# Development of STJ with FD-SOI cryogenic amplifier as a far-infrared single photon detector for COBAND experiment




17th International workshop on Low Temperature d Detectors (LTD17)

Jul. 17-21, 2017 / Kurume City Plaza, Kurume

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**COBAND collaboration**

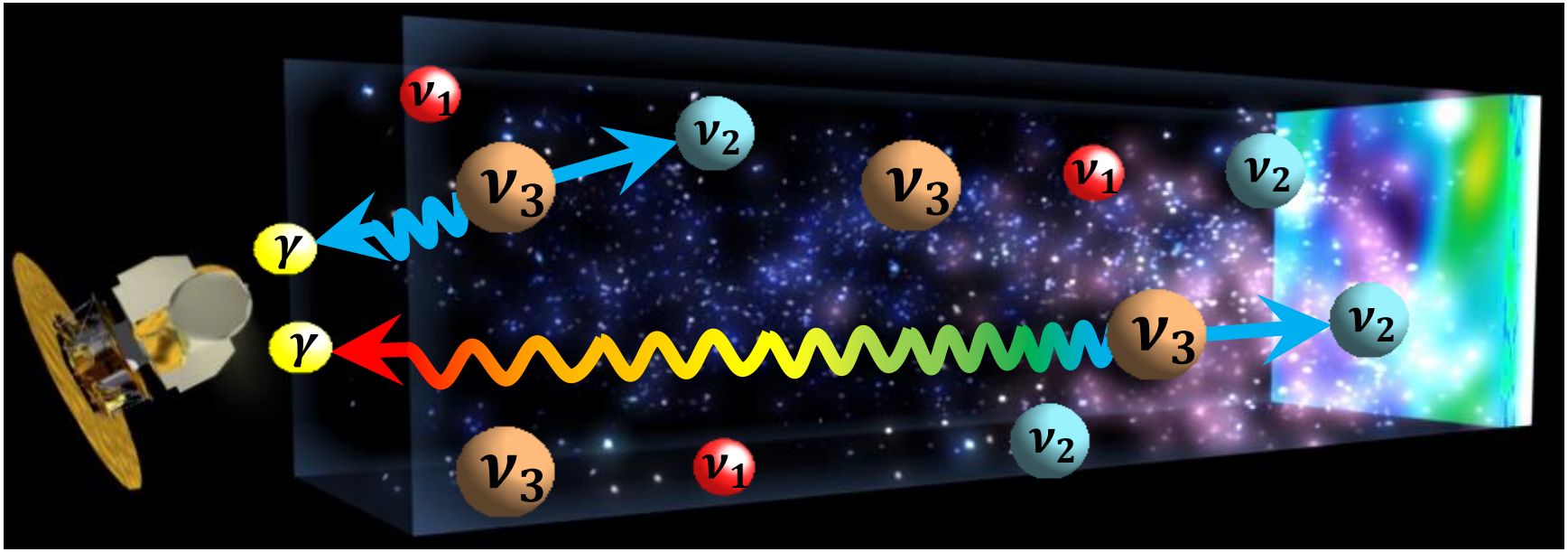
# COBAND (COsmic BAckground Neutrino Decay)

**Search for Neutrino decay in Cosmic background neutrino**

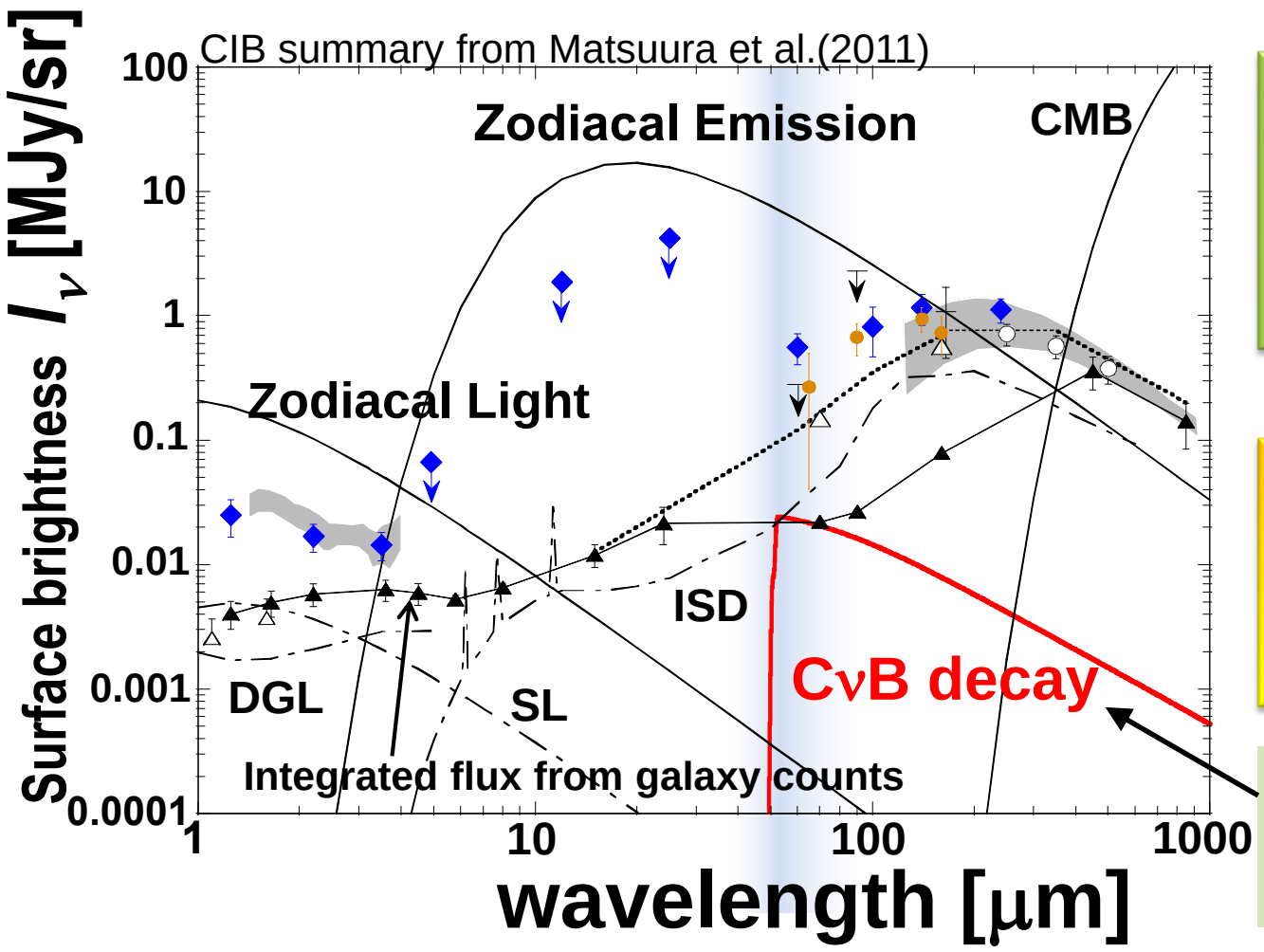
**➔To be observed as far infrared photons of λ~50μm**

COBAND Rocket Experiment

- 200-sec measurement at an altitude of 200~300km
- Aiming at a sensitivity to $10^{14}$ years for the neutrino lifetime



# Neutrino Decay signal and backgrounds




**Zodiacal Emission**
**$I_{ZE}$=8MJy/sr**

**Neutrino Decay**
**$I_\nu$=25kJy/sr**

$\tau = 1 \times 10^{14}\mathrm{yrs}$
$m_3 = 50\ \mathrm{meV}$

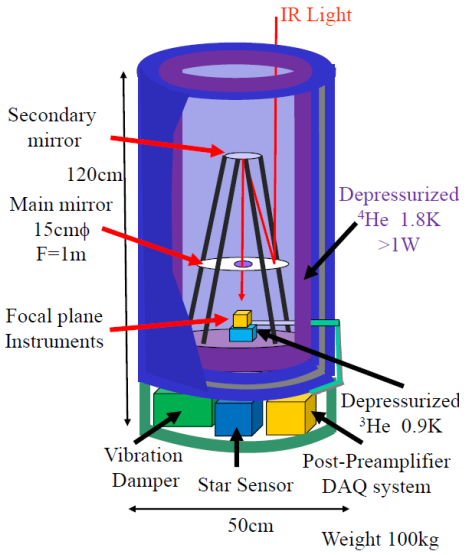
**No other source has such a sharp edge structure!!**

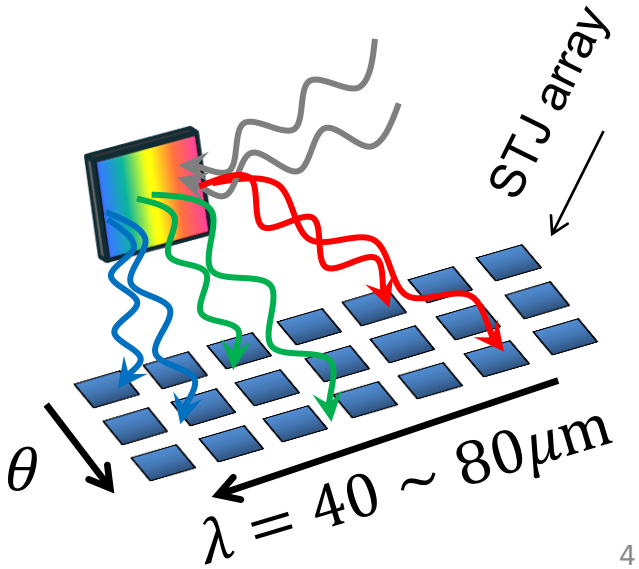
# Proposal for COBAND Rocket Experiment

Aiming at a sensitivity to $\nu$ lifetime for $\tau(\nu_3) = O(10^{14})\ \mathrm{yrs}$

JAXA sounding rocket S-520

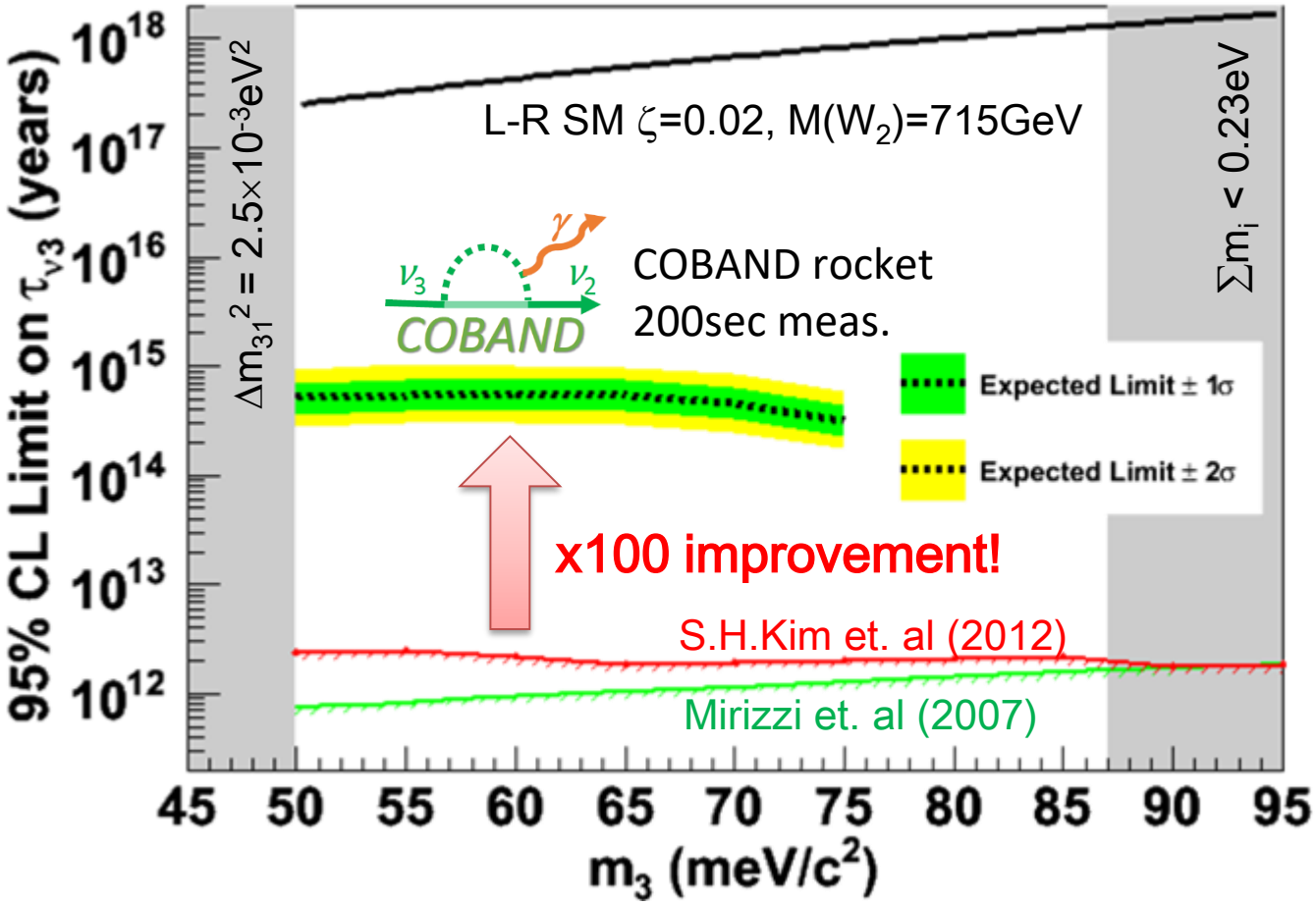
- Telescope with **15cm diameter** and **1m focal length**
- At the focal point, a diffraction grating covering **λ=40-80μm** and an array of photo-detector pixels of **50(λ) x 8(θ)** are placed.
- Each pixel has **100μmx100μm** sensitive area.



# COBAND rocket experiment sensitivity

- 200-sec measurements with a sounding rocket
- 15cm dia. and 1m focal length telescope and grating in 40~80μm range
- Each pixel in 100μm×100μm×8×50pix. array counts number of photons



# Requirements for the photo-detector in COBAND rocket experiment

- Sensitive area of 100μm×100μm for each pixel
- High detection efficiency for a far-infrared single-photon in λ=40μm ~ 80μm
- Dark count rate less than 300Hz (expected real photon rate)

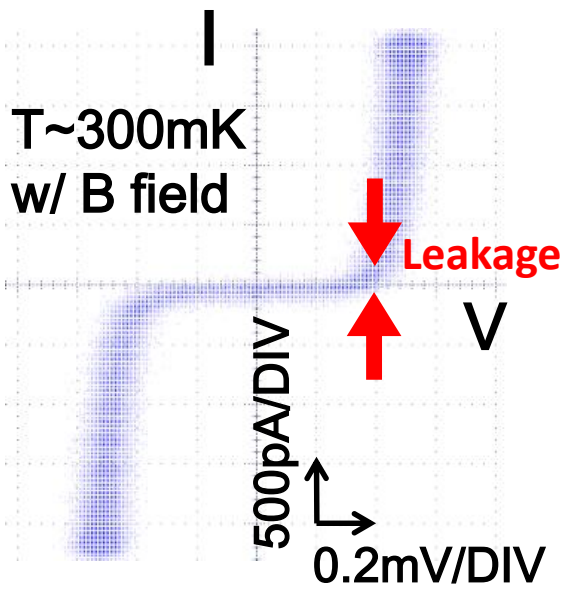
$$\rightarrow \mathrm{NEP} = \epsilon_\gamma \sqrt{2 f_\gamma} \sim 1 \times 10^{-19}\, W/\sqrt{Hz}$$

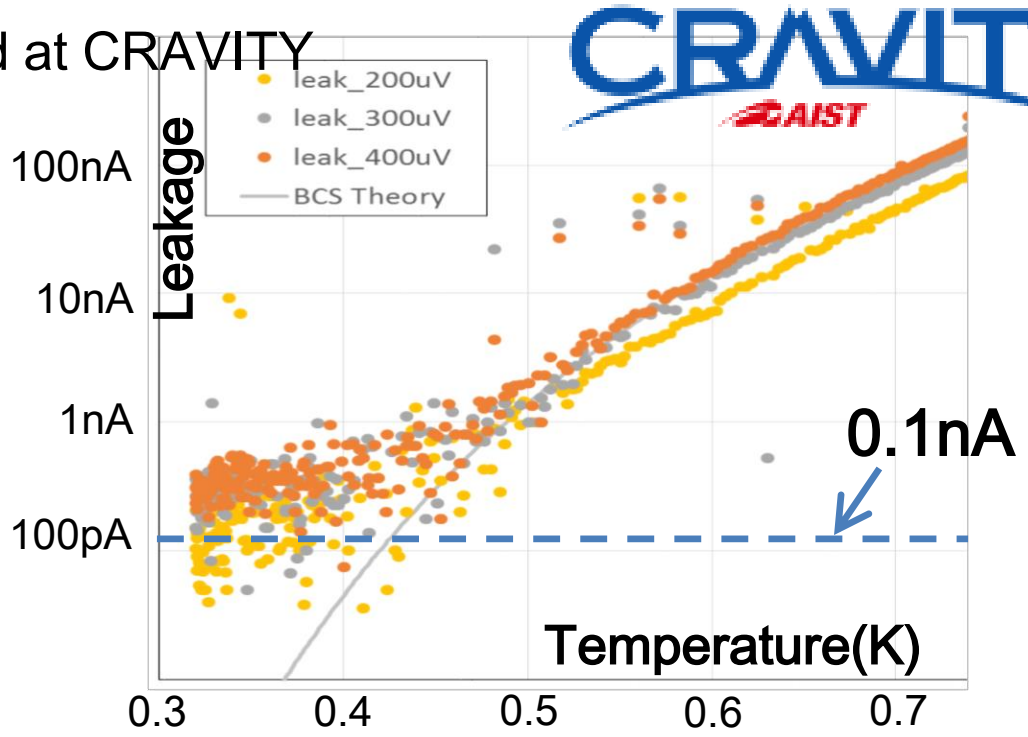
We are trying to achieve $\mathrm{NEP} \sim 10^{-19}\, W/\sqrt{Hz}$ **by using**

- **Superconducting Tunneling Junction detector**
- **Cryogenic amplifier readout**

# Nb/Al-STJ development at CRAVITY

50μm sq. Nb/Al-STJ fabricated at CRAVITY



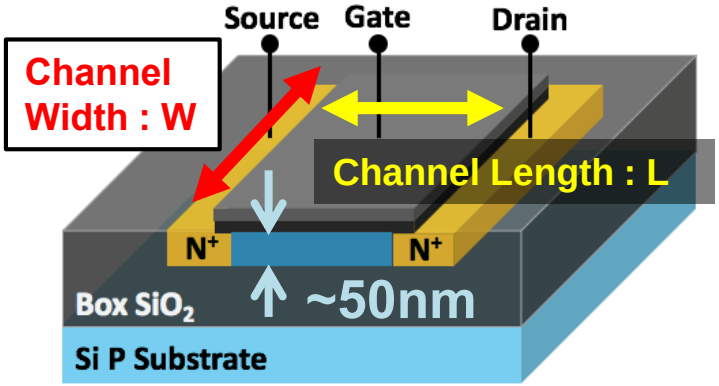

$I_{leak}$~200pA for 50μm sq. STJ, and achieved 50pA for 20μm sq.

➔ This satisfies our requirement!

Far-infrared single photon detection is feasible with this Nb/Al-STJ device and a cryogenic amplifier which can be deployed in close proximity to the STJ.

# FD-SOI-MOSFET at cryogenic temperature

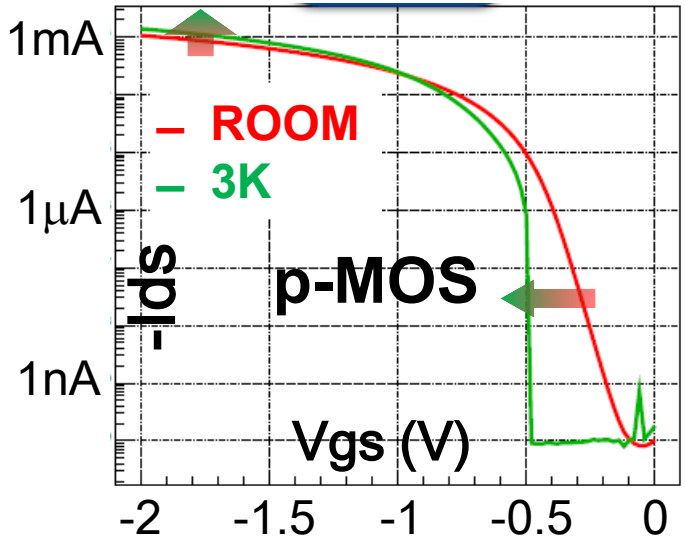
## FD-SOI : Fully Depleted – Silicon On Insulator

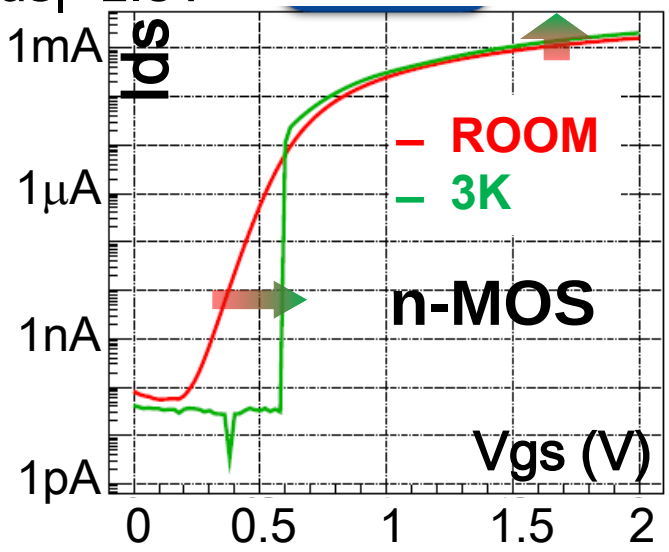



- Very thin channel layer in MOSFET on $SiO_2$
- No floating body effect caused by charge accumulation in the body
- FD-SOI-MOSFET is reported to work at 4K

JAXA/ISIS **AIPC 1185,286-289(2009)**
J Low Temp Phys 167, 602 (2012)

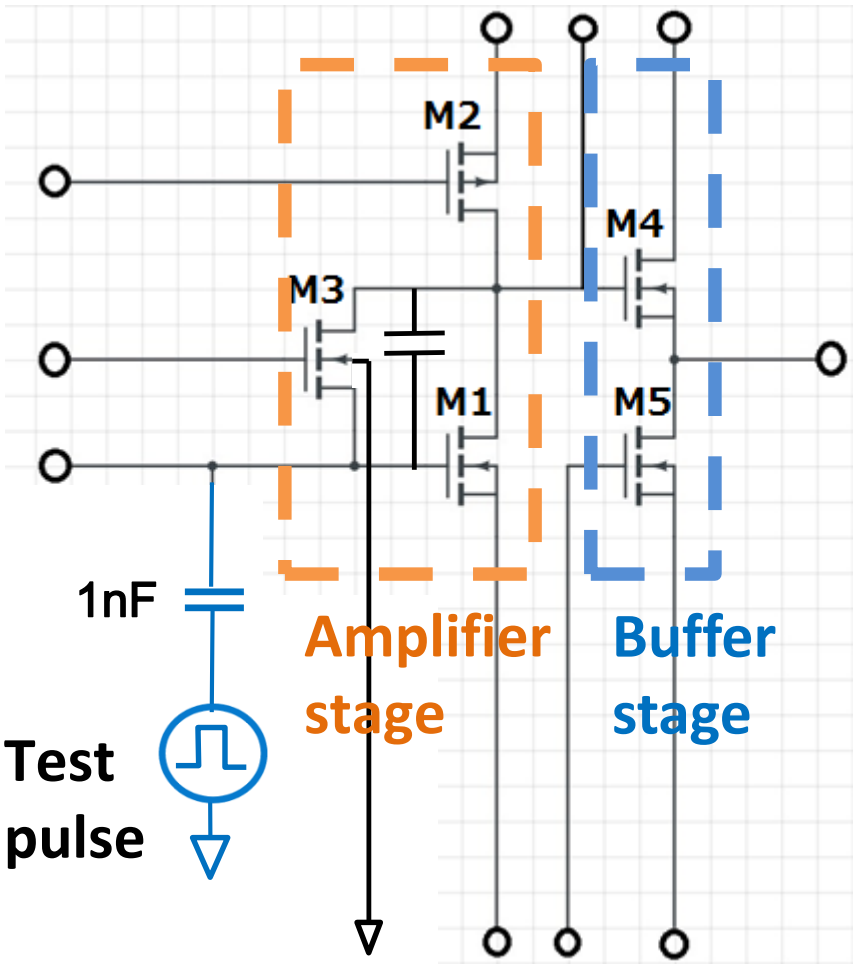
Id-Vg curve of W/L=10μm/0.4μm at |Vds|=1.8V

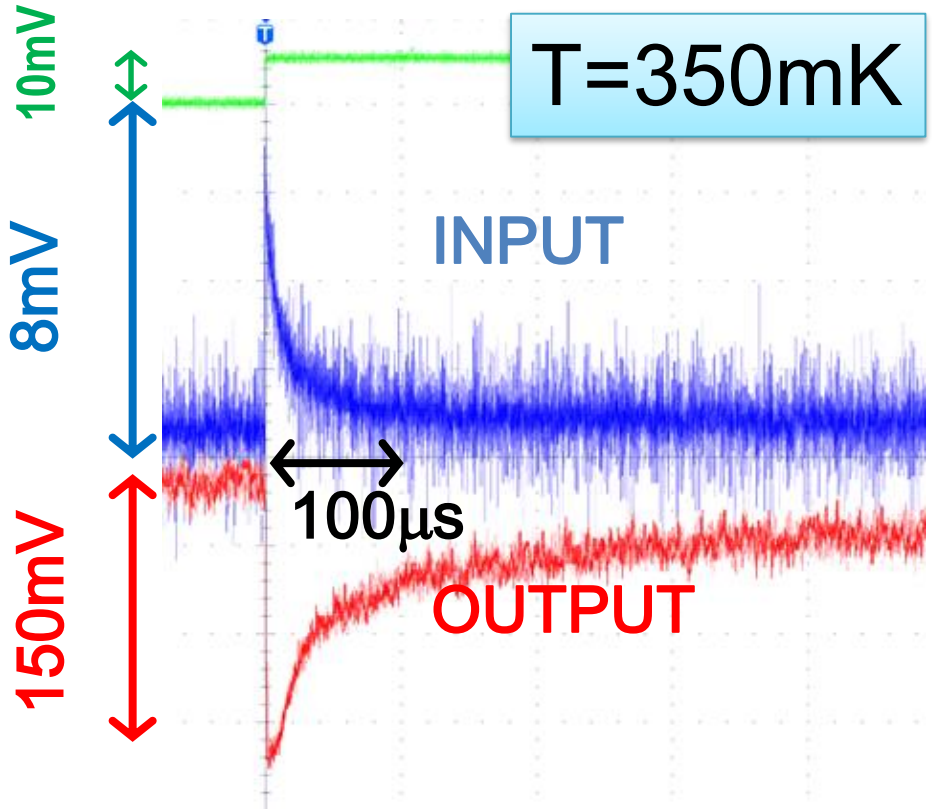



Both p-MOS and n-MOS show excellent performance at 3K and below.

# SOI prototype amplifier for demonstration test



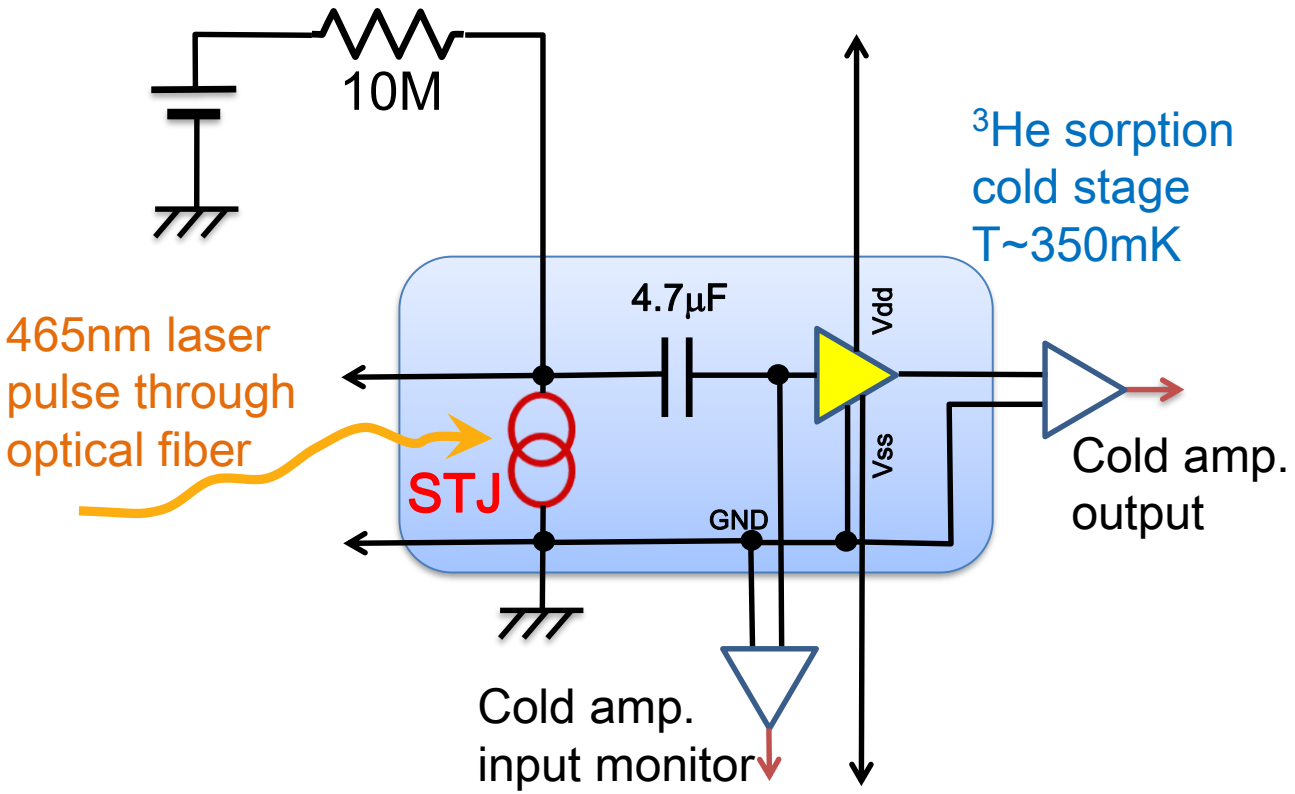



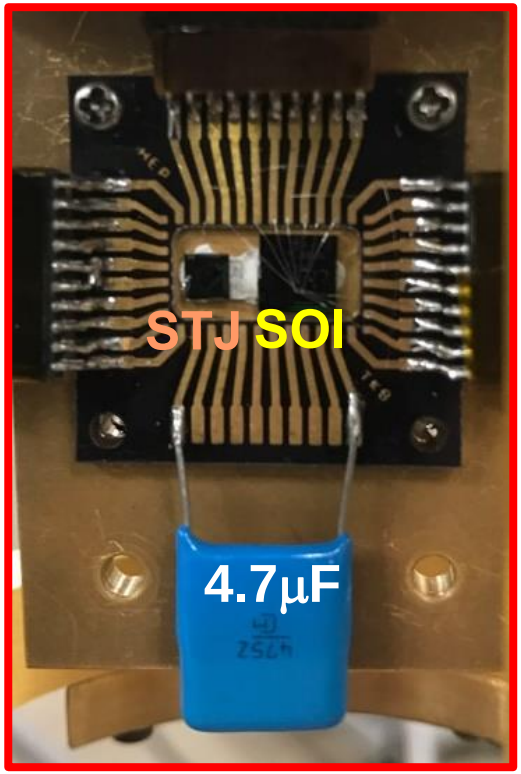

Test pulse input through C=1nF at T=3K and 350mK

- Power consumption: ~100µW
- Output load: 1MΩ and ~0.5nF

We can compensate the effect of shifts in the thresholds by adjusting bias voltages.

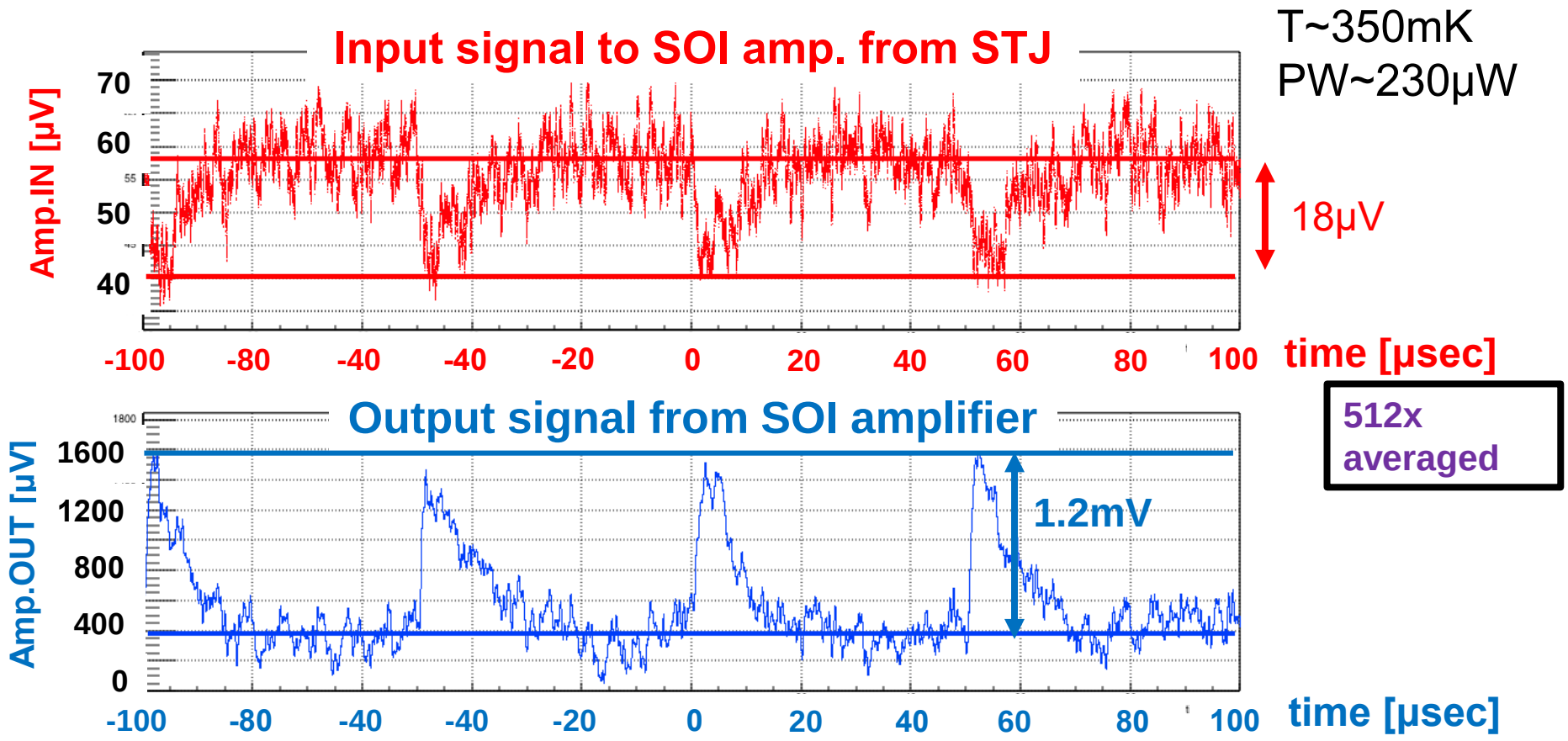
# STJ response to laser pulse amplified by Cold amplifier




We connect 20μm sq. Nb/Al-STJ and SOI amplifier on the cold stage through a capacitance

# STJ response to laser pulse amplified by Cold amplifier




We observe 20μm sq. Nb/Al-STJ responses to laser pulses of λ=465nm amplified by SOI amplifier situated at T=350mK

# Summary

- We propose COBAND experiment to search for neutrino radiative decay in cosmic neutrino background.
- Requirements for the detector is a photo-detector with NEP~$10^{-19}$ W/$\sqrt{}$Hz.
- Nb/Al-STJ array with a diffractive for the sounding rocket experiment.
  - Nb/Al-STJs fabricated at CRAVITY satisfy our requirements.
  - Cryogenic FD-SOI amplifiers are under development and we demonstrated STJ signal amplification by a prototype SOI amplifier at T~350mK.
- Improvement of the neutrino lifetime lower limit up to O($10^{14}$yrs) is feasible for 200-sec measurement in a rocket-borne experiment with the detector.

* SOI design in this work is supported by VDEC, the U. Tokyo in collaboration with Synopsys, Inc., Cadence Design Systems, Inc., and Mentor Graphics, Inc.