at Korea Astronomy and Space Science Institute (KASI)
July 19, 2017

Cosmic Background Neutrino Decay Search – COBAND Experiment –

Continuous Spectral Measurement in Far-Infrared Region using STJ

Shin-Hong Kim （University of Tsukuba, CiRfSE）
for COBAND collaboration

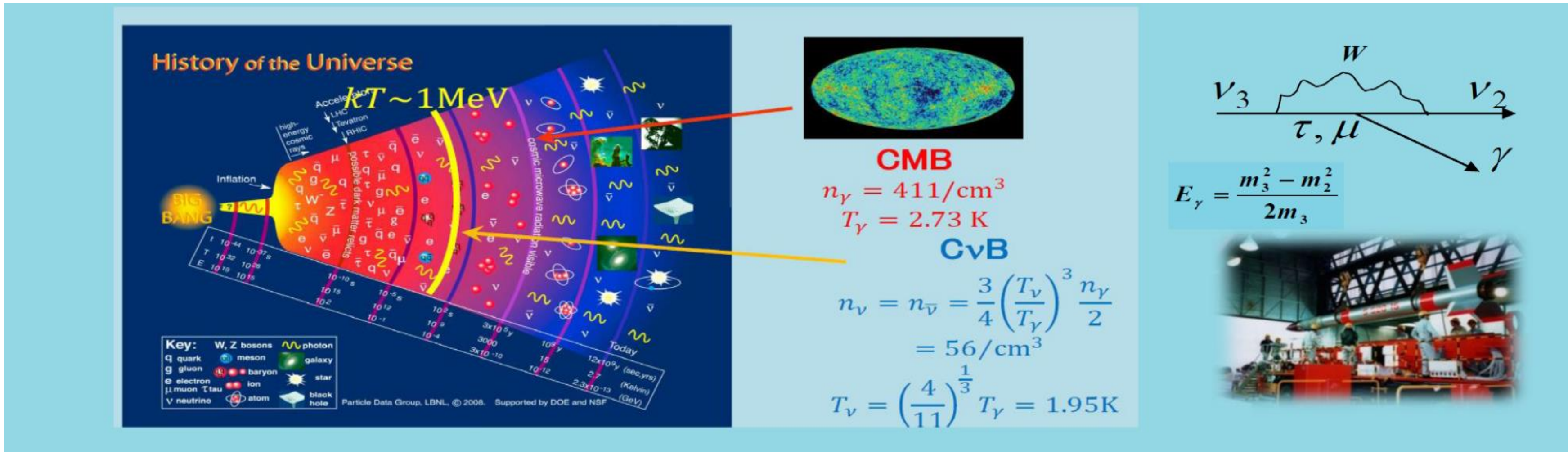
at KASI Colloquium

CiRfSE

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

COBAND

COBAND (COsmic BAckground Neutrino Decay) Collaboration



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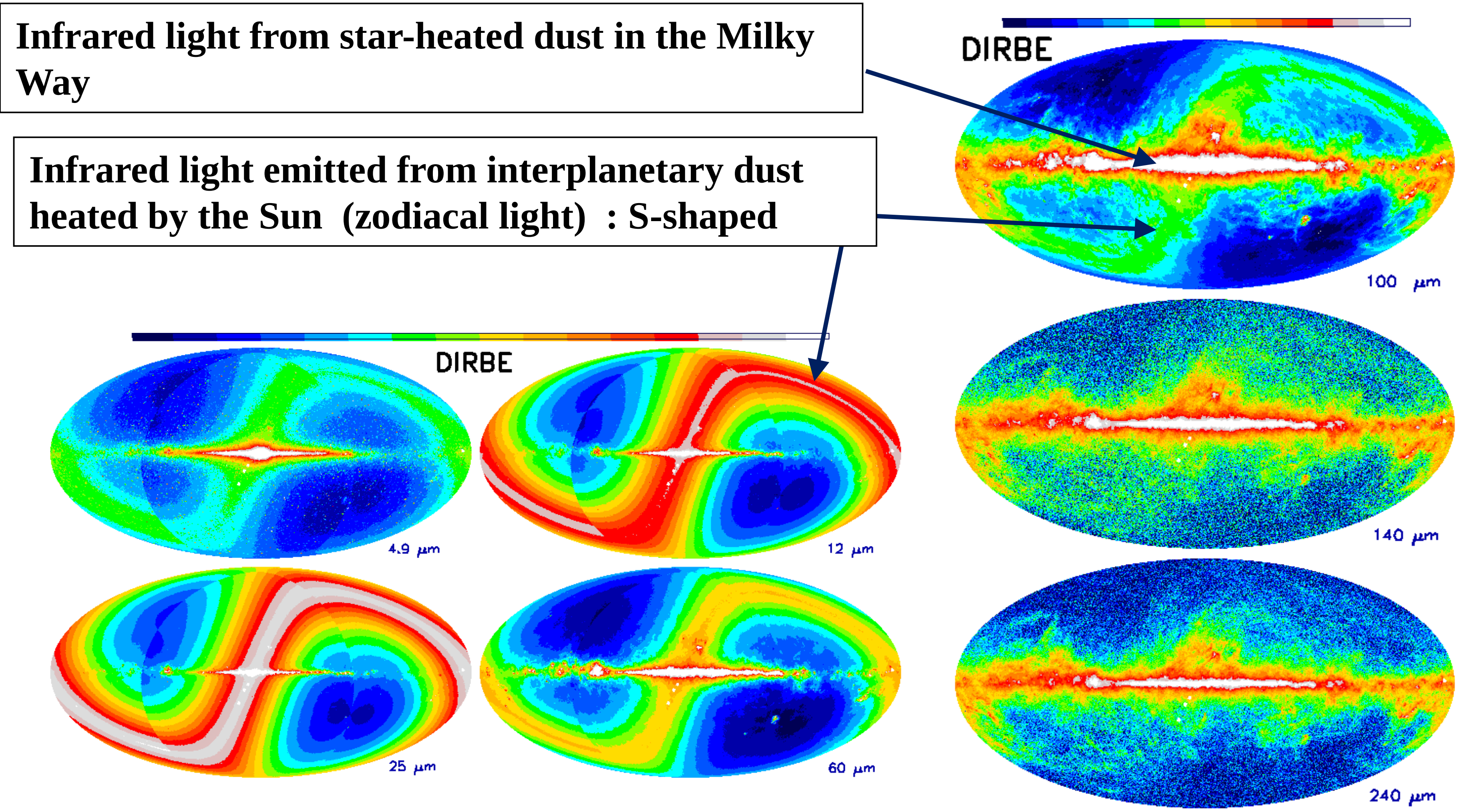
S.B. Kim (Seoul National University)

ν_3 γ ν_2
COBAND

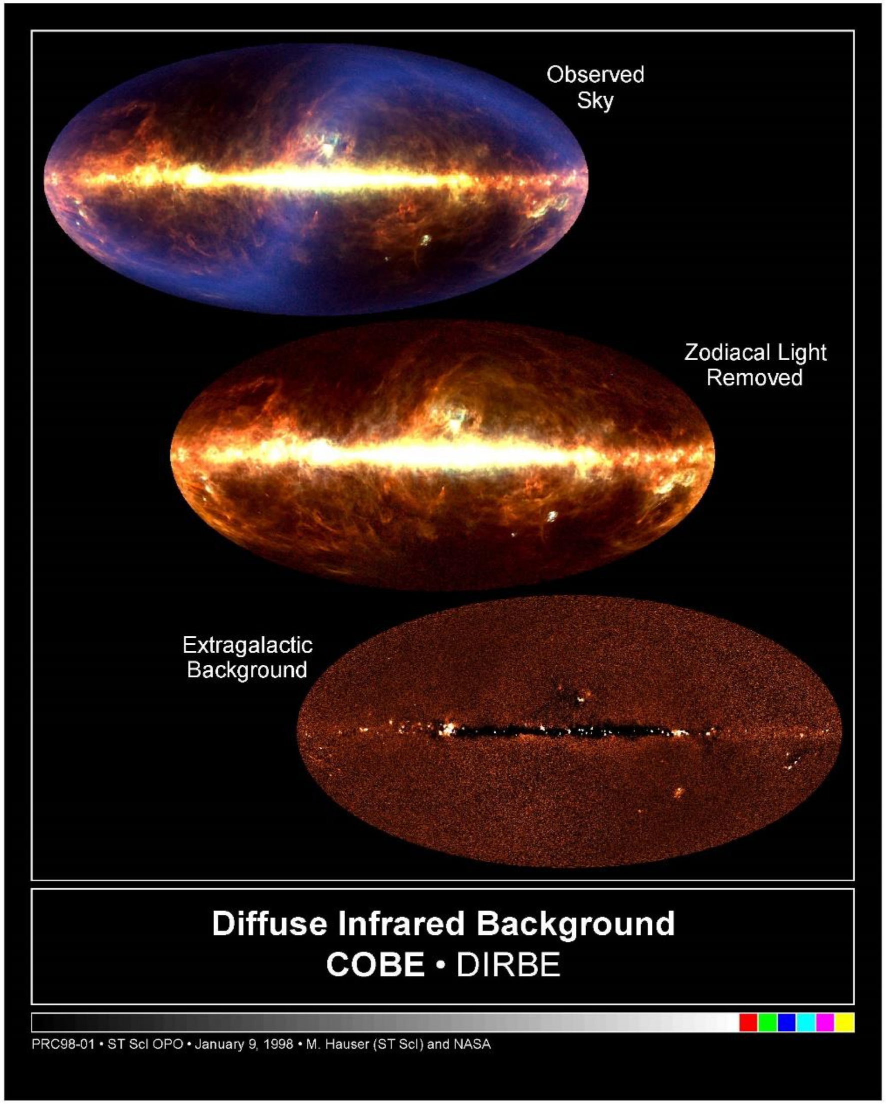
Cosmic Infrared Background Radiation

Cosmic Infrared Background Observation by COBE

January 1998 (Press Release): COBE (Cosmic Background Explorer) announced the first observation of the cosmic infrared background (CIB)



Cosmic Infrared Background Observation by COBE



(Top)
Observed Sky at λ = 60 μm(blue), 100 μm (green) and 240 μm(red).
Horizontal band corresponds to Infrared light from interstellar gas in the plane of our Milky Way Galaxy. The blue S-shaped region corresponds to Infrared light from interplanetary dust in the solar system called zodiacal emission.

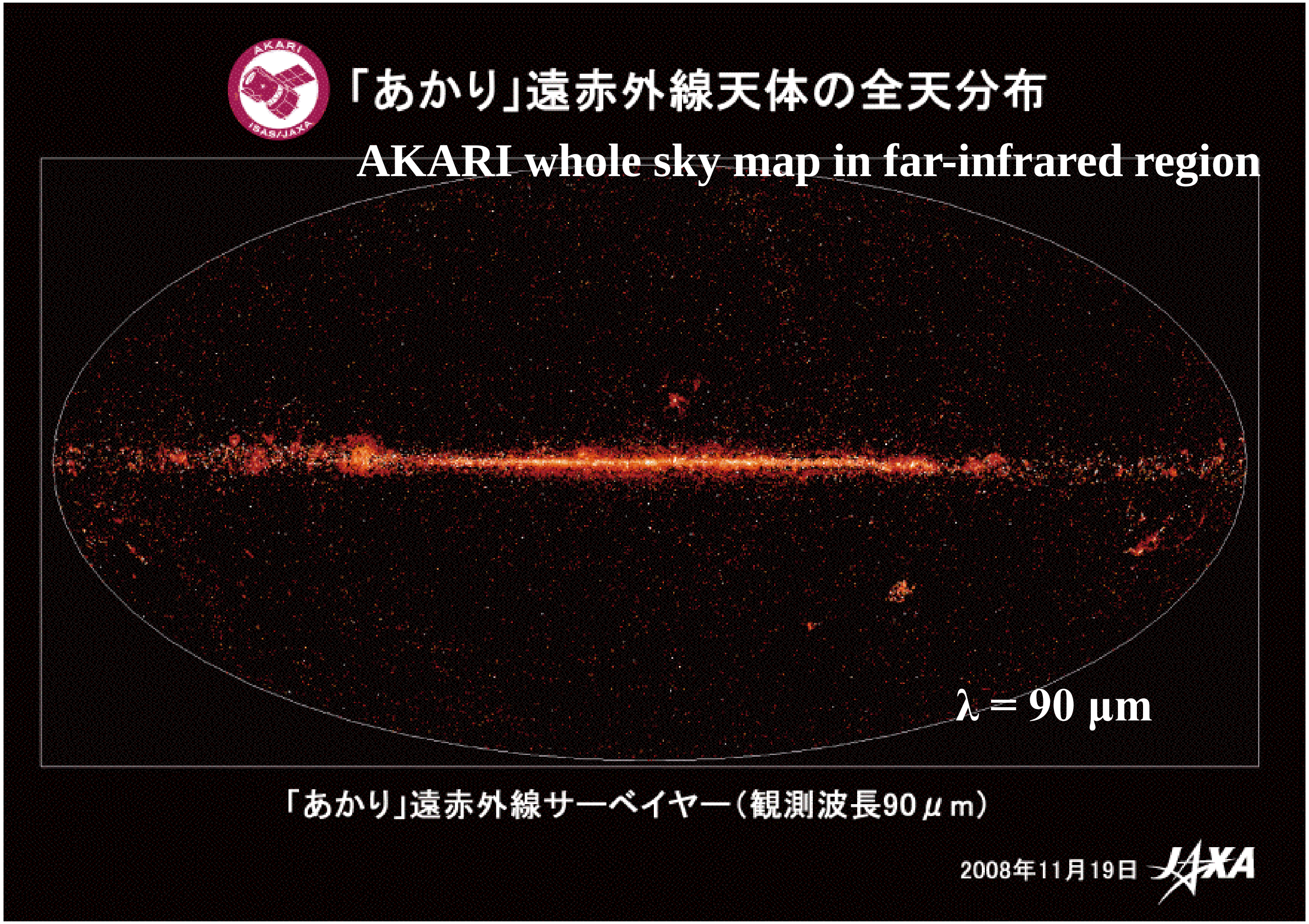
(Middle)
After removing the zodiacal emission.

(Bottom)
After removing the infrared light from our solar system and Galaxy at λ = 240μm.

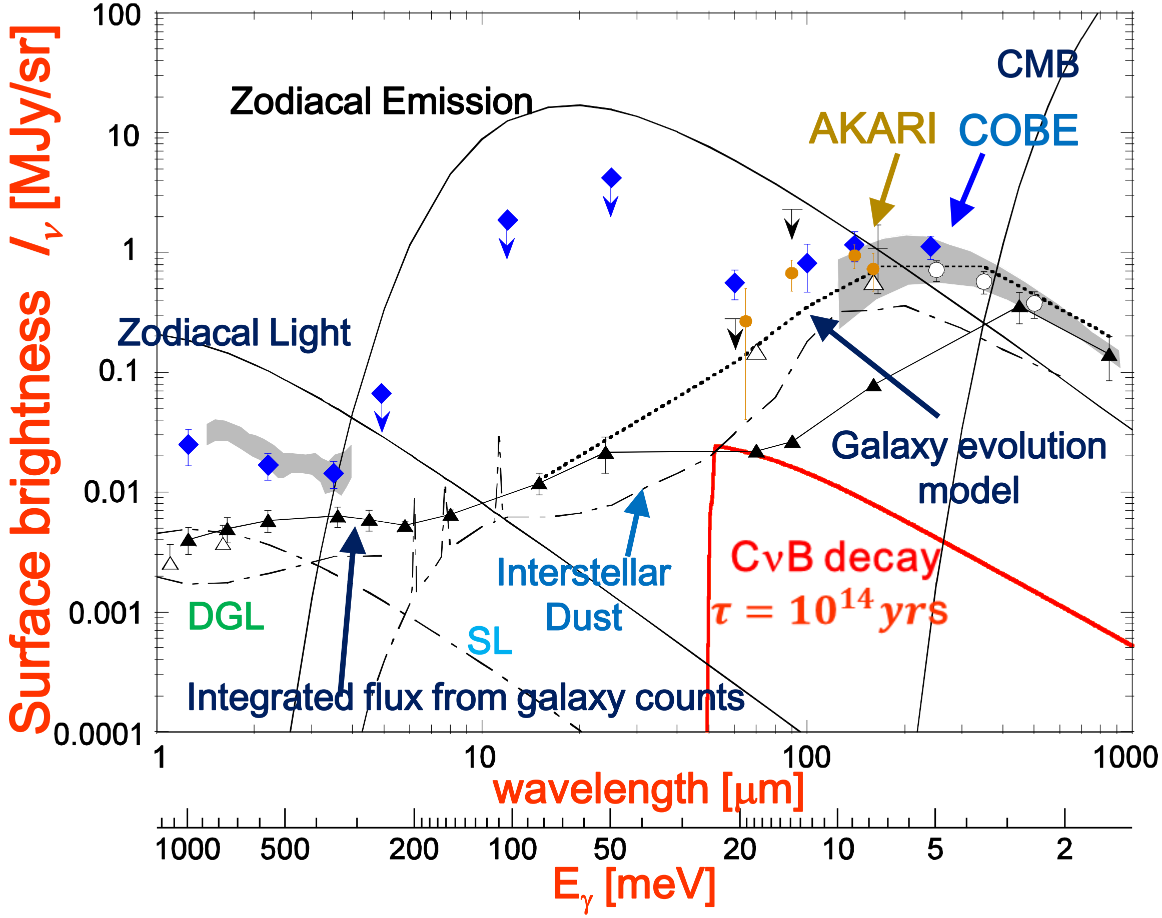
COBE announced that they observed the extragalactic residual infrared light called "Cosmic Infrared Background" at the 240 and 140 micrometer wavelength.

Cosmic Far-Infrared Background Observation by AKARI

November 2008 : AKARI (JAXA Infrared Imaging Satellite) observed 64,000 stars and galaxies at wavelengths of 65, 90, 140 and 160 μm. Made a whole sky map. They extracted CIB map from this observation.



Photon Energy Spectrum from Outer Space



CIB measurements (● AKARI, ◆ COBE)

There was an excess of the CIB measured by COBE and AKARI over the prediction by galaxy evolution model.

Sources at FIR: dusts of far galaxies or far blackhole, or CνB decay ?

Sources of NIR: first-generation stars Ly-α ?

Our paper published in JPSJ on Jan. 18th, 2012

Journal of the Physical Society of Japan **81** (2012) 024101 FULL PAPERS

DOI: 10.1143/JPSJ.81.024101

Search for Radiative Decays of Cosmic Background Neutrino using Cosmic Infrared Background Energy Spectrum

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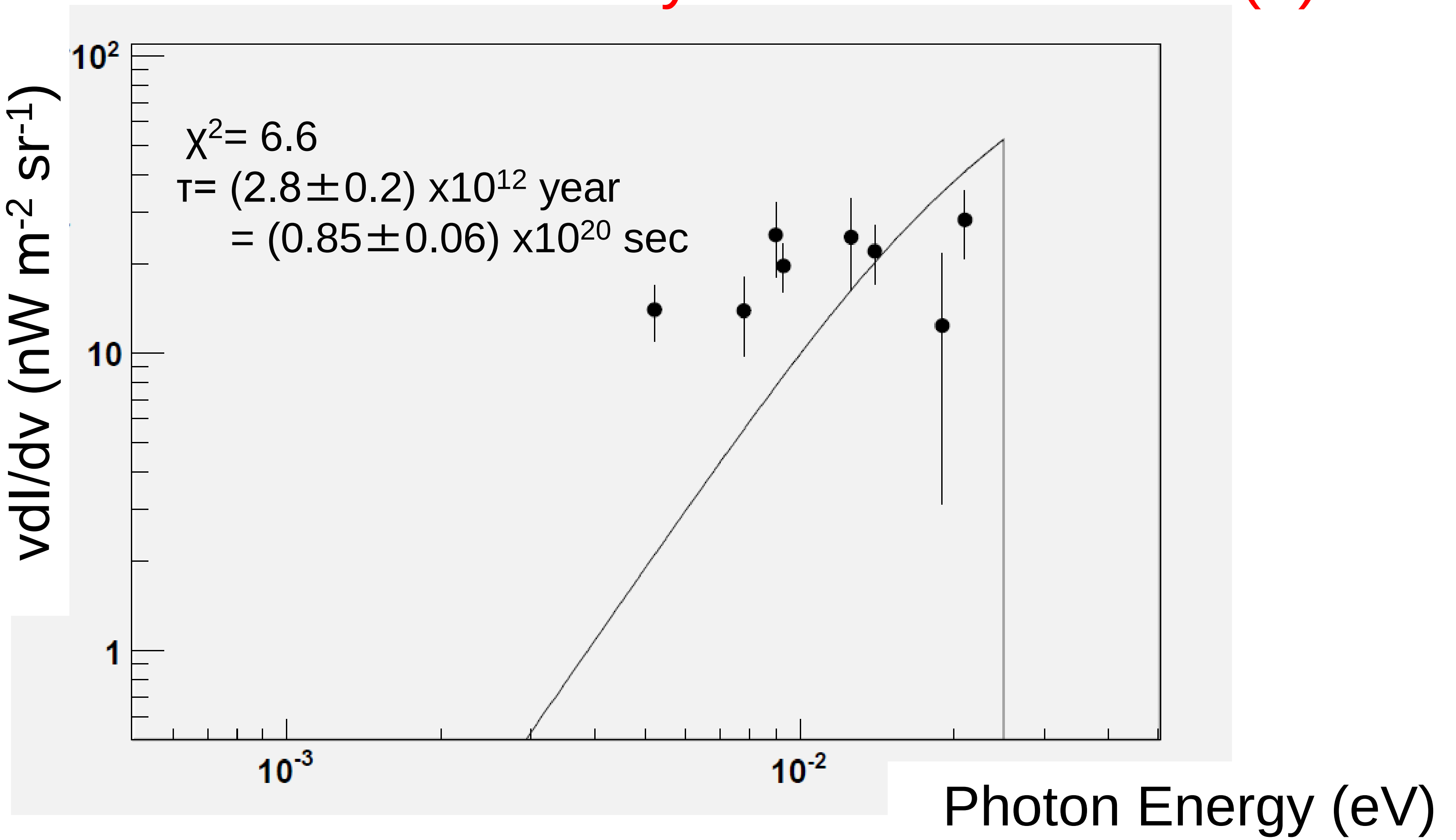
We propose to search for the neutrino radiative decay by fitting a photon energy spectrum of the cosmic infrared background to a sum of the photon energy spectrum from the neutrino radiative decay and a continuum. By comparing the present cosmic infrared background energy spectrum observed by AKARI and Spitzer to the photon energy spectrum expected from neutrino radiative decay with a maximum likelihood method, we obatined a lifetime lower limit of 3.1×10^{12} to 3.8×10^{12} years at 95% confidence level for the third generation neutrino ν_3 in the ν_3 mass range between 50 and 150 meV/c^2 under the present constraints by the neutrino oscillation measurements. In the left–right symmetric model, the minimum lifetime of ν_3 is predicted to be 1.5×10^{17} years for m_3 of 50 meV/c^2. We studied the feasibility of the observation of the neutrino radiative decay with a lifetime of 1.5×10^{17} years, by measuring a continuous energy spectrum of the cosmic infrared background.

KEYWORDS: neutrino radiative decay, neutrino mass, cosmic background neutrino, cosmic infrared background, COBE, AKARI, Spitzer

Search Region: λ = 35〜250μm （E_γ = 35〜5meV）

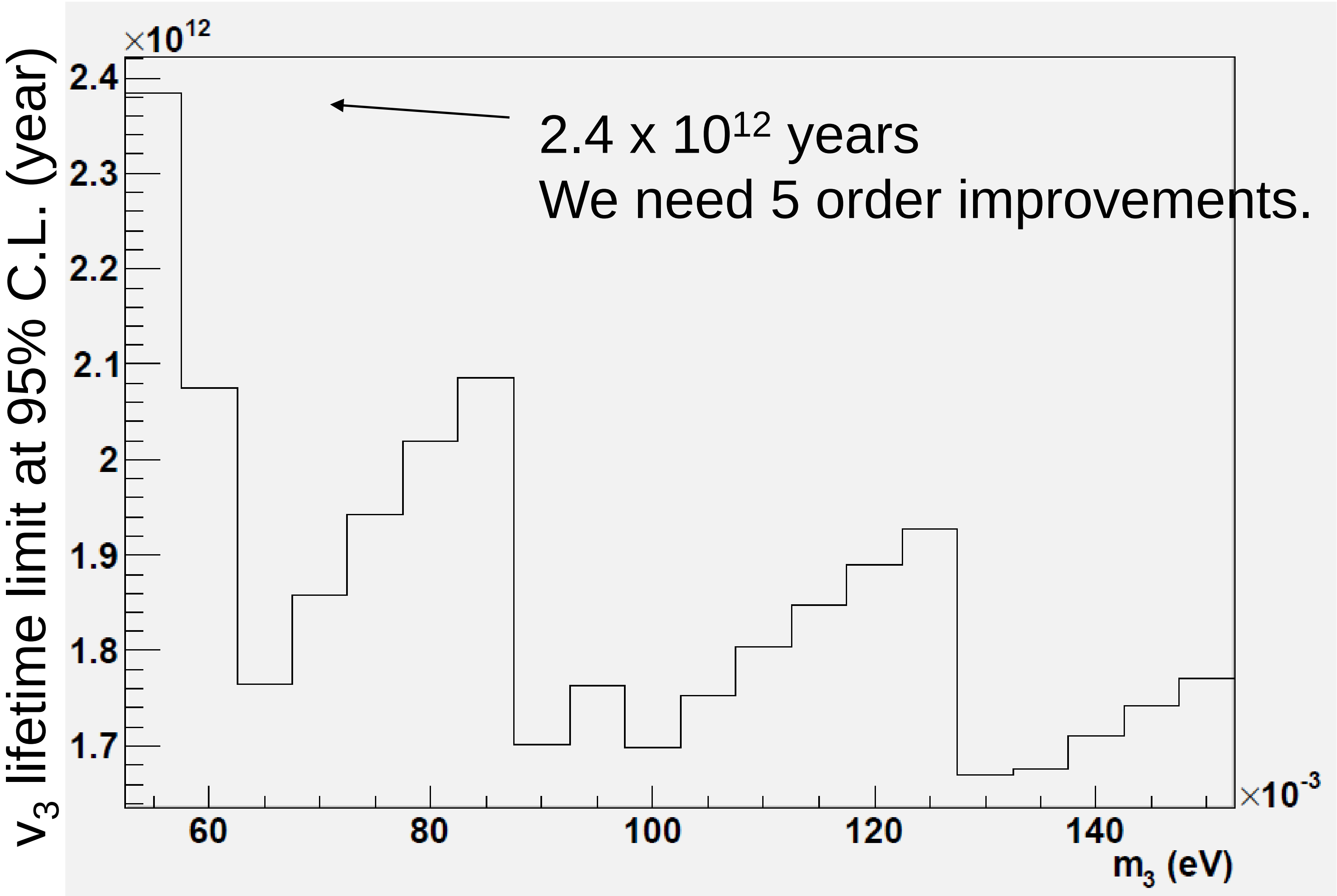
In Rocket experiment, λ = 40〜80μm （E_γ = 31〜15meV）

Lower Limit of Lifetime from the Energy Spectrum Fit the CIB measured by COBE and AKARI(1)



Using the CIB at 60, 100 (ApJ, 544, 81, 2000), 140, 240 μm (ApJ, 508, 25, 1998), 65, 90, 140, and 160 μm (arXiv:1002.3674, 2010), the photon energy spectrum from neutrino radiative decay gives a lifetime lower limit of 2.4 x 10^{12} year at 95% C.L. for m_3 = 0.05eV and m_2 = 0.01eV. (My calculation)

Lower Limit of Lifetime from the Energy Spectrum Fit to the CIB measured by COBE and AKARI(2)

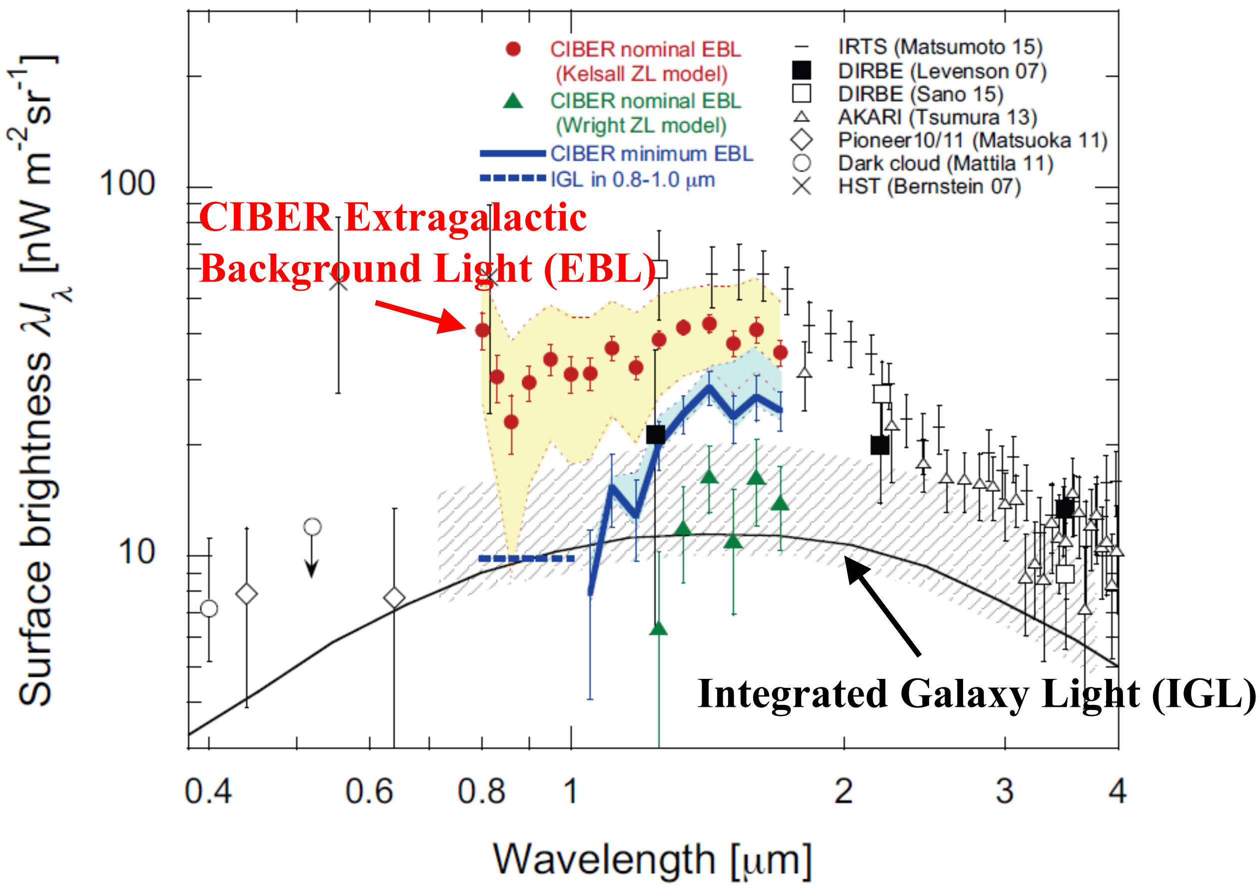


ν_3 mass (eV)

$\Delta m_{23}^2 = 0.00243\ eV^2$

Near-Infrared Photon Energy Spectrum from Outer Space

April 2017 (Press Release): CIBER rocket experiment measured the energy spectrum of the cosmic infrared background (CIB) in the near-infrared region. They found an excess of the CIB spectrum over the prediction by integrated galaxy light (IGL).

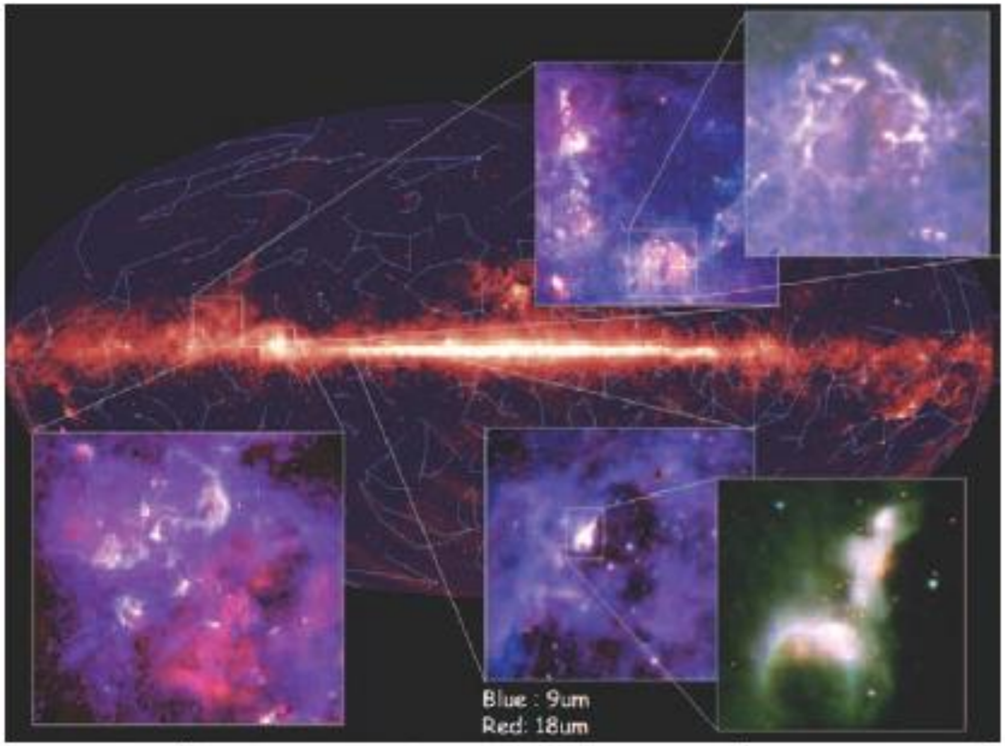


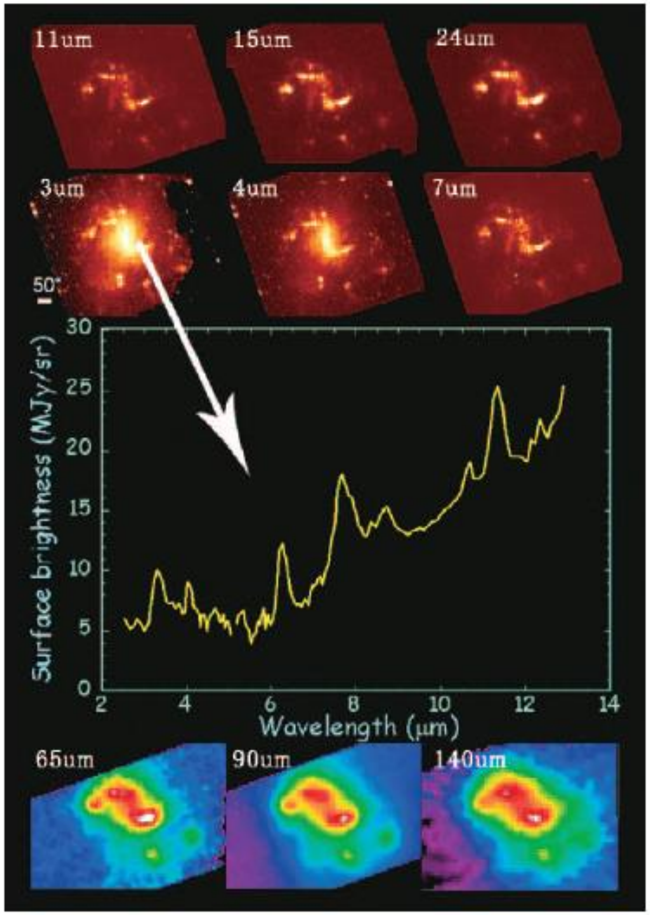
This excess might be due to first-generation stars Ly-α.
CIBER collaboration plans to do CIBER-2 rocket experiment which has 10 times larger sensitivity.

Astrophysics with NIR and FIR by AKARI

- **NIR and FIR from interstellar gas → Formation and evolution of galaxies, stars and dusts**
- **NIR: Search for first-generation stars using Ly-α line.**
- **FIR: Search for first-generation heavy element dusts.**

Map of NIR from Milky Way Galaxy measured by AKARI



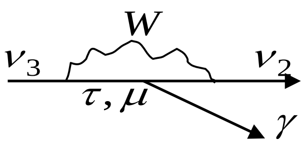


Molecular cloud IR in the arm of NGC1313 measured by AKARI

Cosmic Background Neutrino Decay Search (COBAND)

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.



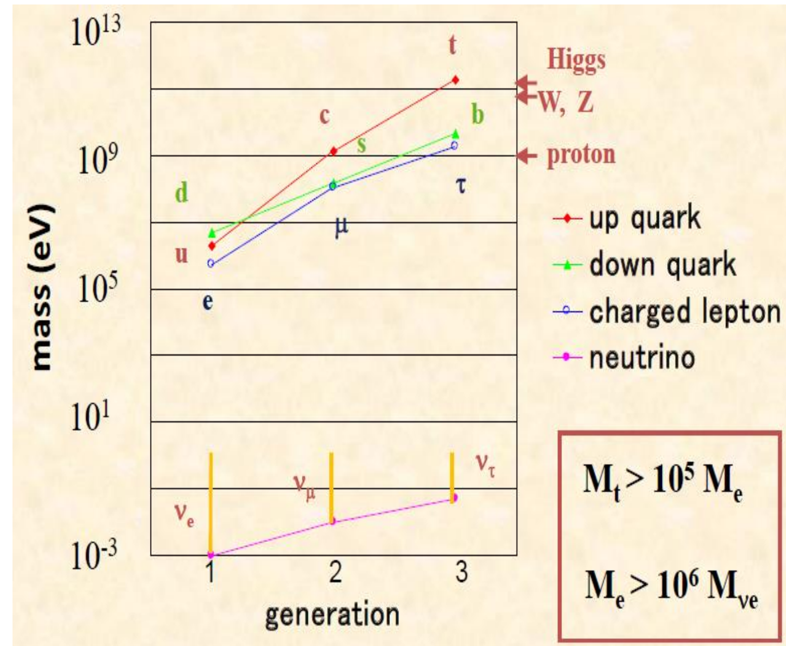
$$\nu_3 \rightarrow \nu_2 + \gamma$$

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

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.

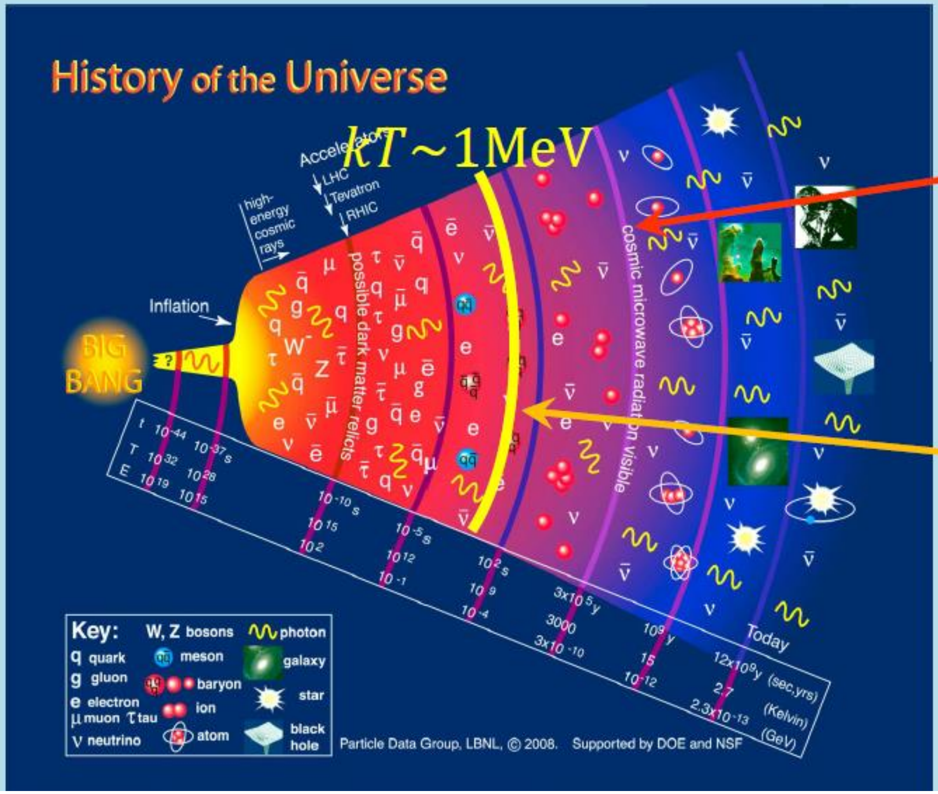
(Far - Infrared region $\lambda = 50 \sim 125\ \mu$)

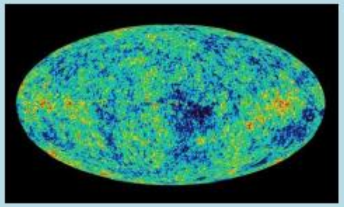


- As the neutrino lifetime is very long, we need use cosmic background neutrino to observe the neutrino decay. To observe this decay of the cosmic background neutrino means a discovery of the cosmic background neutrino predicted by cosmology.

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

Big-Bang Cosmology
and Cosmic Background Neutrino (CνB)





CMB

$$n_\gamma = 411/\mathrm{cm}^3$$
$$T_\gamma = 2.73\ \mathrm{K}$$

CνB

$$n_\nu = n_{\bar{\nu}} = \frac{3}{4}\left(\frac{T_\nu}{T_\gamma}\right)^3 \frac{n_\gamma}{2}$$
$$= 56/\mathrm{cm}^3$$
$$T_\nu = \left(\frac{4}{11}\right)^{\frac{1}{3}} T_\gamma = 1.95\mathrm{K}$$

- **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 $F(E) = \frac{1}{e^{(E-\mu)/kT} \pm 1}$

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

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

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

Temperature:

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

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

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

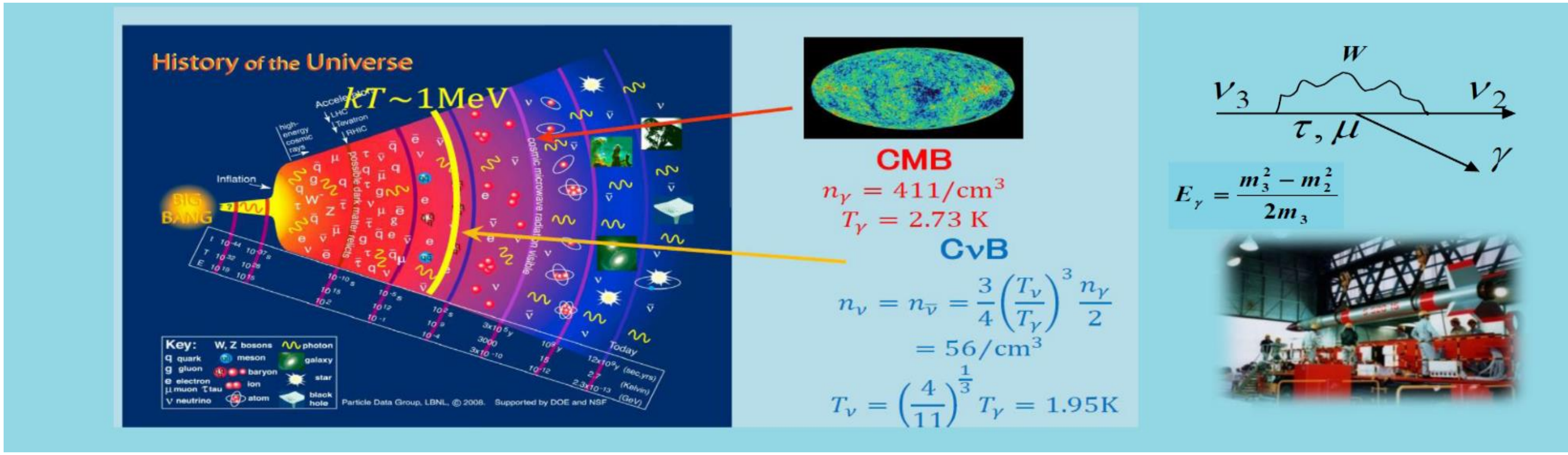
where *g* is the spin degree of freedom, and *F* = 1(for fermions) and 0 (for bosons).

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

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

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

Cosmic Background Neutrino



Temperature:

T_ν= 1.95K

Number density:

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

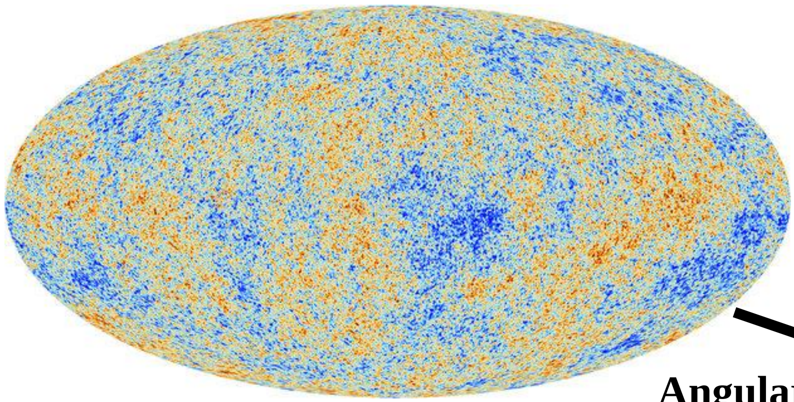
where *g* is the spin degree of freedom, and *F* = 1(for fermions) and 0 (for bosons).

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

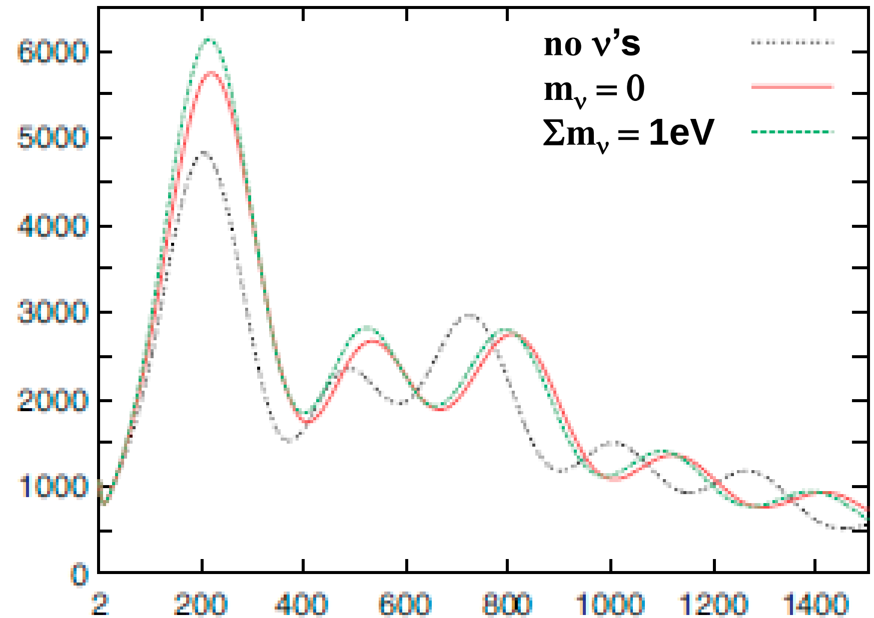
$$\therefore n_{\nu_\alpha} \approx n_{\bar{\nu}_\alpha} \approx 56\mathrm{cm}^{-3} \quad (\alpha = e, \mu, \tau)$$

Large Scale Structure of the Universe and CνB

Temperature fluctuation of CMB observed by Planck satellite



Theoretical prediction on Power Spectra of the angular correlation of the CMB temperature fluctuation （depending on the neutrino mass）



Large Angular scale(180° /*l*) Small

High Temperature ＝ High Galaxy matter density

CνB exists → large angular correlation at high angle

higher neutrino mass → larger angular correlation at high angle

Decision Factor of Temperature Fluctuation：

Dark matter, Dark energy, Neutrino

↓

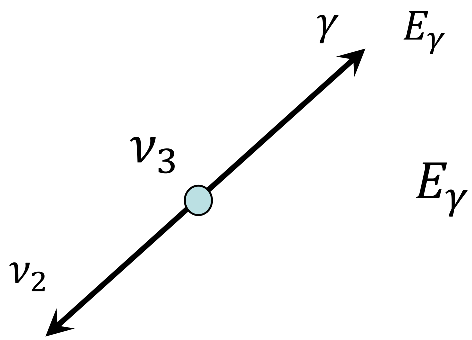
Matter density
or Large scale structure of the Universe

Ref. J. Lesgourgues, S. Pastor Phys. Rep. 429 (2006) 307

Photon Energy from Neutrino Decay

Neutrino decay

$$\nu_3 \rightarrow \nu_{2,1} + \gamma$$

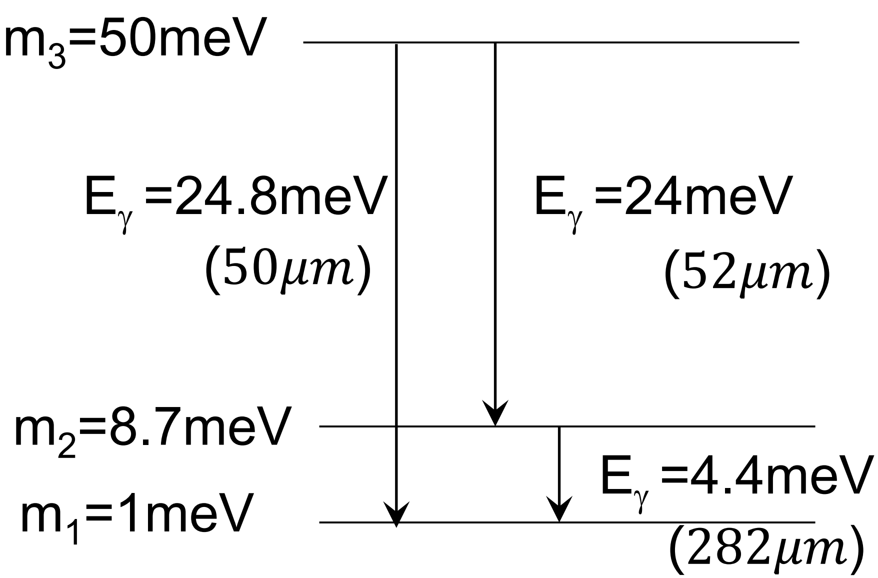


$$E_\gamma = \frac{m_3^2 - m_{1,2}^2}{2m_3}$$

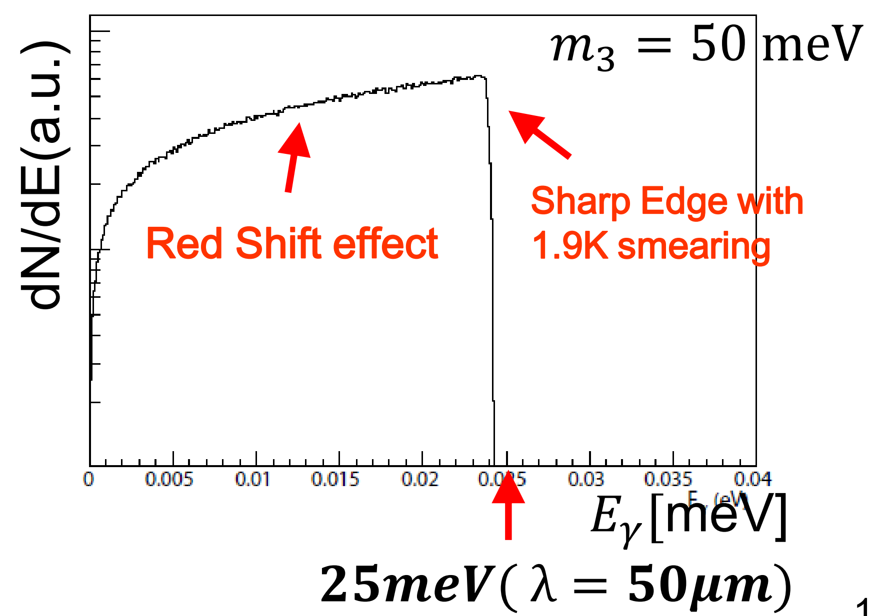
- **Neutrino oscillation results**
  - $|\Delta m_{23}^2| = |m_3^2 - m_2^2| \sim 2.4 \times 10^{-3}\ eV^2$
  - $\Delta m_{12}^2 \sim 7.65 \times 10^{-5}\ eV^2$
- **Space observatory results (Planck+WP+highL+BAO)**
  - $\sum m_i < 0.23\ eV$

➔ **50meV<m_3<87meV**

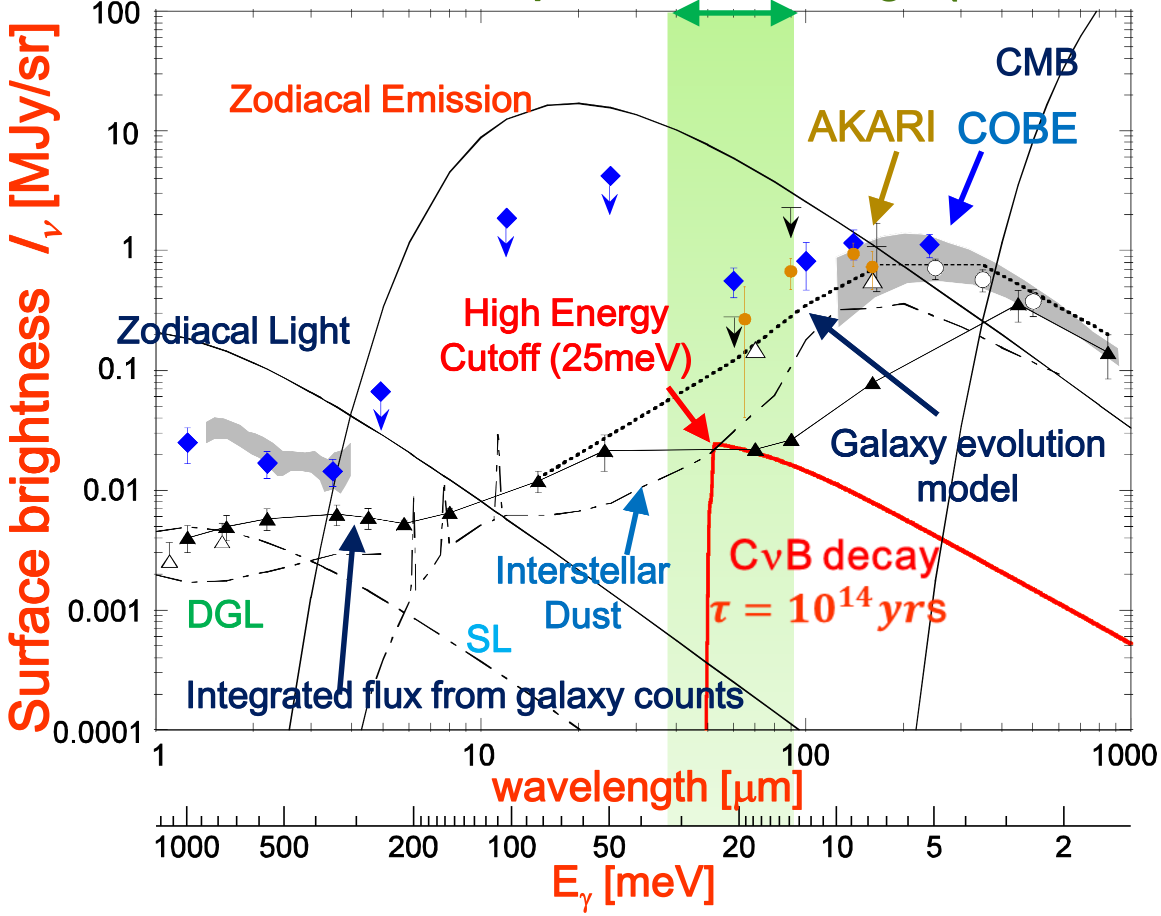
E_γ =14~24meV (λ_γ =51~89μm)



Photon energy distribution $\nu_3 \rightarrow \nu_2 + \gamma$



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 $E_\gamma \sim 25\,\mathrm{meV} (\lambda = 50\mu m)$
- 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

COBAND (COsmic BAckground Neutrino Decay Search) Experiment

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

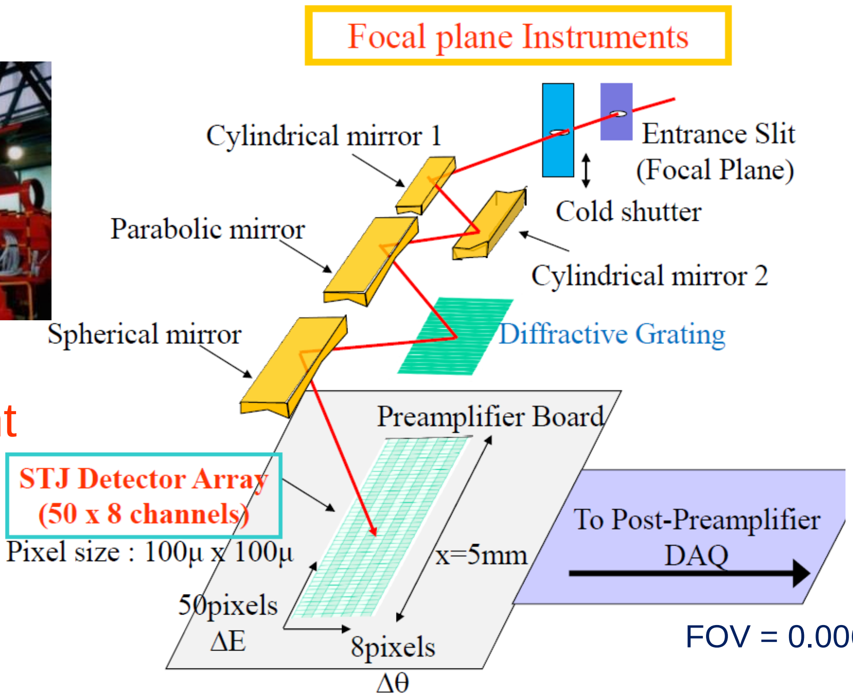
Improve the current limit of lifetime $\tau(\nu_3)$ by two orders of magnitude (~10^{14}years).

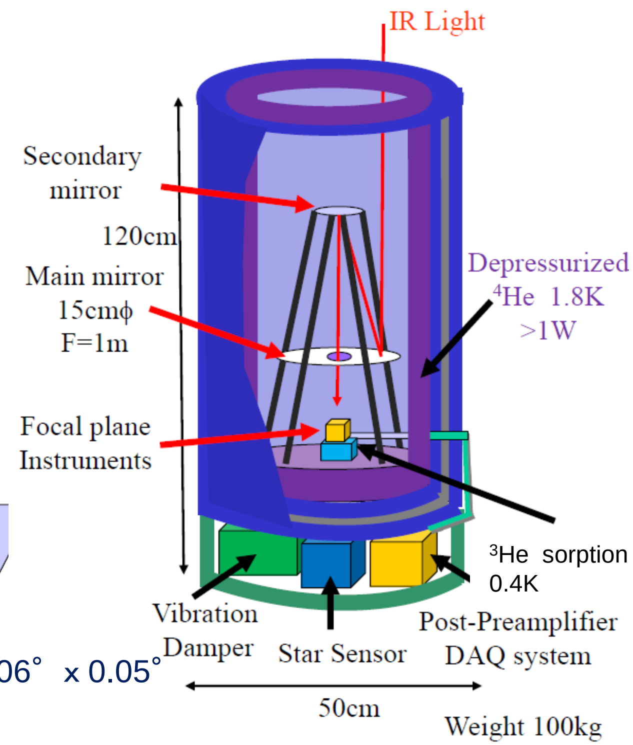
»**Superconducting Tunneling Junction (STJ) detectors in development**

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

JAXA Rocket
CIB Experiment

（Feb 2, 1992）





FOV = 0.006° x 0.05°

Satellite experiment after 2020 → **sensitivity of $\tau(\nu_3)$ ~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
- $N_{q.p.} = 25\text{meV}/1.7\Delta = 735$ for 25meV photon: $\Delta E/E < 2\%$ if Fano-factor is less than 0.3

Zodiacal Emission

Thermal emission from the interplanetary dust cloud

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

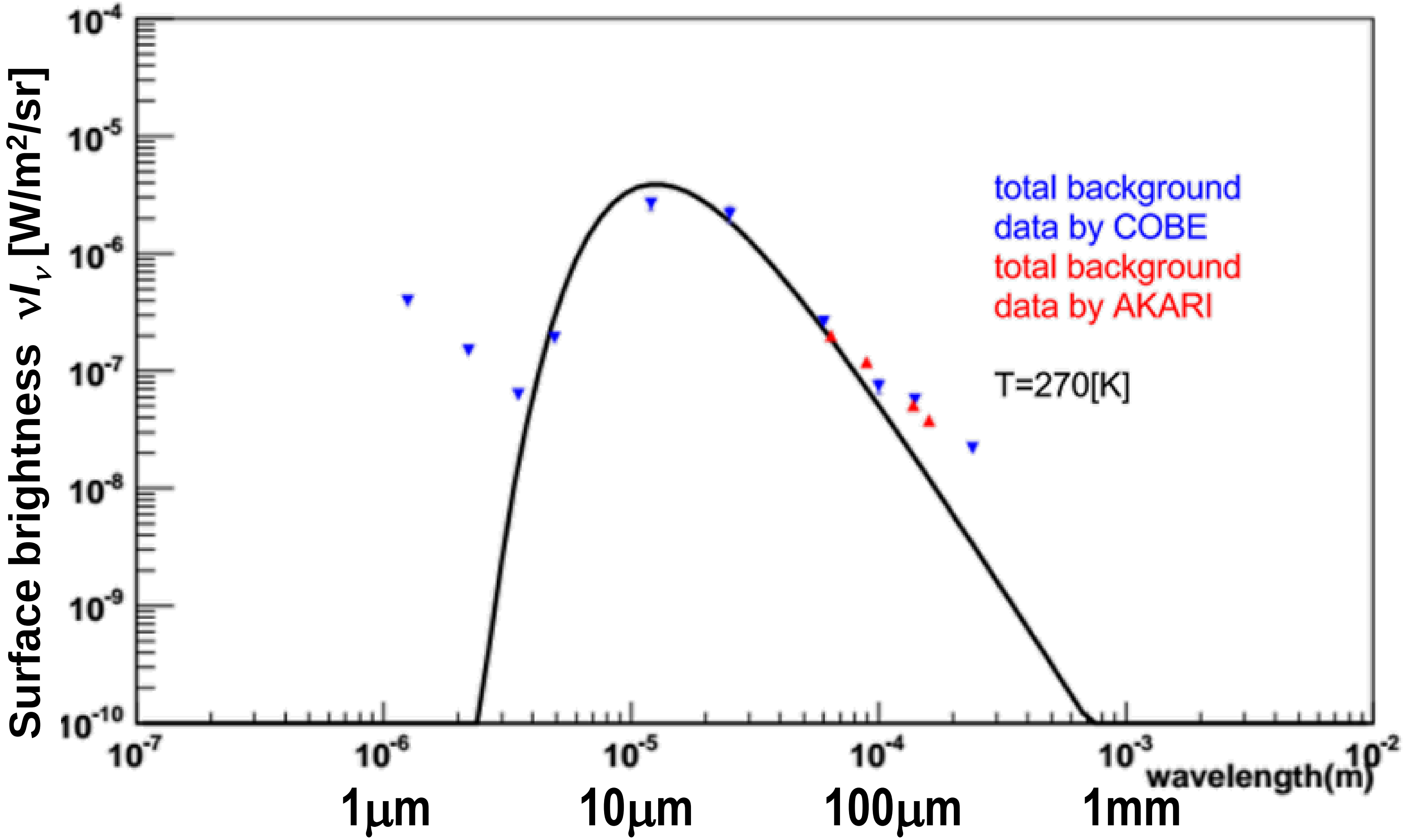
$$\times A \left(\frac{\nu}{c} \times 10^{-5}\right)^B \ \mathrm{Wm^{-2}sr^{-1}}$$

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

h [Js], c [m/s], λ [m]

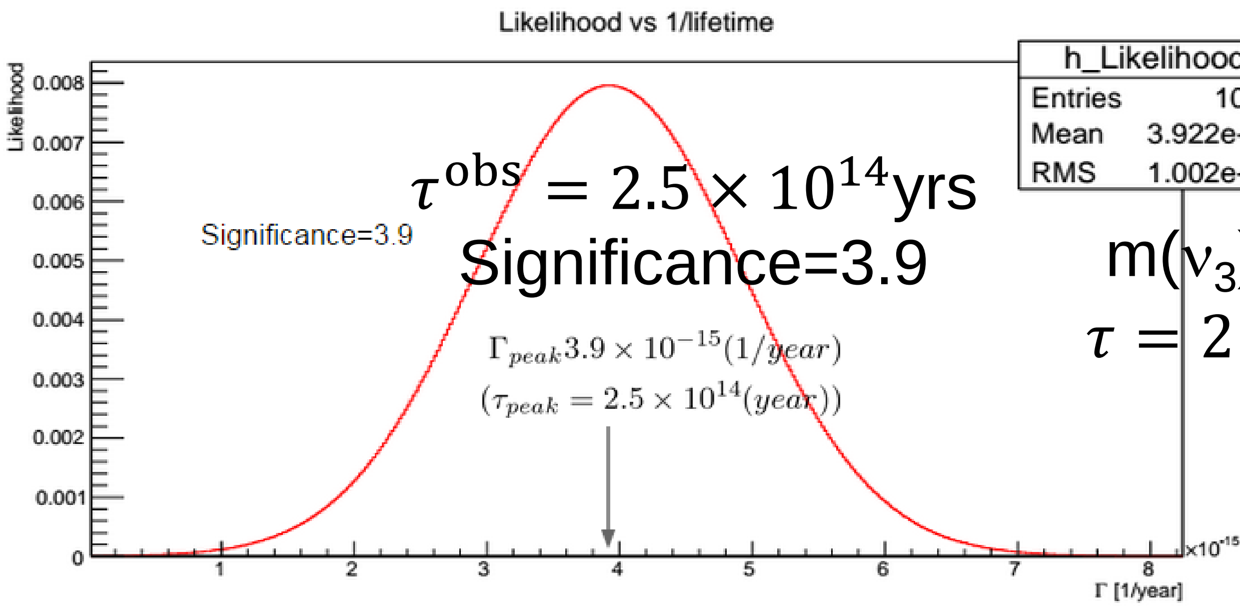
Zodiacal Emission(ZE) is overwhelmingly dominating. Here we consider only ZE as the background.

Zodiacal Emission



Discovery potential for neutrino decay

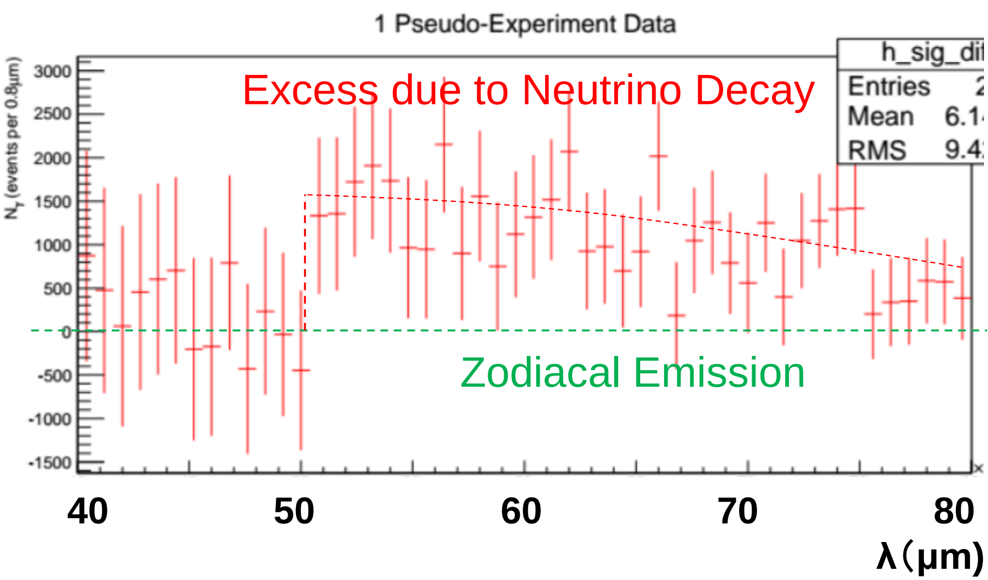
1. Create a pseudo-data for ND and ZE expectation on assumption of ν_3 mass and lifetime: $N_{obs}(m^{true}, \Gamma^{true})$
2. Calculate expected distribution of ND+ZE on assumption of ν_3 mass and lifetime: $N_{exp}(m, \Gamma)$
3. Calculate likelihood of the pseudo-data as a function of the decay width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

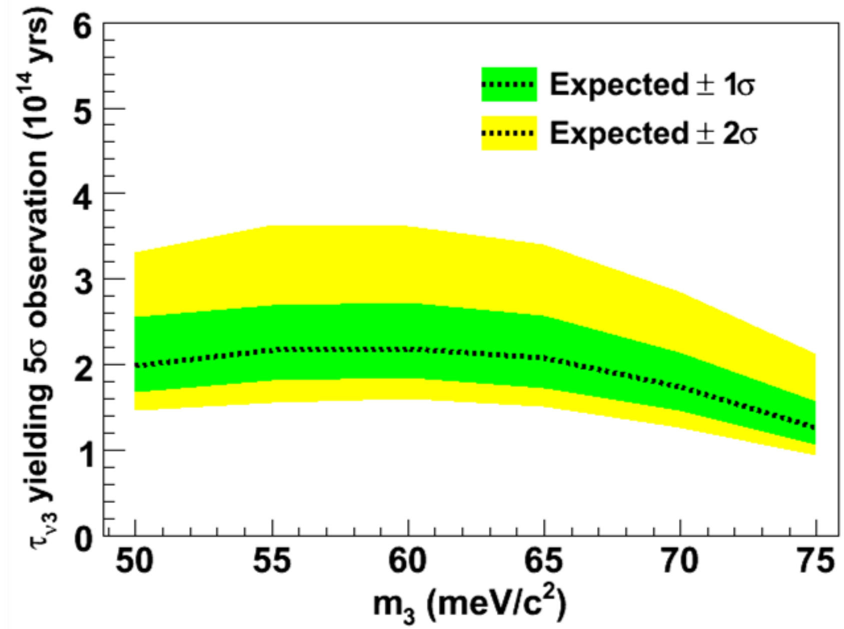


Sensitivity to neutrino decay

Parameters in the rocket experiment simulation

- telescope dia.: 15cm
- 50-column (λ: 40μm – 80 μm) × 8-row array
- Viewing angle per single pixel: 100μrad × 100μrad
- Measurement time: 200 sec.
- Photon detection efficiency: 100%



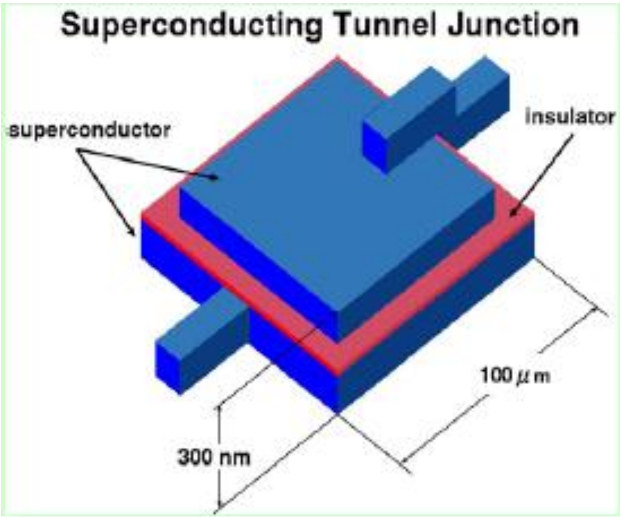


- If ν_3 lifetime were 2×10^{14} yrs, the signal significance is at 5σ level

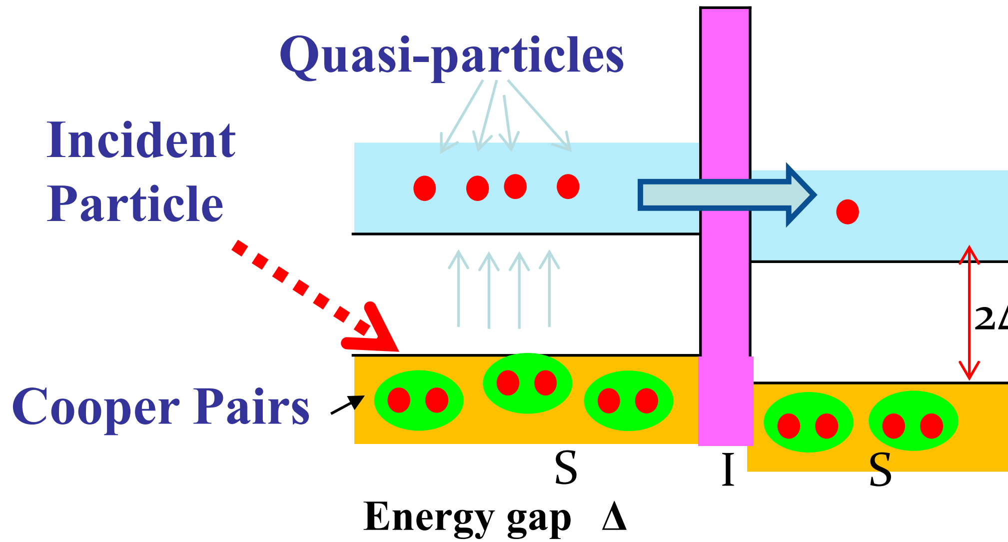
R&D Status of Superconducting Tunnel Junction Detector for COBAND experiment

STJ (Superconducting Tunnel Junction) Detector

Superconductor / Insulator / Superconductor Josephson Junction

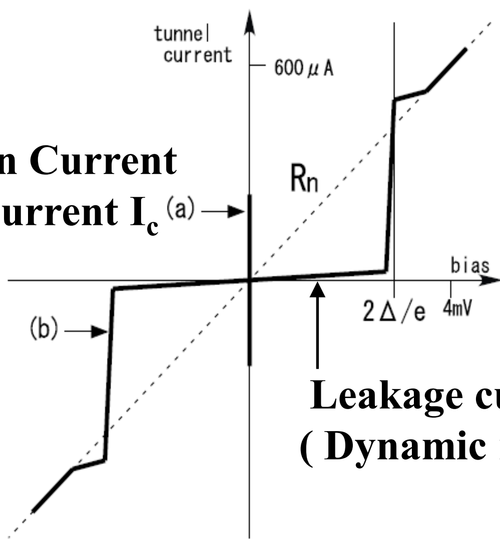


At the superconducting junction, quasi-particles over their energy gap go through tunnel barrier by a tunnel effect. By measuring the tunnel current of quasi-particles excited by an incident particle, we measure the energy of the particle.



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

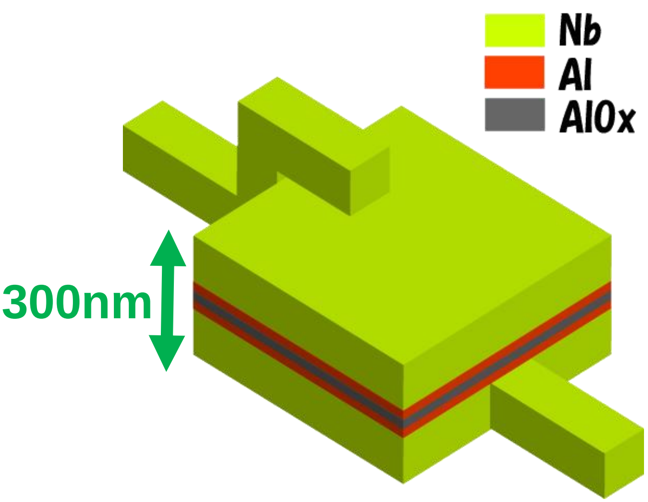
Material	$T_c(K)$	$\Delta(\text{meV})$
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

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

$$N_q = 10\,\frac{25\ meV}{1.7 * 0.57\ meV}$$
$$= 250\ e$$

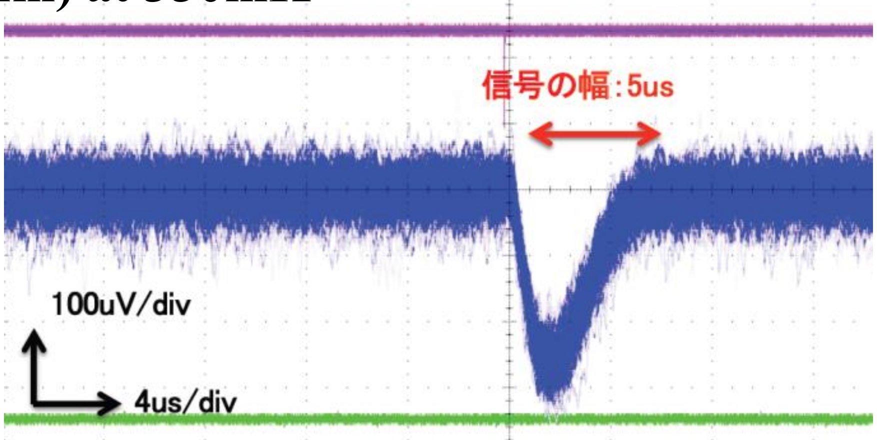
Back tunneling Effect → Trapping Gain

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(200nm)/Al(70nm)/AlOx/Al(70nm)/Nb(100nm)

  $\Delta_{Nb/Al} = 0.57meV$

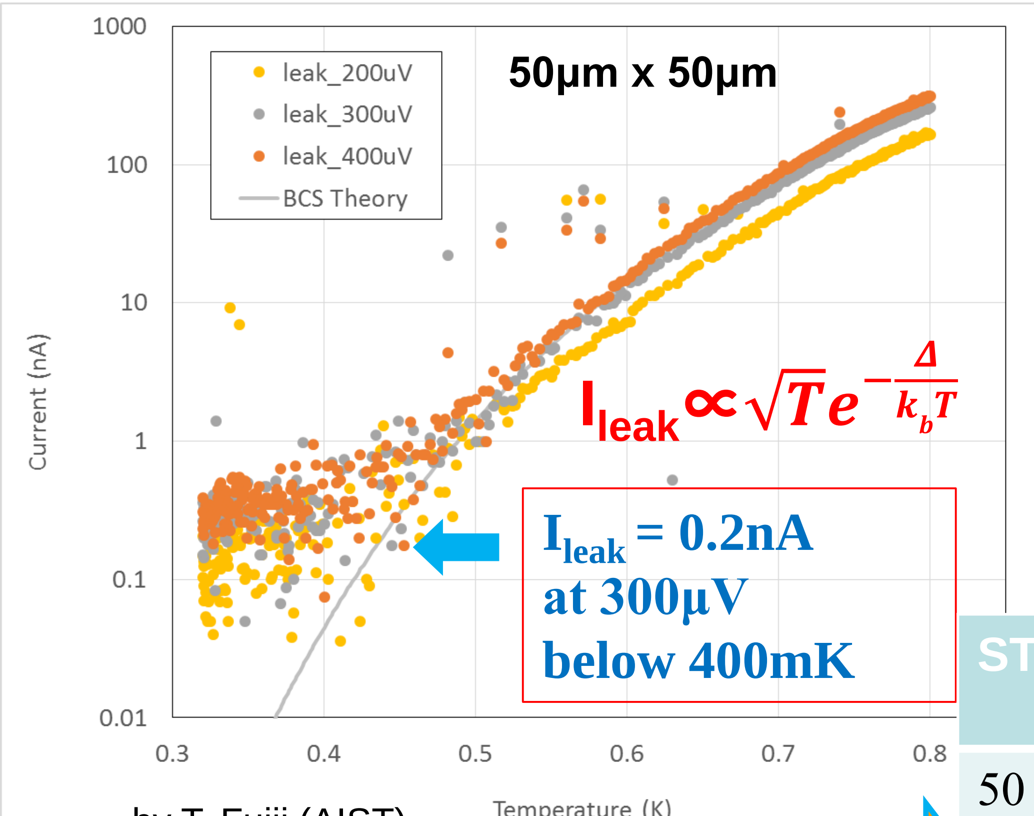
Response of Nb/Al-STJ to visible laser light pulse (λ=465nm) at 350mK



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 -80μm) .**

Temperature Dependence of Leakage Current



by T. Fujii (AIST)

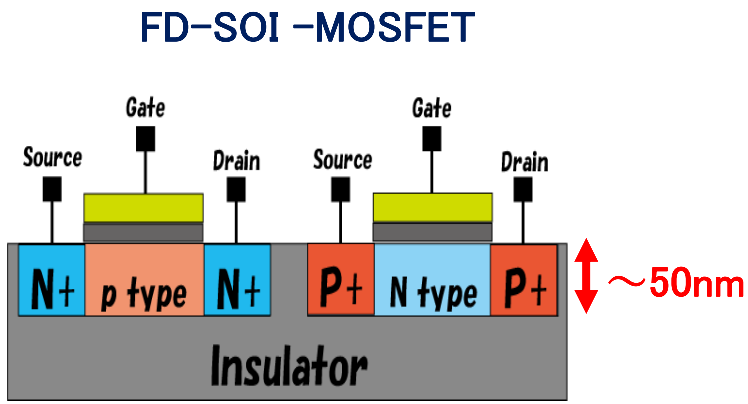
In 2014,
AIST group joined us and produced Nb/Al-STJ with AIST CRAVITY processing system.
Leakage current has satisfied our requirement of 0.1nA .

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**

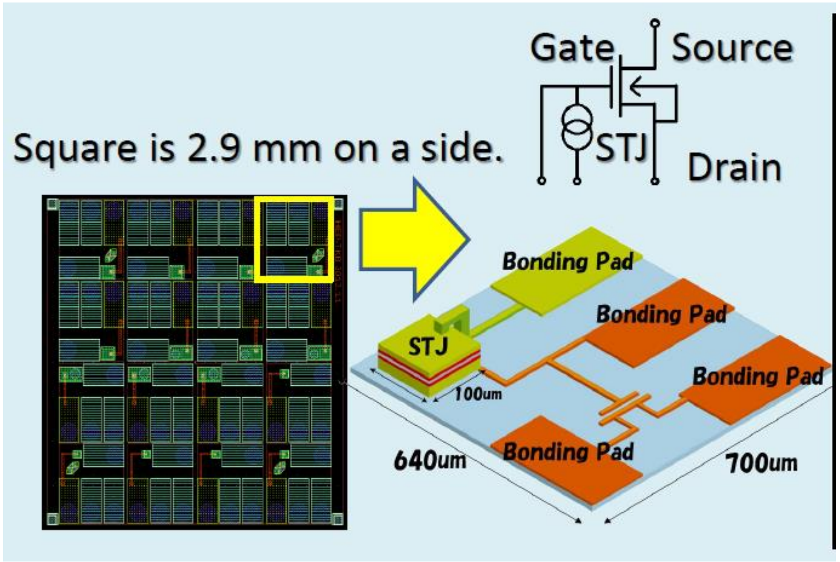
R&D Status of SOI Cryogenic Preamplifier for STJ

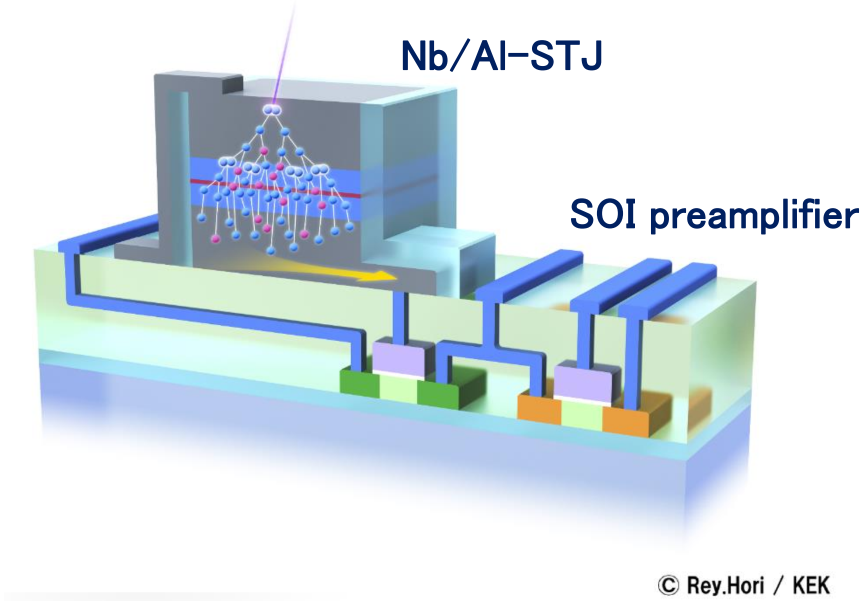
R&D of SOI-STJ Detector

FD-SOI (Fully Depleted 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).



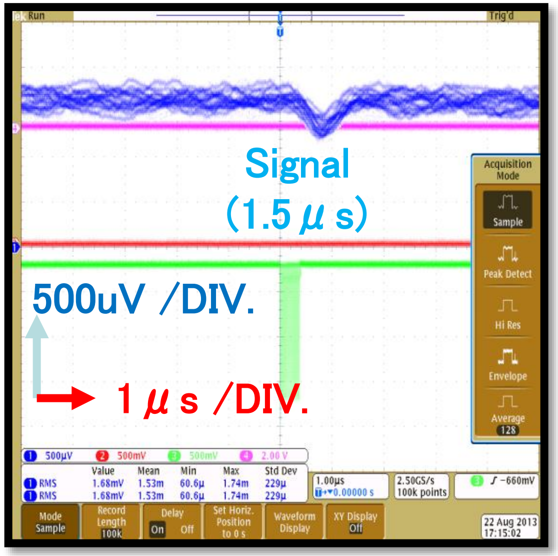
To improve the signal-to-noise ratio and to make multi-pixel device easily, we made a SOI-STJ detector where we processed Nb/Al-STJ on a SOI transistor board.

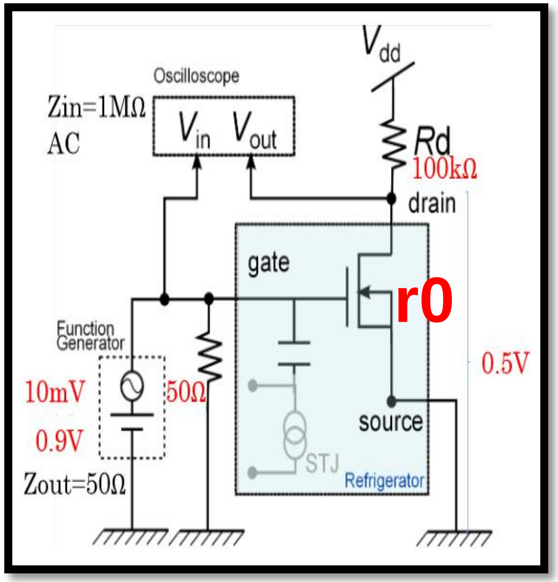


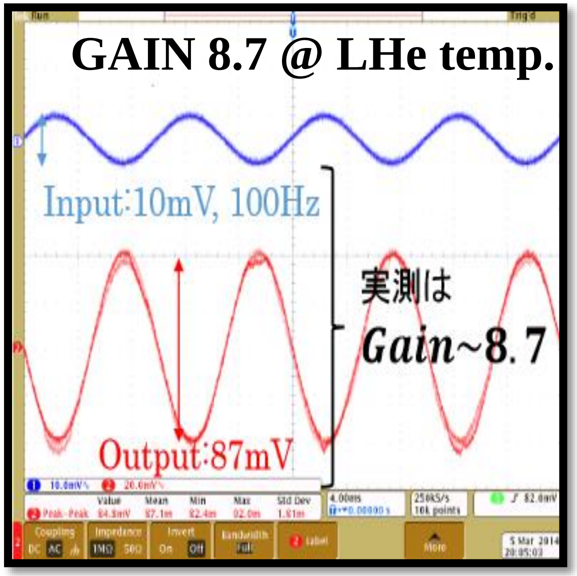


Performance of STJ and SOIFET in SOI-STJ detector

- We observed the signal of Nb/Al-STJ processed on the SOI board to 465nm laser pulse at 700mK.



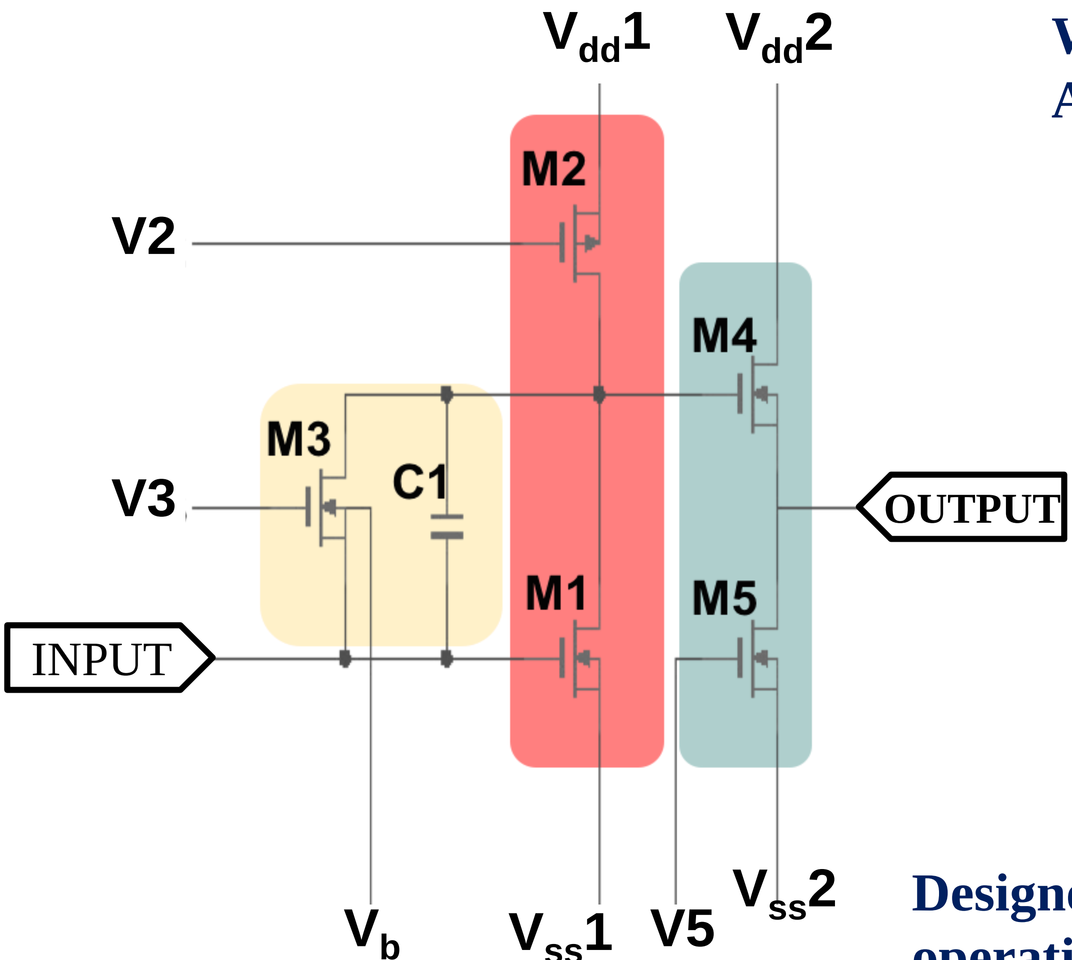




- We confirmed that the SOI-FET work as a preamplifier with a gain of 8.7 at 4K up to 100kHz.

SOI Cryogenic Amplifier

SOI-STJ4 (the 4th prototype)



We updated the SOI cryogenic Amplifier for Nb/Al-STJ.

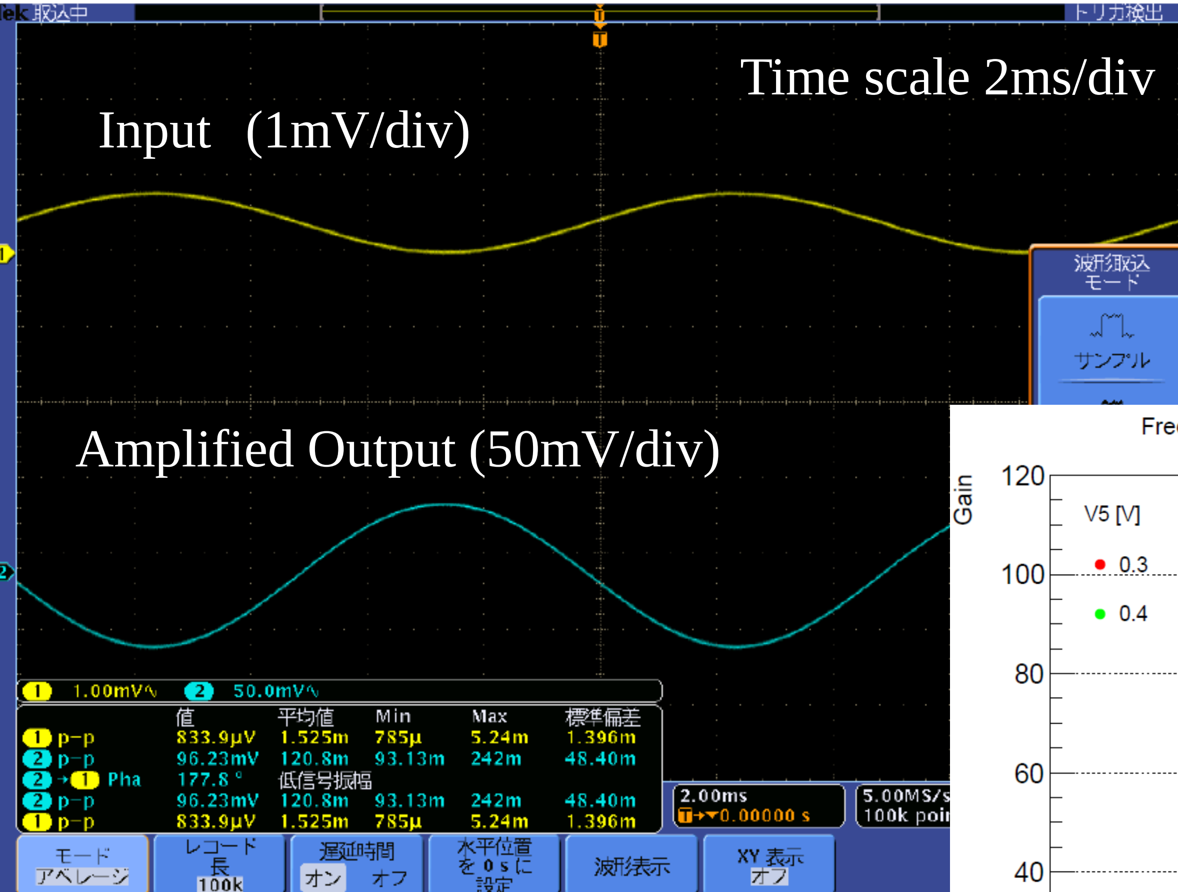
Amplification
Replace the resistance by a SOIFET as a current source (M2).
Feedback
Use the feedback between the drain and the gate of M1 to apply a stable bias voltage (M3).
Buffer
Add the follower to reduce the output impedance (M4 and M5).

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

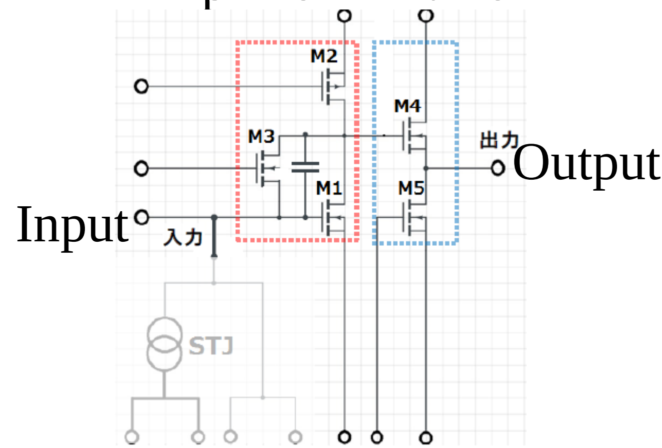
This SOI amplifier board was made by LAPIS semiconductor company.

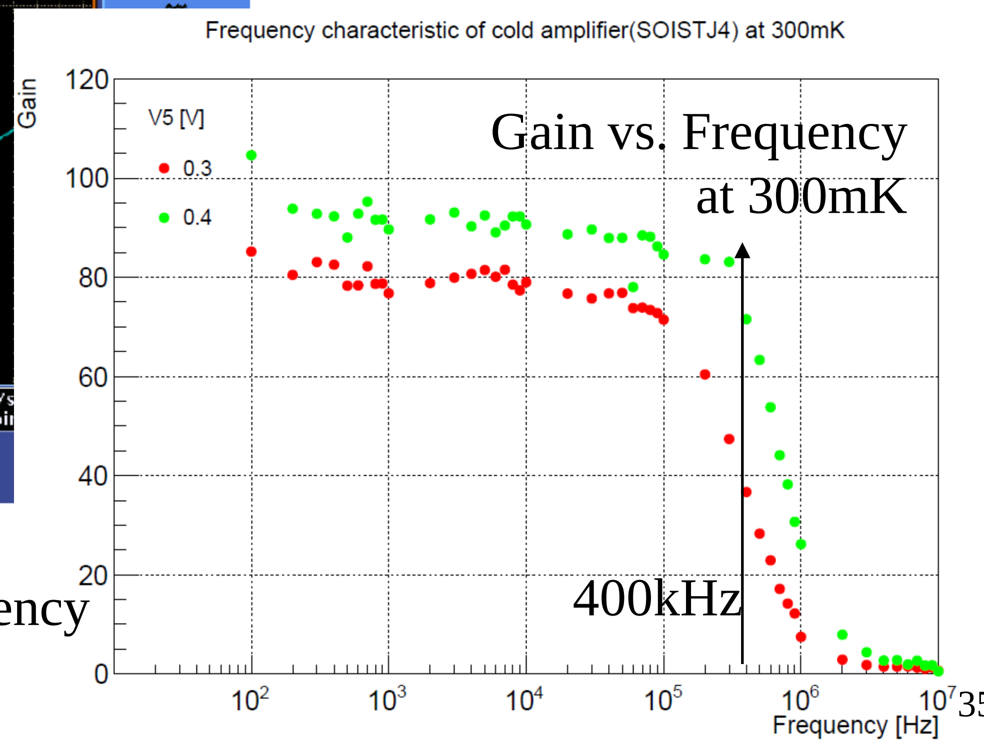
Test Results of the SOI Cryogenic Amplifier

Input and Amplified Output



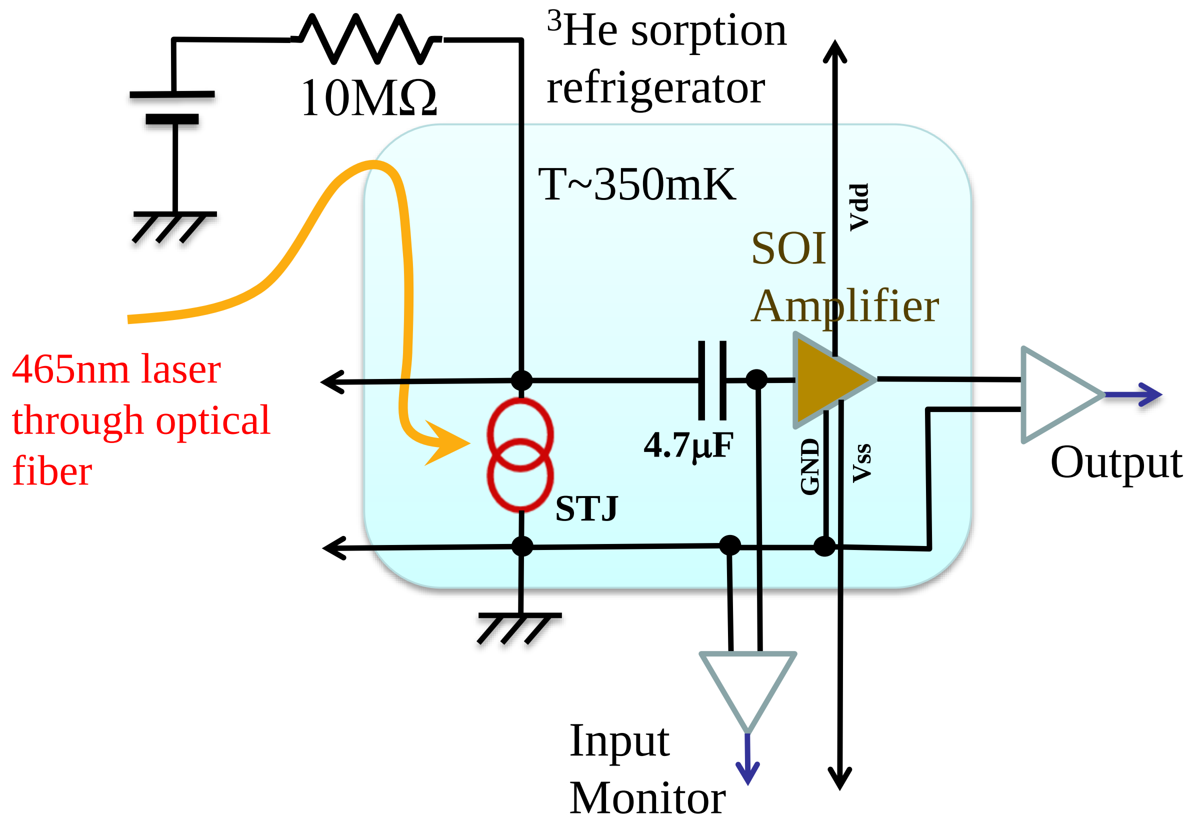
Amplifier + Buffer

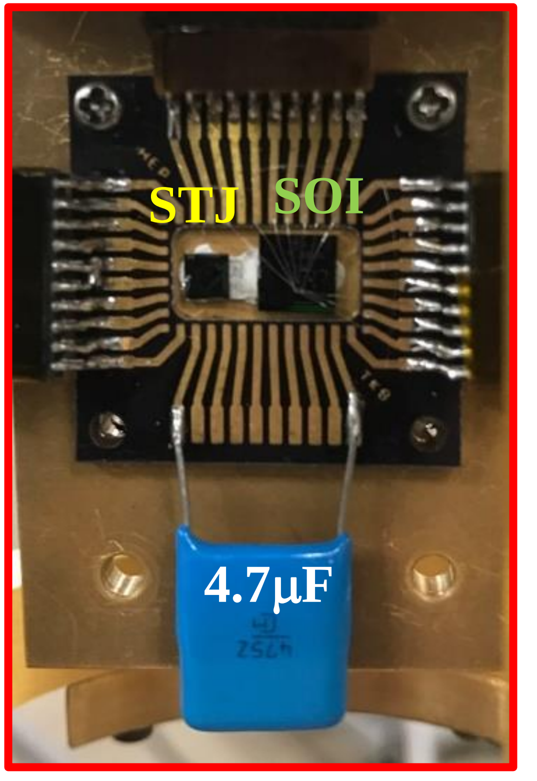




Gain of 80 was achieved for a signal frequency up to 400kHz signals at 300mK.

Setup of STJ Signal Amplification with the SOI Cryogenic Amplifier

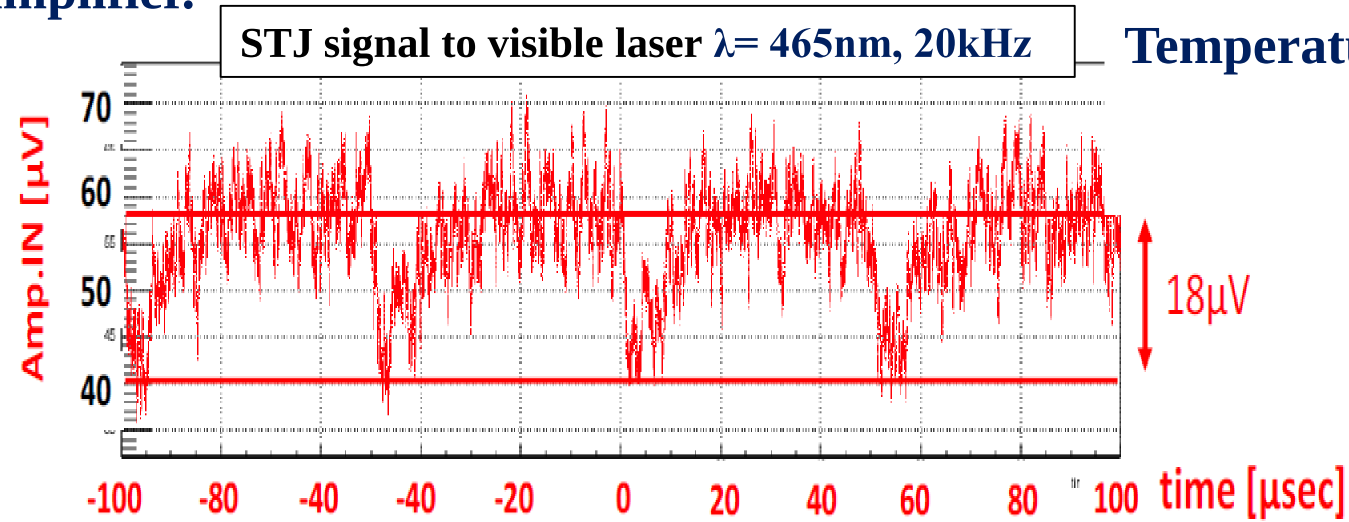




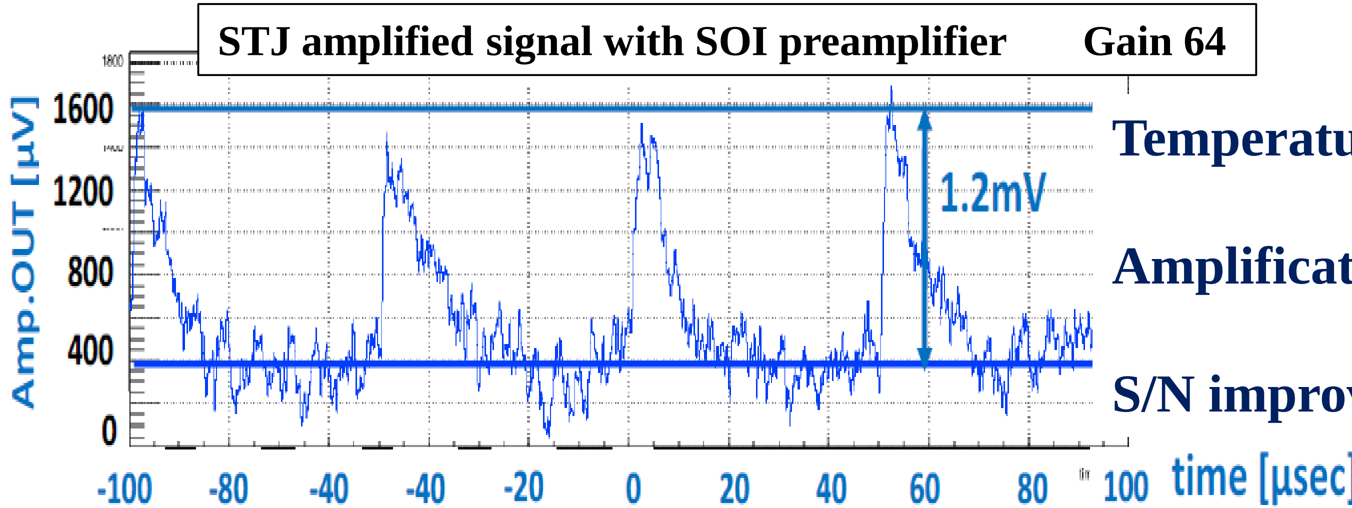
- **20μm-square Nb/Al-STJ with SOI-STJ4 amplifier through 4.7μF capacitance.**
- **Input impedance of the SOI amplifier is about 20kΩ.**
  - **STJ operation at a constant current mode.**
  - **STJ bias cable capacitance is around 1nF : Z=160Ω for 1μs signal.**

STJ signal amplified with the SOI cryogenic preamplifier

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



Temperature : 350mK



Temperature : 350mK

Amplification Gain : 70

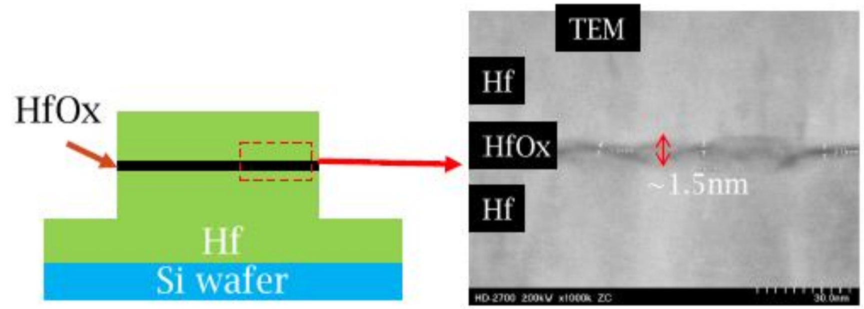
S/N improved by a factor of 2

R&D Status of Hf-STJ

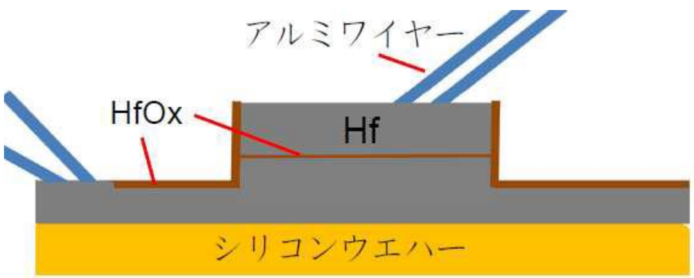
R&D Status of Hf-STJ

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

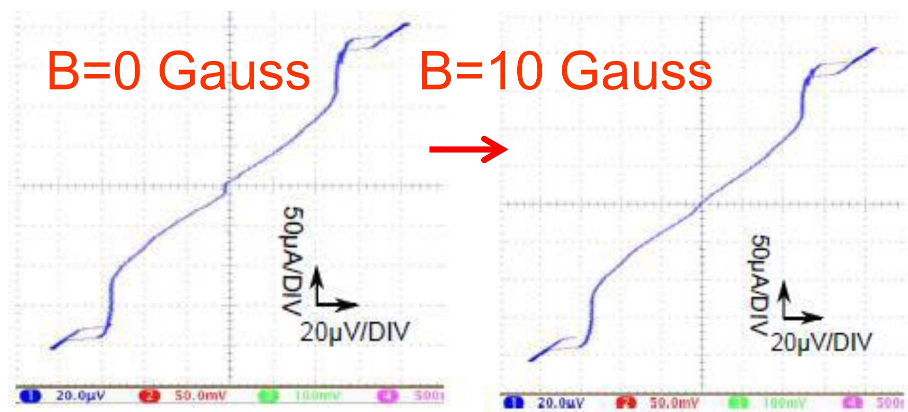
Micro-calorimeter: Hf-STJ cab generate enough quasi-particles from cooper pair breakings to achieve 2% energy resolution for photons with $E\gamma$ = 25meV.



Direct wire bonding on Hf layer



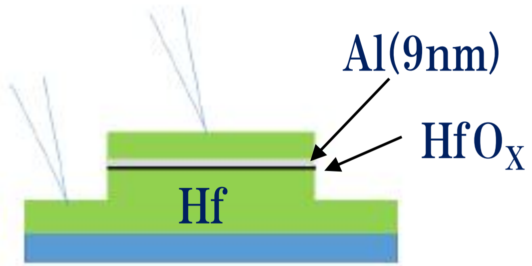
I-V curve of Hf-STJ (**100x100μm²**)
- T~40mK, I_c=10 μ A, **R_d=0.6Ω**

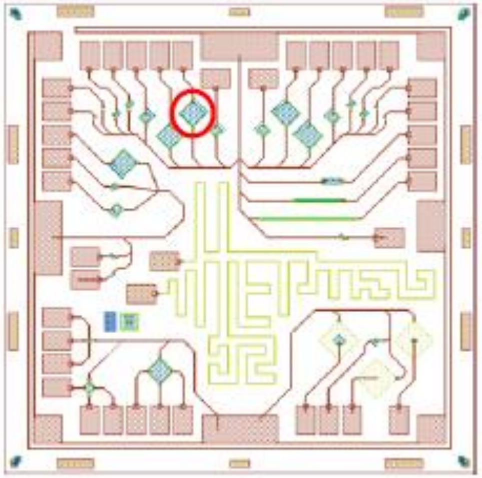


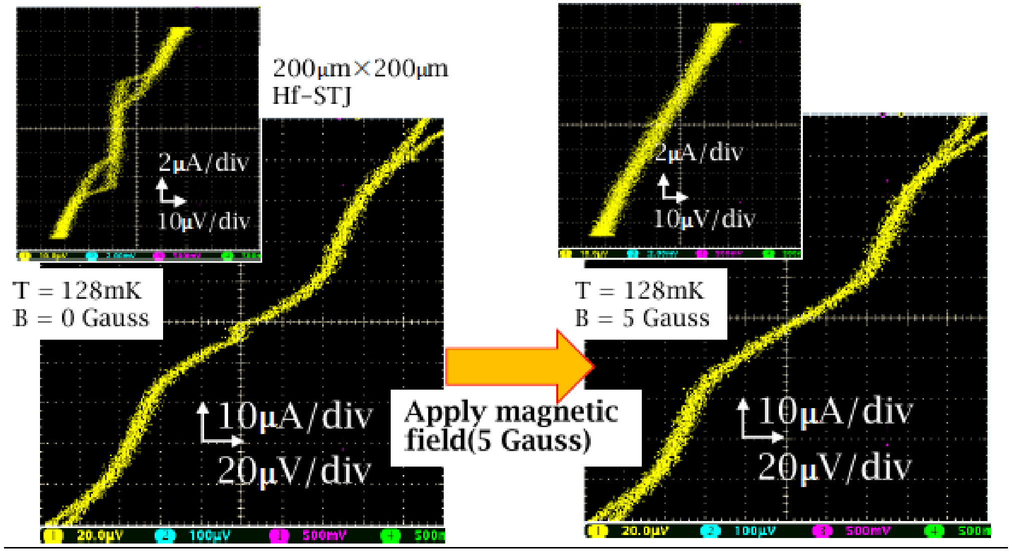
STJ size	# of samples	R_d
200 x 200μm²	3	0.22±0.01 Ω
100 x 100 μm²	3	0.60±0.10 Ω

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





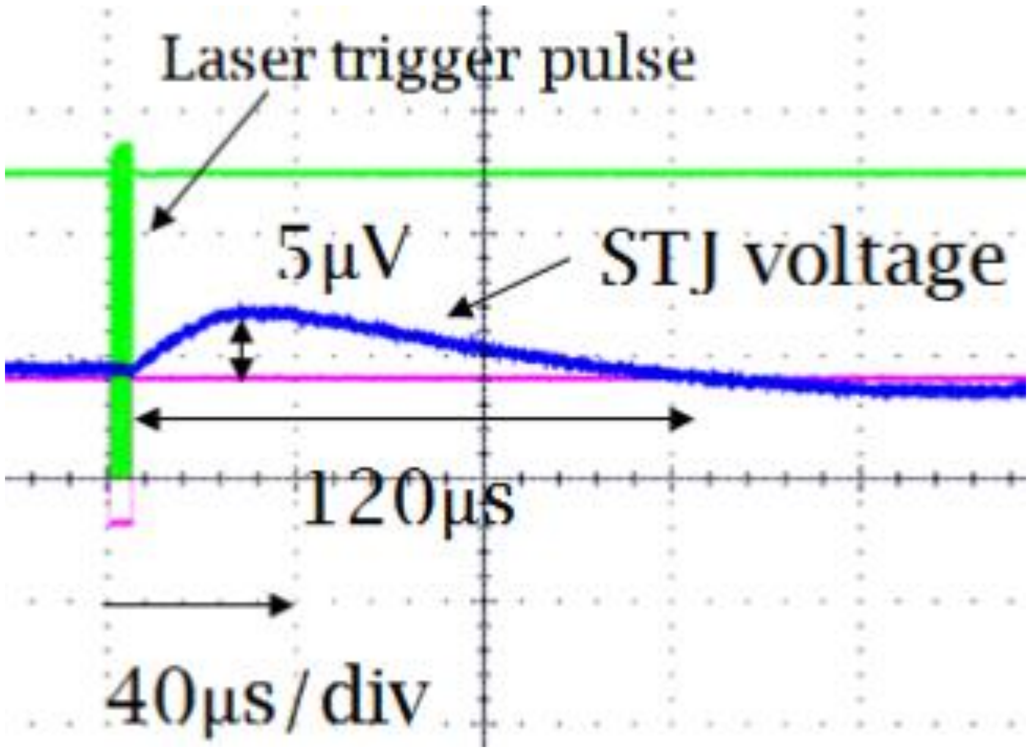


I_{leak} = 5 μA at 10 μV.
R_d = 2 Ω
Dynamic Resistance was improved by a factor of 15 in Hf/Al/HfO_X/Hf-STJ.

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 fewμs).

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				or 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	

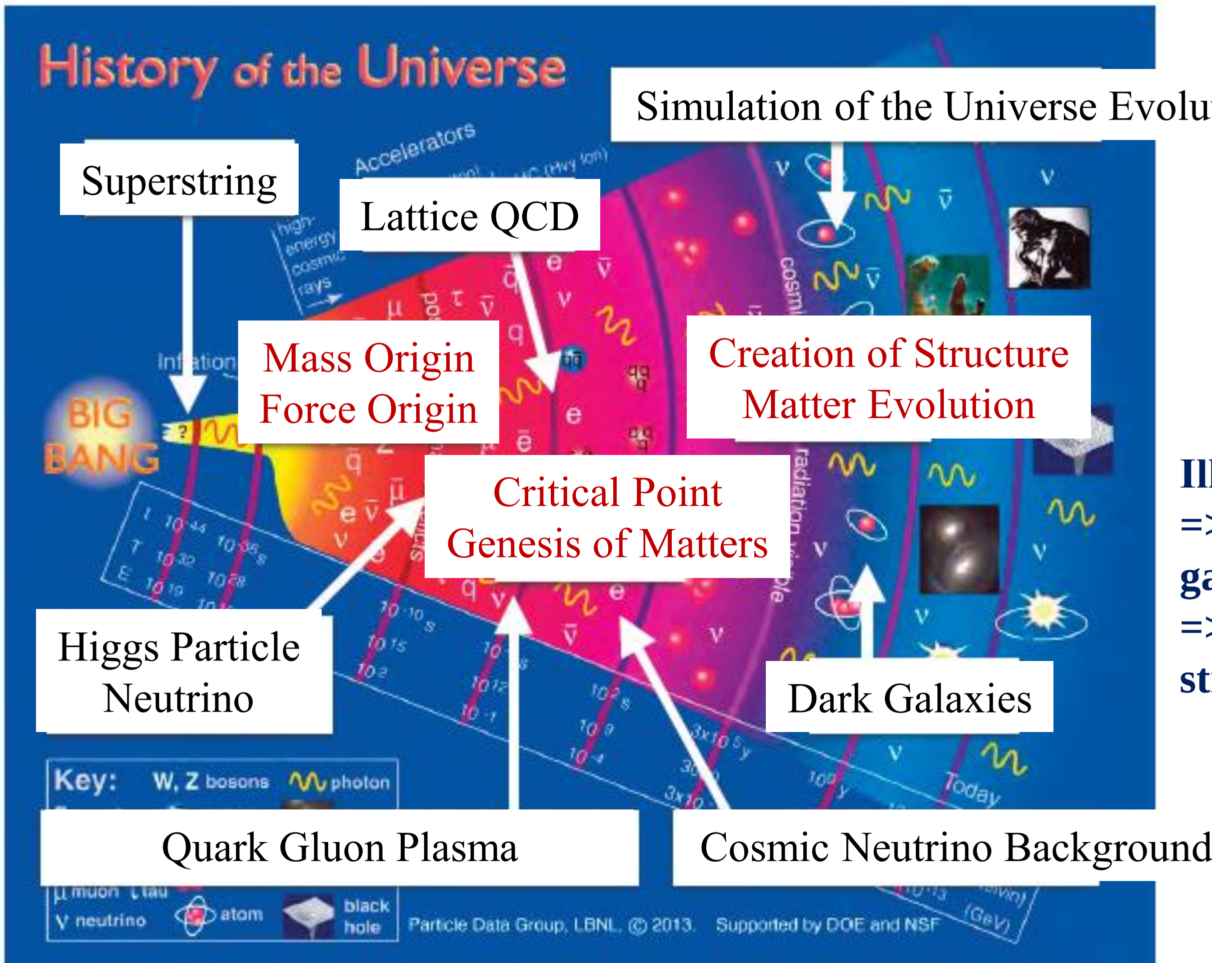
Research Core for the History of the Universe

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

筑波大学 University of Tsukuba

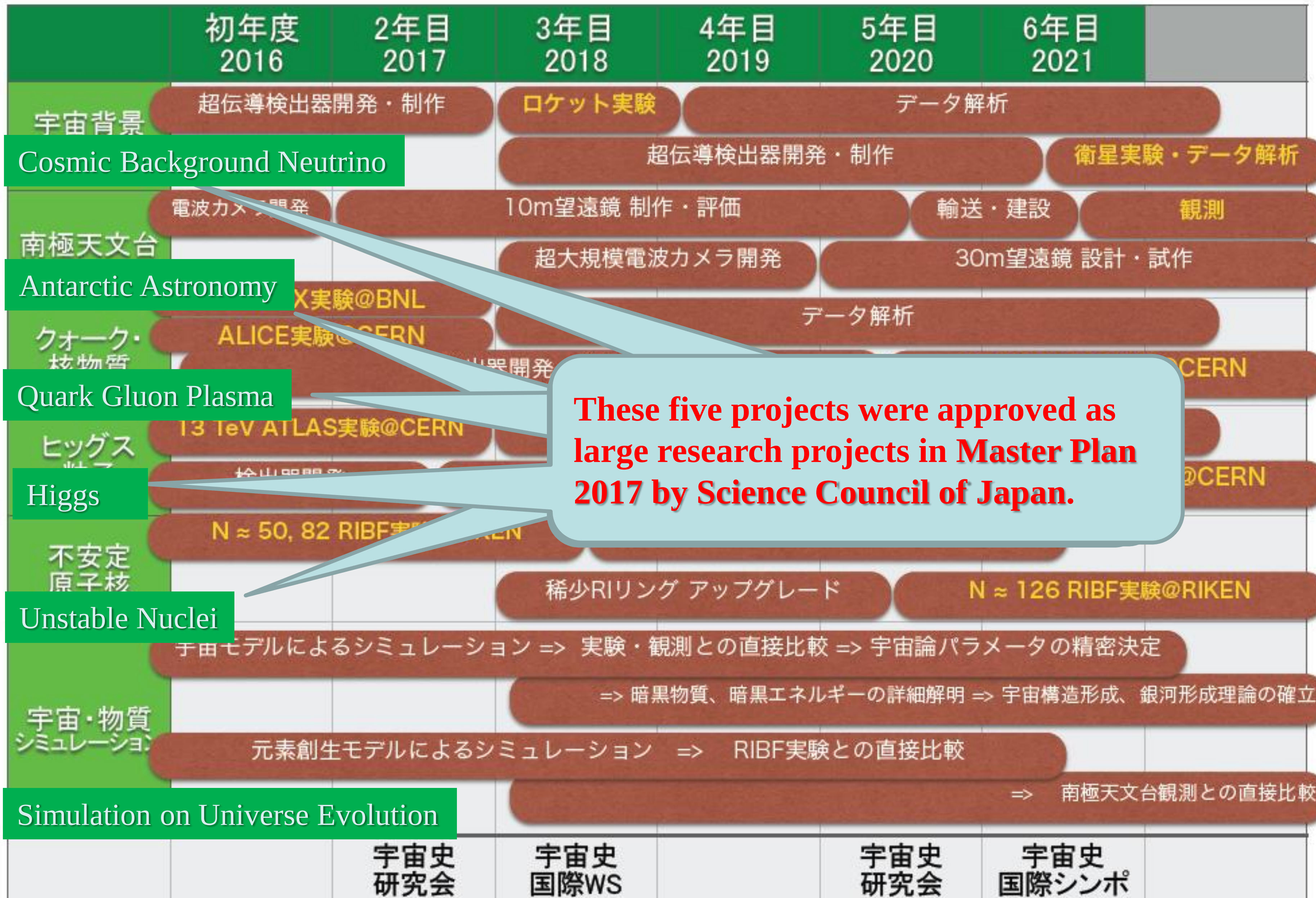
CiRfSE

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

Schedule of Research Core for the History of the Universe

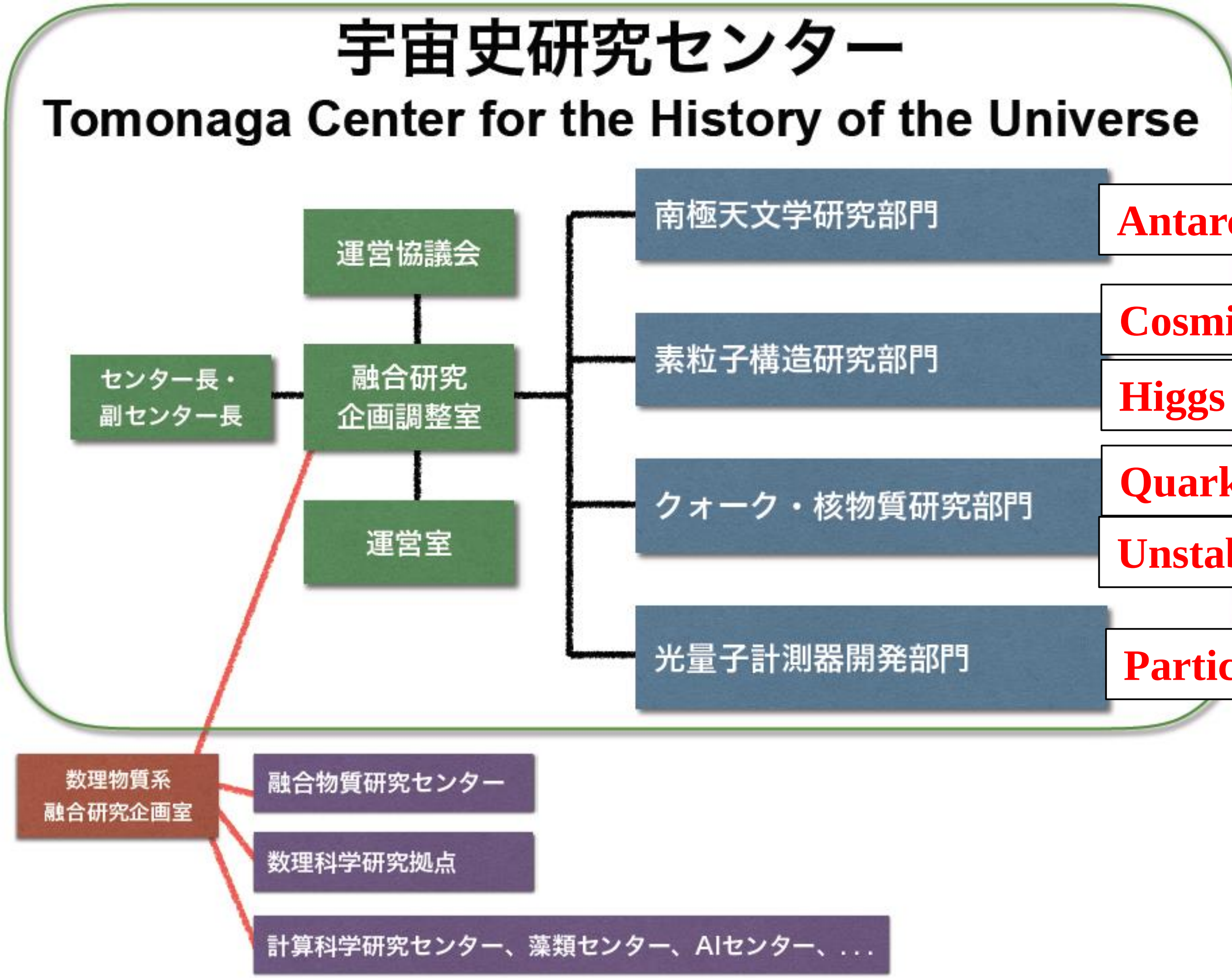


Research Core for the History of the Universe

→ Tomonaga Center for the History of the Universe

Re-Organization

From Oct. 2017



Antarctic Astronomy

Cosmic Background Neutrino

Higgs (ATLAS)

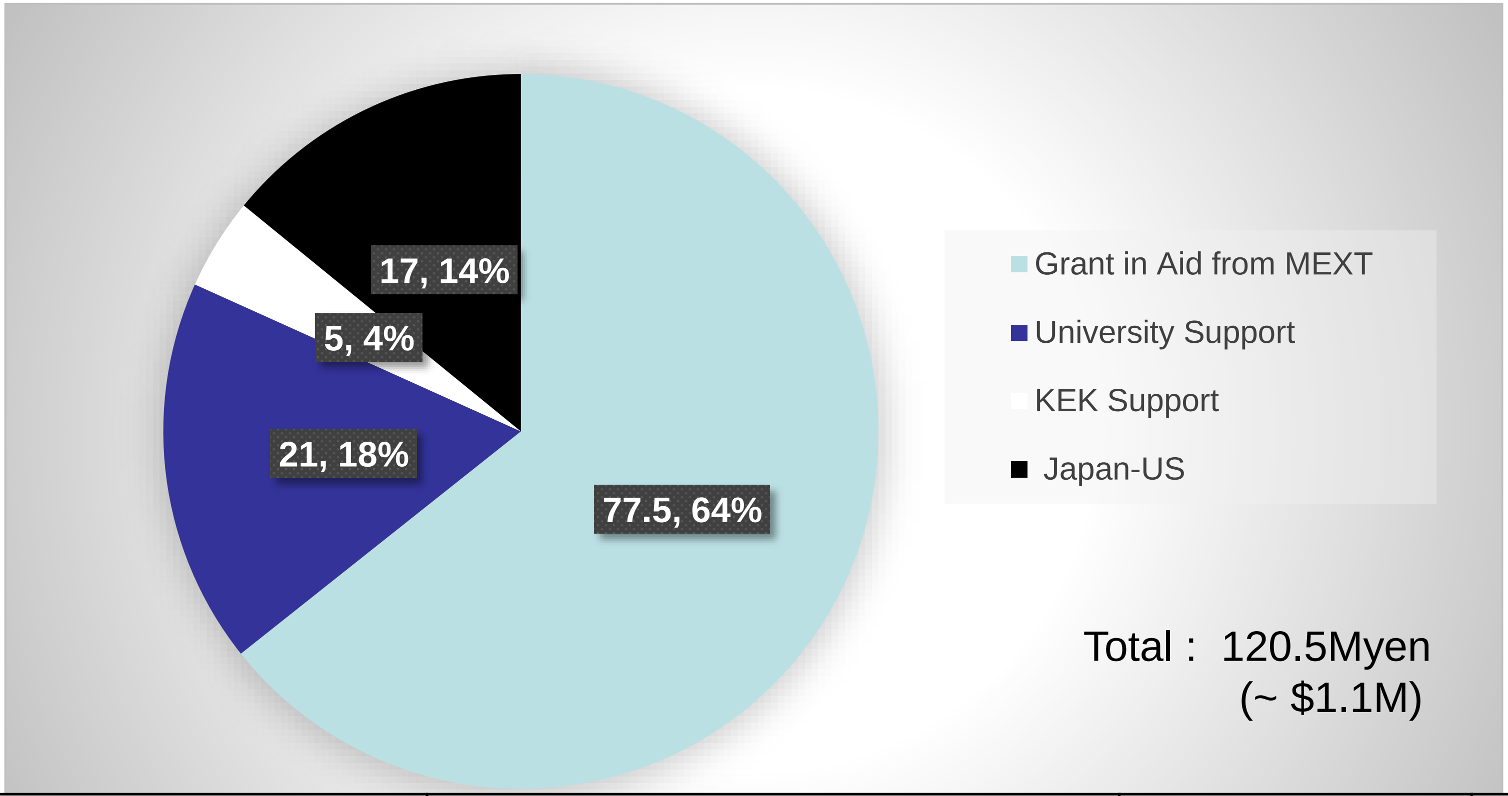
Quark Gluon Plasma

Unstable Nuclei

Particle Detector R&D

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	**^{3}He 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**

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.

COBAND WEB page http://hep.px.tsukuba.ac.jp/coband/eng/

People who will join COBAND collaboration are very welcome.

Please join us.

BACKUP

CIBER latest paper

New Spectral Evidence of an Unaccounted Component of the Near-infrared Extragalactic Background Light from the *CIBER*

S. Matsuura[1,2], T. Arai[3,2], J. Bock[4,5], A. Cooray[6,4], P. Korngut[4,5], M.G. Kim[7,8], H.M. Lee[7], D.H. Lee[8,12], L. Levenson[4], T. Matsumoto[2,8], Y. Onishi[9,2], M. Shirahata[3,2], K. Tsumura[10], T. Wada[2] and M. Zemcov[11,5]

matsuura.shuji@kwansei.ac.jp

Received ______________; accepted ______________

[1]School of Science and Technology, Kwansei Gakuin University, Sanda, Hyogo 669-1337, Japan

[2]Department of Space Astronomy and Astrophysics, the Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Kanagawa 252-5210, Japan

[3]Genesia Corporation, Mitaka, Tokyo 181-0013, Japan

[4]Department of Physics, California Institute of Technology, CA 91125, USA

[5]Jet Propulsion Laboratory, California Institute of Technology, CA 91109, USA

目的と背景

宇宙背景放射： 個別には検出が困難な宇宙初期天体をまとめて背景放射として検出

過去の観測： COBE(米国)や IRTS(日本)によれば、近赤外と遠赤外波長域の宇宙背景放射には銀河では説明のつかない超過エネルギーが存在

超過成分の解釈：

近赤外 – 赤方偏移～10の時代に宇宙で最初に形成された第一世代の星によるライマンα線

遠赤外 – 遠方銀河の星生成や活動的銀河核（ブラックホール）に伴うダスト熱放射

課題：前景放射（主に、黄道光と系外銀河）の寄与推定に不定性

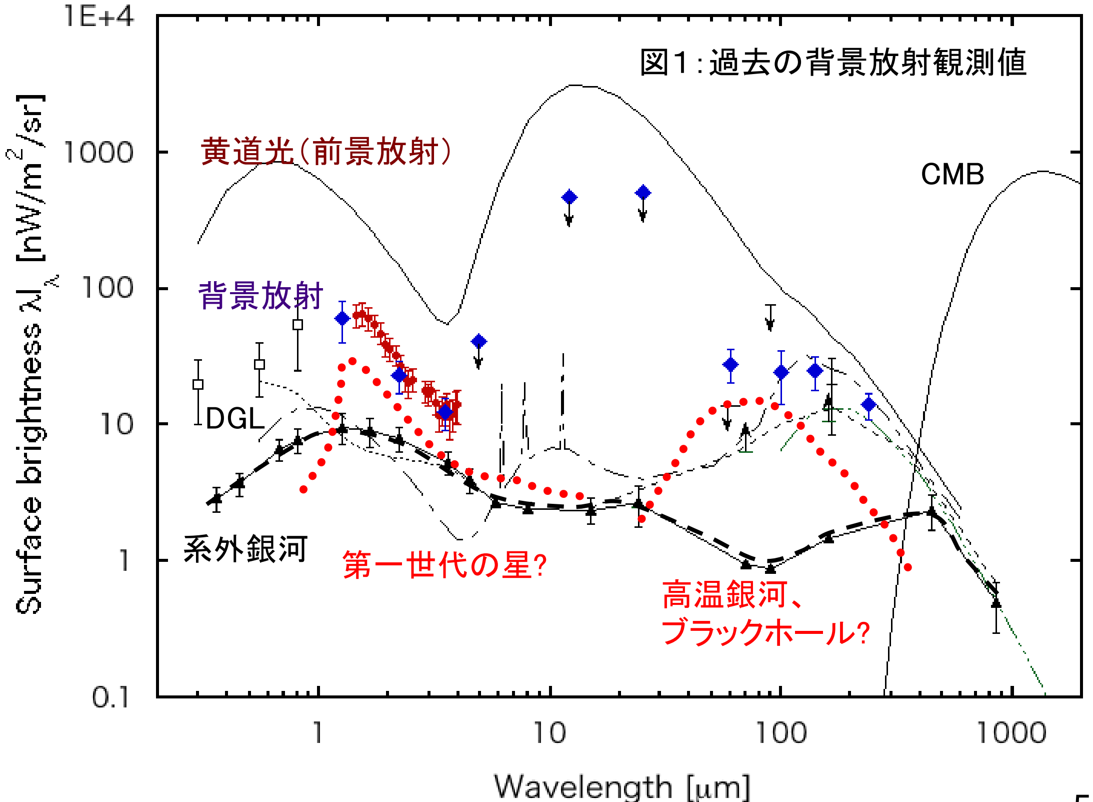
あかりによるブレークスルー：

COBEやIRTSよりも10-100倍高い角分解能により、

・遠方の暗い銀河や星を除外した背景放射測定

・黄道光の影響が小さい背景放射の角度ゆらぎ測定

が可能、宇宙初期起源を検証



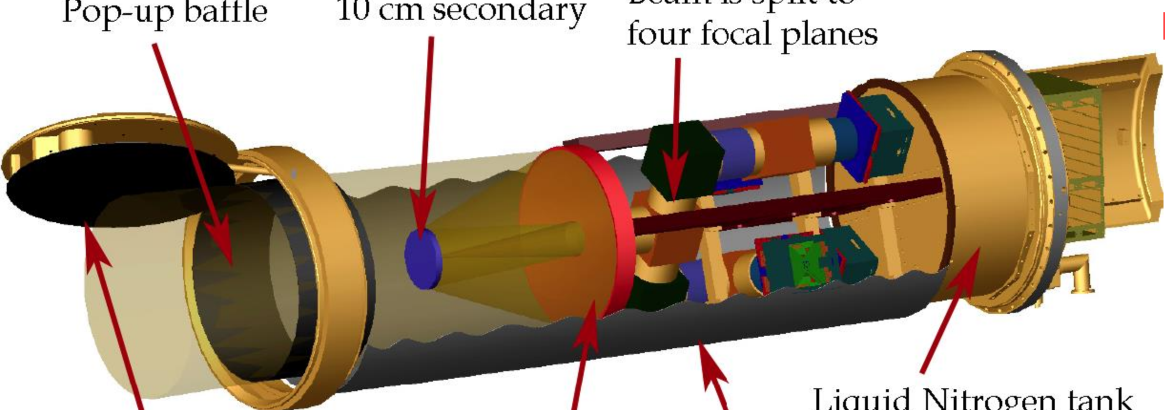
次期ロケット実験シリーズ　CIBER-2

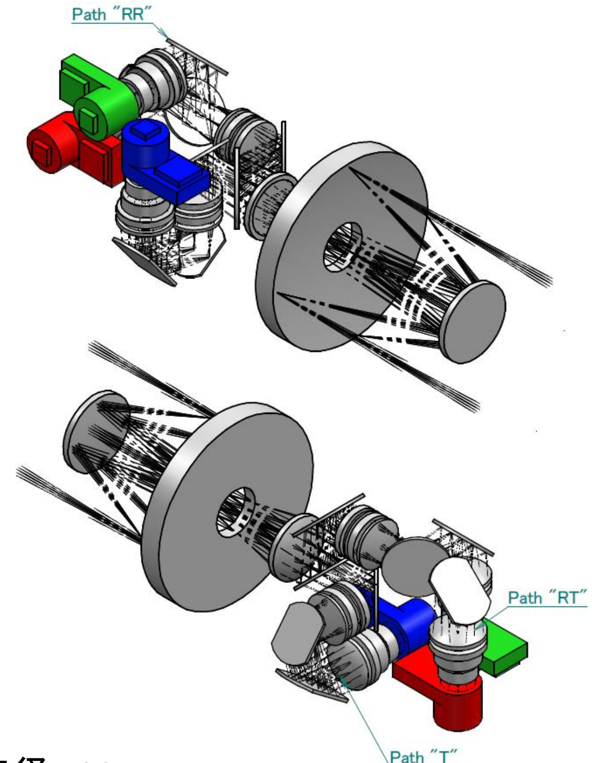
大口径望遠鏡、可視域カバー

宇宙背景放射のゆらぎ（むらむら）やスペクトルをより詳しく調べる

2014年の打上げ目標

装置の詳細な構成は検討中





- 口径: 30cm
- 検出器: HAWAII-2 （2K×2Kアレイ）
- 可視-近赤外3バンド
  - 0.5-2.0um
- さらに細かいバンド分割や分光も検討
- CIBERと同型のロケットを使用
- 2014年（H25年度）の打上げ目標

より大きく:　次世代大型赤外天文衛星SPICA

2020年打上げ目標

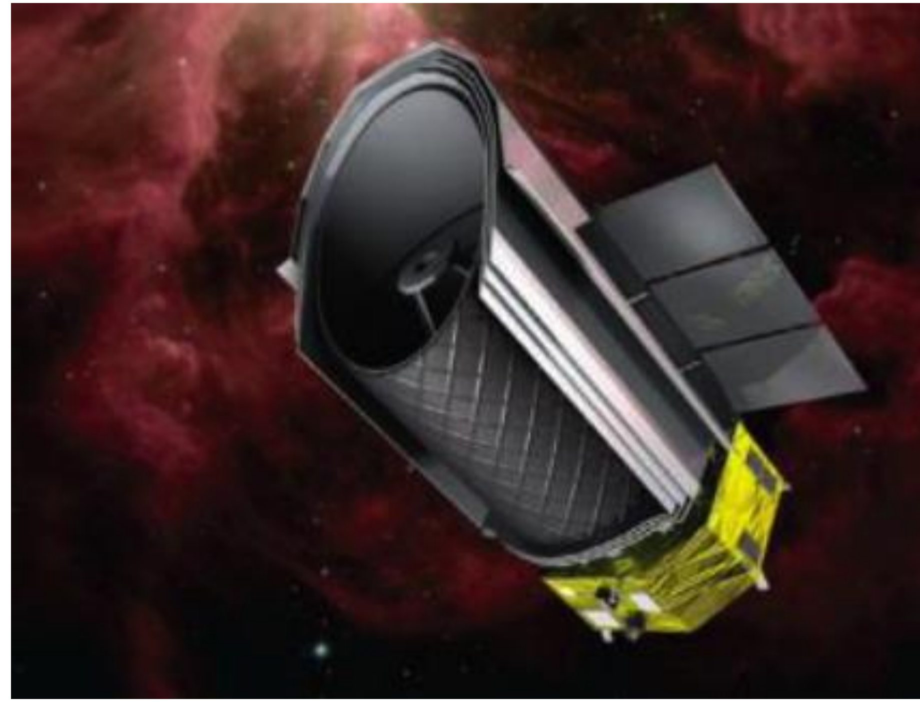
国際共同ミッション

地球-太陽L2軌道

3m超の冷却望遠鏡

コア観測波長:5-200μm

超高感度超伝導検出器の採用



高い解像度と感度

→　あかりの1000倍性能改善

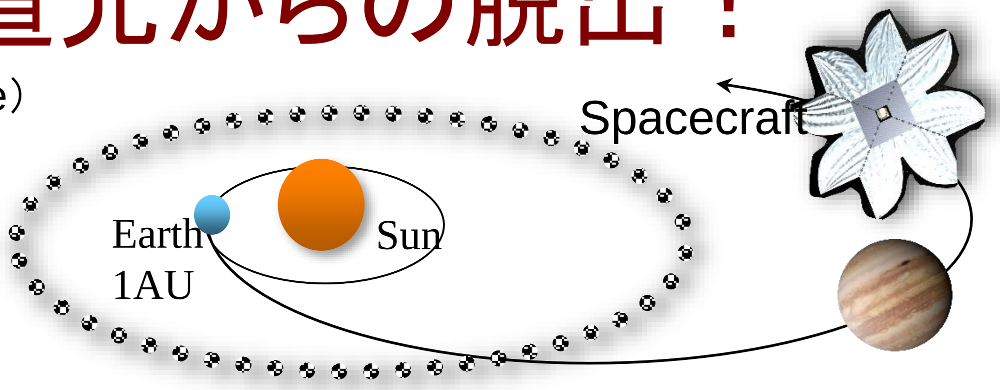
空前の高感度宇宙探査が可能

宇宙背景放射の90%以上を個々の点源に分解する

銀河系内物質や系外惑星系も

EXZIT: 黄道光からの脱出！

（EXZIT: EXo-Zodiacal Infrared Telescope）

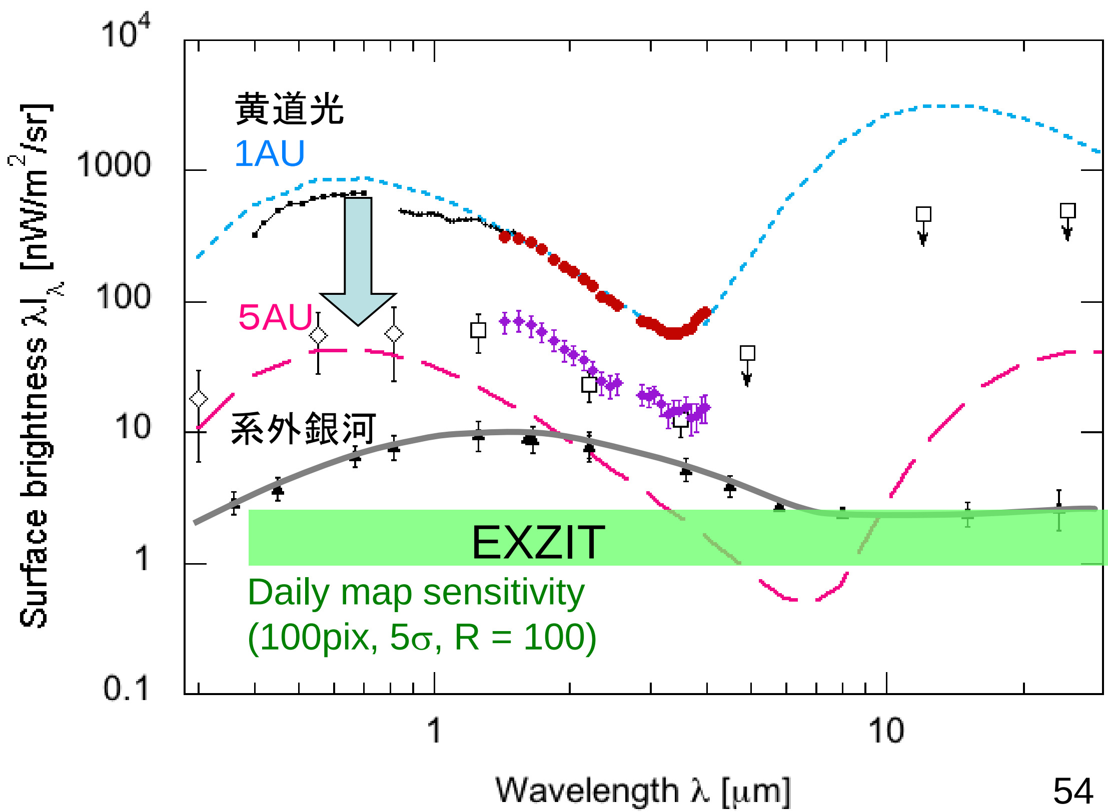


惑星探査機を用いて
黄道ダスト密度が低い
深宇宙から観測

5AUでは黄道光が
1/30 ~ 1/100に低下

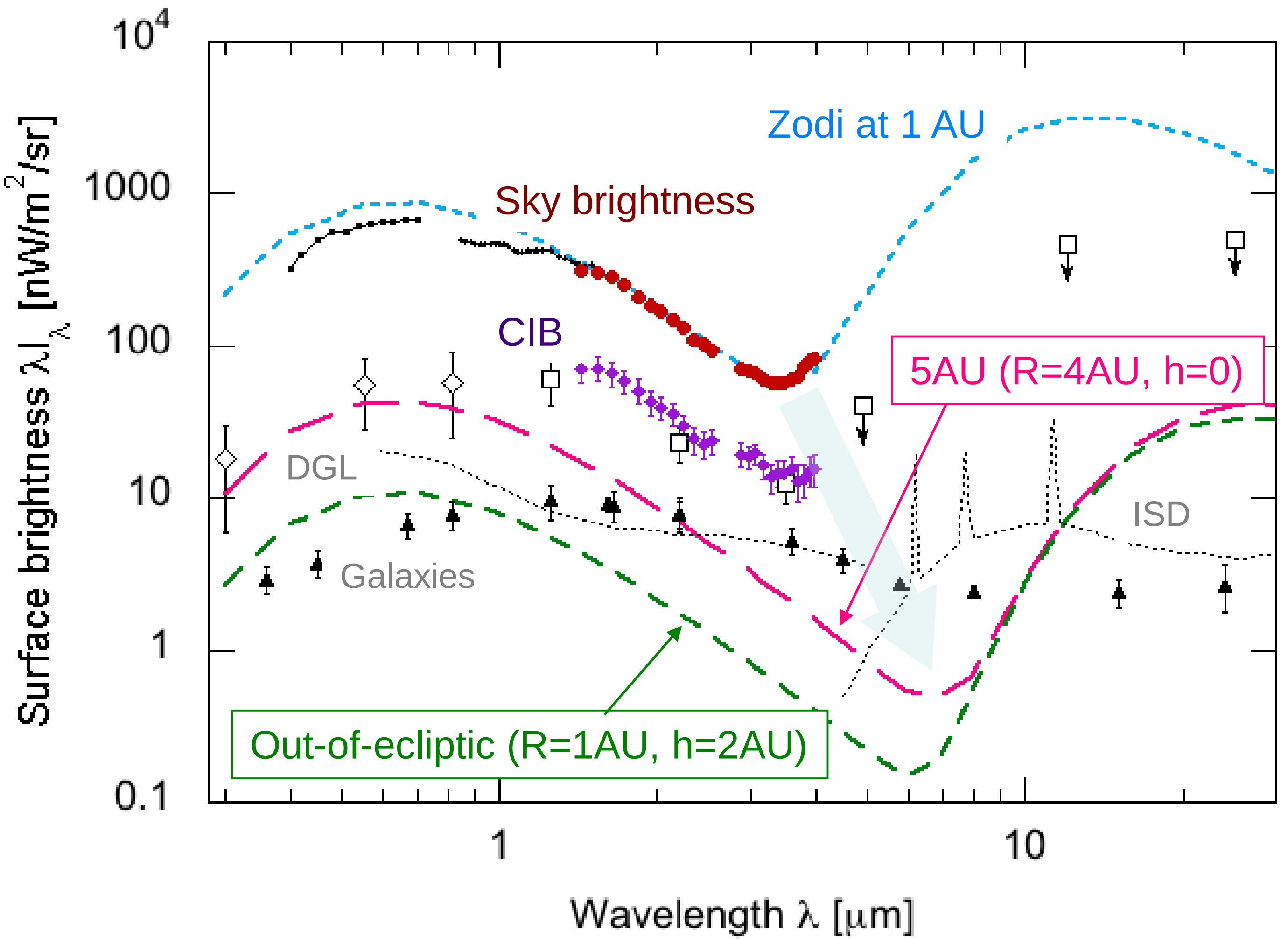
黄道光の影響がない
理想的なCIB測定可能

黄道光割合が大きい
可視や中赤外域の
CIB観測が可能に！



5AU site is suitable for the CIB measurement

"Cosmological window" shifts from 3 um to > 6 um

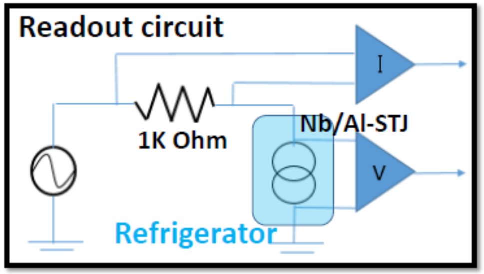


Foreground subtraction (ZL, DGL, Gals) is still required. > How ?

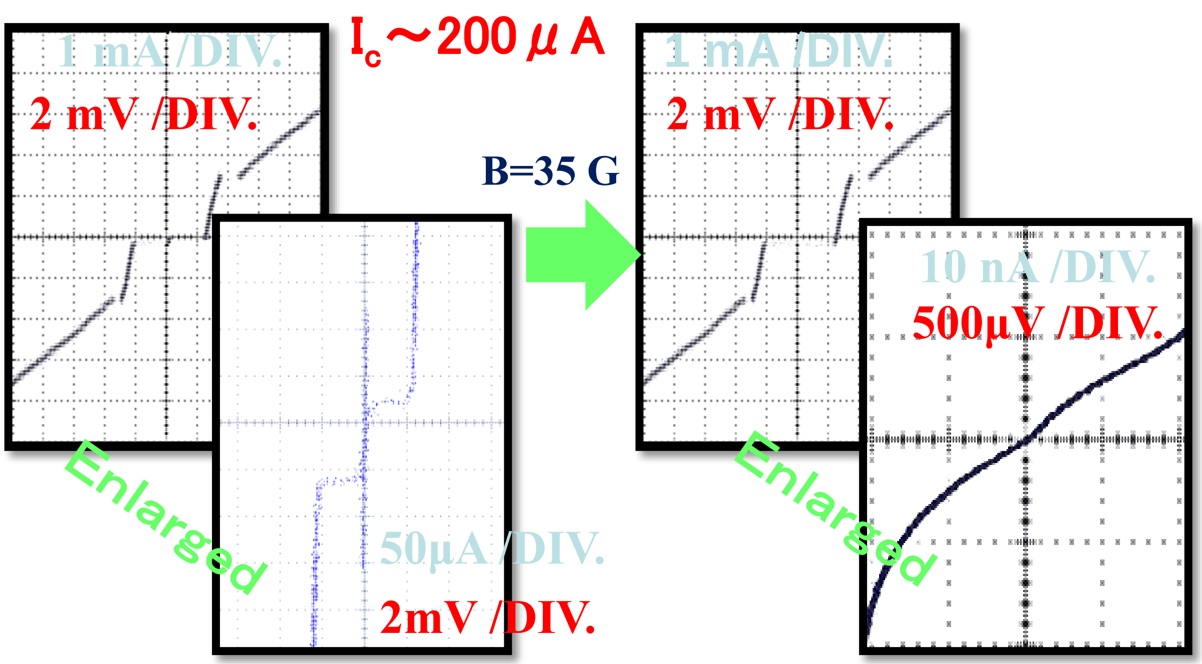
Performance of Nb/Al–STJ in SOI–STJ Detector

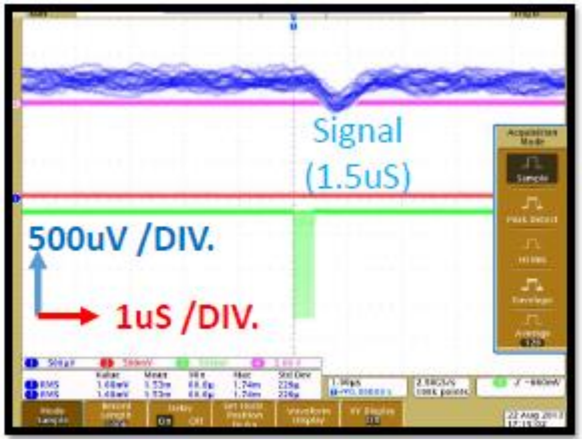
We measured the I–V curve of the Nb/Al–STJ (50 x 50 μ m² junction) processed on the SOI wafer

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



- **I–V curve of Josephson Junction**





- Quality Factor ($R_{dynamic}/R_{normal}$) — **On Si wafer : 5 x 10⁵**
  On SOI wafer : 3 x 10⁵

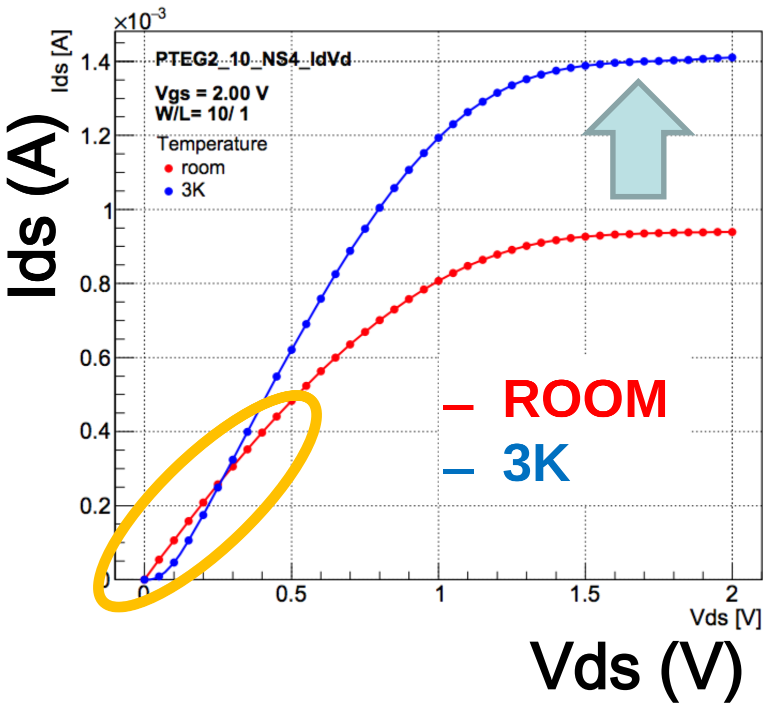
Performance of SOIFET at Cryogenic Temperature

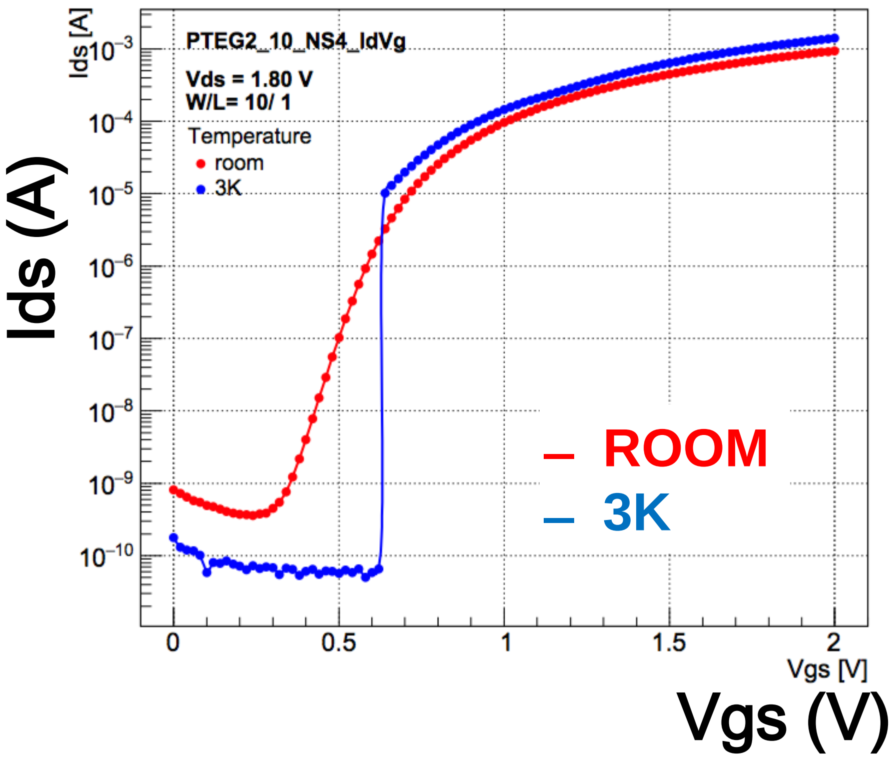
Saturating current is higher as the temperature becomes lower.

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

At cryogenic temperature (3K),

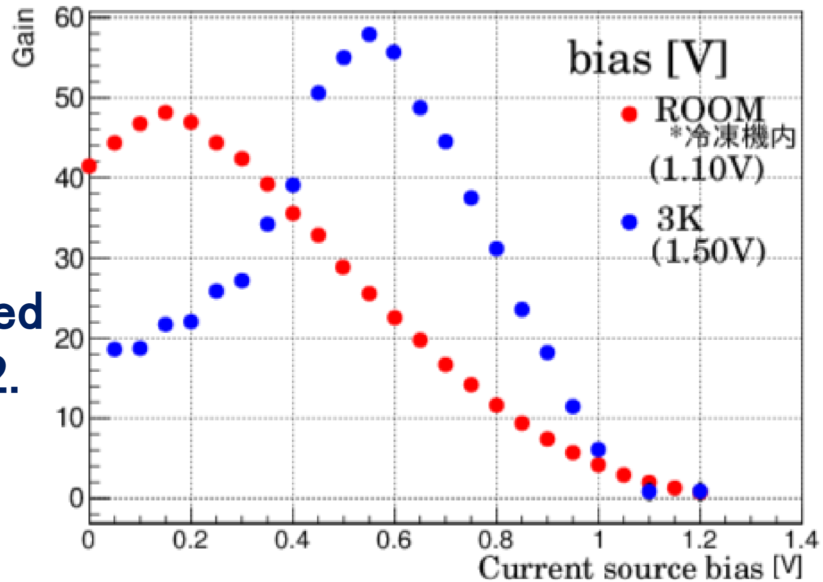
- **Threshold rise in I_{ds}-V_{ds} curve become much sharper.**
- **Subthreshold current is suppressed.**



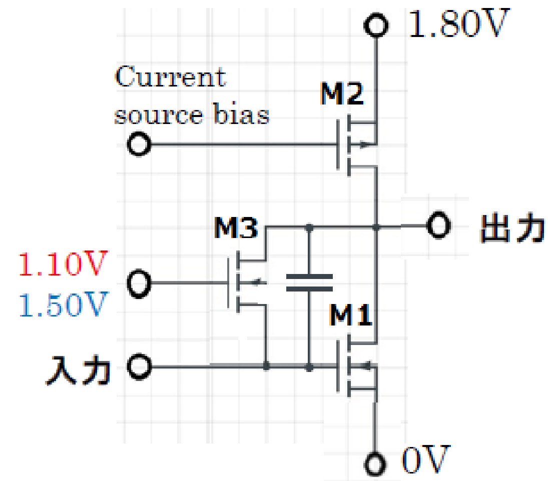


Test Results of the cryogenic SOI preamplifier

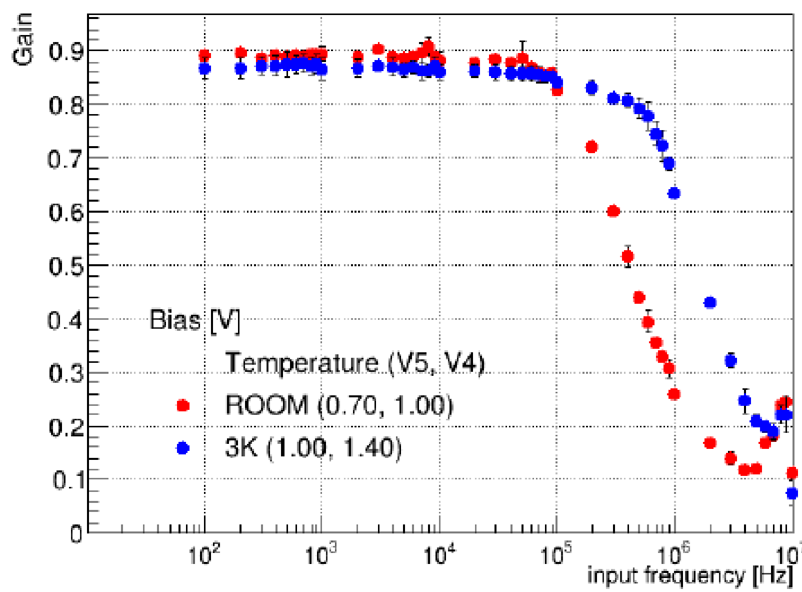
Amplifier gains are around 50 both at room temperature and 3K with adjusted bias voltages of M2.



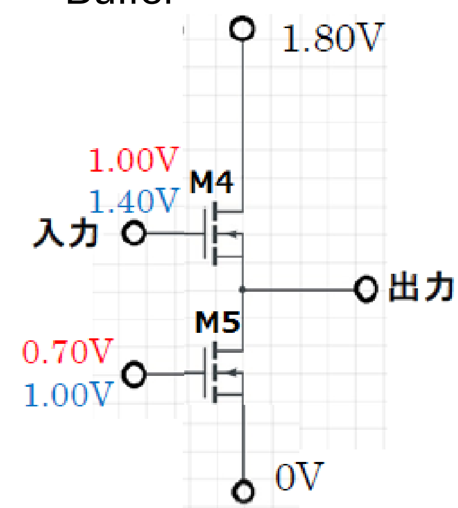
Amplifier



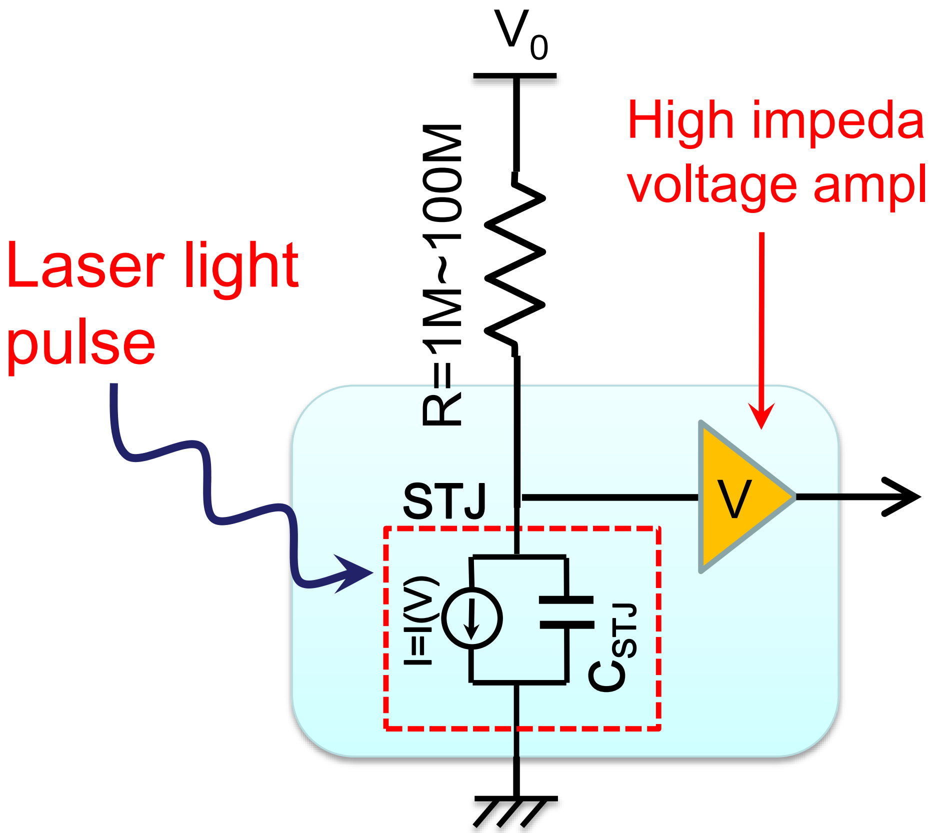
Bandwidth of buffer is enough high for the amplifier of STJ signal (up to 200kHz) both at room temperature and 3K.

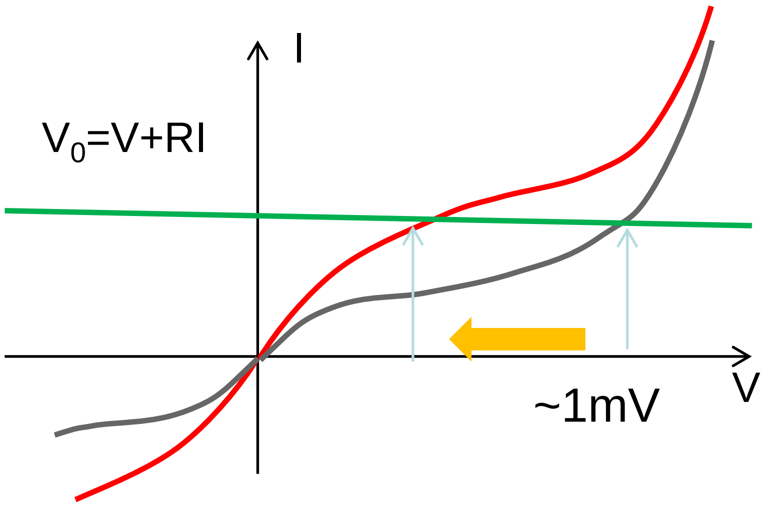


Buffer



STJ response at a constant current mode





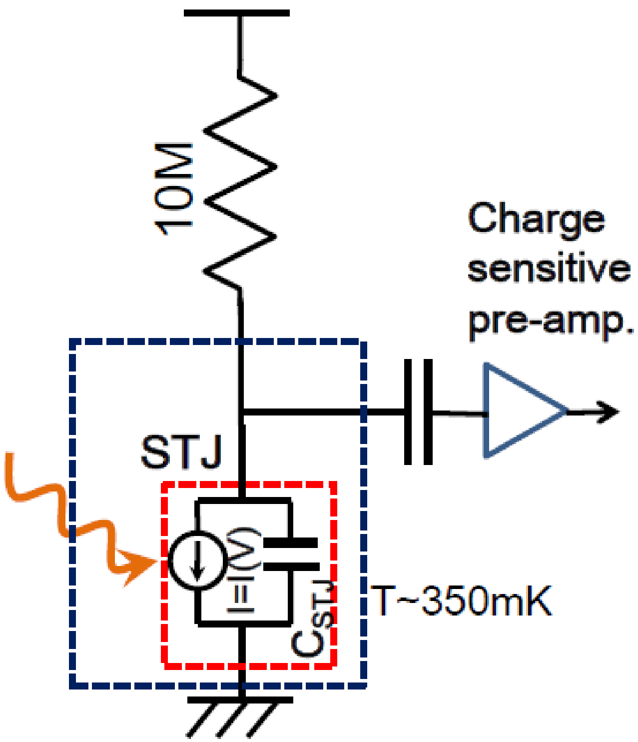
STJ I-V curve w/light w/o light

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

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.

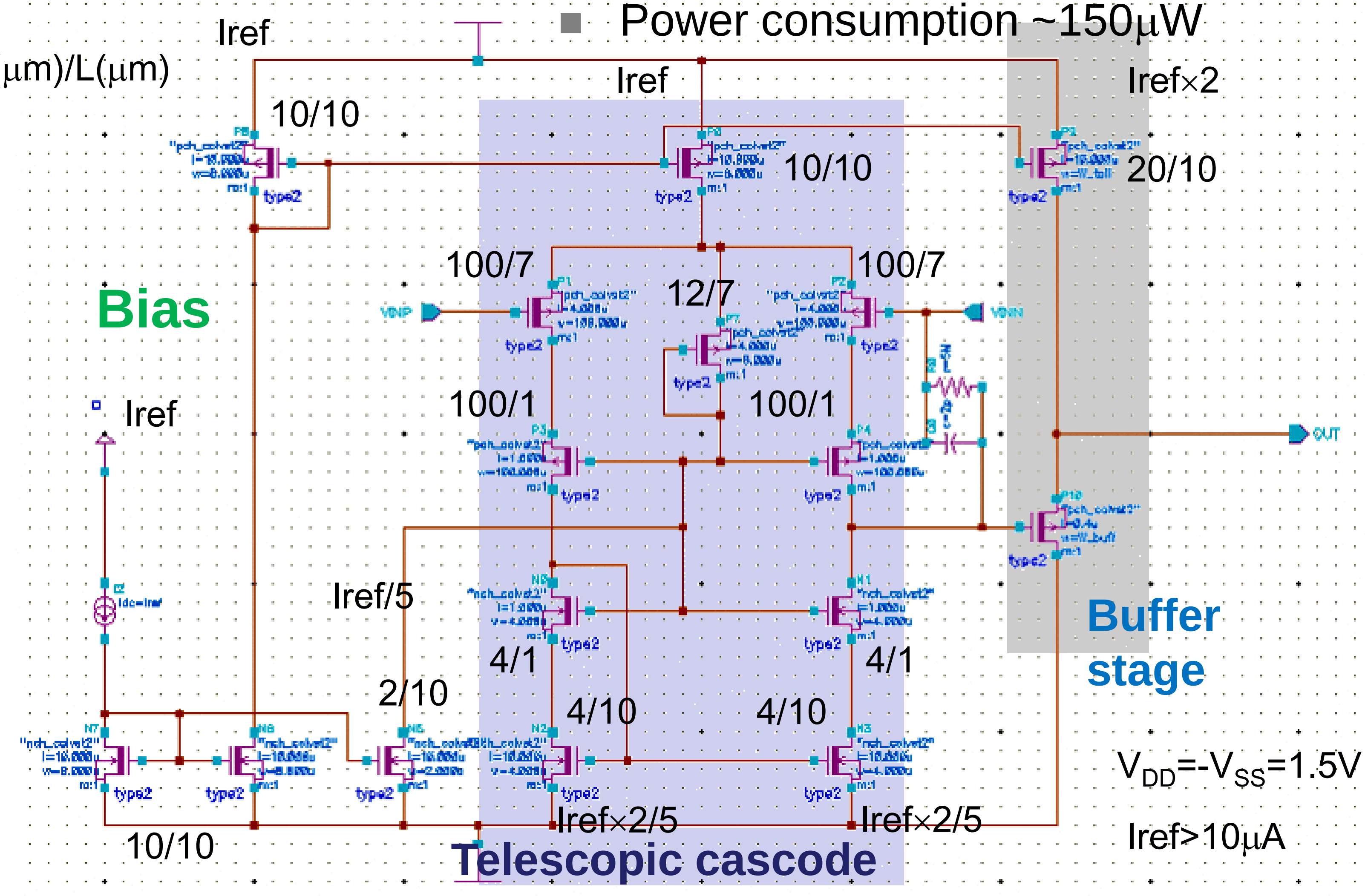
  → Low input impedance charge amplifier operational for 1MHz.



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



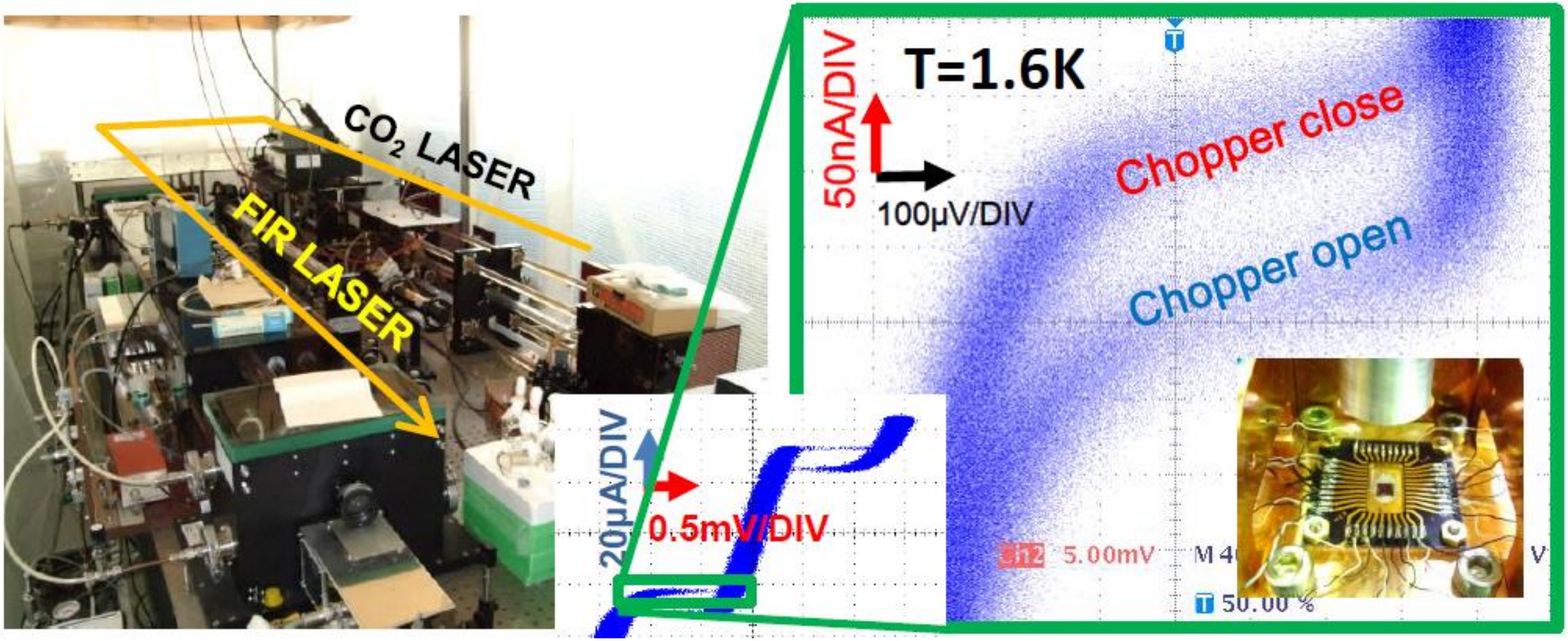
V_{DD}=-V_{SS}=1.5V

Iref>10μA

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

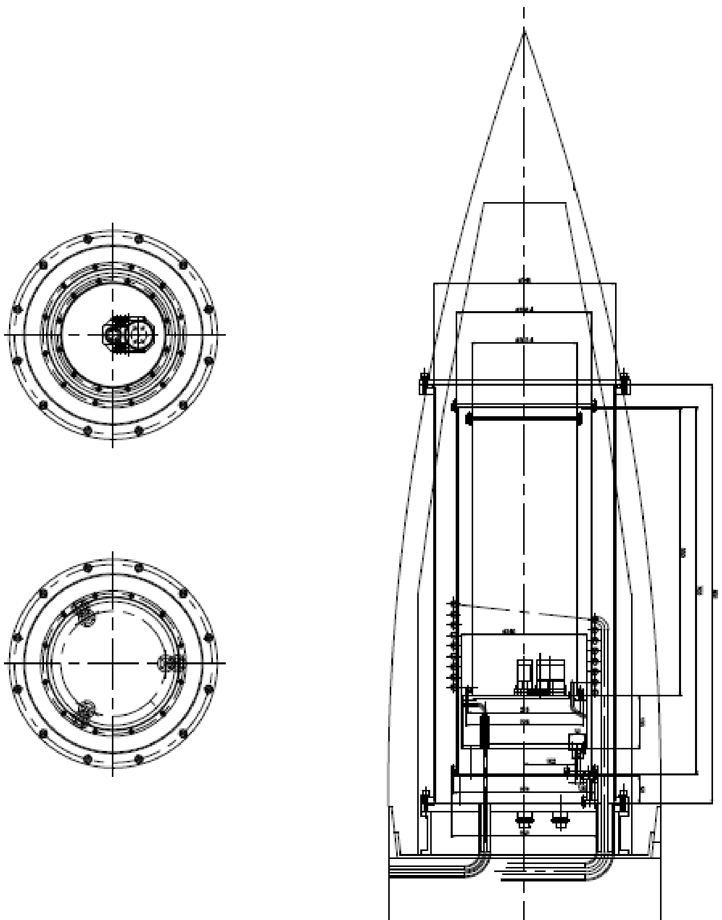


- 20μm-square Nb/Al-STJ made at AIST CRAVITY system
- Laser light was turned on and off with a chopper at a frequency of 200Hz. Measured the change of the I-V curve between the laser on and off to be 50~100nA in current.

Prototype of Cryostat for the Rocket Experiment

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

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.

COBAND Collaboration
(Cosmic Background Neutrino Decay Search)

A part of the consortium of the History of the Universe

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S. B. Kim
STJ detector

Fukui Univ.
T. Yoshida
FIR photon beam source

Kindai Univ.
Y. Kato
Data transfer

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Electronics

KEK
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Electronics

Univ. of Tsukuba
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STJ detector,
Electronics,
Cryostat, Optical system

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2014 AIST

2011 FNAL, Okayama Univ., Fukui Univ., Kindai Univ.

2007 Univ. of Tsukuba, JAXA/ISAS, RIKEN, KEK, Seoul National Univ.