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Search for Cosmic Background Neutrino Decay

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Neutrino Decay Collaboration

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Introduction

From several neutrino oscillation experiments, the mass difference between neutrino generations (m_1, m_2, m_3) has been already established, i.e.

$$|\Delta m_{12}^2| = m_2^2 - m_1^2 \sim 7.6\times10^{-5}\ \mathrm{eV}^2,\ \text{and}\ |\Delta m_{23}^2| = m_3^2 - m_2^2 = 2.4\times10^{-3}\ \mathrm{eV}^2$$

If we assume $m_1^2 \ll m_2^2$, we would obtain

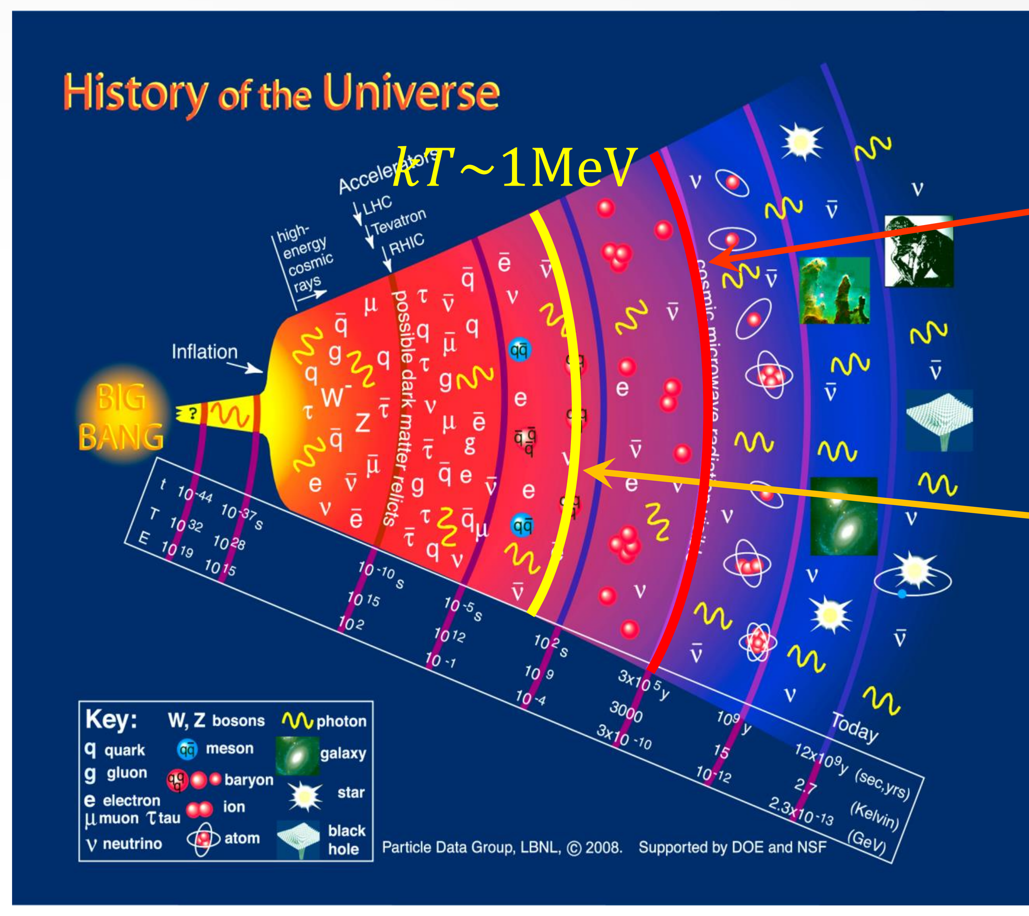
$$m_2 \sim 8.7\ \mathrm{meV},\ \text{and}\ m_3 \sim 50\ \mathrm{meV}.$$

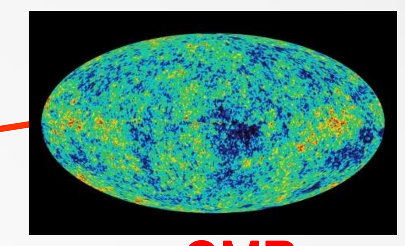
A heavier neutrino can decay into a lighter neutrino with a photon.

$$\nu_3 \to \nu_2 + \gamma \qquad E_\gamma(\text{at } \nu_3 \text{ rest frame}) = \frac{m_3^2 - m_2^2}{2m_3}$$

If we assume $m_3 = 50$ meV, E_γ at ν_3 rest frame would be 25 meV, which corresponds to $\lambda_\gamma = 50\ \mu$m. Thus we propose an experiment to search for the photon emission from the decay of cosmic background neutrino (CνB) in the far infrared region of photon energy spectrum.

- Search for $\nu_3 \to \nu_{1,2} + \gamma$ in cosmic background neutrino(CνB)
  - Direct detection of CνB
  - Direct detection of neutrino magnetic moment
  - Direct measurement of neutrino mass
- Aiming at sensitivity of detecting γ from ν decay for $\tau(\nu_3) \sim O(10^{17}\mathrm{yr})$
  - Current experimental lower limit: $\tau(\nu_3) > O(10^{12}\mathrm{yr})$
  - Standard Model expectation $\tau(\nu_3) = O(10^{43}\mathrm{yr})$
  - Manifest L-R symmetric model (w/ light ν_R) predicts $\tau(\nu_3) = O(10^{17}\mathrm{yr})$





CMB

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

$T_\gamma = 2.73$ K

CνB

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

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

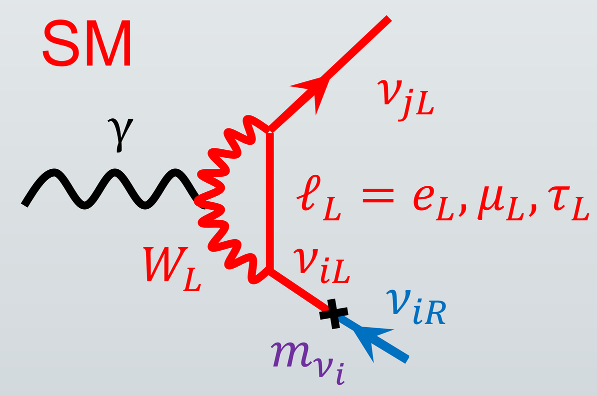
Manifest L-R symmetric model (w/ light ν_R)

PRL 38, 1252(1977), PRD 17, 1395(1978)

$$\begin{pmatrix} W_1 \\ W_2 \end{pmatrix} = \begin{pmatrix} \cos\zeta & -\sin\zeta \\ \sin\zeta & \cos\zeta \end{pmatrix} \begin{pmatrix} W_L \\ W_R \end{pmatrix}$$

Contributions to neutrino magnetic moment term: $\bar\nu_{jL}\sigma_{\mu\nu}\nu_{iR}$

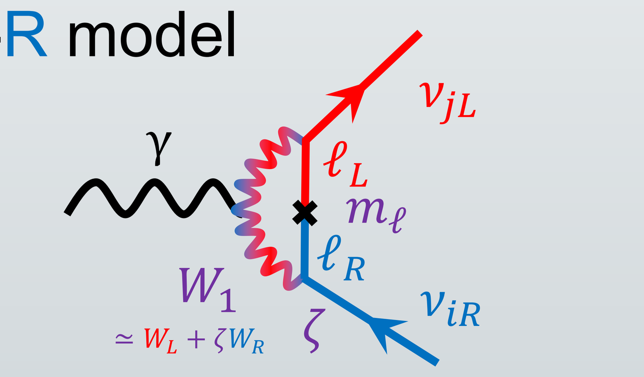
SM



$\Gamma \sim (10^{43}\ \mathrm{yr})^{-1}$

- Suppression from m_ν
- GIM suppression

L-R model



$\Gamma \sim (10^{17}\ \mathrm{yr})^{-1}$

- Suppression only from $\zeta \sim 0.01$

10^{26} enhancement from SM

Feasibility of photon detection from cosmic background neutrino decay

The photon energy spectrum from CνB decay is expected to have a sharp edge at $E_\gamma = 25$ meV ($m_3 = 50$ meV is assumed) with $T_\nu = 1.9$ K smearing and tail in lower energy side due to the red shift effect. We can search for this sharp edge in the cosmic infrared background (CIB) photon energy spectrum.

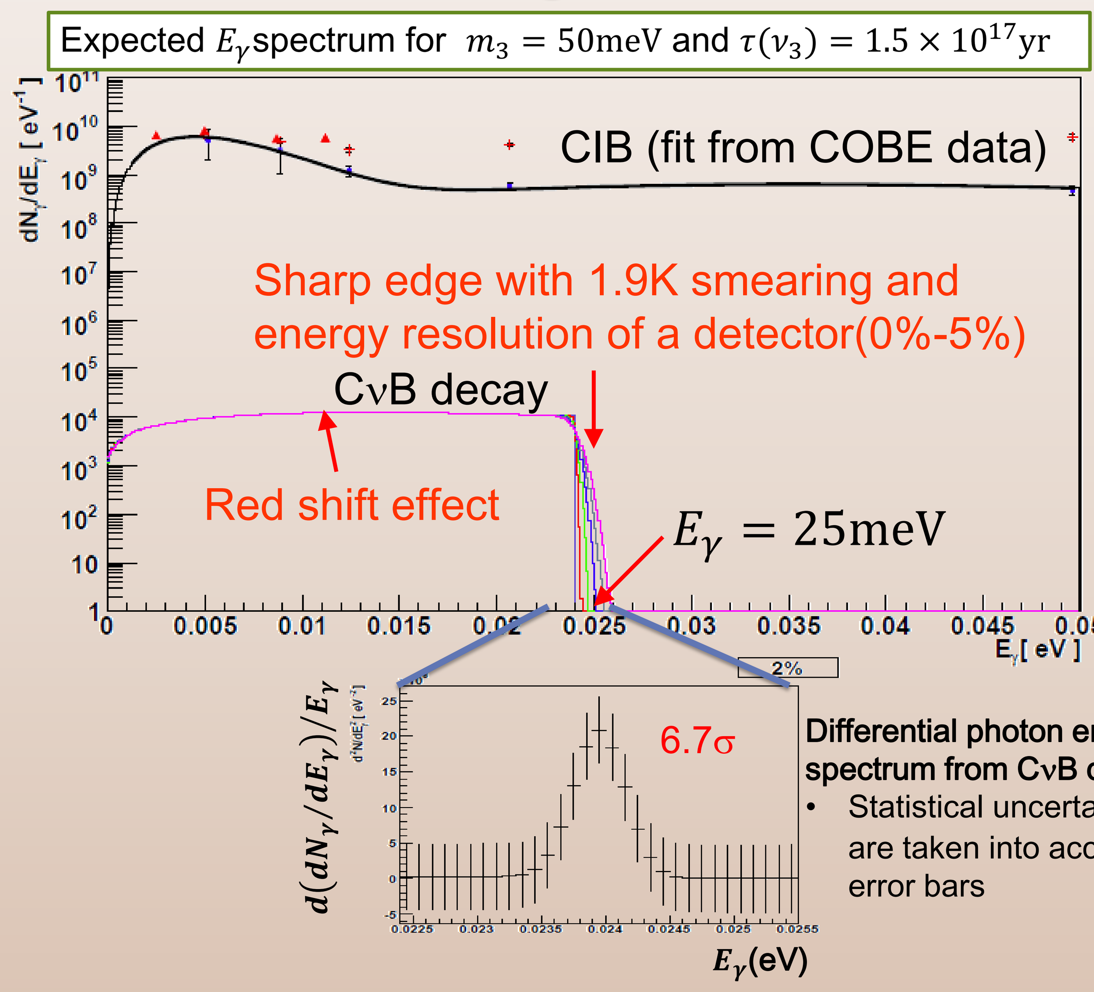
Simulation(JPSJ 81 (2012) 024101)

If we assume

- No zodiacal emission background
- 10 hour measurement
- 20cm diameter and 0.1° viewing angle telescope
- A photon detector with 2% energy resolution

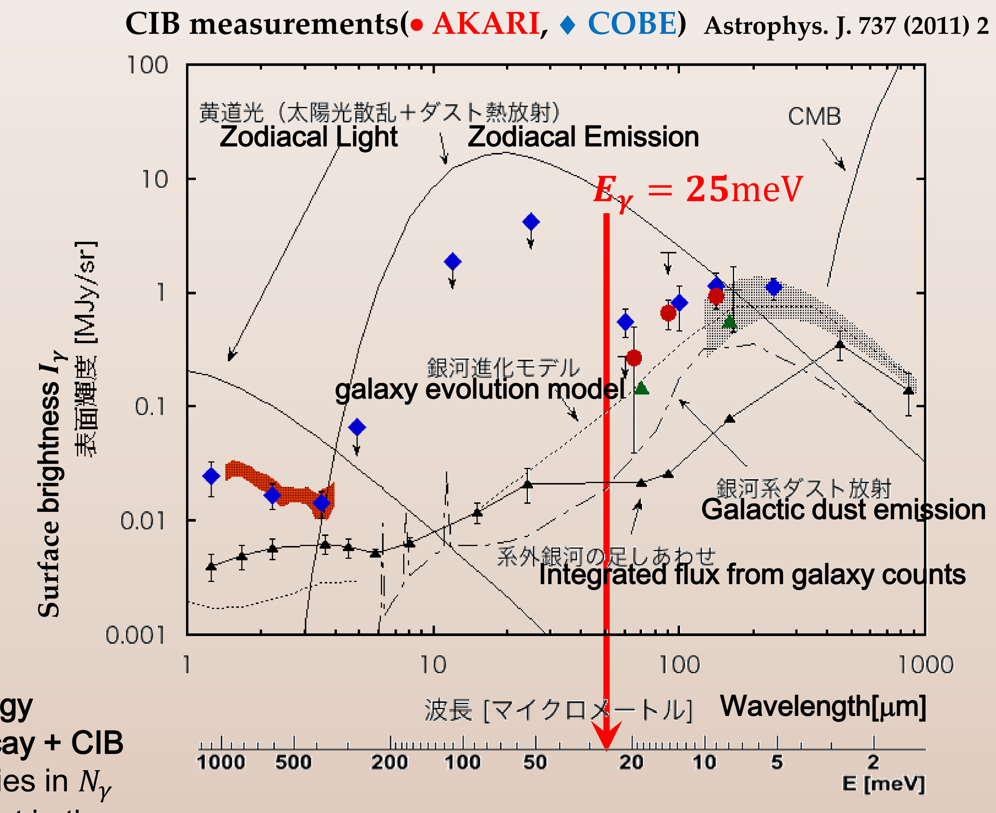
we can detect CνB decay photon for $m_3 = 50$ meV and $\tau(\nu_3) = 1.5\times10^{17}$yr at 6.7σ significance.

Expected E_γ spectrum for $m_3 = 50$meV and $\tau(\nu_3) = 1.5\times10^{17}$yr



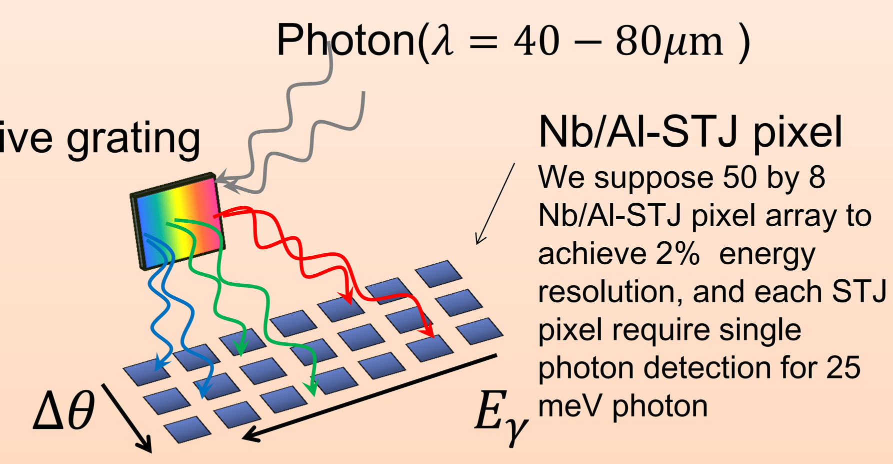
Differential photon energy spectrum from CνB decay + CIB
- Statistical uncertainties in N_γ are taken into account in the error bars

CIB measurements(● AKARI, ♦ COBE) Astrophys. J. 737 (2011) 2

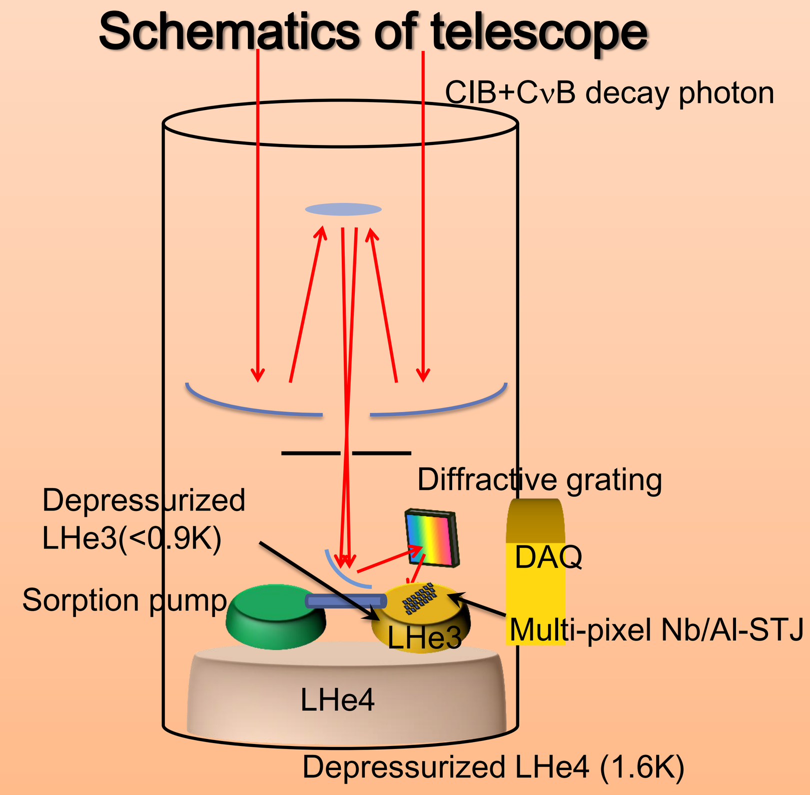


Rocket experiment

We plan to perform a rocket experiment with a superconducting tunneling junction (STJ) based detector in 2016 in the earliest, aiming at improving the current experimental lower limit of the neutrino lifetime by 2 order in a 5-minute measurement: $\tau(\nu_3)$>O(10^{14} yr) . We will also aim at a measurement of $\tau(\nu_3)$>O(10^{17}yr) for the neutrino lifetime in a 10-hour satellite based measurement in further future.



Schematics of telescope



Detector design

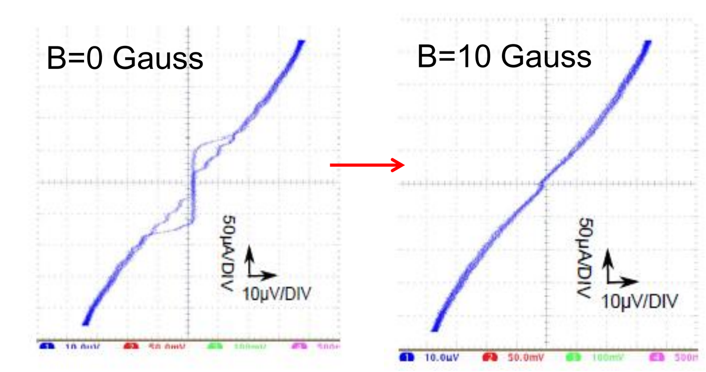
We are developing the following single photon detectors to cope with 2% energy resolution at $E_\gamma = 25$ meV.

- Multi-pixel Nb/Al-STJ with diffractive grating for the photon in $\lambda = 40 - 80\mu m$ ➔P-47, P-48
- Hafnium based STJ (Hf-STJ)

Hf-STJ development

Since hafnium has much smaller superconducting gap energy ($\Delta_{\mathrm{Hf}} = 20\mu$eV) than niobium ($\Delta_{\mathrm{Nb}} = 1.55$meV), 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.

We are developing Hf-STJ and have established to process SIS structure by hafnium in 2011, which could be confirmed by observation of the Josephson current. Currently, our trial Hf-STJ samples have large leak currents, and need more improvement to function as a far infrared photon detector.



I-V curve of Hf-STJ (w/o, w/i magnetic field)
- 200x200μm² junction size
- T~80mK
- Critical current of Josephson current I_c=60μA
- Dynamic resistance R_d=0.2Ω

Summary

- There is a chance to observe to neutrino radiative decay ($\nu_3 \to \nu_{1,2} + \gamma$) in CνB, if we assume L-R symmetric model.
- We are developing STJ-based detectors to detect a photon from CνB decay.
- A rocket experiment using the STJ detectors for neutrino decay search is in preparation.