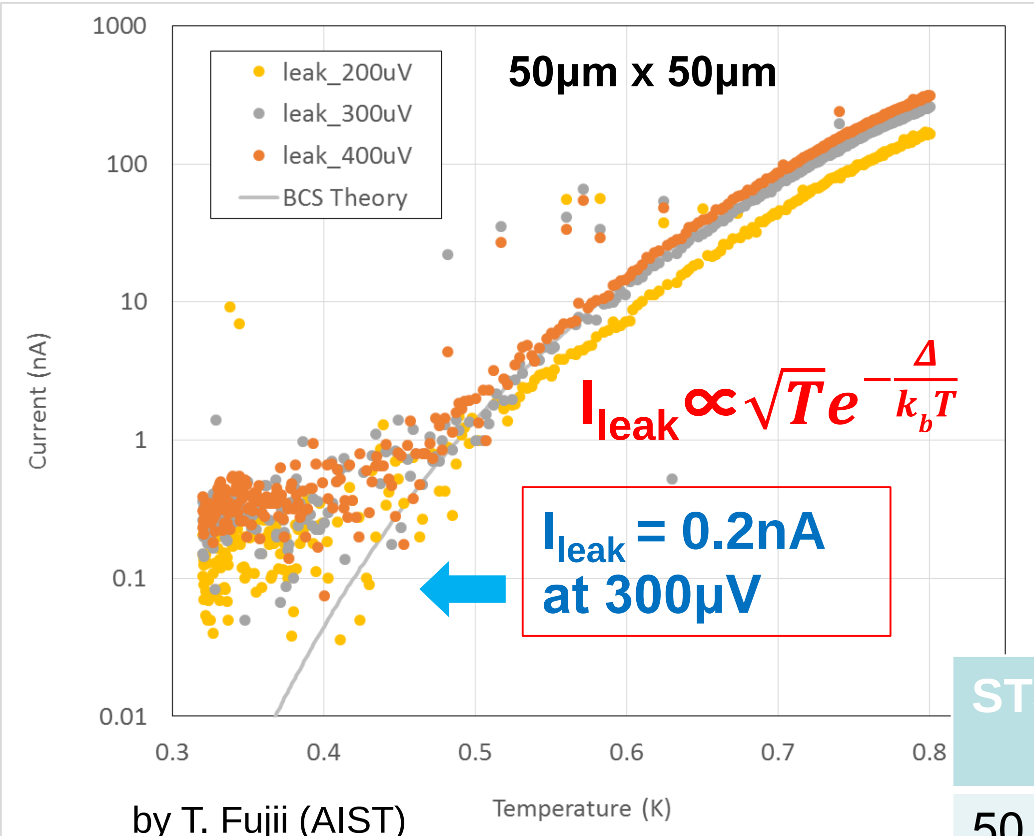
Gain: 2～200

	Si	Nb	Al
Tc[K]		9.23	1.20
Δ[meV]	1100	1.550	0.172

Leakage Current of Nb/Al-STJ

- Leakage current I_{leak} is required to be below 0.1nA to detect a single far-infrared photon (λ = 40 –80 μ m) .

Temperature Dependence of Leakage Current



by T. Fujii (AIST)

In 2014,
AIST group joined us and produced Nb/Al-STJ with AIST CRAVITY processing system.
Leakage current has satisfied our requirement of 0.1nA .

STJ size	# of samples	I_{leak} at 0.3mV
50 x 50μm^2	18	224±29 pA
20 x 20 μm^2	7	**39±13 pA**
10 x 10 μm^2	20	**14±7 pA**

Response of Nb/Al-STJ Detector to Laser Light

Nb/Al-STJ

Goal: detection of a single far-infrared photon in the energy range of 15 – 30 meV (λ= 40 -80μm) for the rocket experiment for neutrino decay search.

- **Refrigerator of setup**

^{3}He sorption refrigerator without refrigerant(0.3K)

- rapid test cycle (2days)

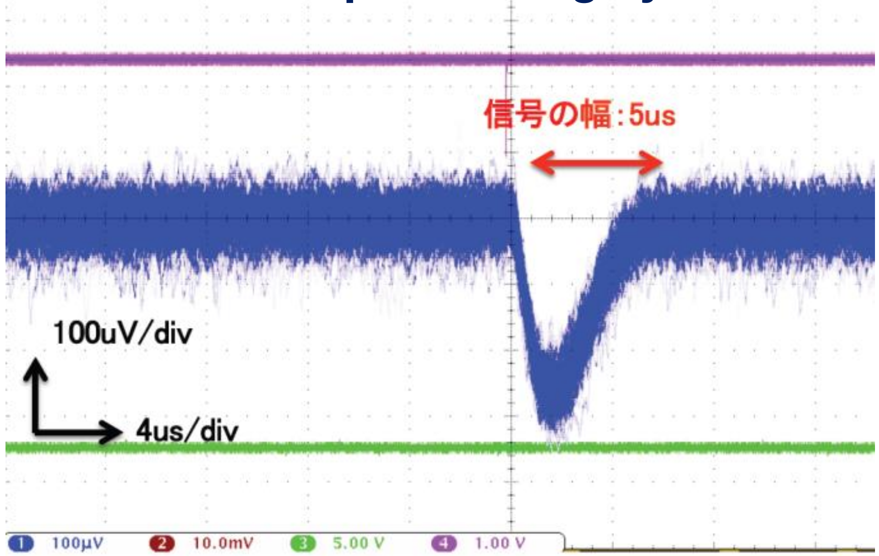
- short preparation period (1day)

- **Structure of Nb/Al-STJ**

Nb/Al/Al_2O_3/Al/Nb layer thickness

100nm/70nm/1nm/70nm/120nm (Δ＝0.57meV)

made with AIST CRAVITY processing system



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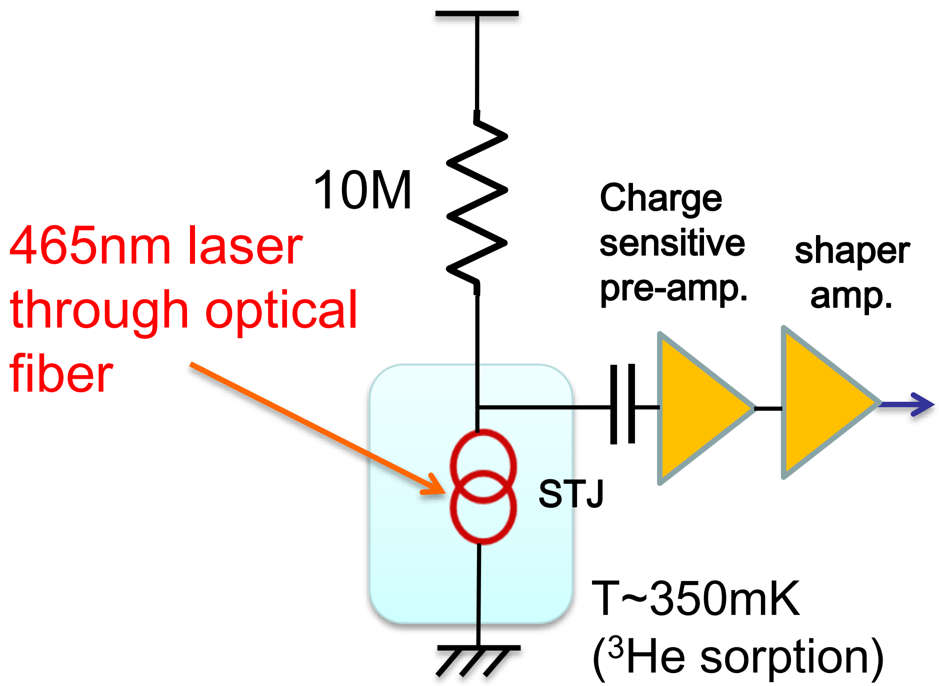
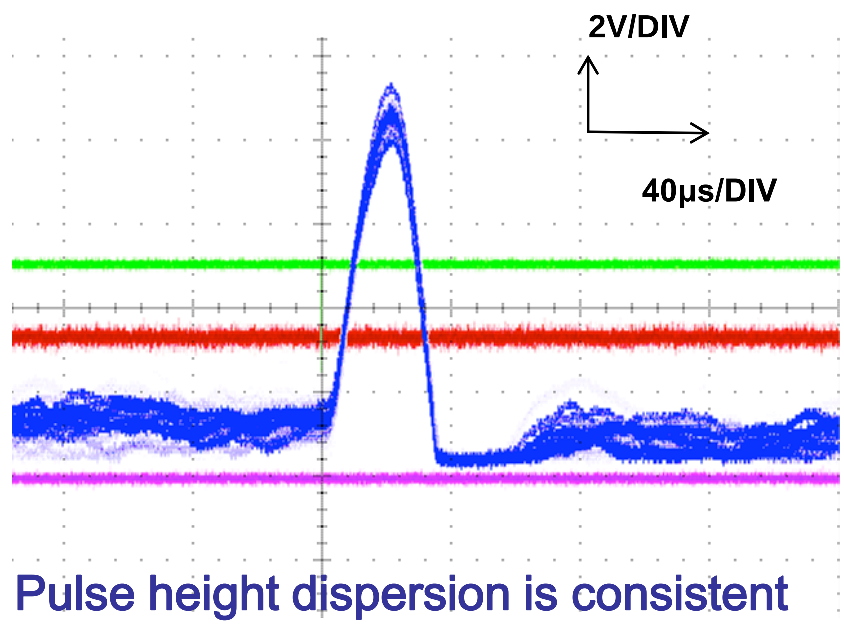




Pulse height dispersion is consistent with 10-photon detection in STJ

A response from Nb/Al-STJs to NIR-VIS photons at single-photon level was observed with a charge-sensitive amplifier at the room temperature

- Response time of STJ: O(1μs)

Due to the readout noise, a FIR single-photon detection is not achieved yet

➔ Need ultra-low noise readout system for STJ signal

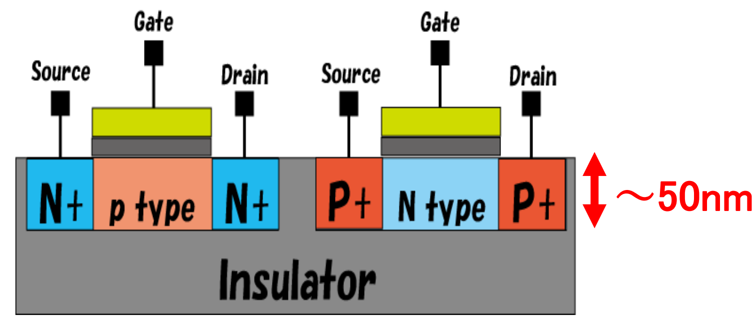
➔ Developing a cryogenic pre-amplifier close to STJ

R&D Status of SOI Cryogenic Preamplifier for STJ

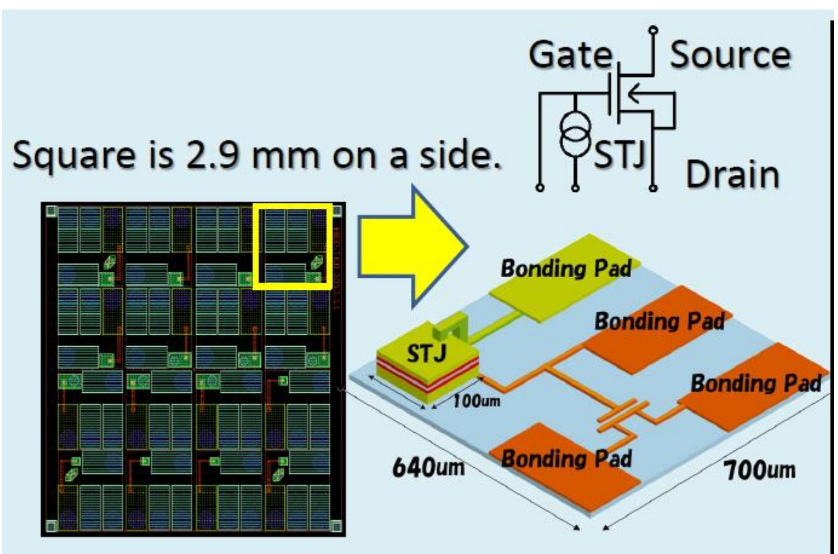
R&D of SOI-STJ Detector

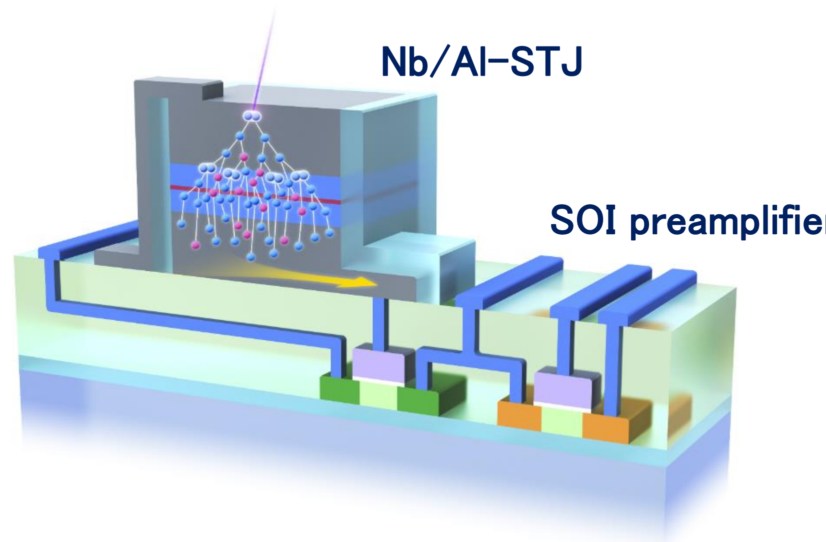
FD-SOI (Silicon-On-Insulator) device was proved to operate at 4K by a JAXA/KEK group (AIPC 1185,286-289(200 FD-SOI 9)). It has the following characteristics:
low-power consumption, high speed, easy large scale integration and suppression of charge-up by high mobility carrier due to thin depletion layer(～50nm).

FD-SOI -MOSFET



To improve the signal-to-noise ratio and to make multi-pixel device easily, we made a SOI-STJ detector where we processed Nb/Al-STJ on a SOI transistor board.

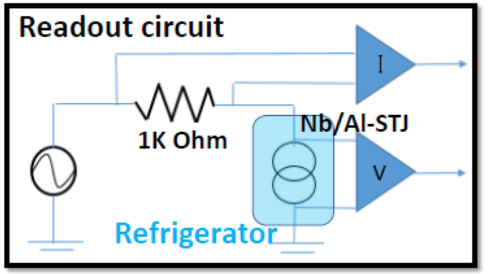




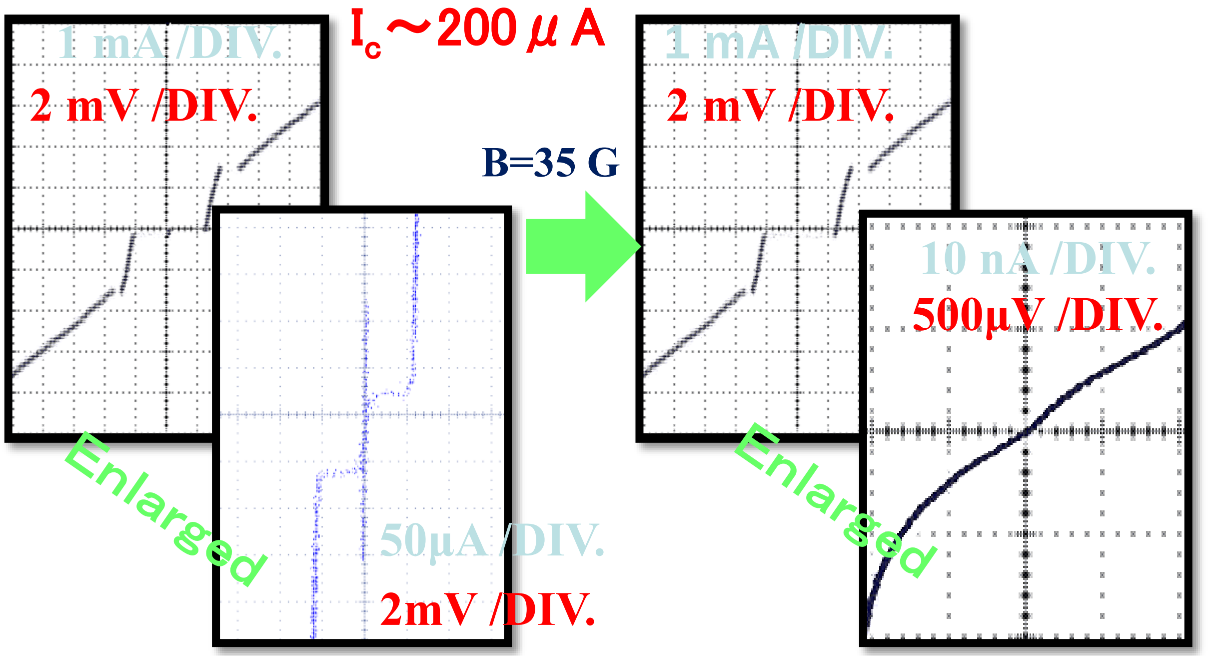
Performance of Nb/Al-STJ in SOI-STJ Detector

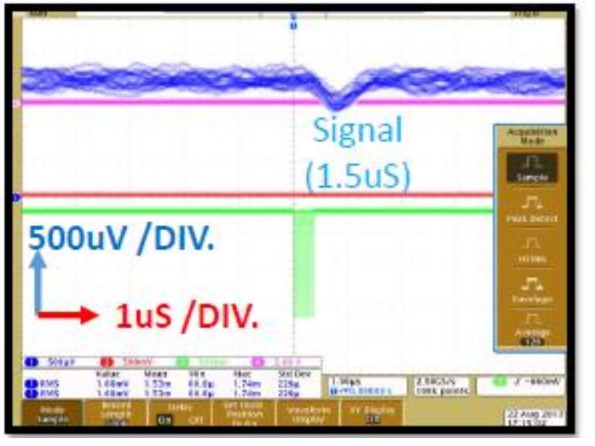
We measured the I-V curve of the Nb/Al-STJ (50 x 50 μ m^2 junction) processed on the SOI wafer

at **700mK** with a dilution refrigerator.



- **I-V curve of Josephson Junction**





- Quality Factor ($R_{dynamic}$/R_{normal})
  - **On Si wafer : 5 x 10^5**
  - **On SOI wafer : 3 x 10^5**

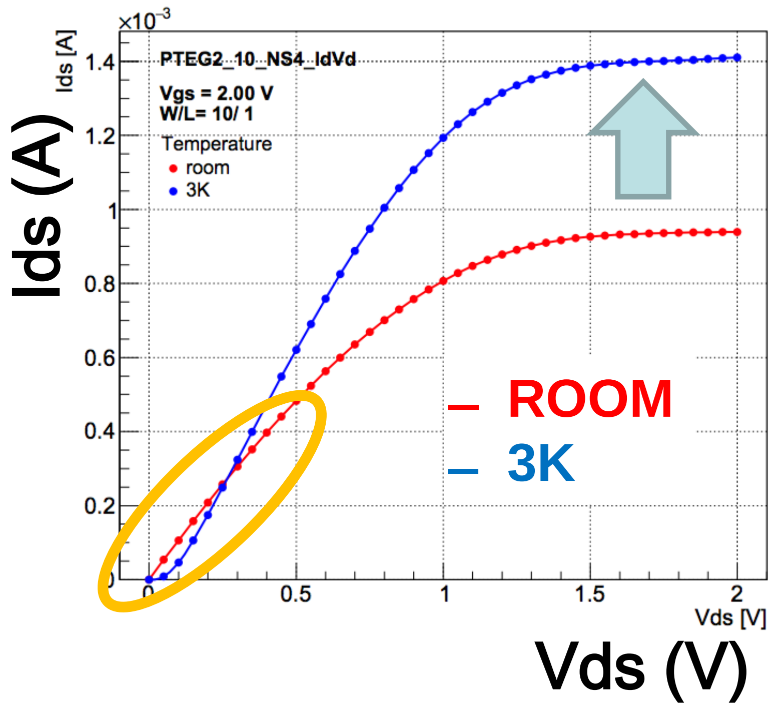
Performance of SOIFET at Cryogenic Temperature

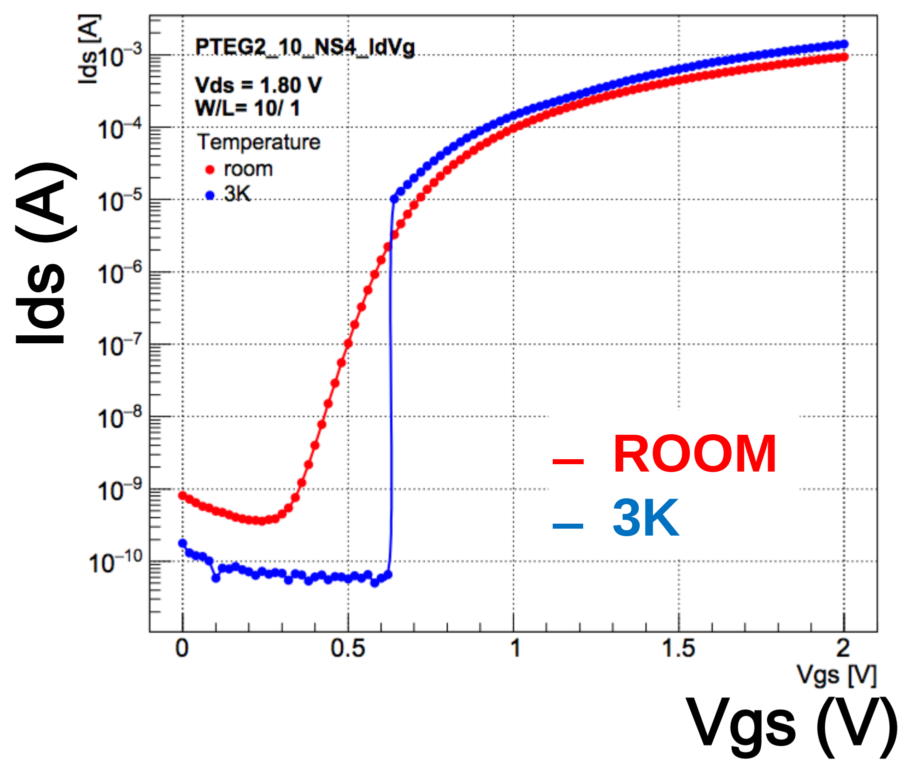
Saturating current is higher as the temperature becomes lower.

Non-linearity was found at cryogenic temperature near threshold region. This problem was solved by improving LDD(Lightly Doped Drain).

At cryogenic temperature (3K),

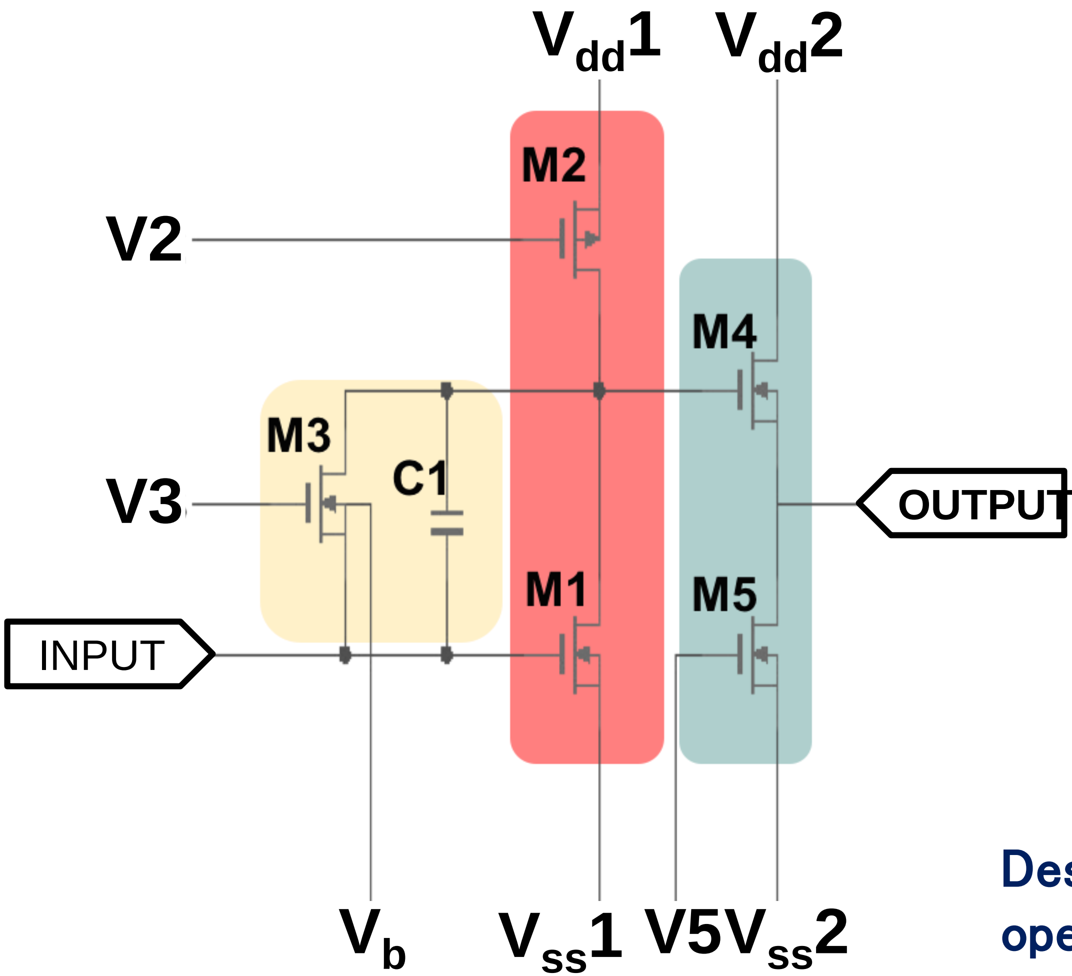
- **Threshold rise in I_{ds}-V_{ds} curve become much sharper.**
- **Subthreshold current is suppressed.**





SOI cryogenic amplifier

SOI - STJ4 (the 4th prototype)



We updated the SOI cryogenic amplifier for the Nb/Al–STJ signal.

Amplification
Replace the resistance by a SOIFET as a current source (M2).

Feedback
Use the feedback between the drain and the gate of M1 to apply a stable bias voltage (M3).

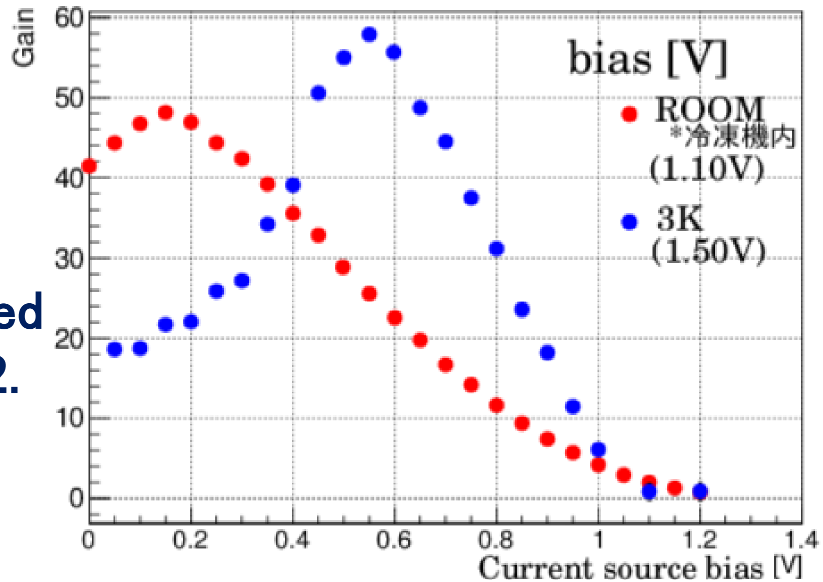
Buffer
Add the follower to reduce the output impedance (M4 and M5).

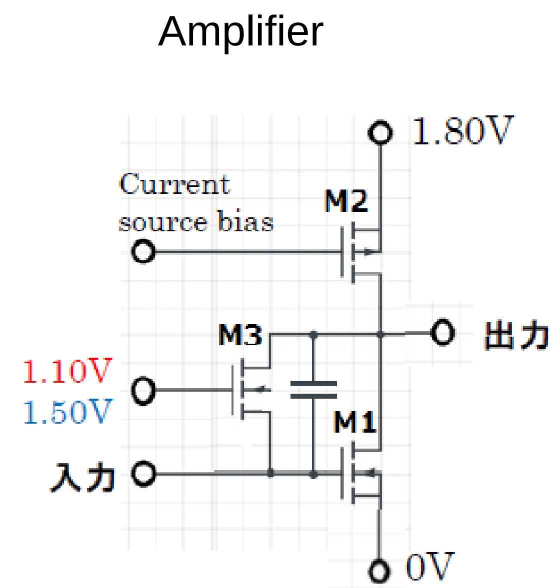
Designed the ratio (W/L) to set the operation power consumption below 120 μW.

This SOI amplifier board was made by LAPIS semiconductor company.

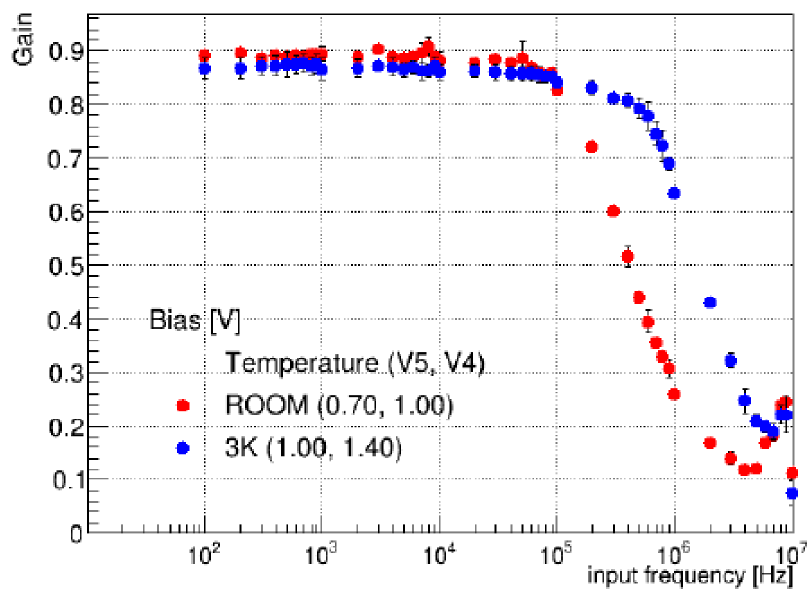
Test Results of the cryogenic SOI preamplifier

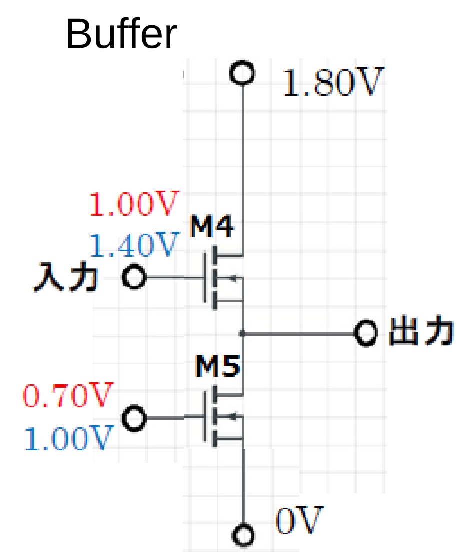
Amplifier gains are around 50 both at room temperature and 3K with adjusted bias voltages of M2.





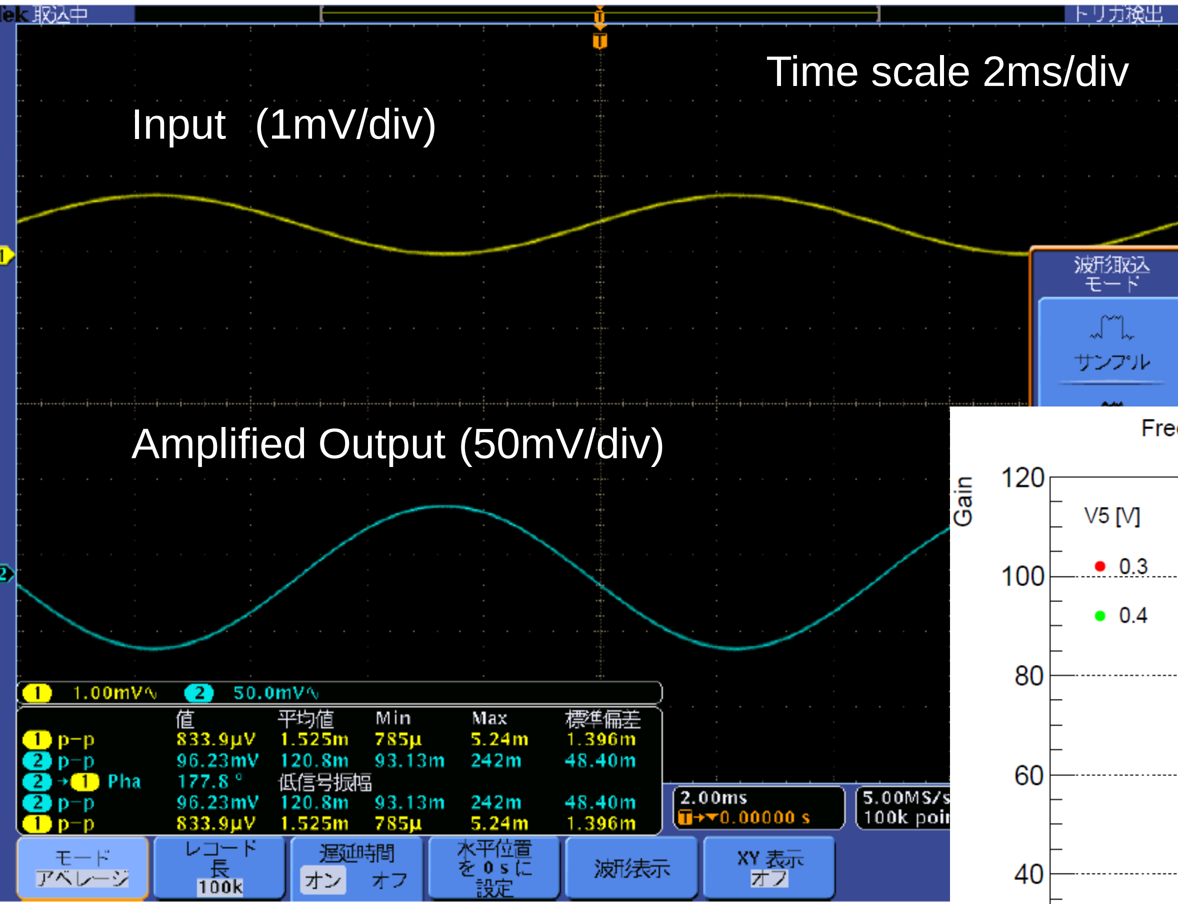
Bandwidth of buffer is enough high for the amplifier of STJ signal (up to 200kHz) both at room temperature and 3K.



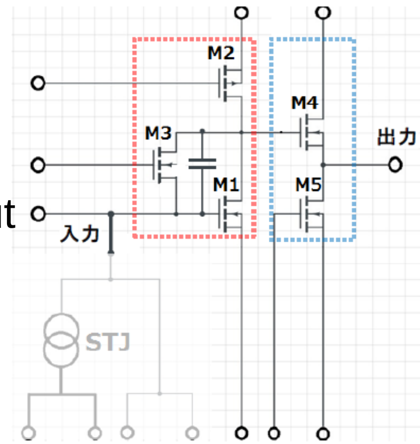


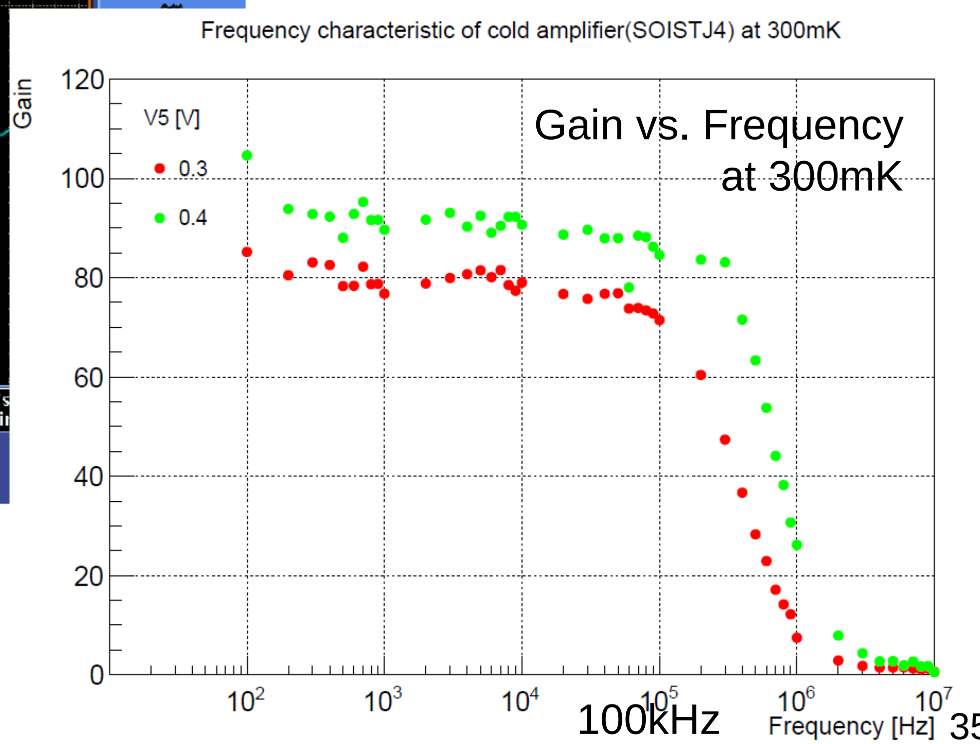
Test Results of the cryogenic SOI preamplifier

Input and Amplified Output



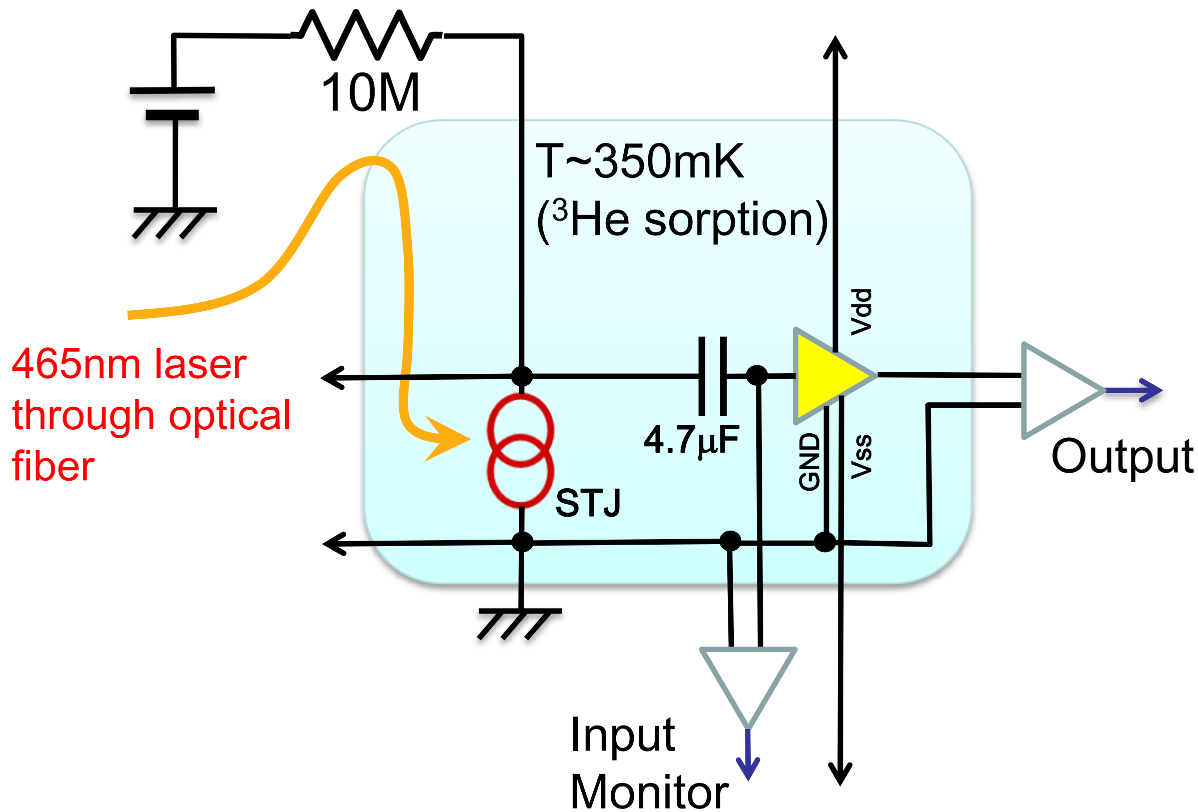
Amplifier + Buffer

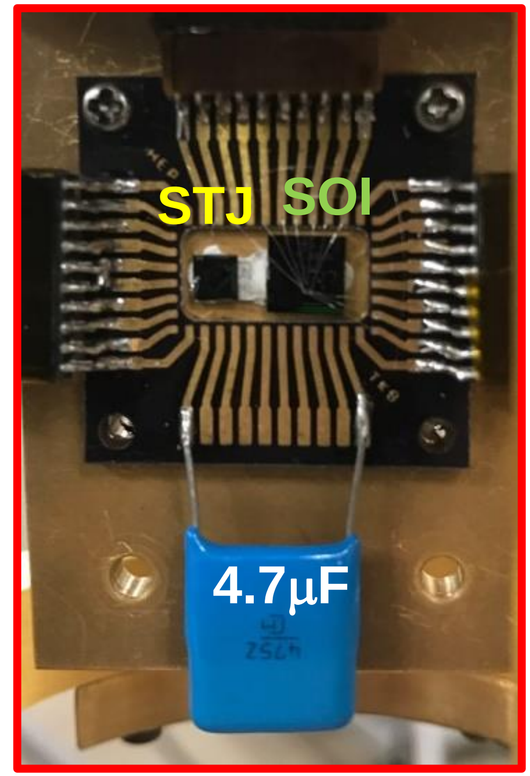




Gain of 80 was achieved for a signal frequency up to 100kHz signals at 300mK.

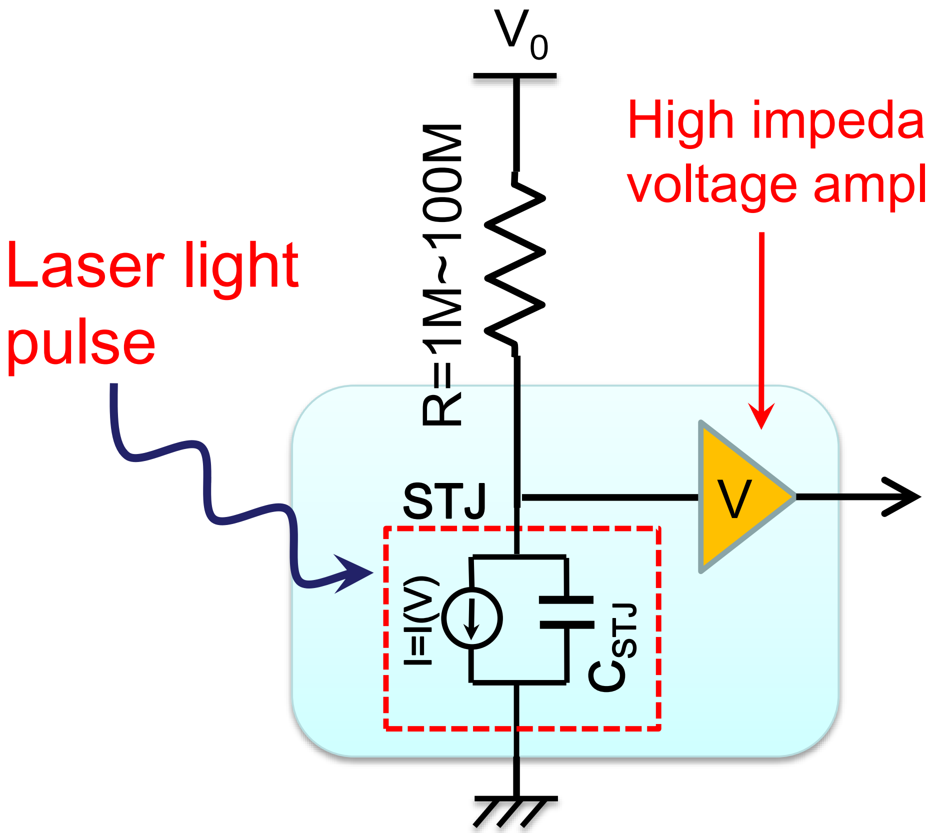
Setup of STJ signal amplification with the cryogenic SOI preamplifier

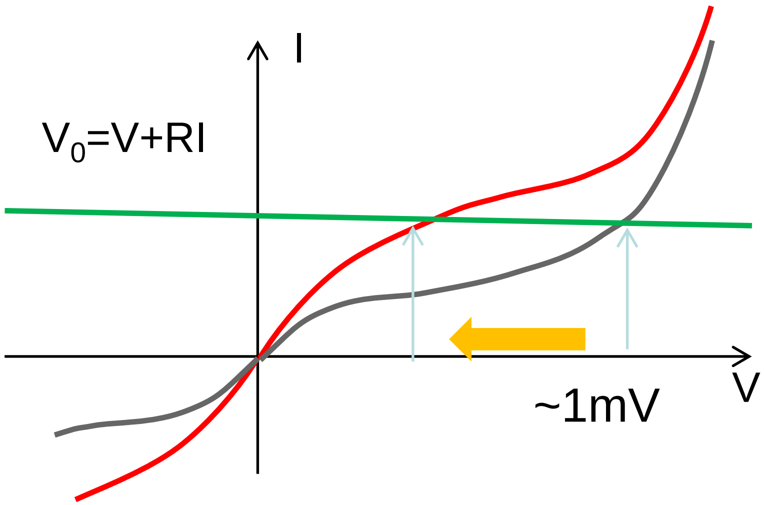




- 20μm-square Nb/Al-STJ with SOI-STJ4 amplifier through 4.7μF capacitance.
- Input impedance of the SOI amplifier is about 20kΩ.
  - STJ operation at a constant current mode.
  - STJ bias cable capacitance is around 1nF：Z=160Ω for 1μs signal.

STJ response at a constant current mode



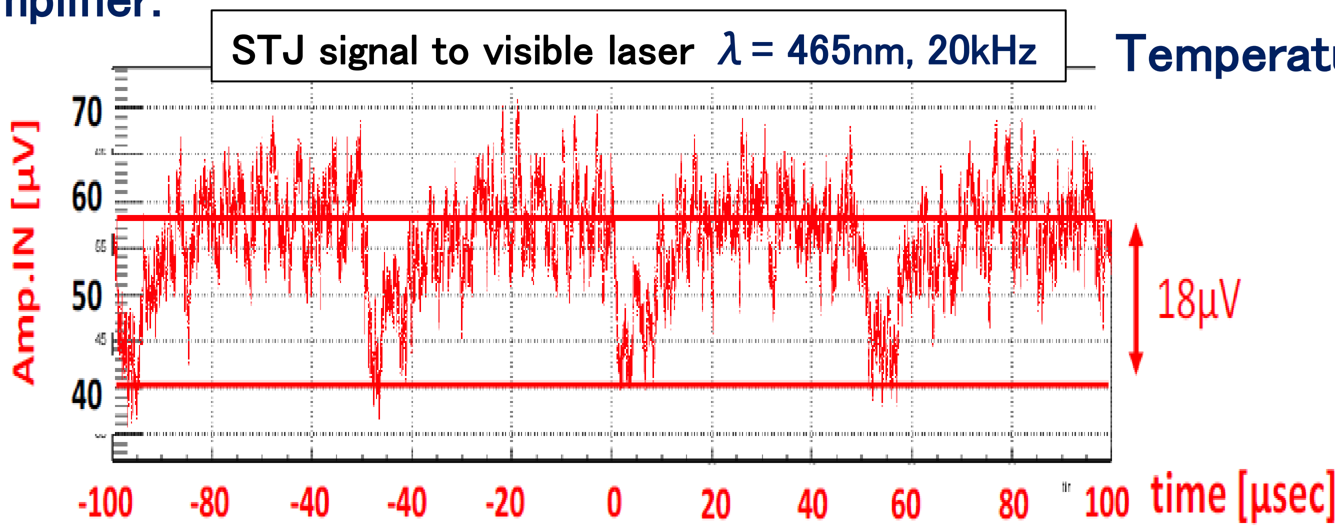


STJ I-V curve w/light w/o light

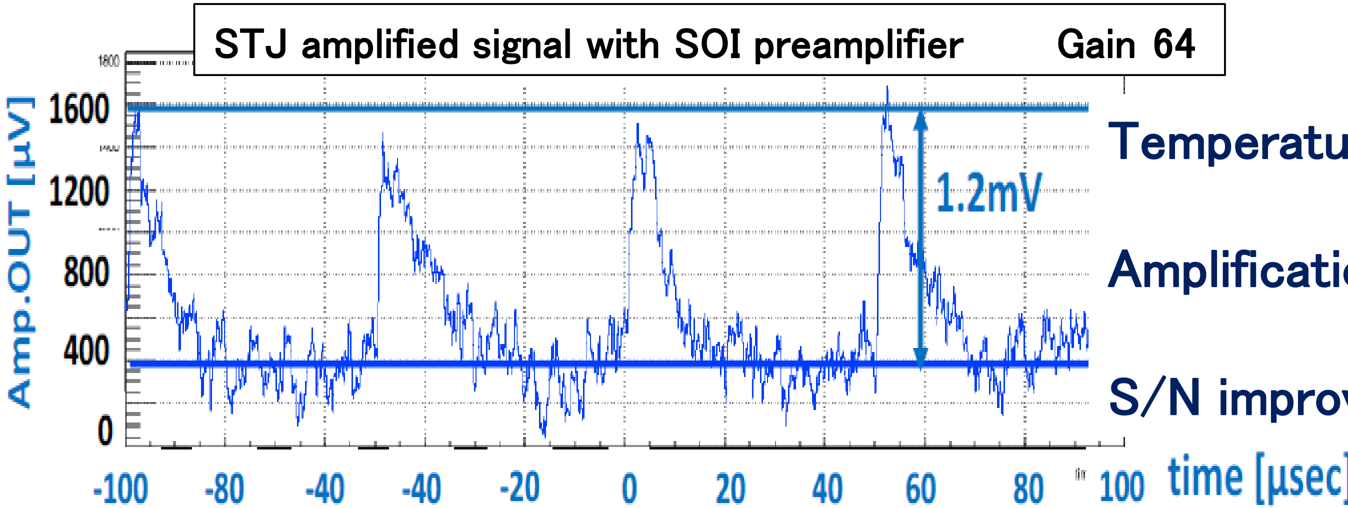
- STJ has a large resistance in series.
  → constant current mode
- STJ response to light is observed as a voltage drop.

STJ signal amplified with the cryogenic SOI preamplifier

Nb/Al–STJ laser light response signal was amplified with this cryogenic SOI preamplifier.



Temperature : 350mK



Temperature : 350mK

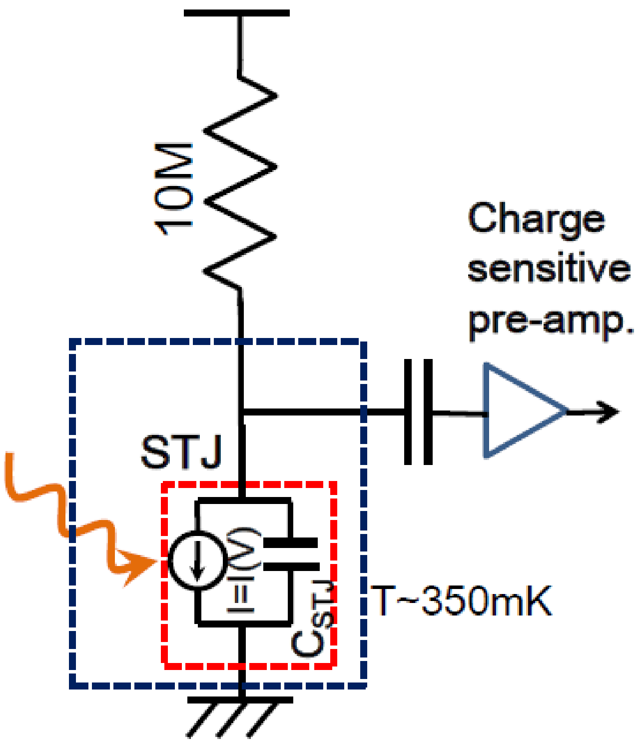
Amplification Gain : 70

S/N improved by a factor of 2

Development of SOI Charge sensitive preamplifier (SOISTJ5)

- STJ capacitance is not so small (20pF for 20μm square STJ).
- STJ response speed is a few μsec.
- STJ operation at a constant voltage mode is favorable.

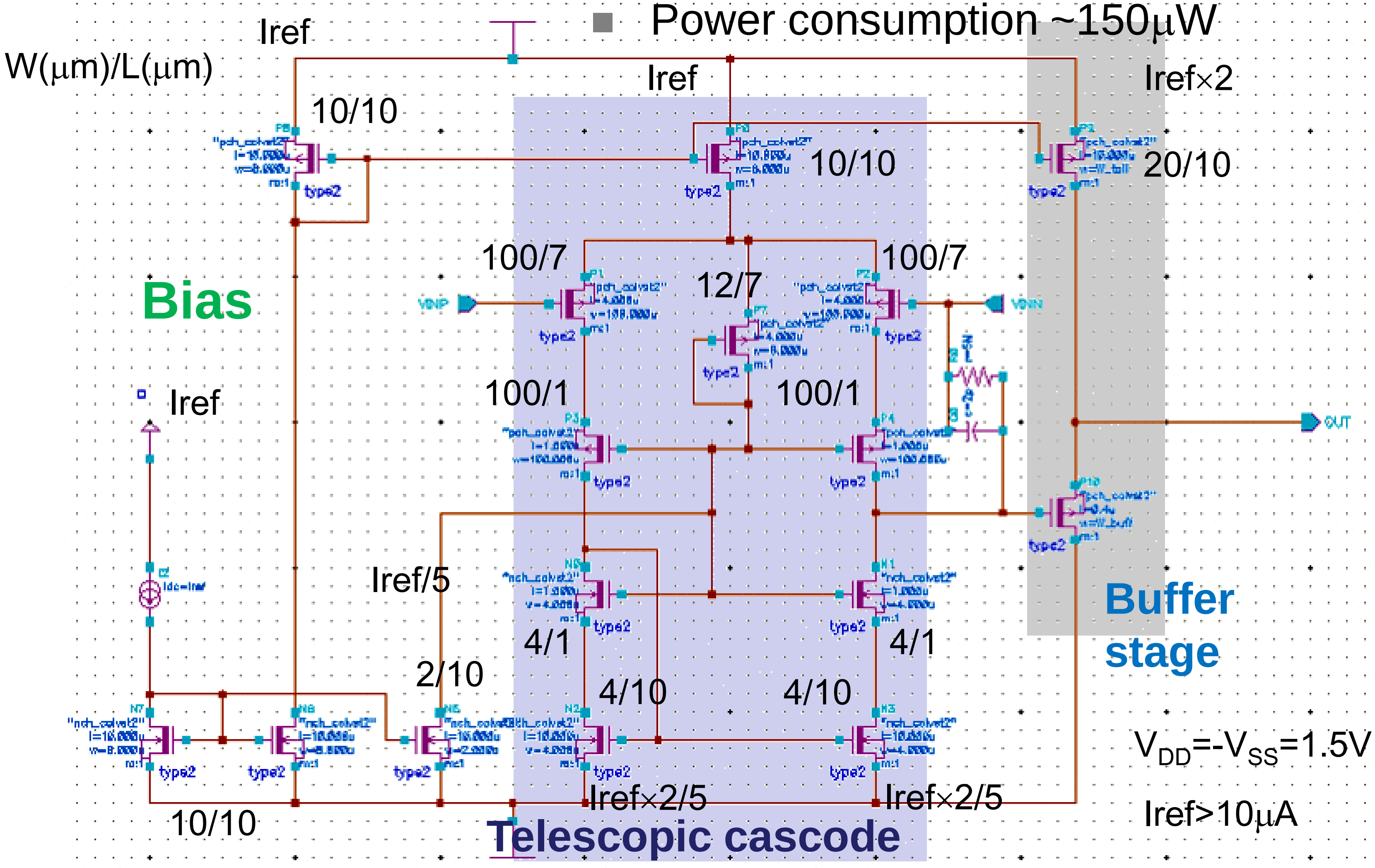
  → Low input impedance charge amplifier operational for 1MHz.



Op-amp Circuit for STJ (SOI-STJ5 design)

This cryogenic charge amplifier test is now underway.

- telescopic cascode differential amplifier
- Feedback C=2pF x R=5MOhm = 10μs
- Power consumption ~150μW



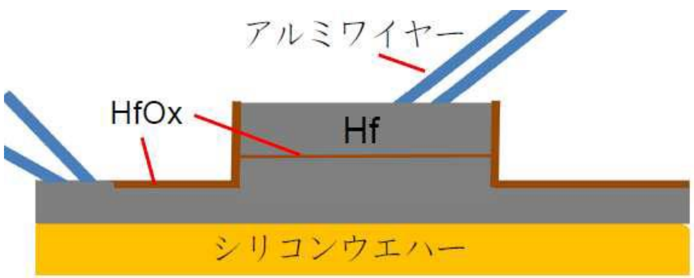
R&D Status of Hf-STJ

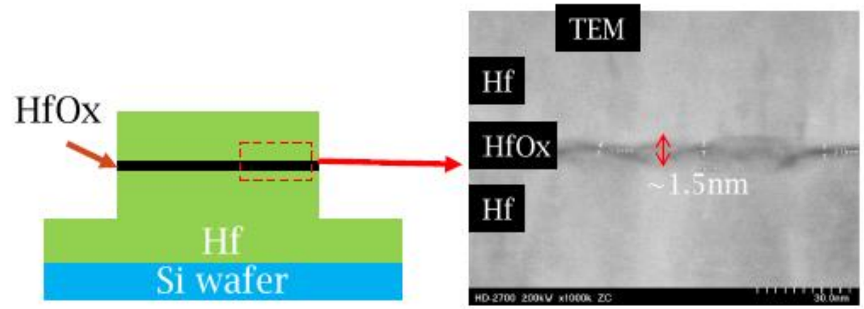
R&D Status of Hf-STJ

Goal: Measure energy of a single far-infrared photon for neutrino decay search experiment within 2% energy resolution.

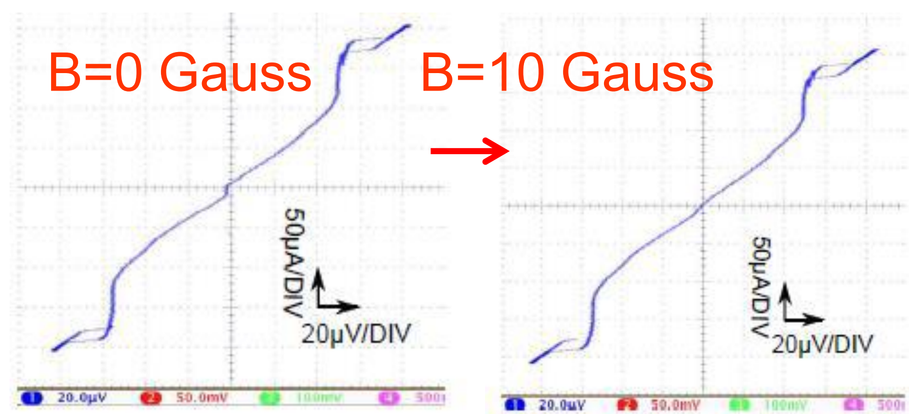
Micro-calorimeter: Hf-STJ cab generate enough quasi-particles from cooper pair breakings to achieve 2% energy resolution for photons with E_γ = 25meV.

Direct wire bonding on Hf layer





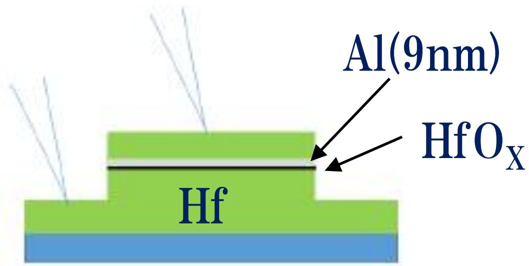
I-V curve of Hf-STJ (**100x100μm²**)
- T~40mK, I_c=10 μA, **R_d=0.6Ω**

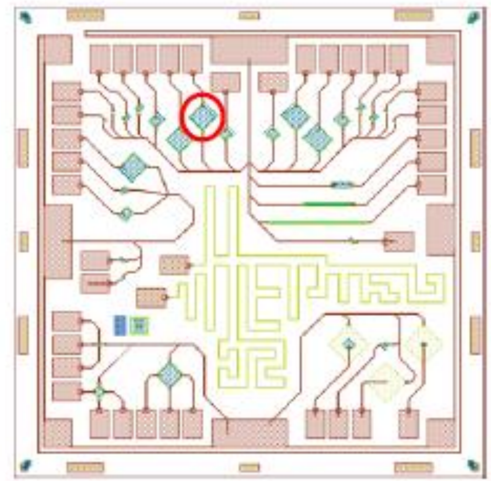


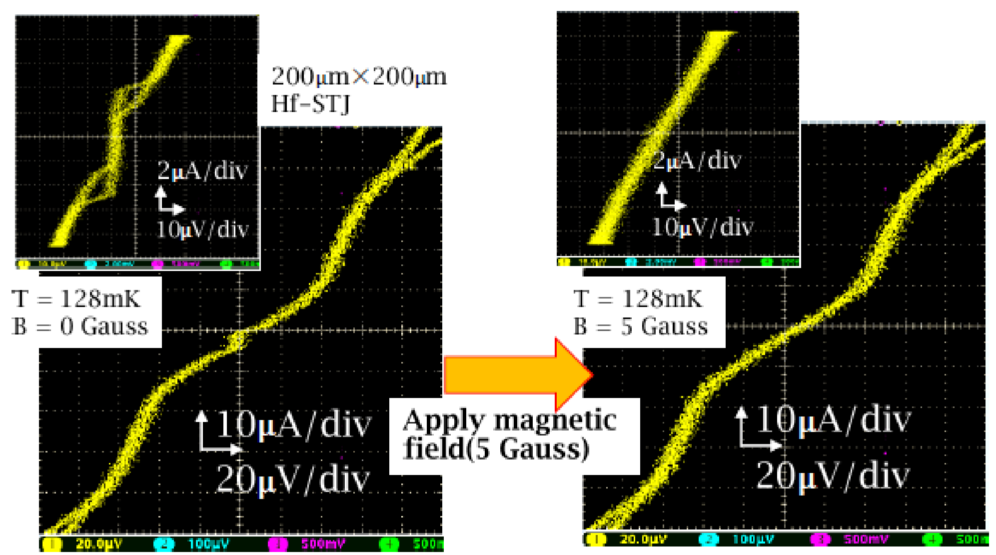
STJ size	# of samples	R_d
200 x 200μm²	3	0.22±0.01 Ω
100 x 100 μm²	3	0.60±0.10 Ω

Latest Results of Hf-STJ R&D

In 2016, we made a thin aluminum layer (9nm) on the HfO layer (1-2 nm) to improve the insulation of the HfO_X layer. $Hf/Al/HfO_X/Hf$-STJ





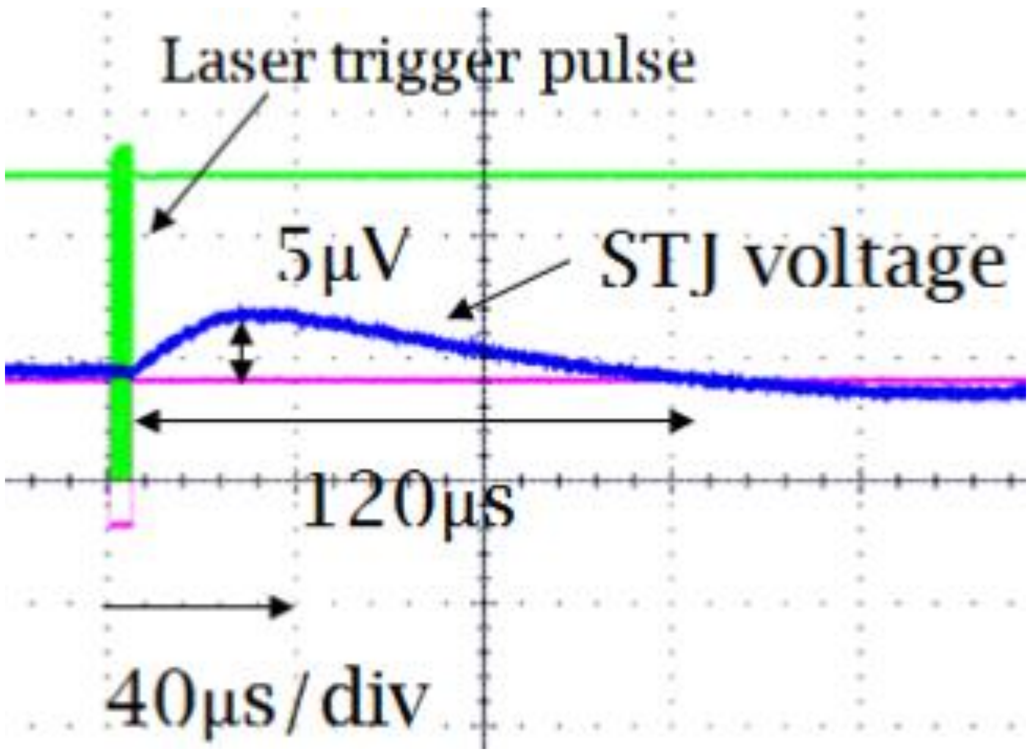


I_{leak} = 5 μA at 10 μV.
R_d = 2Ω
Dynamic Resistance was improved by a factor of 15 in $Hf/Al/HfO_X/Hf$-STJ.

Response of Hf-STJ to Laser Pulse Light

Hf/Al/HfO_X/Hf-STJ

Visible light laser (λ=465nm)　 10Hz duration

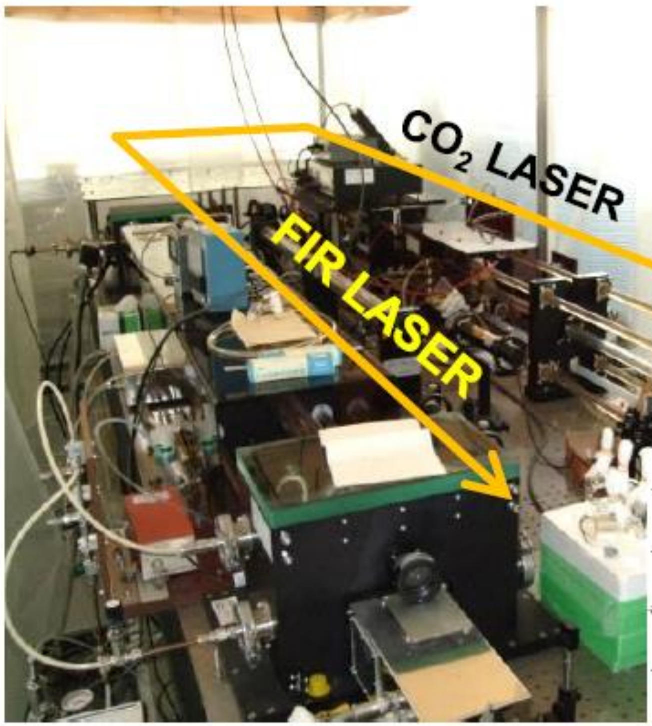


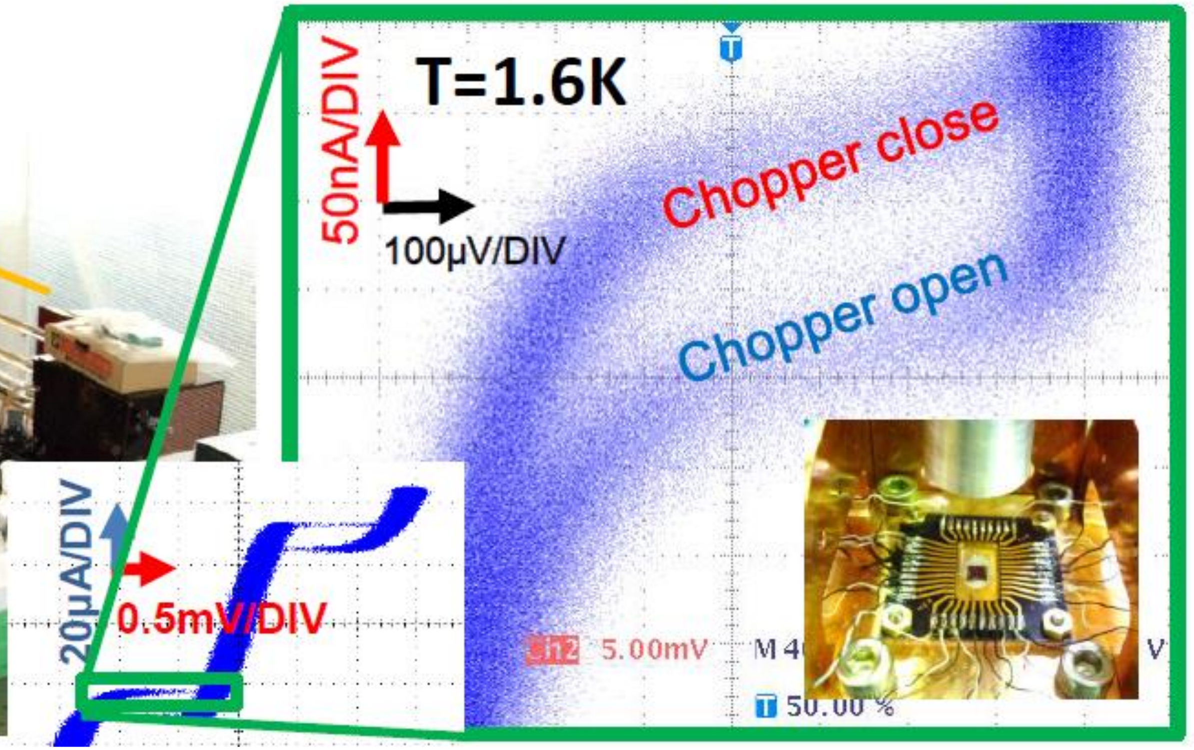
Response speed (120μs) is slower than Nb/Al-STJ response speed (around a few μs).

Test Results of Nb/Al-STJ with Far-Infrared laser

Far-Infrared Laser at University of Fukui (λ=57.2μm)

Nb/Al-STJ Response to Far-Infrared Laser



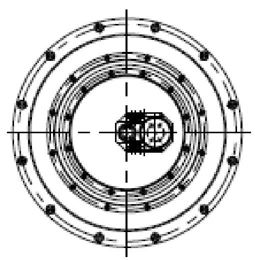


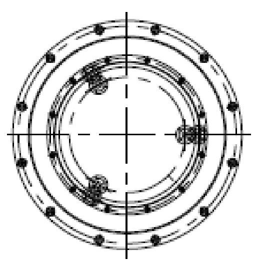
- 20μm-square Nb/Al-STJ made at AIST CRAVITY system
- Laser light was turned on and off with a chopper at a frequency of 200Hz. Measured the change of the I-V curve between the laser on and off to be 50~100nA in current.

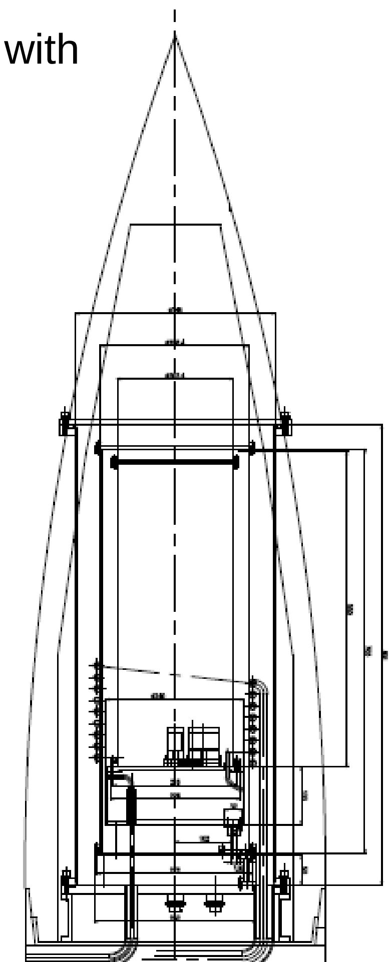
Prototype of Cryostat for the Rocket Experiment

In April 2017, a prototype of the cryostat for the rocket experiment was made. This is a He^3 sorption 0.3K refrigerator inside of a He^4 depressurized 1.8K refrigerator. (For now it does not have a He^3 sorption 0.3K refrigerator inside)

We will test Nb/Al-STJ inside of this cryostat with far-infrared(50μ) photon beam at Fukui this winter.







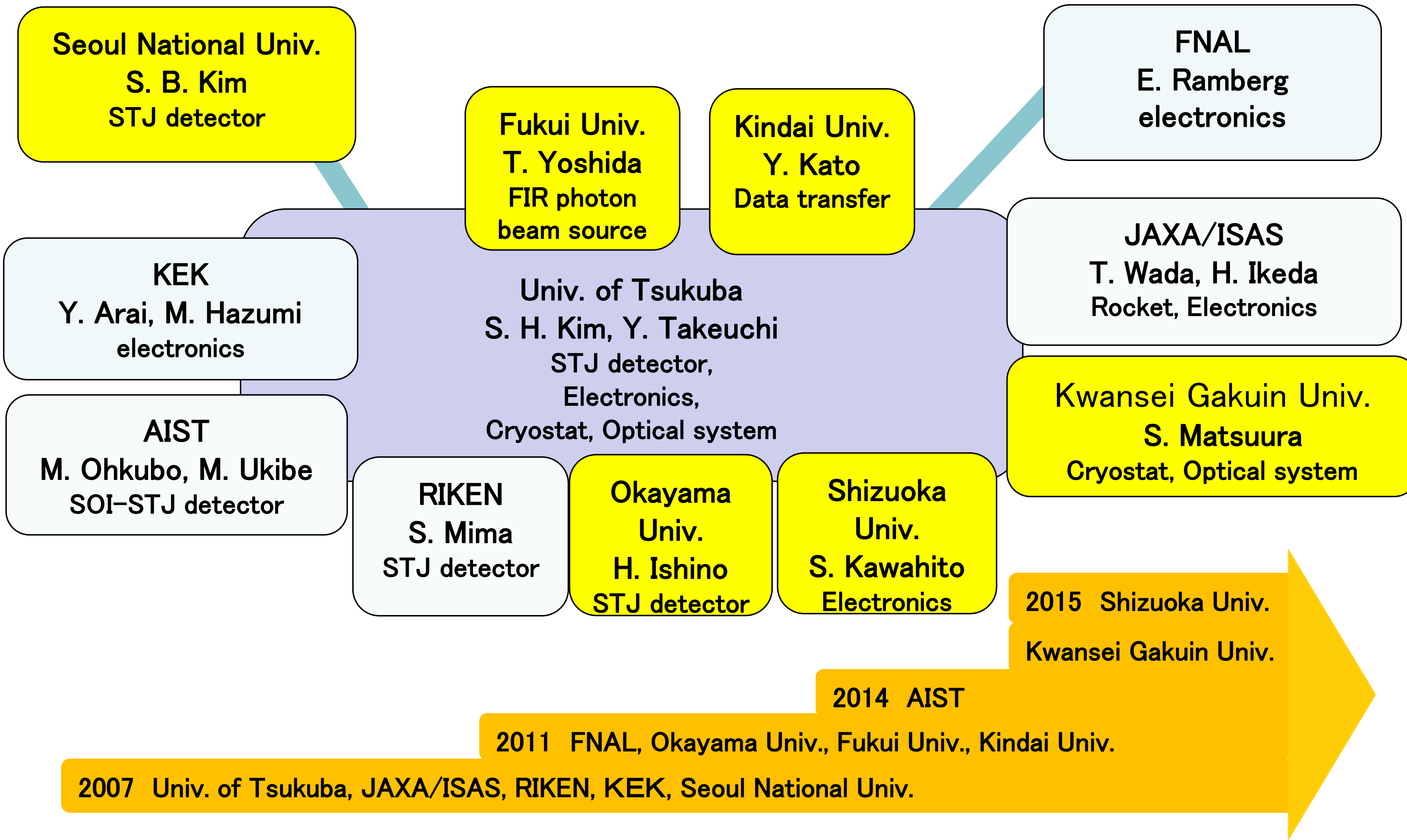
Made by Jeck Tohri company.

Schedule

	2016	2017	2018	2019	2020	2021
Experiment Design	Experiment design with Satellite such as SPICA					
	Experiment design with FIR Rocket			Far-Infrared Observatory Rocket Experiment		
Superconducting Tunnel Junction (STJ) Detector	R&D of Nb/Al-STJ		Production			
	Design and R&D of Hf-STJ Detector				(for Satellite Experiment)	
Preamplifier at 1K and Post-Preamp (Fermilab, JAXA, KEK,AIST,Tsukuba)	Design and R&D		Production		Design, R&D, Production	
Dispersive Element, Optics	Design and R&D		Production		Design, R&D, Production	
Cryostat	Design and R&D		Production		Design, R&D, Production	
Measurements＋Analysis		Analysis Program				
	Simulation				Analysis	

Collaboration of Cosmic Background Neutrino Decay Search

A part of the consortium of the History of the Universe



Summary

- R&D of STJ detectors and the design of the COBAND rocket experiment are underway.
    - ➢ Determination of the neutrino mass
        - ☐ origin of elementary particle mass spectra
    - ➢ Discovery of the cosmic background neutrino
        - ☐ new probe of the very early universe

- New far-infrared photon detector is being developed:
    - ➢ Nb/Al-STJ satisfied our requirement for leakage current less than 0.1pA
    - ➢ Cryogenic amplifier with the SOI technology worked at 300mK

      We have succeeded in amplifying the STJ signal with the SOI cryogenic amplifier.
    - ➢ Aiming at one photon detection in the far-infrared range
    - ➢ applicable to the other fields such as X-ray energy measurement with higher energy resolution.