APPC12 July 17, 2013

Search for Cosmic Background Neutrino Decay

Shin-Hong Kim (University of Tsukuba)
for Neutrino Decay collaboration

Neutrino Decay Collaboration
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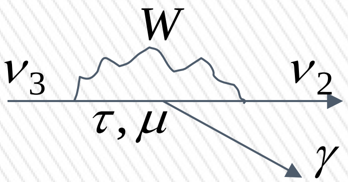
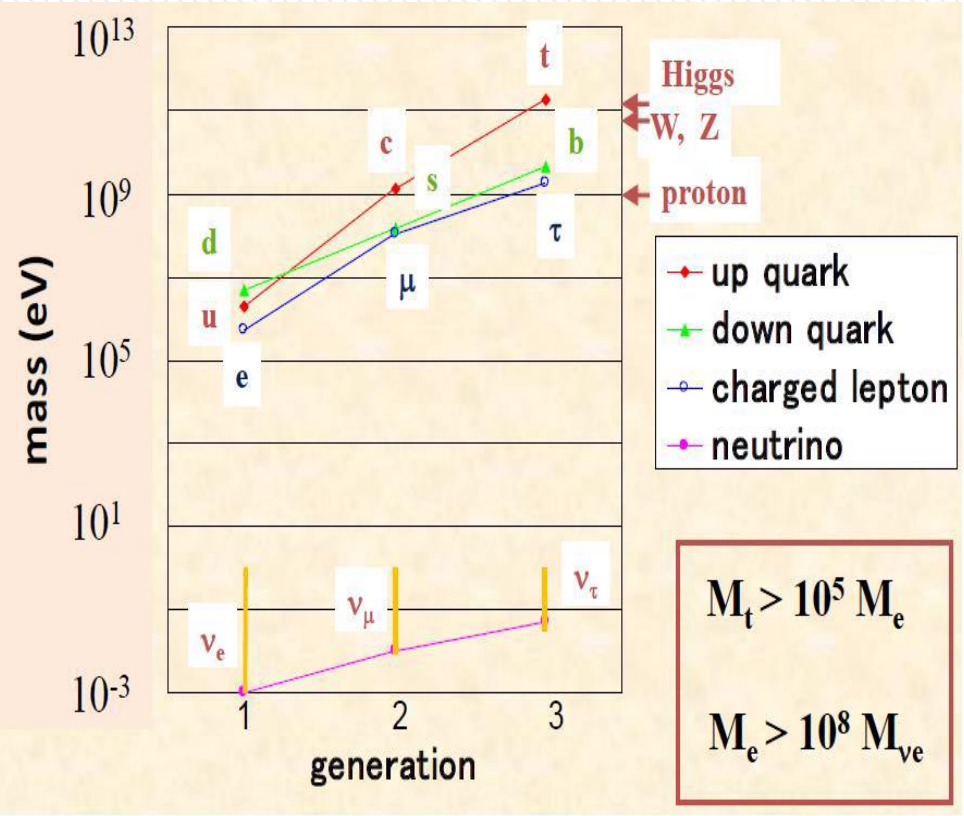
- Introduction
  - Motivation
  - Cosmic Infrared Background Measurement by COBE and AKARI
- Proposal on Search for Cosmic Background Neutrino Decay
  - Preparatory Rocket experiment
- R&D of Superconducting Tunnel Junction (STJ) Detector

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.



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



$M_t > 10^5 M_e$

$M_e > 10^8 M_{\nu e}$

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

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

$E_\gamma = 10\sim25$ meV at ν_3 rest frame.

(Far-Infrared region $\lambda = 50\sim125\ \mu$)

- **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.**

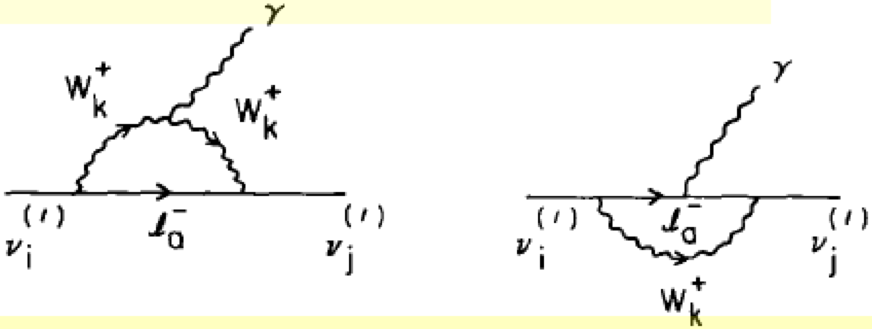
Neutrino Lifetime

In the Left - Right Symmetric Model $SU(2)_L \otimes SU(2)_R \otimes U(1)$ (PRL 38, 1252(1977), PRD 17, 1395(1978) NP B206, 359(1982)), there are two Weak Boson mass eigenstates:

$$W_1 = W_L \cos\zeta - W_R \sin\zeta,$$

$$W_2 = W_L \sin\zeta + W_R \cos\zeta.$$

W_L and W_R are fields with pure V-A and V+A couplings, respectively, and ζ is a mixing angle.

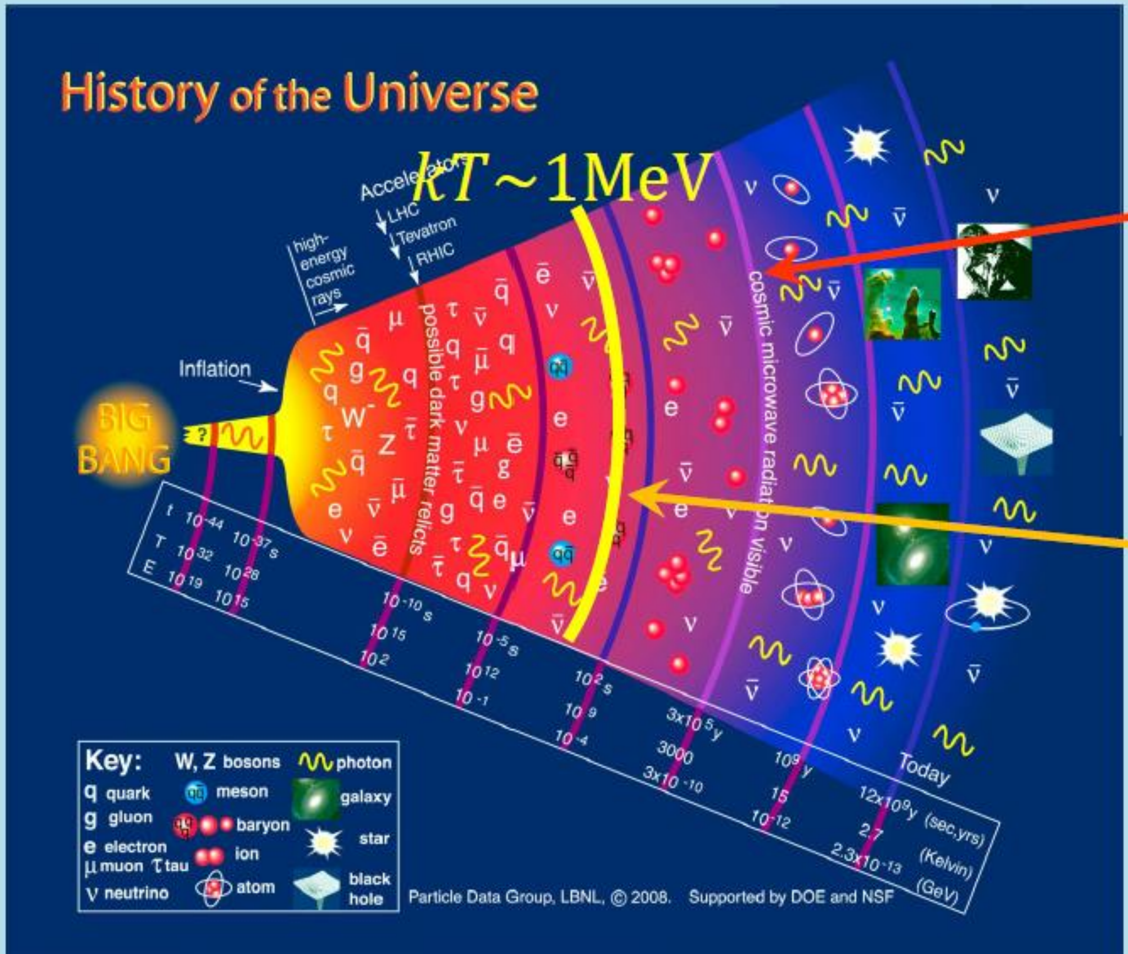


Using a lower mass limit $M(W_R) > 715\mathrm{GeV/c^2}$, a mixing angle limit $\zeta < 0.013$, and $m_3 = 50\mathrm{meV}$,

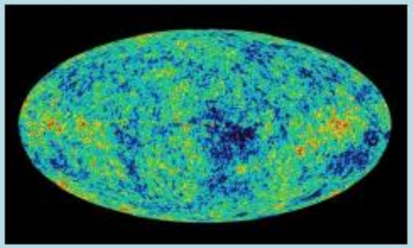
$$\tau(\nu_3 \to \nu_2 + \gamma) = \boxed{1.5\times10^{17}\,\mathrm{year}} \quad (\ 2.1\times10^{43}\,\mathrm{year\ in\ Standard\ Model}\ )$$

Measured neutrino lifetime limit τ < 3 x 10^{12} year from CIB results measured by COBE and AKARI

Big-Bang Cosmology
and Cosmic Background Neutrino (CνB)



Particle Data Group, LBNL, © 2008. Supported by DOE and NSF



CMB

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

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

CνB

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

$$= 56/\mathrm{cm}^3$$

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

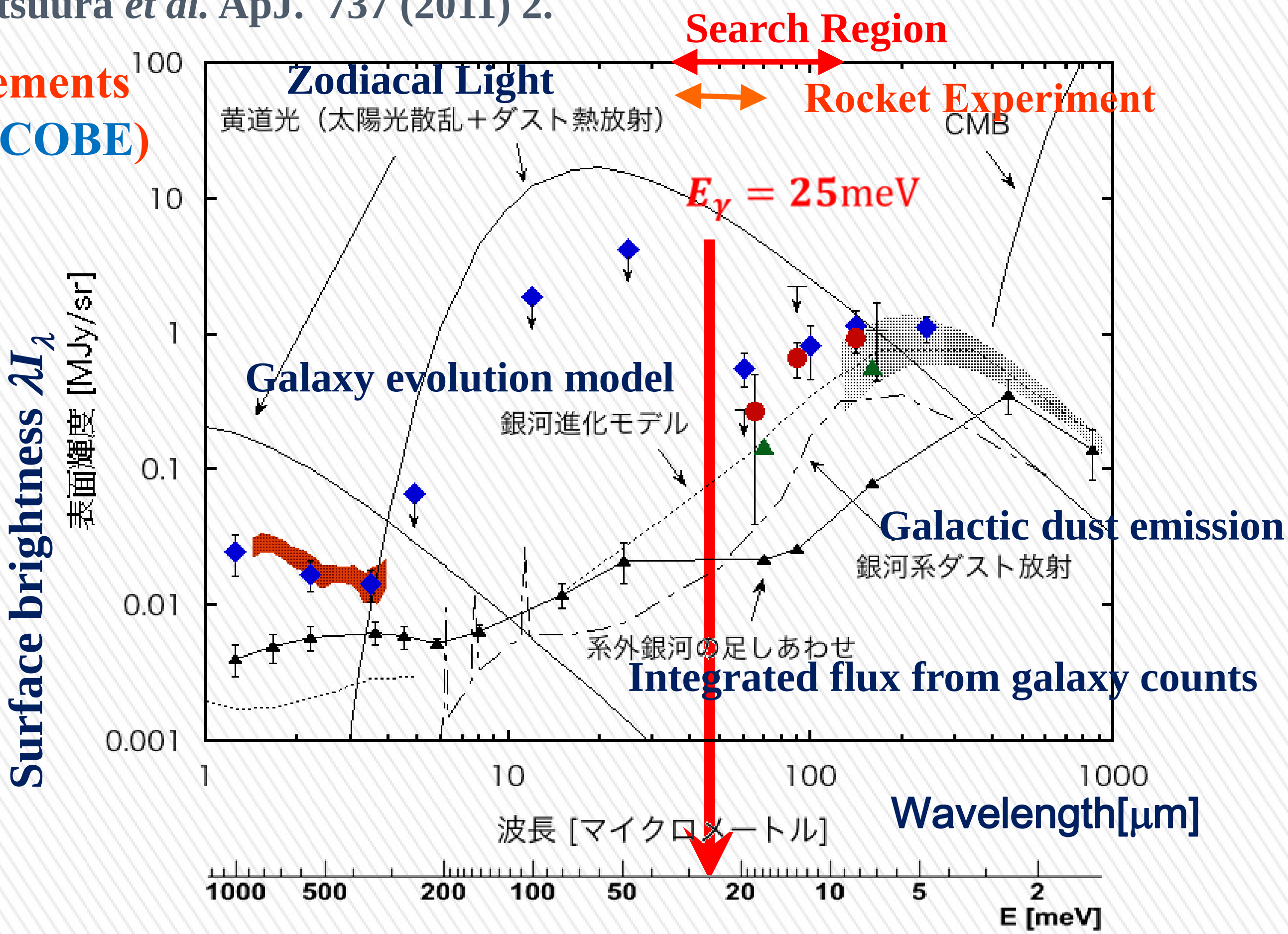
Cosmic Infrared Background measured by COBE and AKARI

COBE: M. G. Hauser *et al.* ApJ 508 (1998) 25. D. P. Finkbeiner *et al.* ApJ 544 (2000) 81.

AKARI: S. Matsuura *et al.* ApJ. 737 (2011) 2.

CIB measurements

(● AKARI, ♦ COBE)



A. Mirizzi, D. Montanino and P. Serpico PRD76, 053007 (2007)

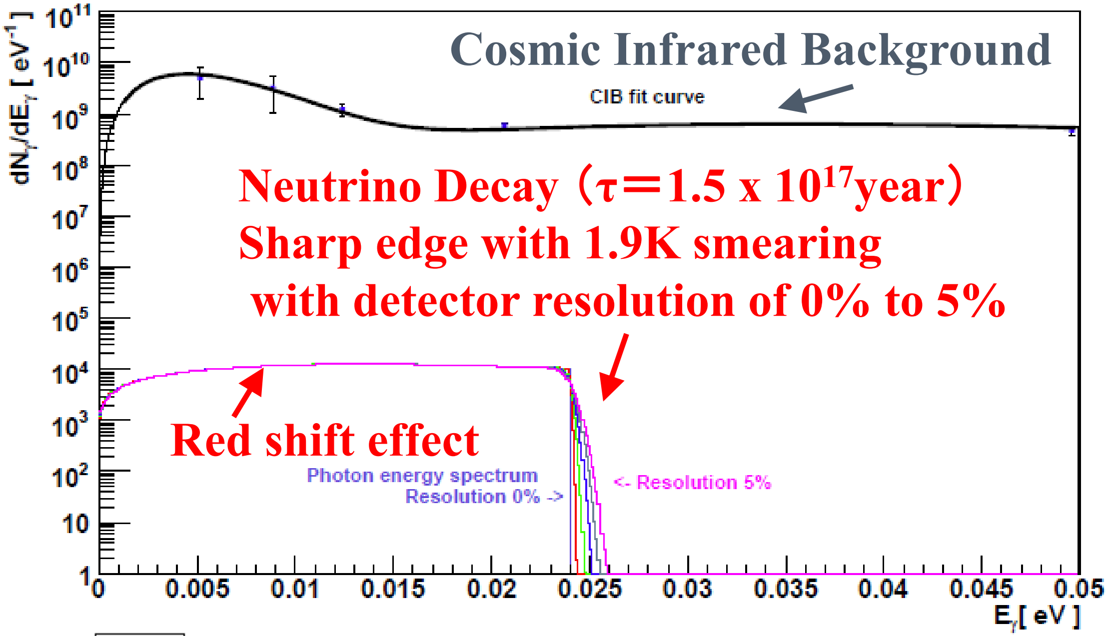
Neutrino lifetime τ < (1.6~3.1)x10^{12} year from CIB results by COBE

S.H. Kim, K. Takemasa, Y. Takeuchi and S. Matsuura JPSJ 81, 024101 (2012)

Neutrino lifetime τ < (3.1~3.8)x10^{12} year from CIB results by AKARI and SPITZER

Neutrino Decay Detection Sensitivity

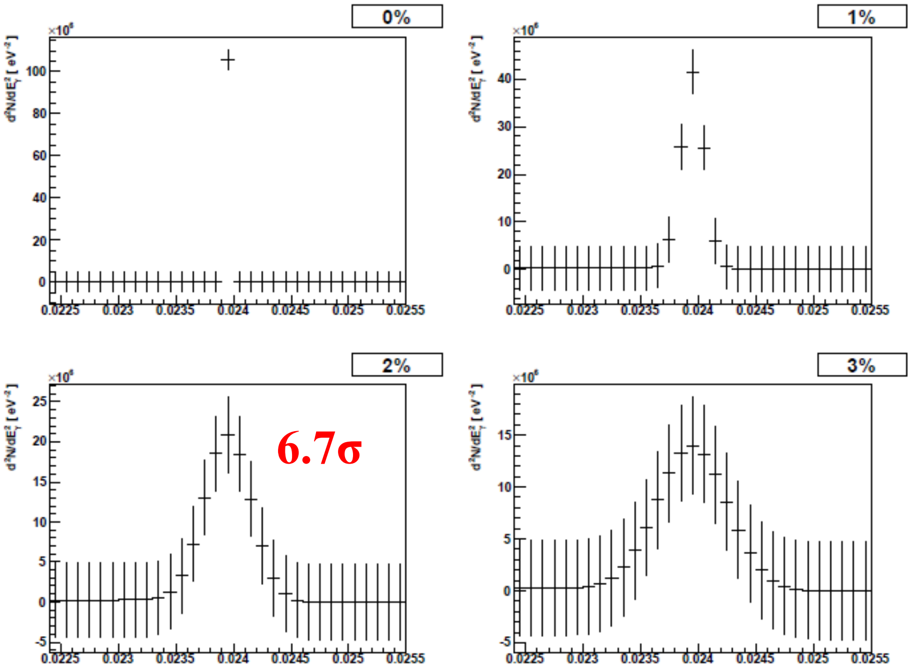
10-hour running with
a telescope with 20cm diameter,
a viewing angle of 0.1 degrees
and 100% detection efficiency
(Satellite Experiment)



Cosmic Infrared Background

Neutrino Decay（τ＝1.5 x 10^{17}year）
Sharp edge with 1.9K smearing
with detector resolution of 0% to 5%

Red shift effect

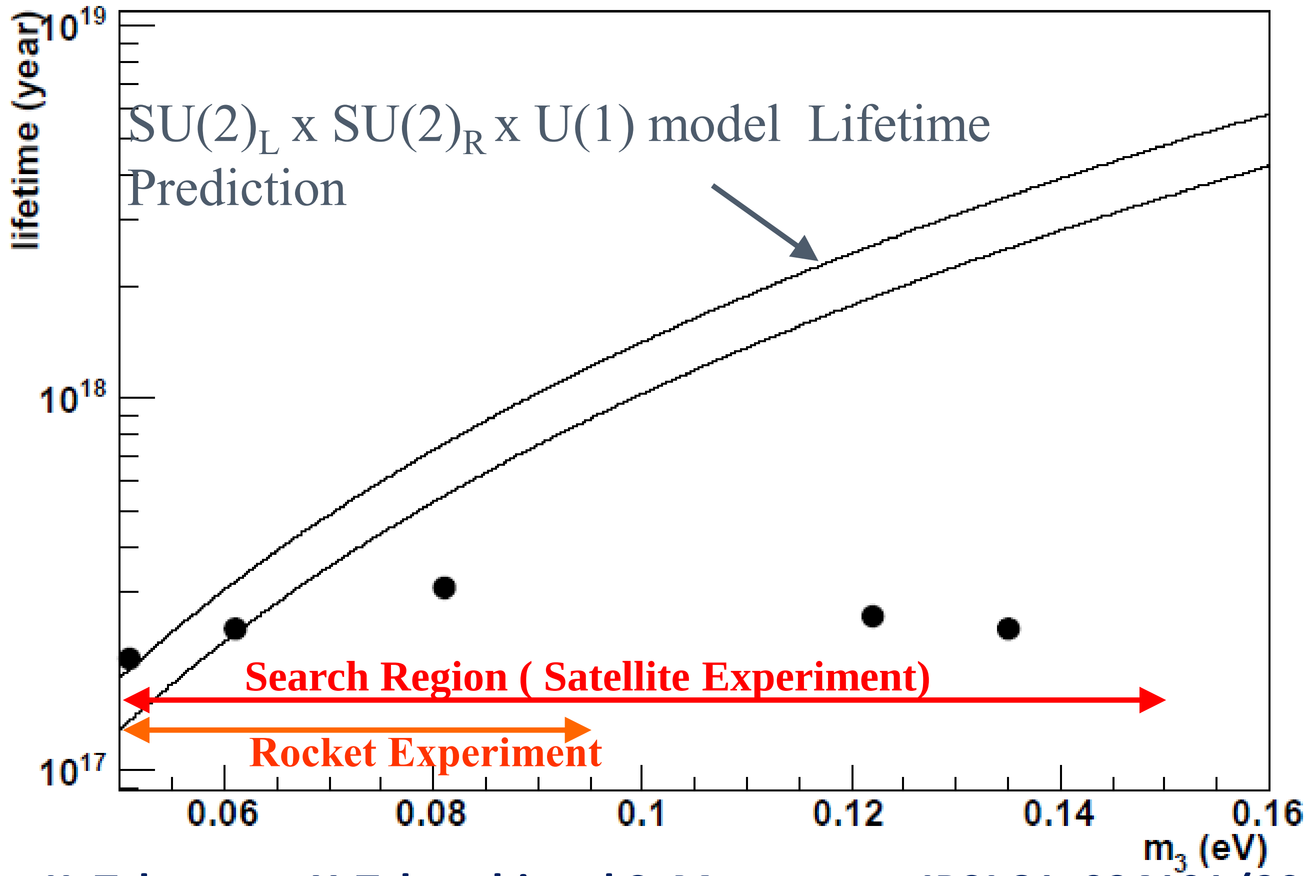


dN/dE$_\gamma$

- d^{2}N$_\gamma$/dE$_\gamma$^{2}

- Need the energy resolution better than 2%.
- Can observe the ν_3 decay with a mass of 50meV, and a lifetime of 1.5 x 10^{17}year at 6.7σ.

5σ observation sensitivity by 10-hour measurement with a telescope with 20 cm diameter, a viewing angle of 0.1 degree



S.H. Kim, K. Takemasa, Y. Takeuchi and S. Matsuura JPSJ 81, 024101 (2012)

Search Region: λ＝ 40～150μm （E_γ ＝ 8～30meV）

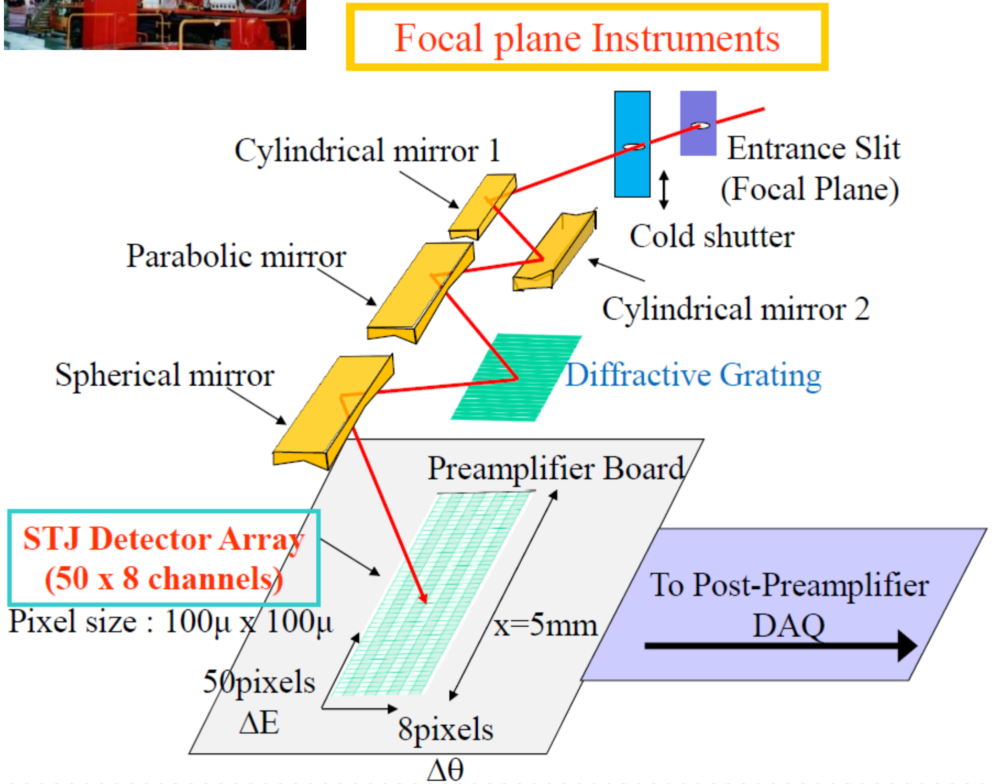
In Rocket experiment, λ＝ 40～80μm （E_γ ＝ 15～30meV）

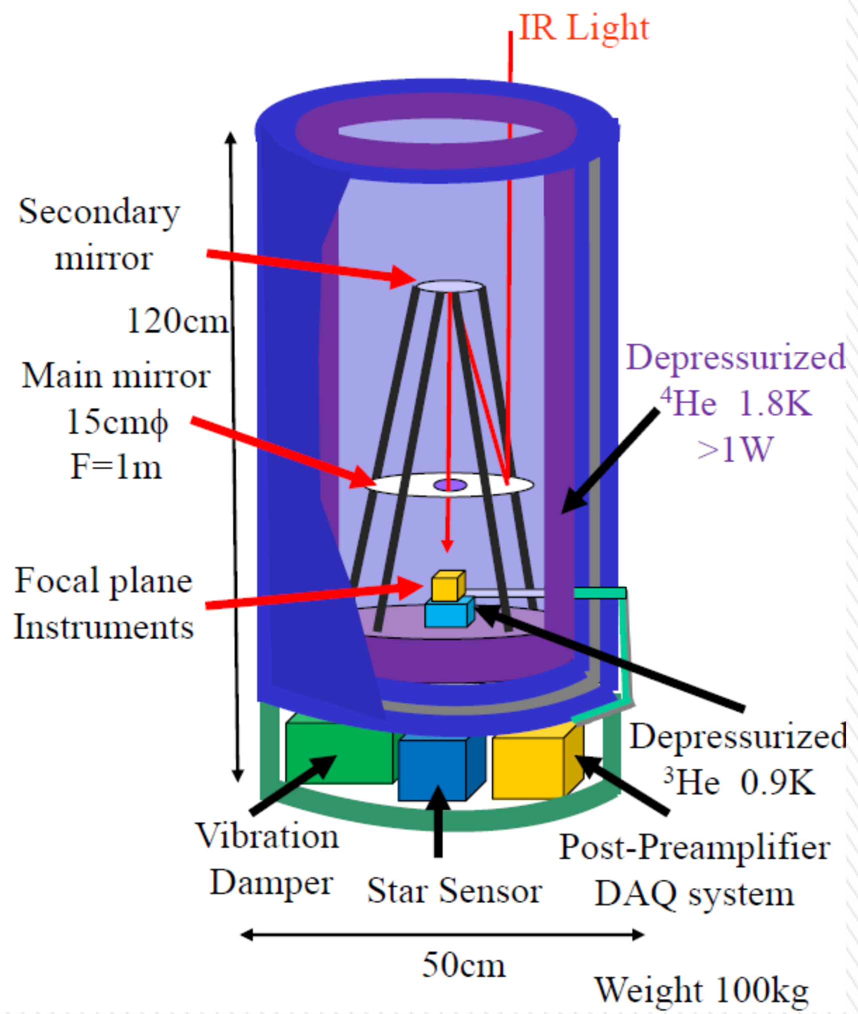
Nb/Al-STJ sensisitive region > 8meV ($N_{\text{quasi-particles}} = 60$)

JAXA Rocket Experiment for Neutrino Decay Search

Plan: 5minutes data acquisition at 200 km height in 2016.
Improve lifetime limit by two orders of magnitude (~10^{14}year).

JAXA Rocket CIB Experiment
（Feb 2, 1992）





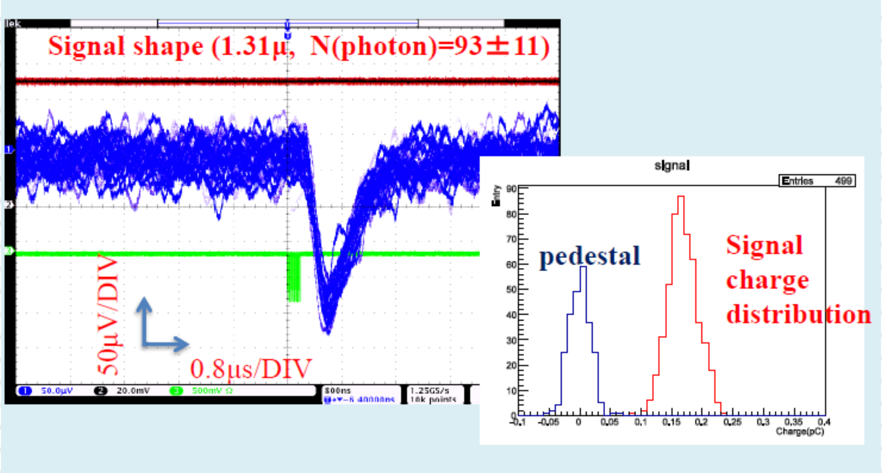
R&D of Superconducting Tunnel Junction (STJ) Detctor

Nb/Al-STJ

Goal: detection of a single far-infrared photon in energy range between 15meV and 30meV for the rocket experiment for neutrino decay search.

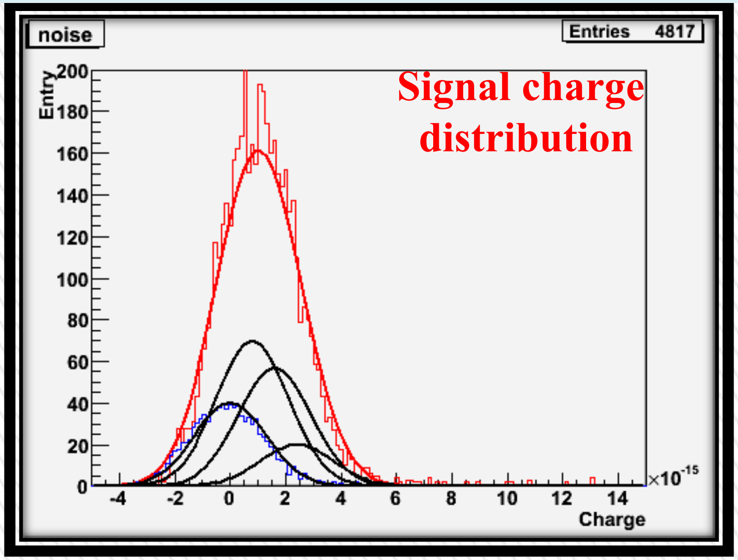
Signal of Nb/Al-STJ (100 x 100 μm^2) to infrared (1.31 μm) light at 1.9K.

Time spread at FWHM is 1 μsec.
The number of photon : 93±11
(from the spread of
the signal charge distribution).


Signal shape (1.31μ, N(photon)=93±11)

the response of Nb/Al-STJ (4 μm^2) to the visible light (456nm) at 1.9K.
a single photon peak is separated from pedestal by 1σ.

The signal charge distribution (Red histogram) is fitted by four Gaussians of 0, 1, 2 and 3 photon peaks. Single photon peak has a mean of 0.4fC and σ of 0.4fC.

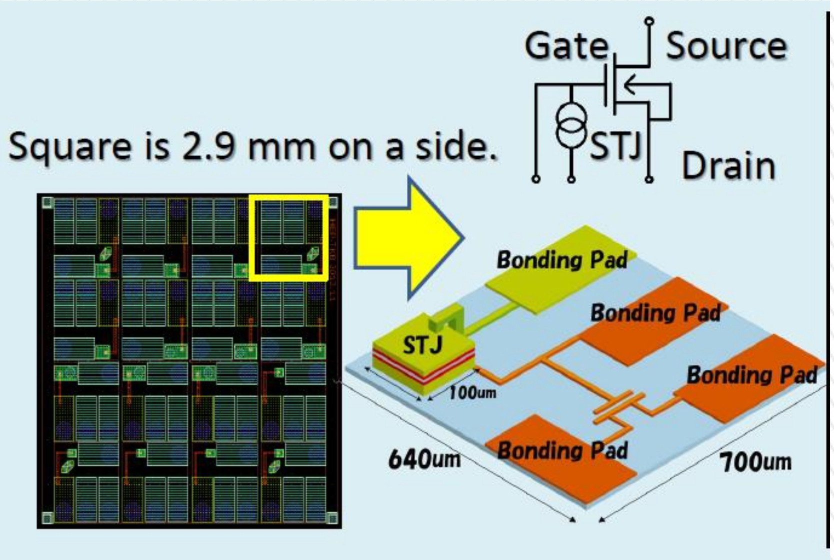

Signal charge distribution

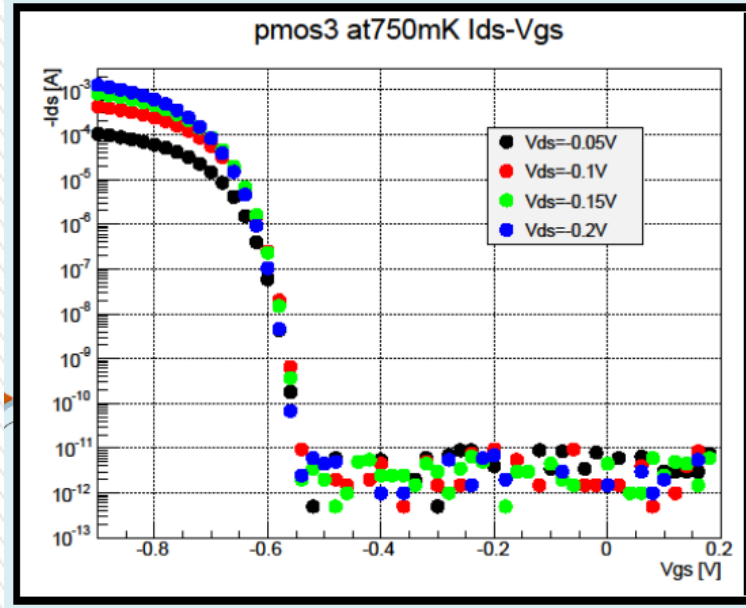
R&D of Superconducting Tunnel Junction (STJ) Detctor

SOI-STJ

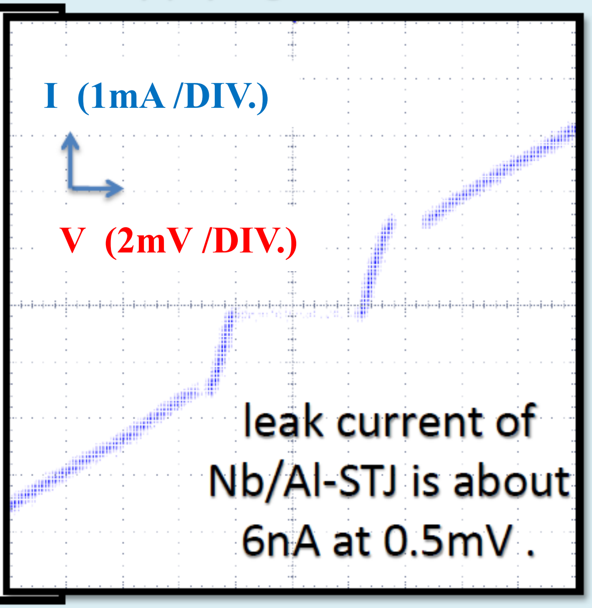
SOI (Silicon-On-Insulator) preamplifier :
Low noise preamplifier working around 1K.

We have processed Nb/Al-STJ on a SOI transistor board, and confirmed that both Nb/Al-STJ detector and SOI MOSFET worked normally **at 700mK.**


Square is 2.9 mm on a side.



After applying150 Gauss to STJ.



leak current of Nb/Al-STJ is about 6nA at 0.5mV .

In the next step, we will look at the response of SOI-STJ to infrared photons.

R&D of Superconducting Tunnel Junction (STJ) Detctor

Hf-STJ

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

Micro-calorimeter: Hf-STJ can generate enough statistics of quasi-particles from cooper pair breakings to achieve 2% energy resolution for photon with $E_\gamma = 25$ meV.

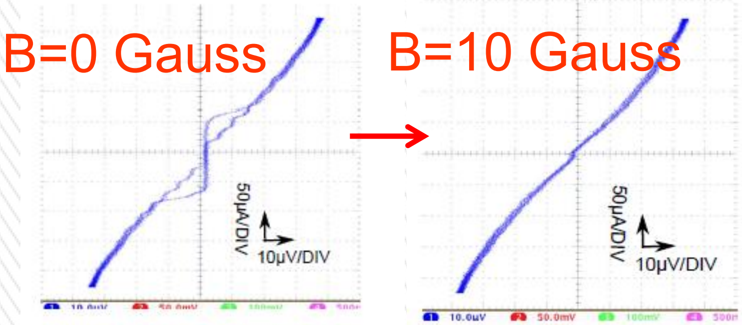
Material	$T_c(K)$	Δ(meV)
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

Hf-STJ (100x100µm²) shows smaller leakage current than **Hf-STJ (200x200µm²)** which we have established to work as a STJ in 2011.

The work to reduce a large leakage current of Hf-STJ is underway.

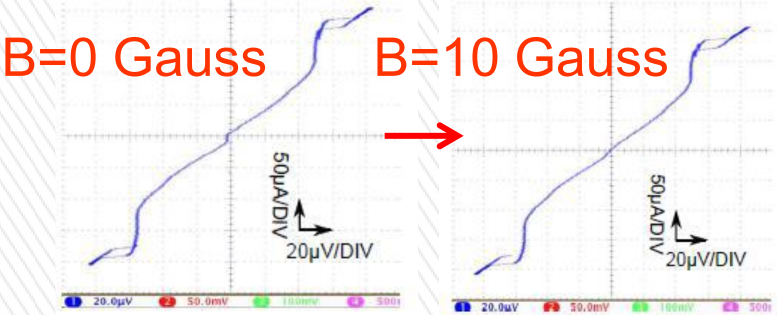
I-V curve of Hf-STJ (**200x200µm²**)

- T~80mK, I_c=60 µA, **R_d=0.2Ω**



I-V curve of Hf-STJ (**100x100µm²**)

- T~40mK, I_c=10 µA, **R_d=0.6Ω**



Summary

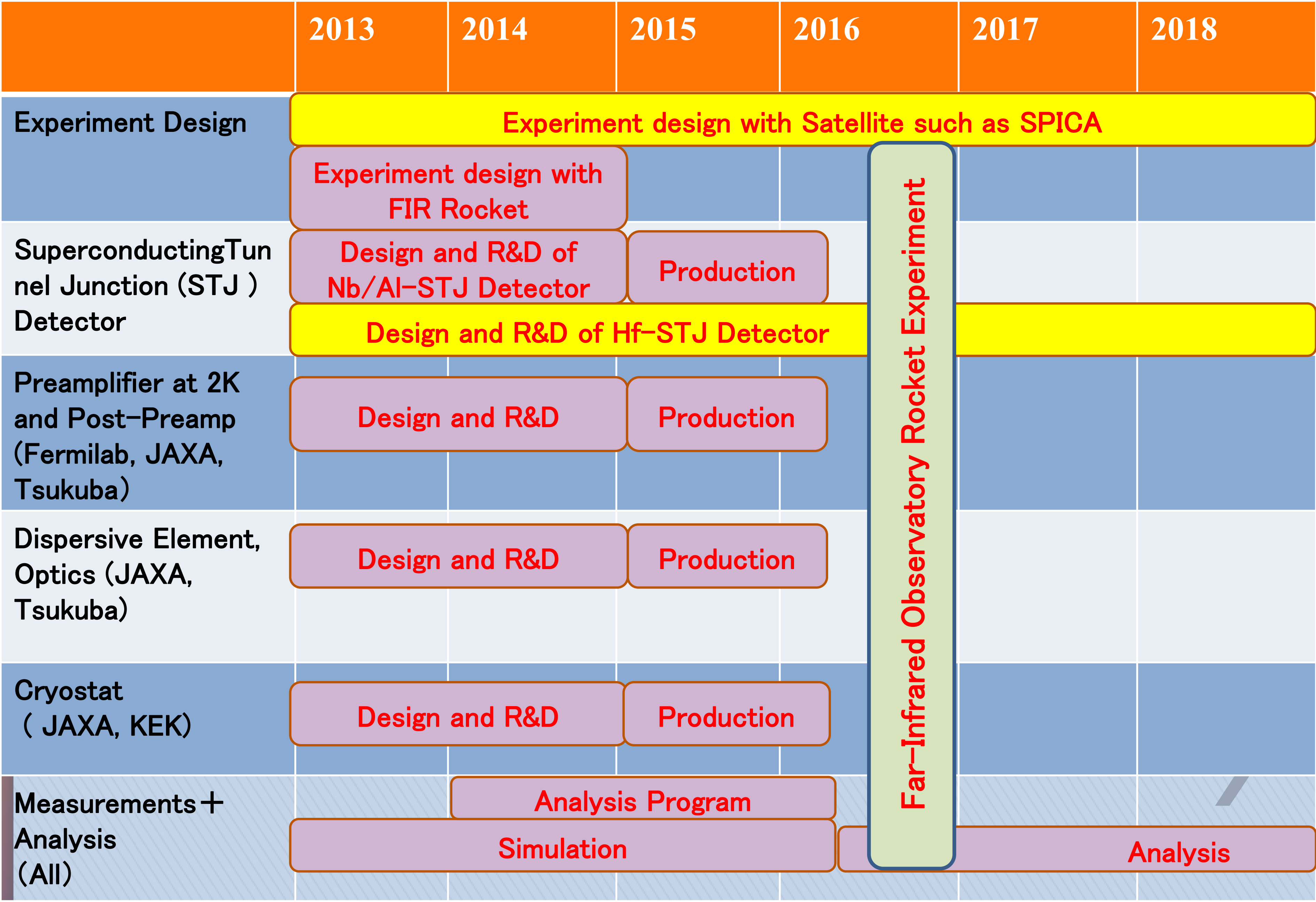
1. It is feasible to observe the cosmic background neutrino decay with a satellite experiment, if we assume Left-Right Symmetric Model.

2. We are developing STJ-based detectors to detect a far-infrared photon in energy range between 8 and 30meV to search for cosmic background neutrino decay.

3. A rocket experiment using the STJ detectors for neutrino decay search is in preparation. It will improve the neutrino lifetime sensitivity from the present 10^{12} year to 10^{14} year.

BACKUP

Schedule

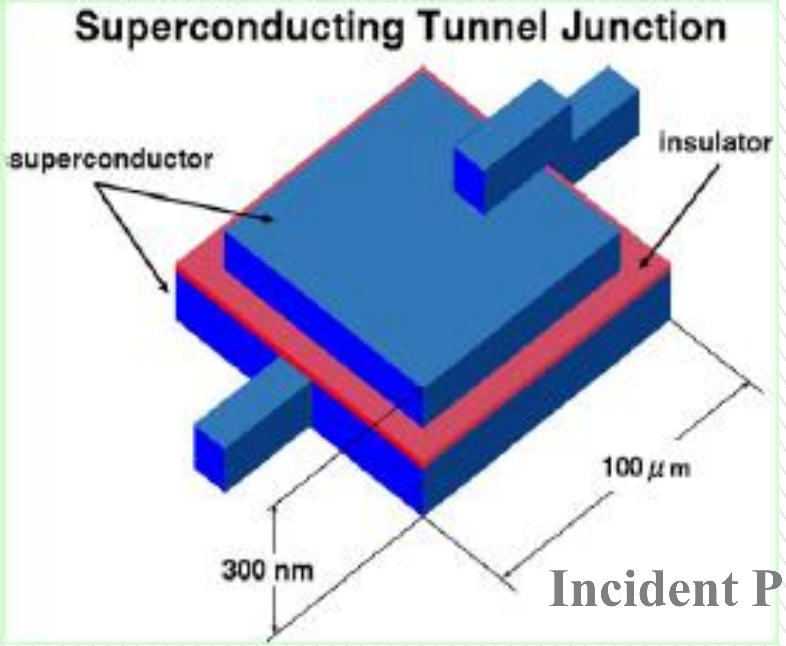


	2013	2014	2015	2016	2017	2018
Experiment Design	Experiment design with Satellite such as SPICA Experiment design with FIR Rocket					
SuperconductingTunnel Junction (STJ) Detector	Design and R&D of Nb/Al-STJ Detector Design and R&D of Hf-STJ Detector		Production			
Preamplifier at 2K and Post-Preamp (Fermilab, JAXA, Tsukuba)	Design and R&D		Production			
Dispersive Element, Optics (JAXA, Tsukuba)	Design and R&D		Production			
Cryostat (JAXA, KEK)	Design and R&D		Production			
Measurements＋Analysis (All)	Simulation	Analysis Program		Analysis		

Far-Infrared Observatory Rocket Experiment

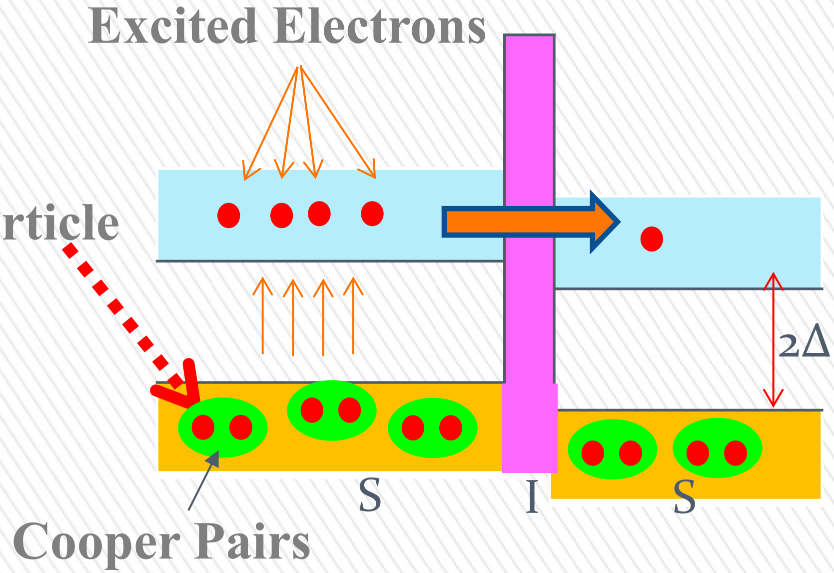
STJ (Superconducting Tunnel Junction）Detector

- Superconductor / Insulator / Superconductor Josephson Junction



At the superconducting junction, excited electrons (quasi-particles) over their energy gap go through tunnel barrier by a tunnel effect.

By measuring the tunnel current of electrons excited by an incident particle, we measure the energy of the particle.



STJ Energy Resolution

STJ Energy Resolution

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

Using Hf as a superconductor,

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

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

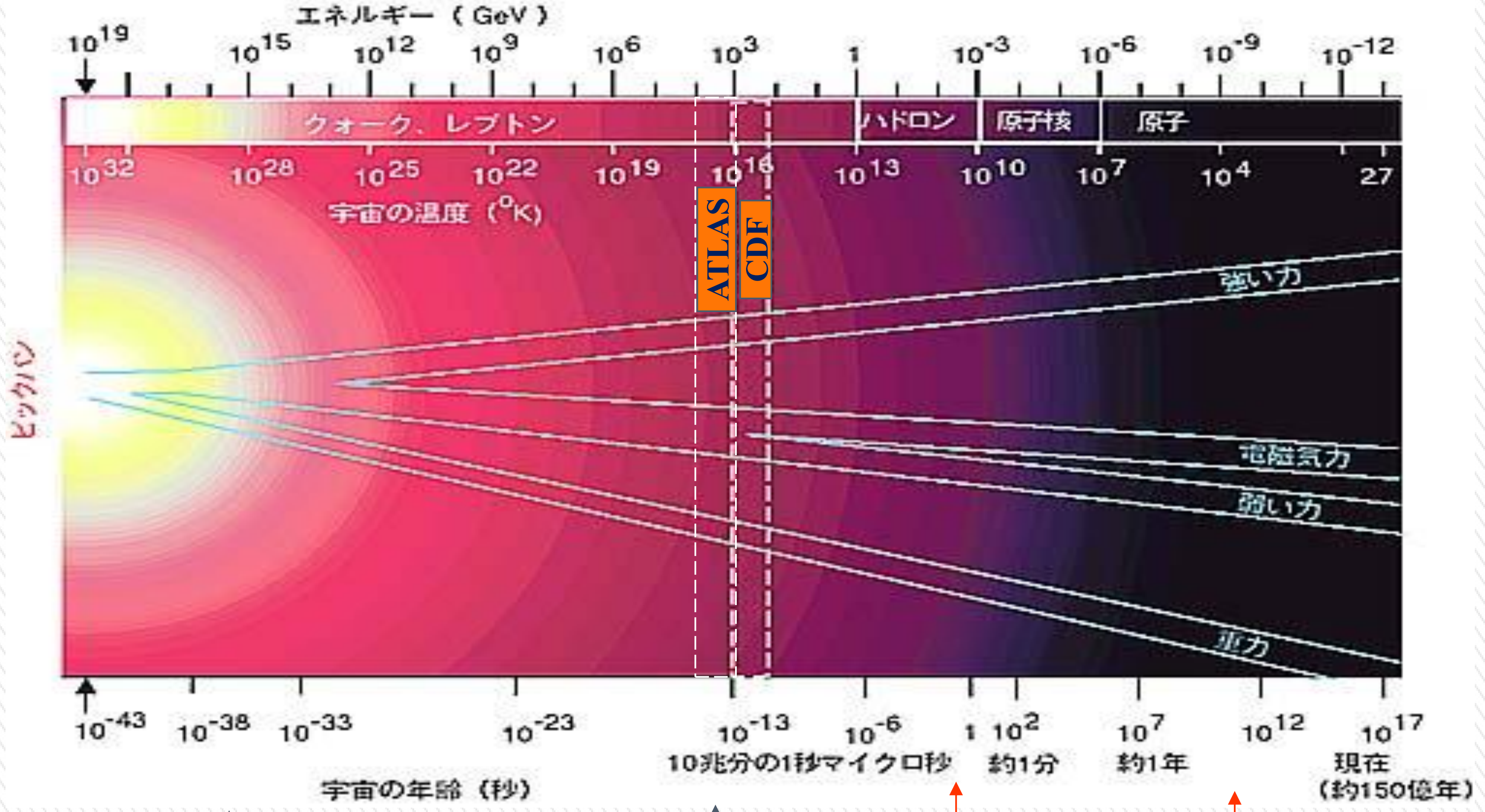
Material	$T_c(K)$	$\Delta(\text{meV})$
Niobium	9.20	1.550
Aluminum	1.14	0.172
Hafnium	0.13	0.021

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.

Big-Bang Cosmology and Elementary Particle Physics



GUT
Phase Transition in vacuum

Electroweak
Higgs particle

1.9K Cosmic background neutrino
(110/cm^3)

2.7K Cosmic background
radiation(420/cm^3)

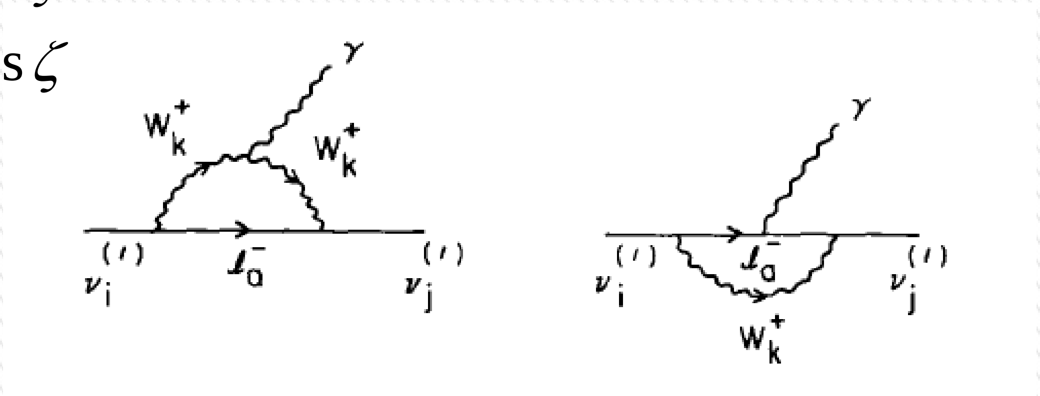
Neutrino Decay Lifetime

M. Beg, W. Marciano and M. Rudeman Phys. Rev. D17 (1978) 1395-1401
R. E. Shrock Nucl. Phys. B206 (1982) 359-379

Calculate the neutrino decay width in $SU(2)_L$ × $SU(2)_R$ × $U(1)$ model with Dirac neutrinos. $M(W_R)=\infty$ and $\sin\zeta = 0$ corresponds to Standard Model.

$$W_1 = W_L\cos\zeta - W_R\sin\zeta$$
$$W_2 = W_L\sin\zeta + W_R\cos\zeta$$

W_L and W_R are fields with pure V-A and V+A couplings, respectively, and ζ is a mixing angle.



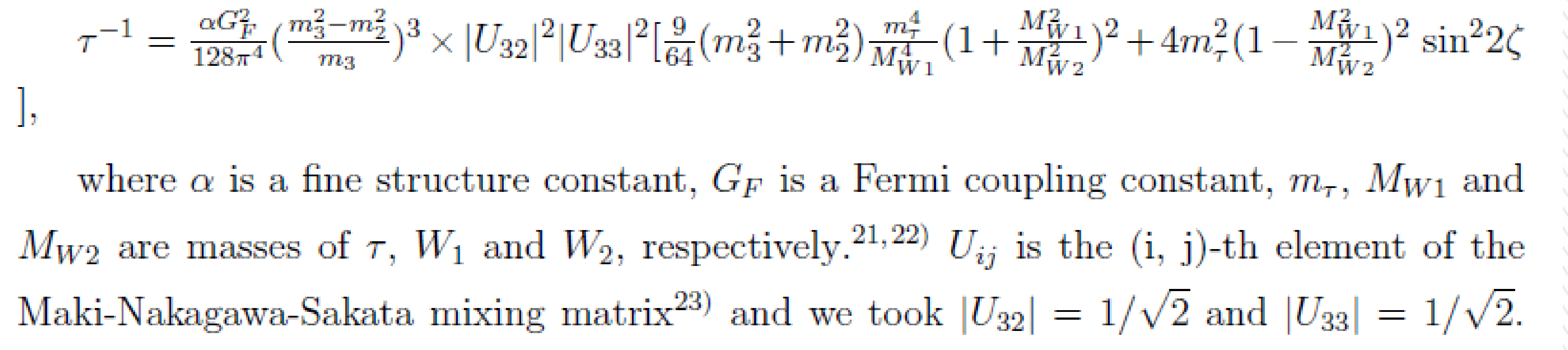
Using a lower mass limit $M(W_R) > 715\text{GeV/c}^2$, a mixing angle limit $\zeta < 0.013$, and $m_3 = 50\text{meV}$,

$$\tau(\nu_3 \to \nu_2 + \gamma) = \boxed{1.5\times10^{17}\text{year}} \qquad (\ 2.1\times10^{43}\text{year in Standard Model})$$

Lifetime Calculation

R. E. Schrock, Nucl. Phys. 28 (1982) 359.

Calculate the neutrino decay width in $SU(2)_L \times SU(2)_R \times U(1)$ model



$$\tau^{-1} = \frac{\alpha G_F^2}{128\pi^4}\left(\frac{m_3^2-m_2^2}{m_3}\right)^3 \times |U_{32}|^2|U_{33}|^2\left[\frac{9}{64}(m_3^2+m_2^2)\frac{m_\tau^4}{M_{W1}^4}\left(1+\frac{M_{W1}^2}{M_{W2}^2}\right)^2 + 4m_\tau^2\left(1-\frac{M_{W1}^2}{M_{W2}^2}\right)^2 \sin^2 2\zeta\right],$$

where α is a fine structure constant, G_F is a Fermi coupling constant, m_τ, M_{W1} and M_{W2} are masses of τ, W_1 and W_2, respectively.[21,22] U_{ij} is the (i, j)-th element of the Maki-Nakagawa-Sakata mixing matrix[23] and we took $|U_{32}| = 1/\sqrt{2}$ and $|U_{33}| = 1/\sqrt{2}$.

$$\tau^{-1} \approx \frac{\alpha G_F^2}{64\pi^4}\left(\frac{\Delta m_{32}^2}{m_3}\right)^3 m_\tau^2 \sin^2 2\zeta$$

$M_{W2} = 0.715\text{TeV}$, $\sin\zeta = 0.013$, $\Delta m_{32}^2 = 2.43\times10^{-3}\text{eV}^2$, $m_\tau = 1.78\text{GeV}$, $m_3 = 50\text{meV}$,

$$\tau = 1.5\times10^{17}\text{year}$$

In the standard model,

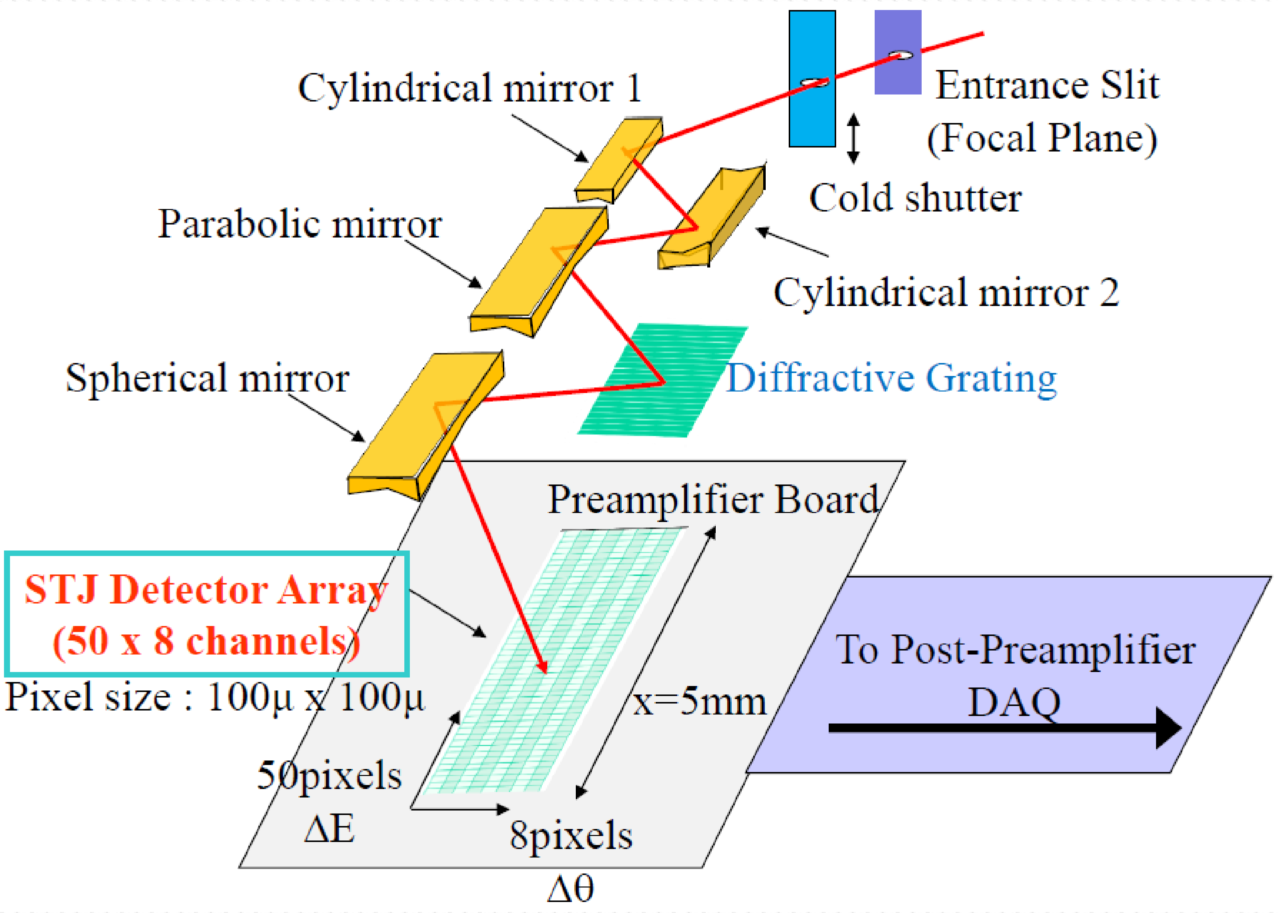
$$\tau^{-1} \approx \frac{9\alpha G_F^2}{8192\pi^4}\left(\frac{\Delta m_{32}^2}{m_3}\right)^3 (m_3^2+m_2^2)\left(\frac{m_\tau^2}{M_W^2}\right)^2$$

Thus $\tau = 2.1\times10^{43}$year

ref. K. Sato and M. Kobayashi, Prog. Theor. Phys. 58 (1977) 1775. and others.

JAXA Rocket Experiment for Neutrino Decay Search

Focal plane Instruments



Incident rays are made parallel through cylindrical mirrors 1, 2 and a parabolic mirror before diffracted by a grating, and are finally focused on the STJ detector array by a spherical mirror.

Rate/50pixel-spectrometer = 15 kHz（300Hz/pixel)
Measurements for 200 s → 3M events /50pixel-spectrometer.
Using 8 x 50pixel-spectrometer, σ/N=0.02%
2σ = 0.04% x 0.5μW/m^2/sr = 0.2nW/m^2/sr (0.4% times present limit 50nW/m^2/sr)