COBAND プロジェクト

TCHoU

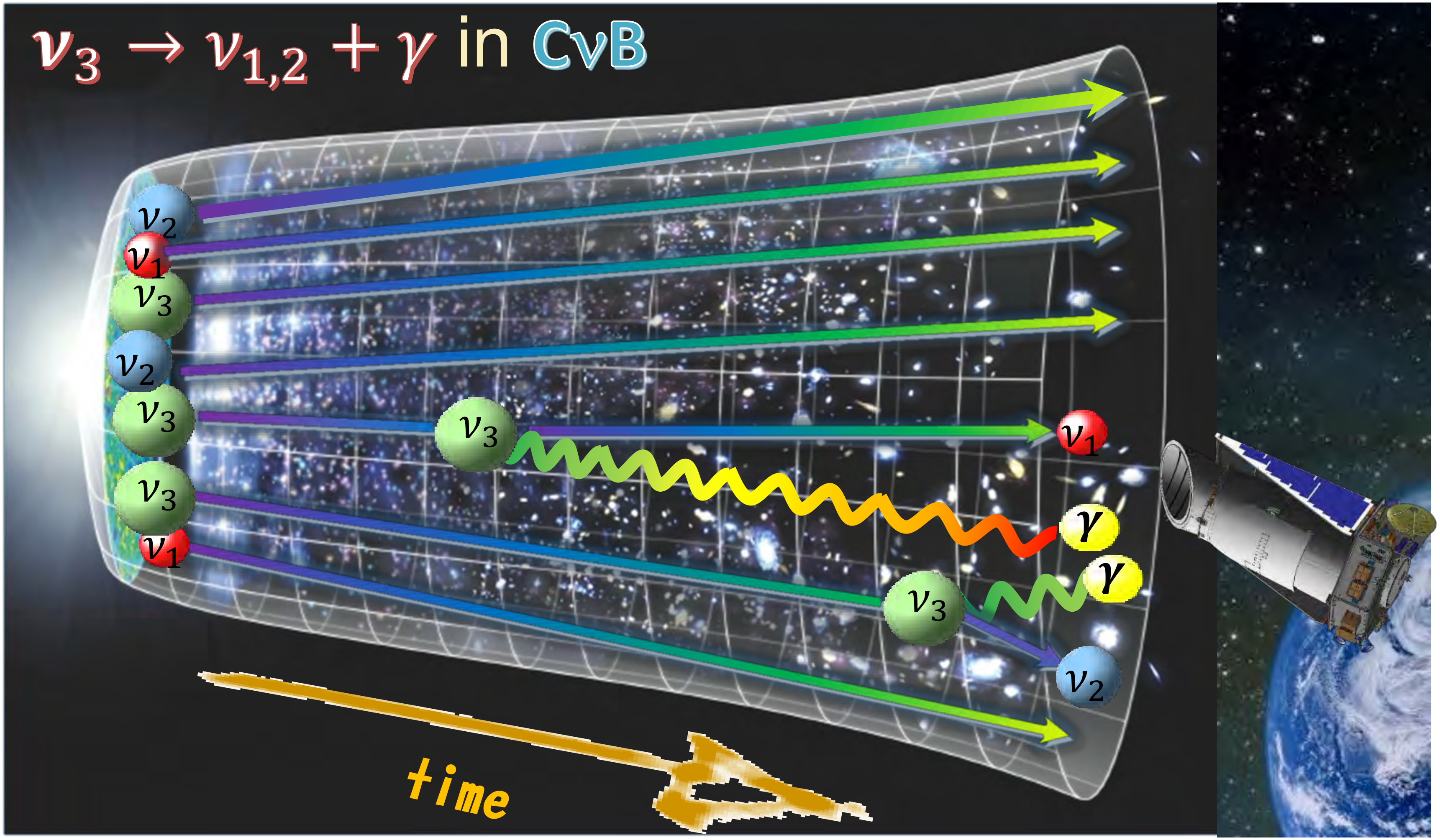
成果報告会 2018/6/4

武内 勇司

COBAND (COsmic BAckground Neutrino Decay)

Search for Neutrino decay in Cosmic background neutrino

➔To be observed as photons in neutrino decays



COBAND Collaboration Members (As of Mar. 2018)

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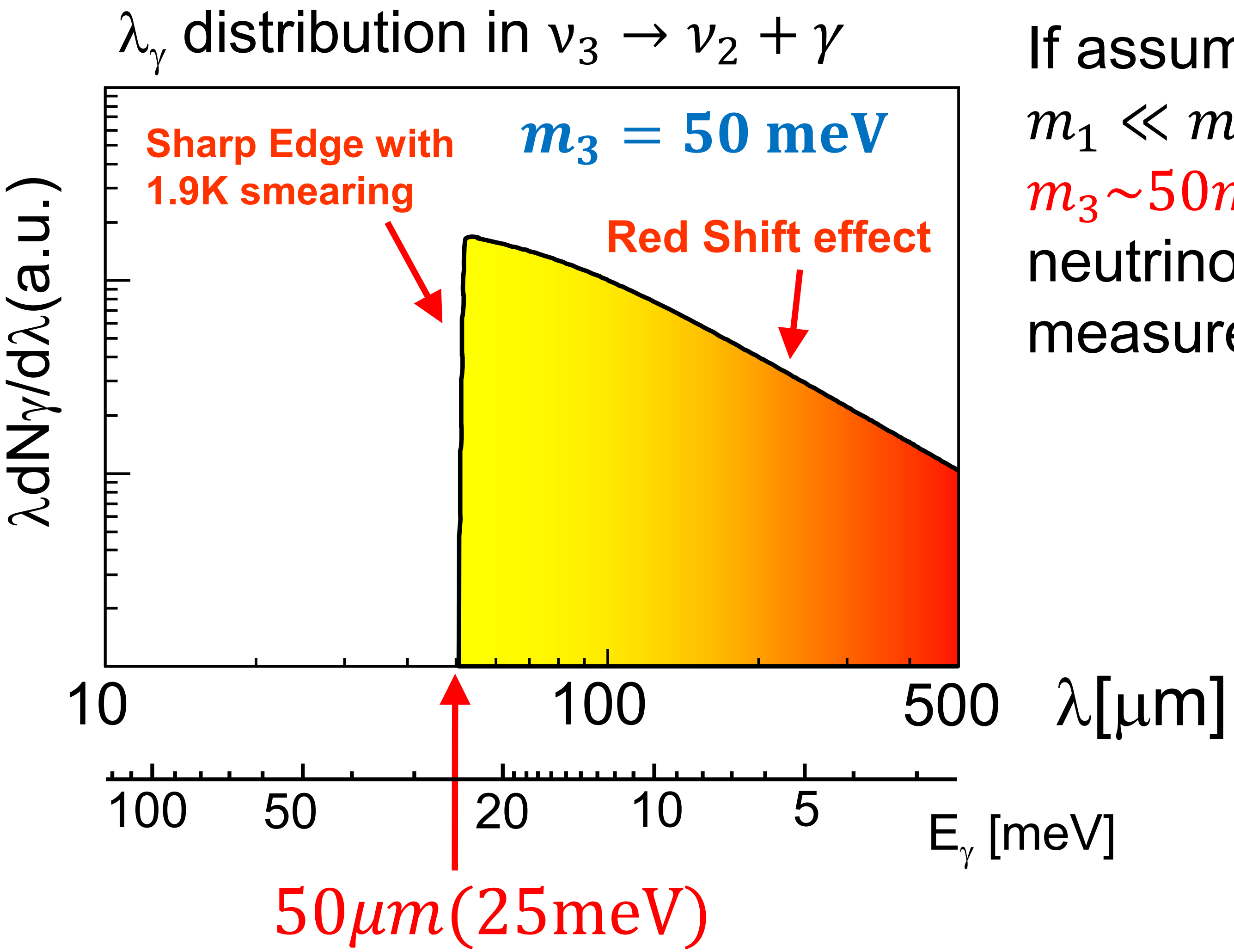
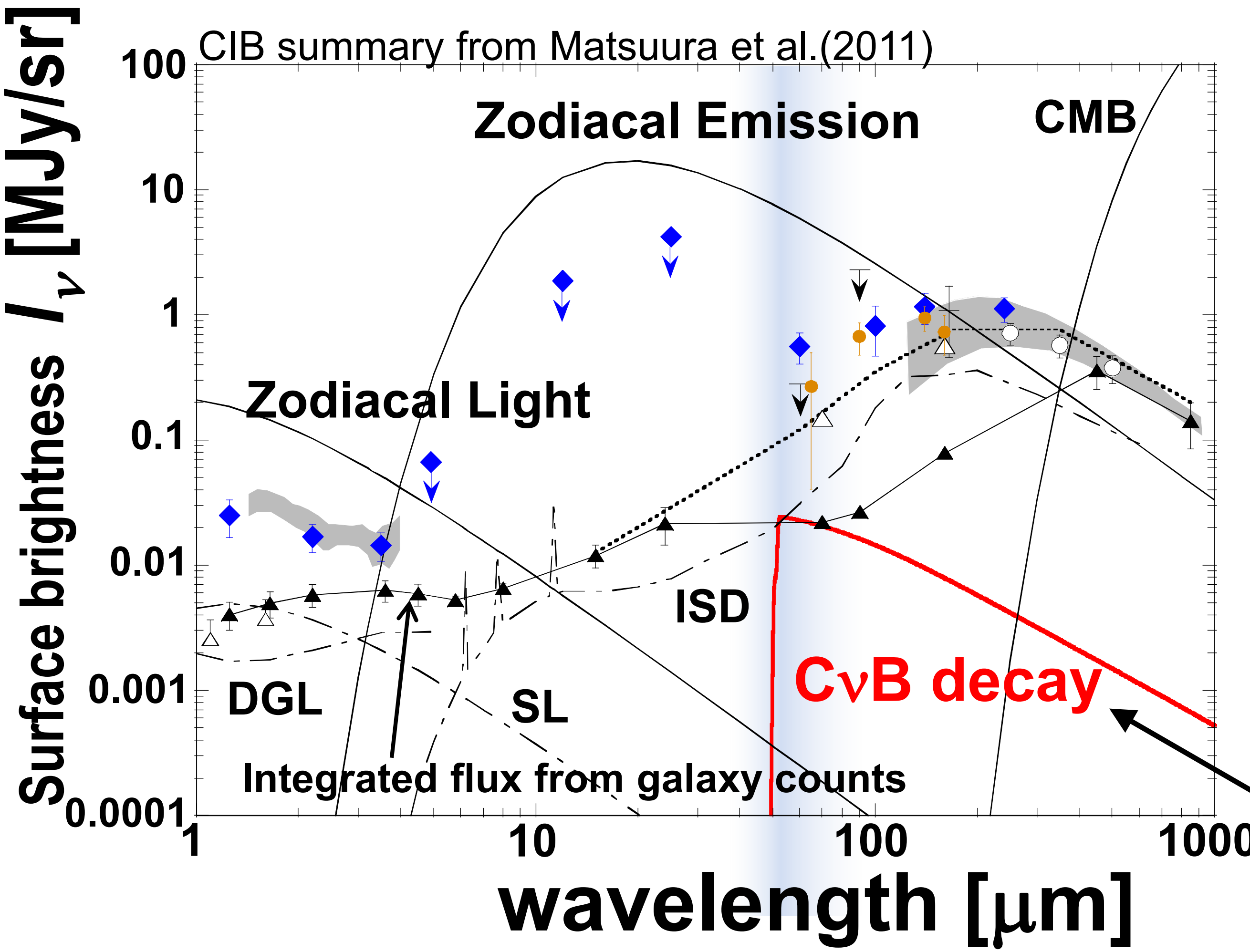
Expected photon wavelength spectrum from CνB decays



If assume $m_1 \ll m_2 < m_3$, $m_3 \sim 50meV$ from neutrino oscillation measurements

No other source has such a sharp edge structure!!

Neutrino Decay signal and backgrounds



Zodiacal Emission

I_{ZE}**=8MJy/sr**

Neutrino Decay

I_ν**=25kJy/sr**

$\tau = 1 \times 10^{14}\text{yrs}$

$m_3 = 50\ \text{meV}$

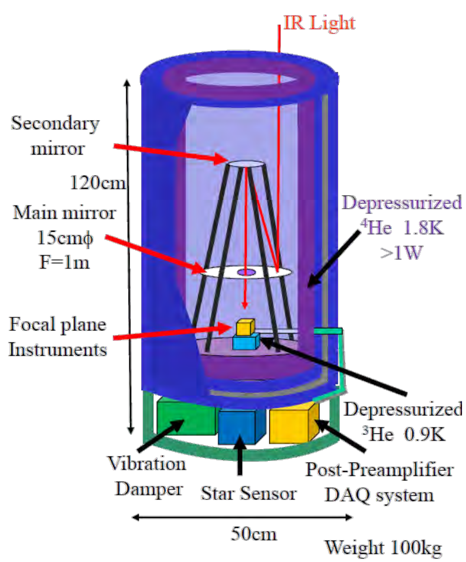
No other source has such a sharp edge structure!!

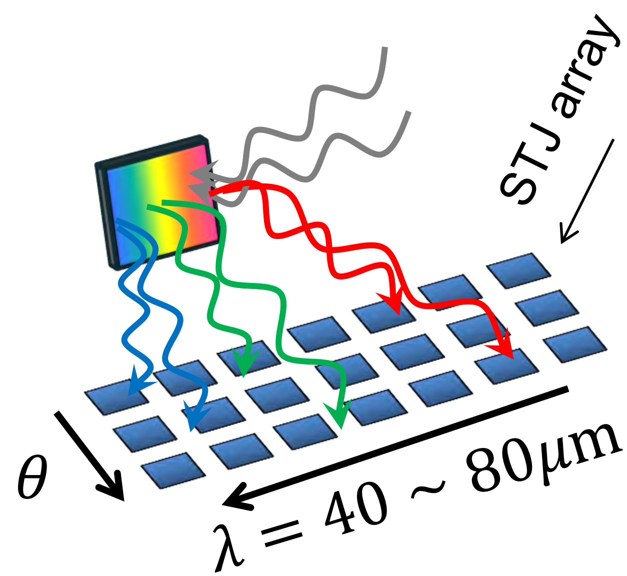
Proposal for COBAND Rocket Experiment

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

JAXA sounding rocket S-520

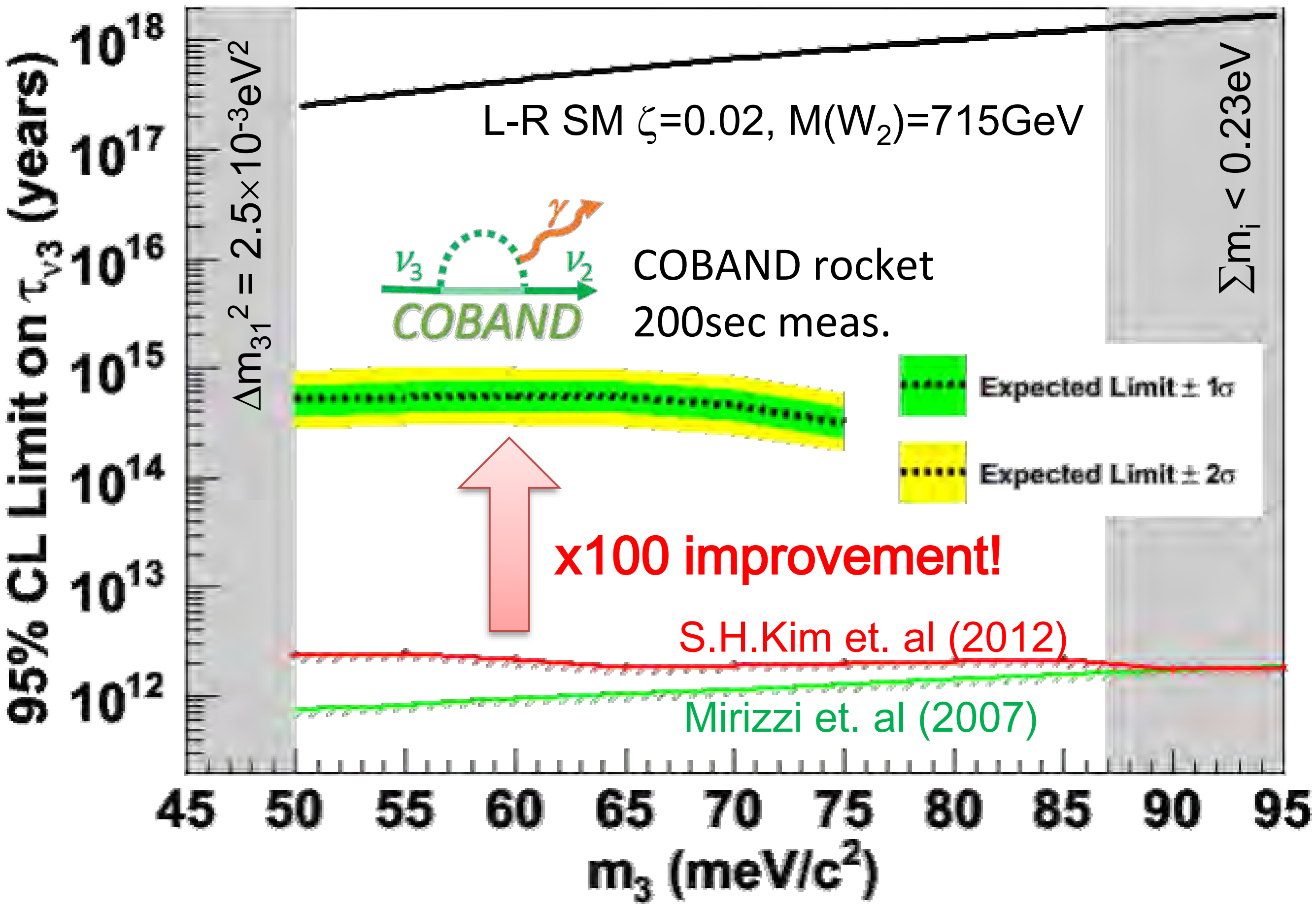
- Telescope with **15cm diameter** and **1m focal length**
- At the focal point, a diffraction grating covering **λ=40-80μm** and an array of photo-detector pixels of **50(λ) x 8(θ)** are placed.
- Each pixel has **100μmx100μm** sensitive area.





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-sensor 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)

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

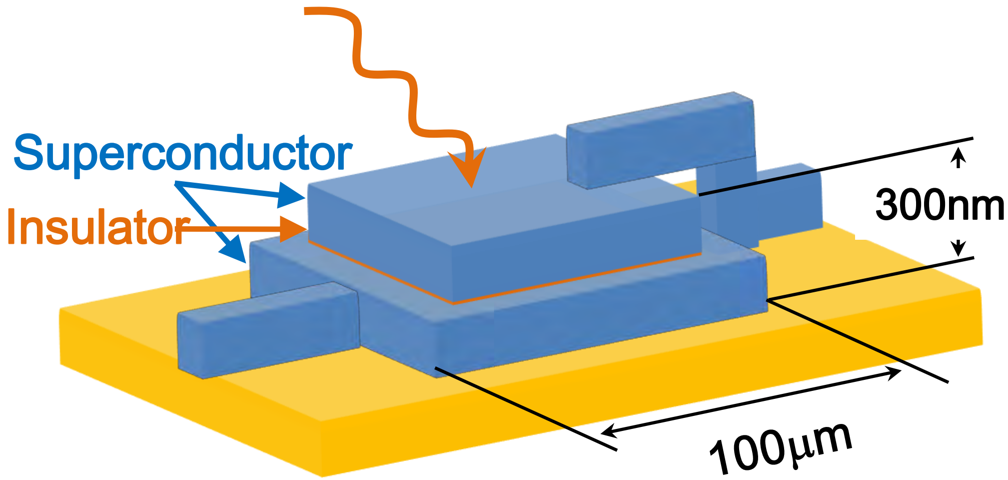
We are trying to achieve $\mathrm{NEP} \sim 10^{-19}\, W/\sqrt{Hz}$ **by using**

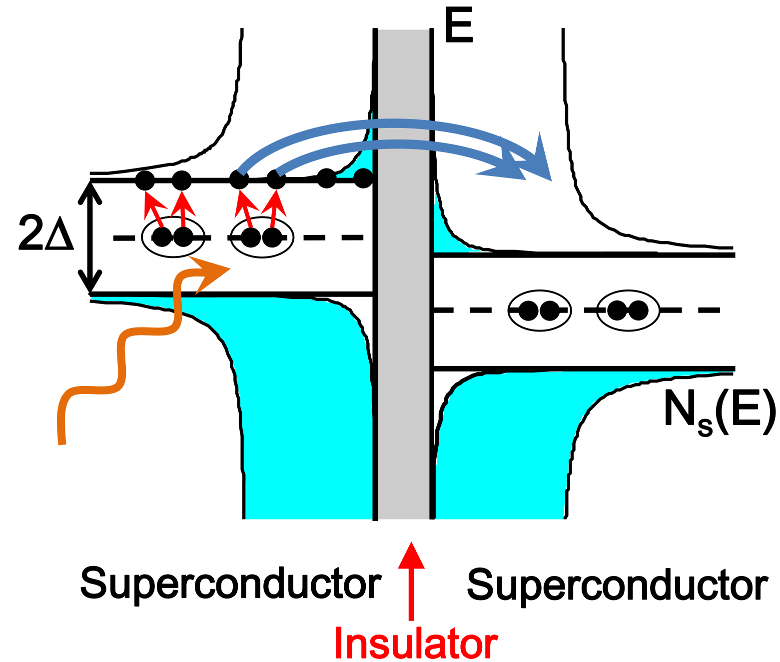
- **Superconducting Tunneling Junction detector**
- **Cryogenic amplifier readout**

Superconducting Tunnel Junction (STJ)

Superconductor / Insulator /Superconductor

Josephson junction device





Δ: Superconducting gap energy

A constant bias voltage (|V|<2Δ) is applied across the junction.
A photon absorbed in the superconductor breaks Cooper pairs and creates tunneling current of quasi-particles proportional to the deposited photon energy.

- Much lower gap energy (Δ) than FIR photon ➔ Can detect FIR photon
- Faster response (~μs) ➔ Suitable for single-photon counting

STJ candidates

	Si	Nb	Al	Hf
Tc[K]		9.23	1.20	0.165
Δ[meV]	1100	1.550	0.172	0.020

Nb/Al-STJ

- Well-established
  - Δ~0.6meV by the proximity effect from Al
  - Operation temperature <400mK
  - Back-tunnelling gain G_{Al}~10
- $N_{q.p.}$=25meV/1.7Δ×G_{Al}~ 250 σ_E/E~10% for E=25meV

➔ 25meV single-photon detection is feasible in principle

➔ Developing for the rocket experiment

Hf-STJ

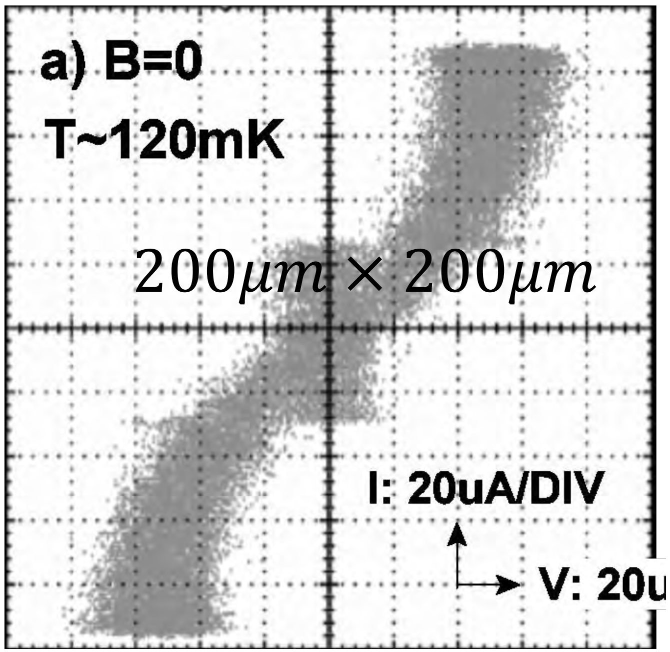
- Not established as a practical photo-detector yet by any group
- $N_{q.p.}$=25meV/1.7Δ~ 735 σ_E/E<2% for E=25meV

➔ Spectrum measurement without a diffraction grating

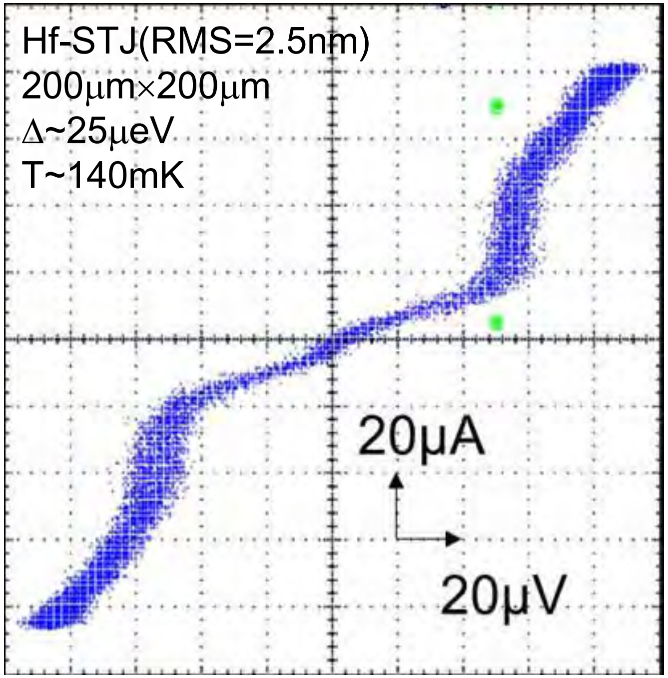
➔ Developing for a future satellite experiment

Hf-STJ development

We successfully made a device with SIS in 2010. We need to suppress leakage down to ~pA for practical usage.



200μm sq. Hf-STJ in 2010

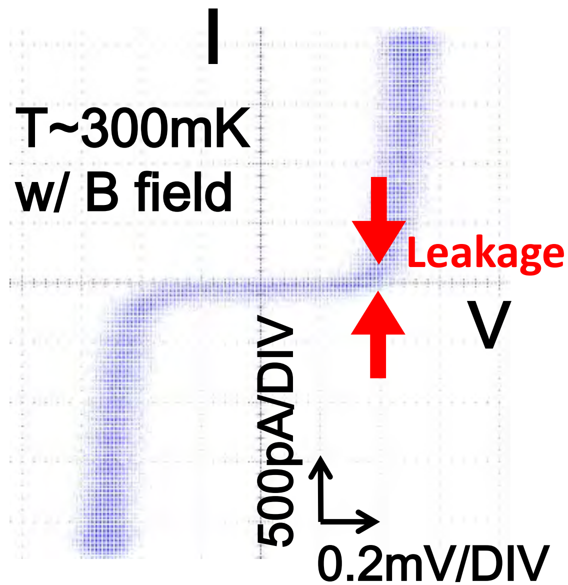


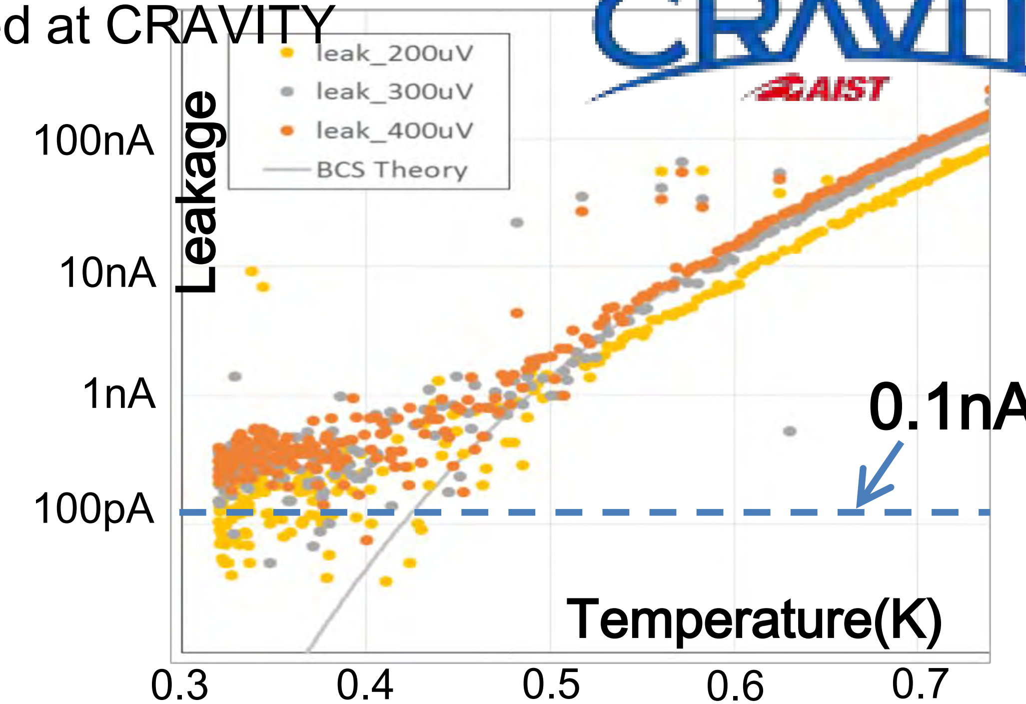
200μm sq. Hf-STJ in 2017

Detailed status in K.Takemasa's talk

Nb/Al-STJ development at CRAVITY

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



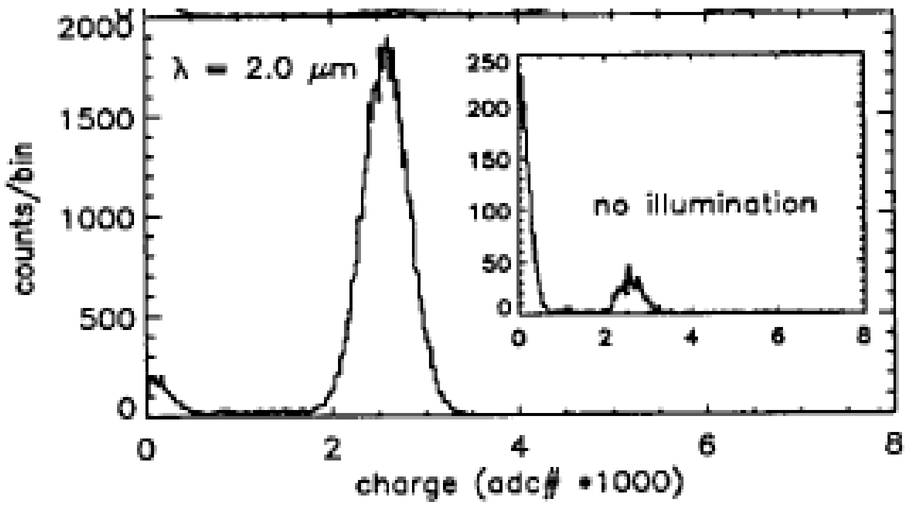


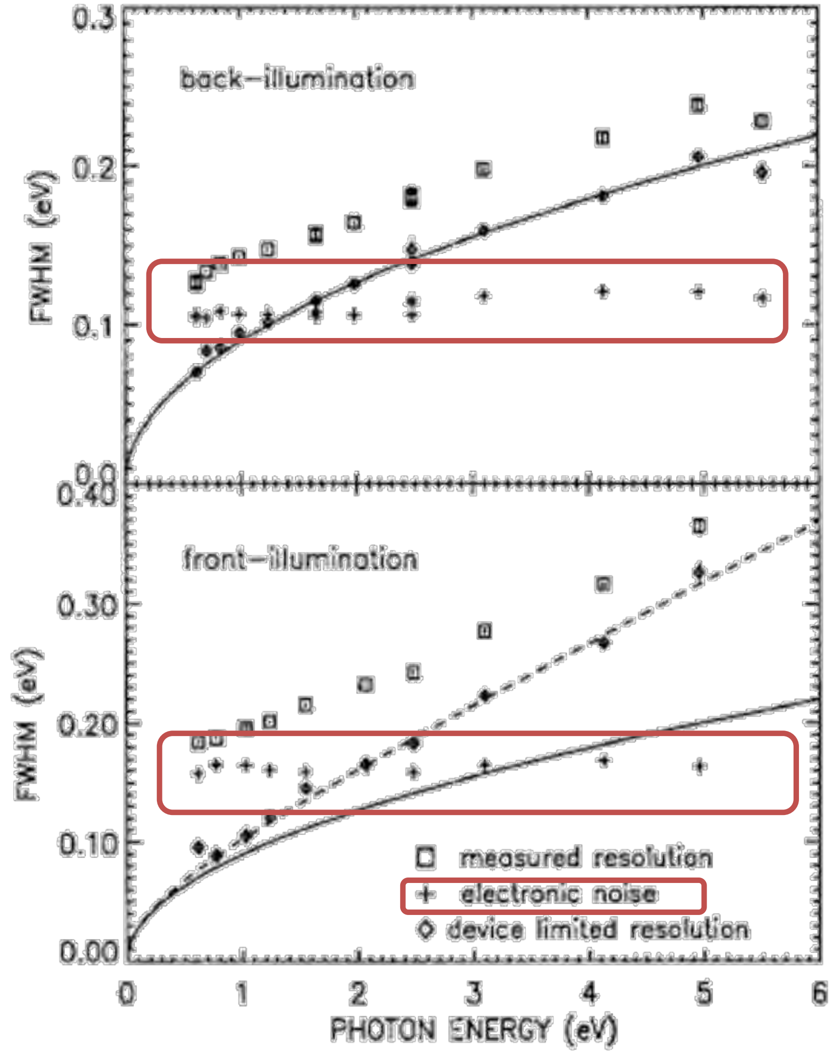
I_{leak}~200pA for 50μm sq. STJ, and achieved 50pA for 20μm sq.

➔ This satisfies our requirement!

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

STJ energy resolution for near infrared photon





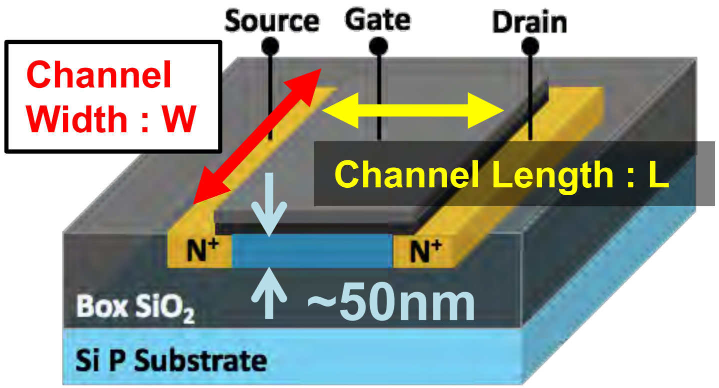
P. Verhoeve et. al 1997

- 30μm sq. Ta/Al-STJ
- ΔE~130meV @ E=620meV(λ=2μm)
- Charge sensitive amplifier at room temp.
  - Electronic noise ~ 100meV

In sub-eV ~ several-eV region, STJ gives the best energy resolution among superconductor based detectors, but limited by readout electronic noise.

FD-SOI-MOSFET at cryogenic temperature

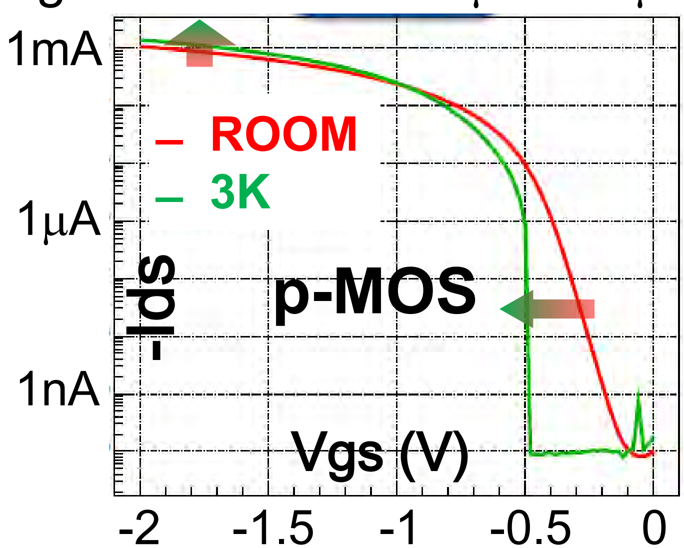
FD-SOI : **F**ully **D**epleted – **S**ilicon **O**n **I**nsulator

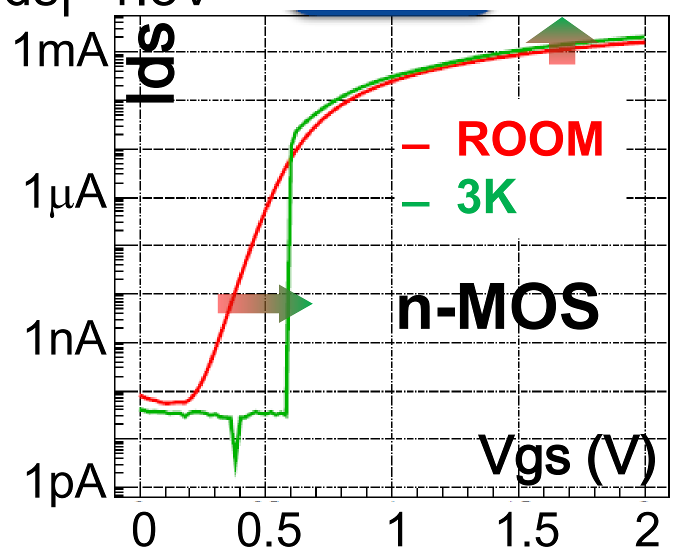


- Very thin channel layer in MOSFET on SiO_2
- No floating body effect caused by charge accumulation in the body
- FD-SOI-MOSFET is reported to work at 4K

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

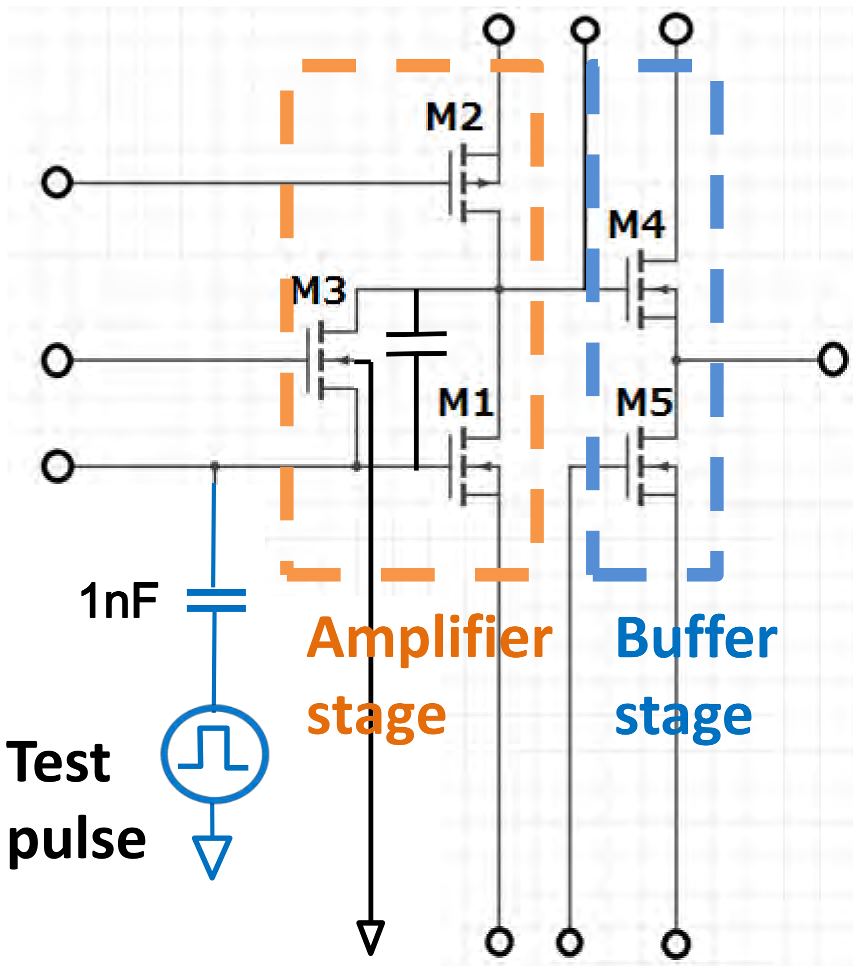
Id-Vg curve of W/L=10μm/0.4μm at |Vds|=1.8V

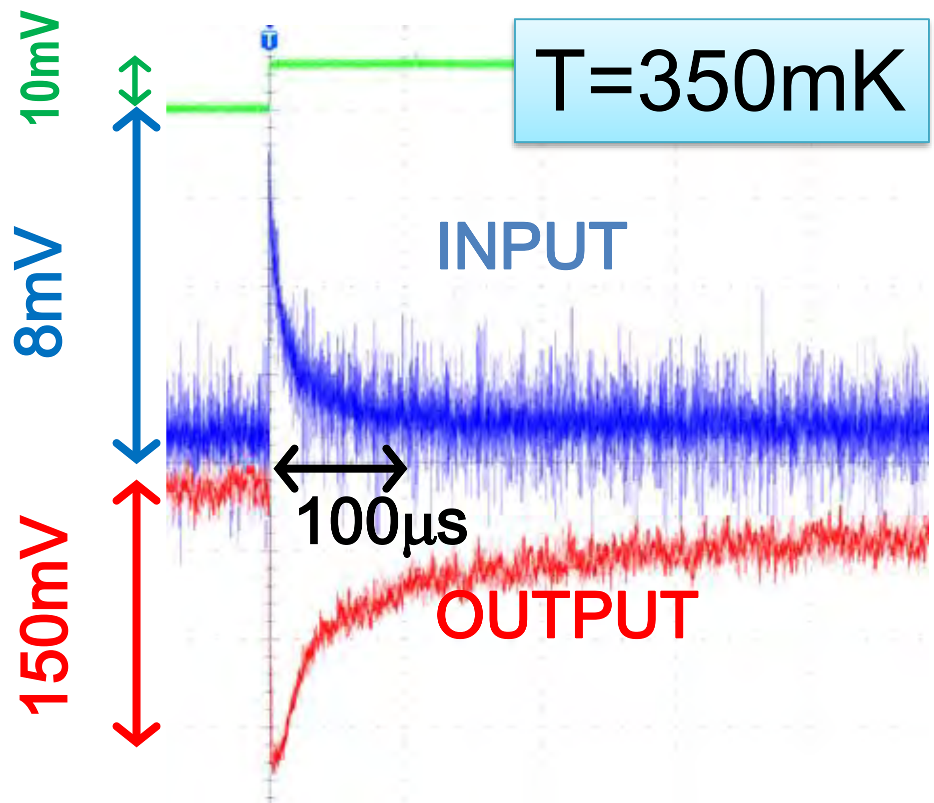




Both p-MOS and n-MOS show excellent performance at 3K and below.

SOI prototype amplifier for demonstration test



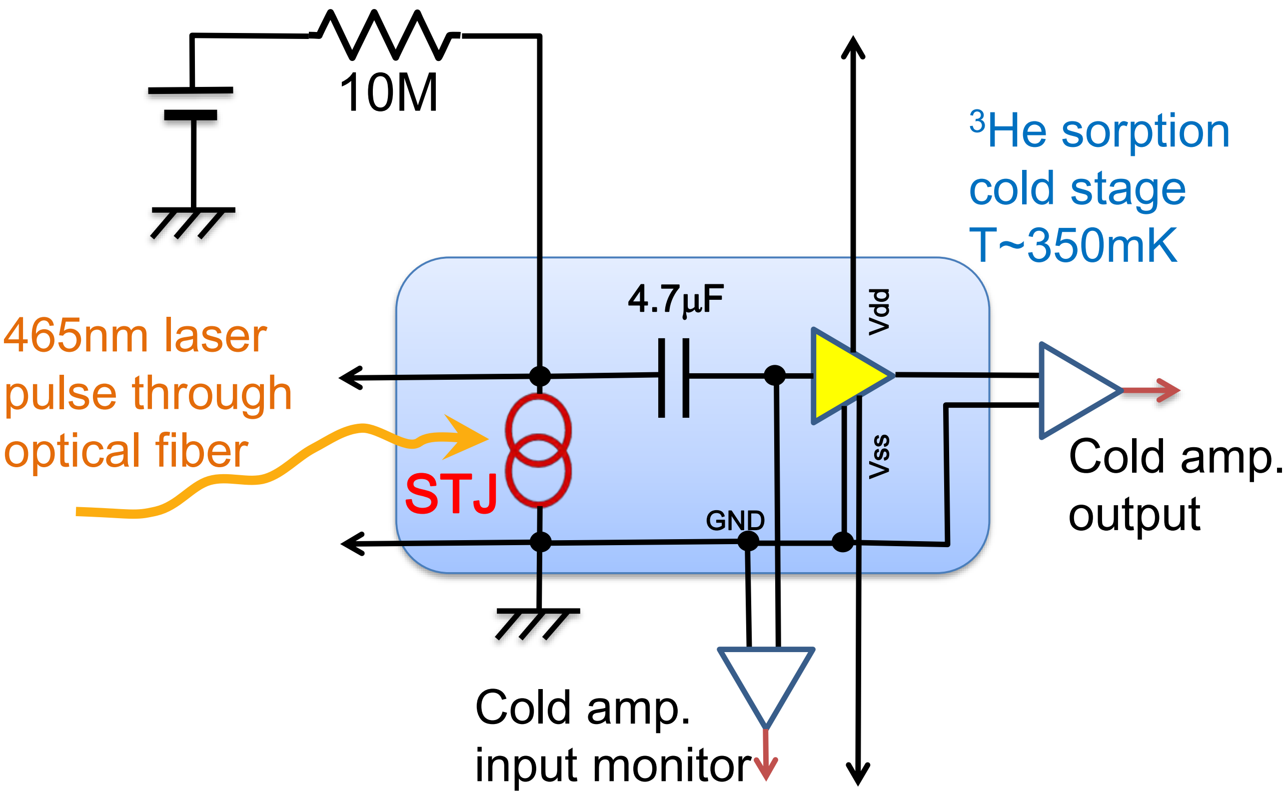


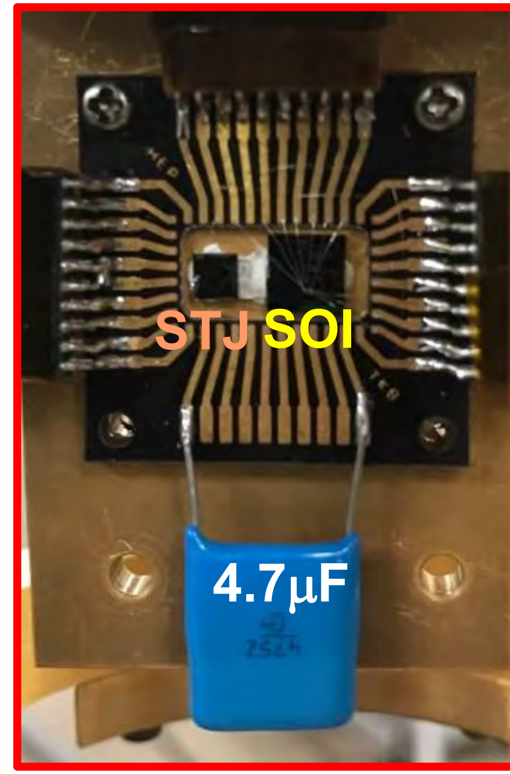
Test pulse input through C=1nF at T=3K and 350mK

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

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

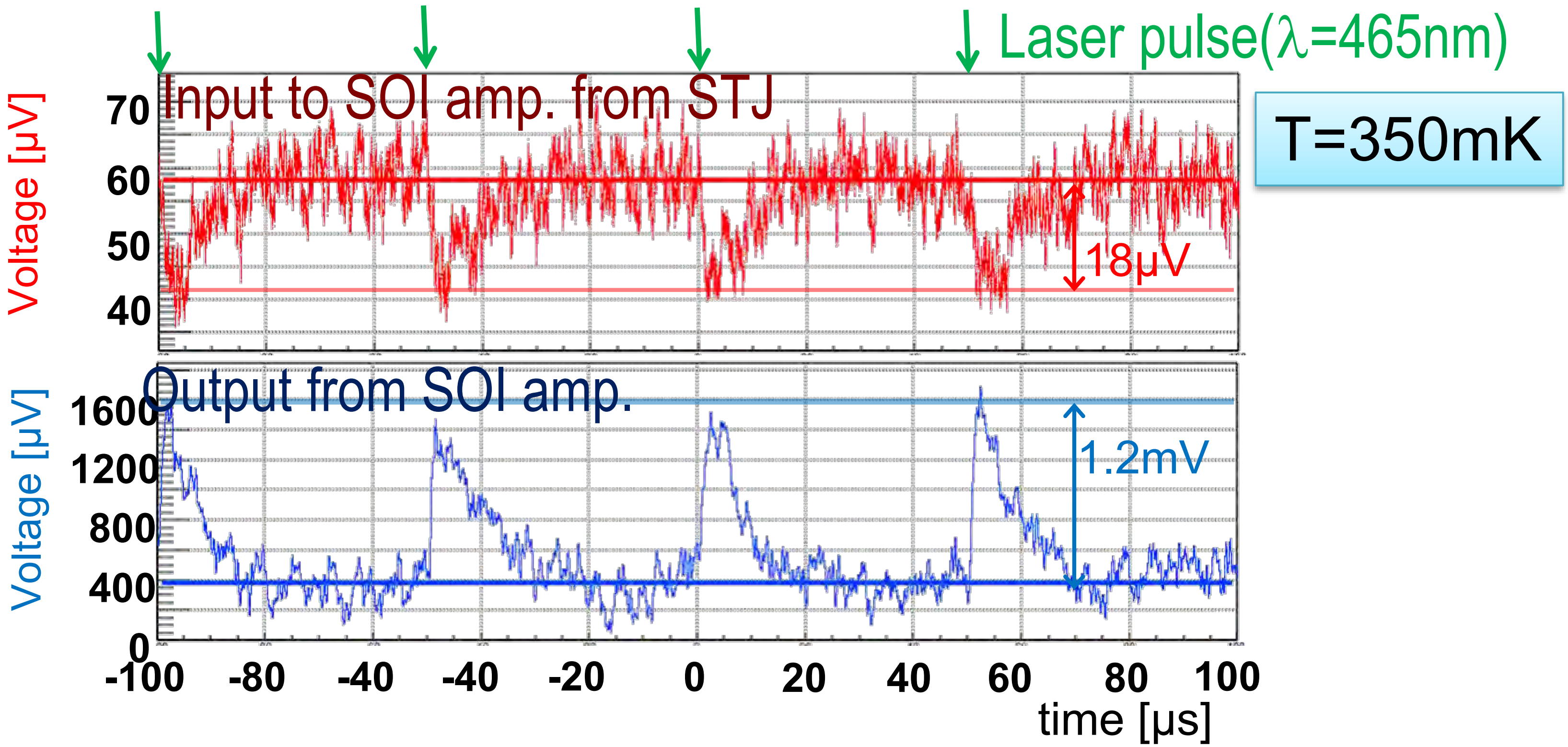
Amplification of STJ response to laser pulse on cold stage





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

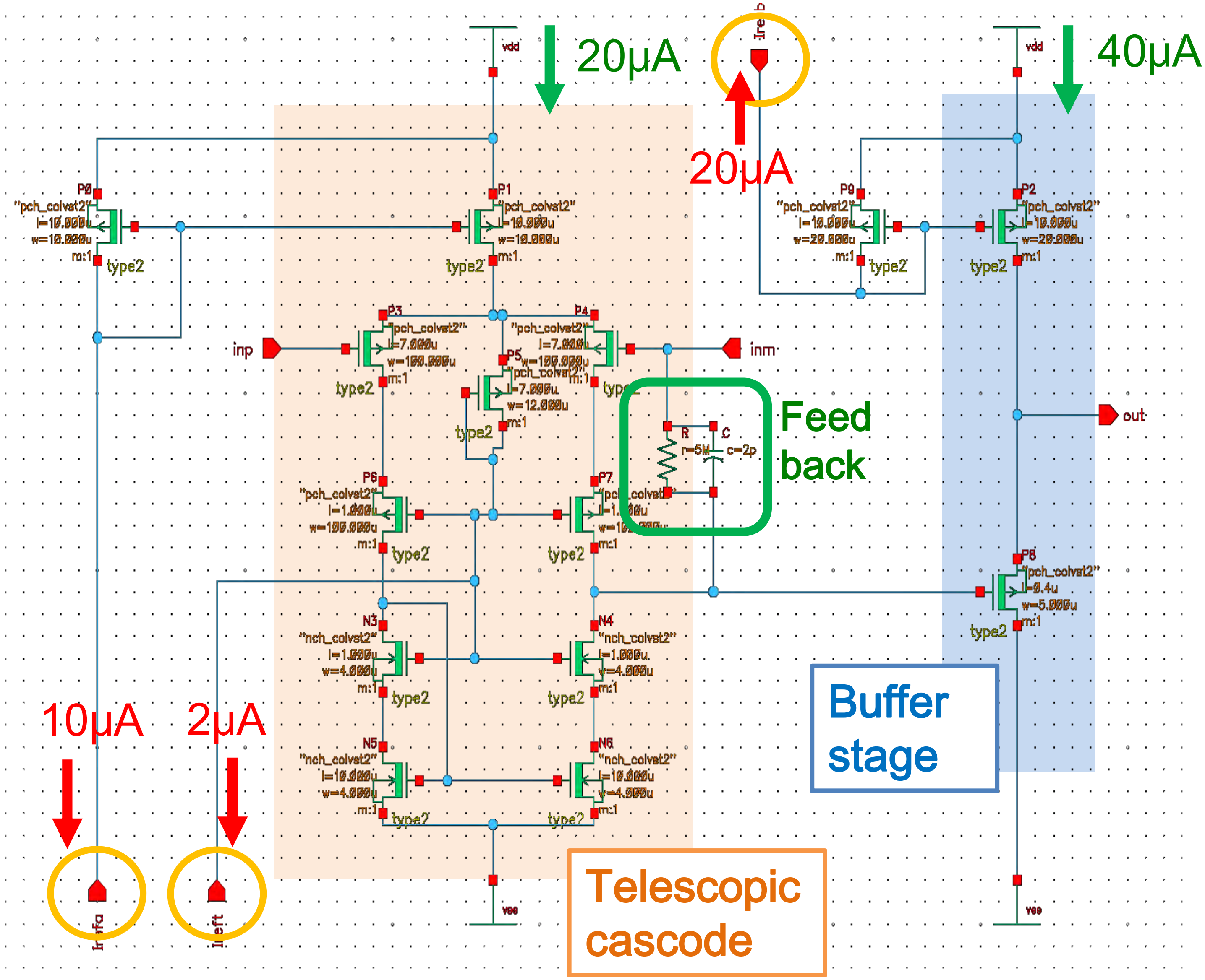
Amplification of STJ response to laser pulse on cold stage



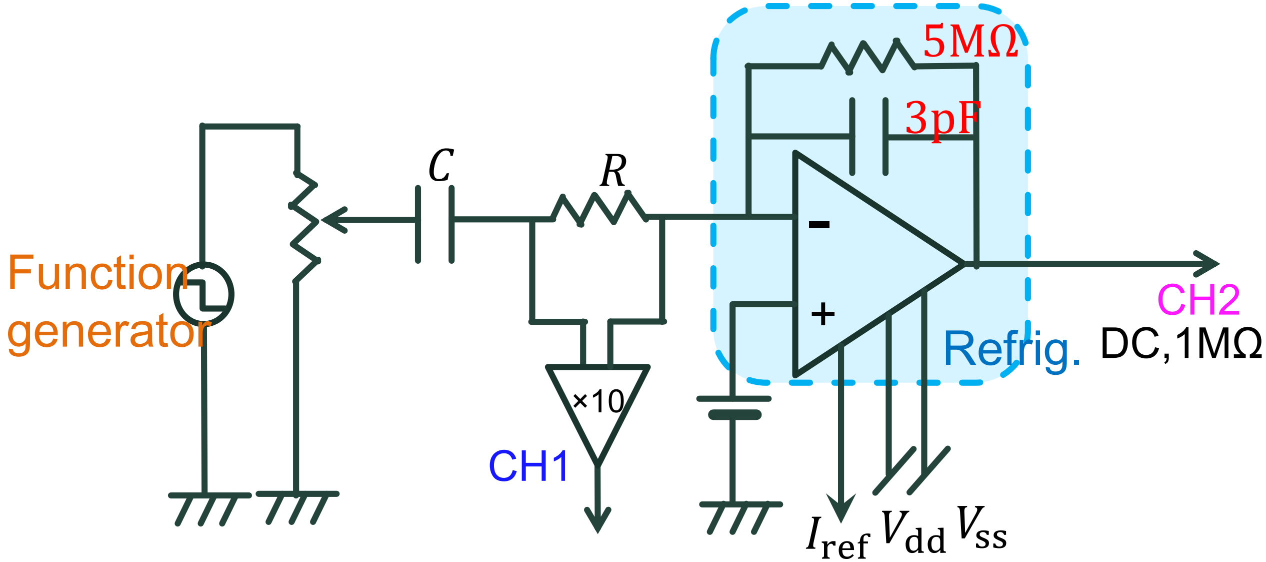
Demonstrated to show amplification of Nb/Al-STJ response to laser pulse by SOI amplifier situated close to STJ at T=350mK

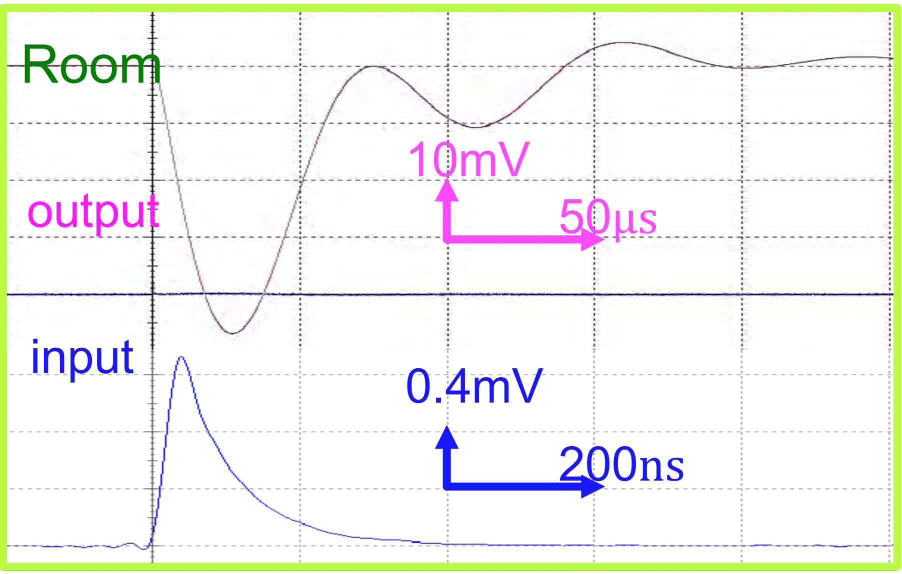
Development of SOI cryogenic amplifier for STJ signal readout is now moving to the stage of design for practical use !

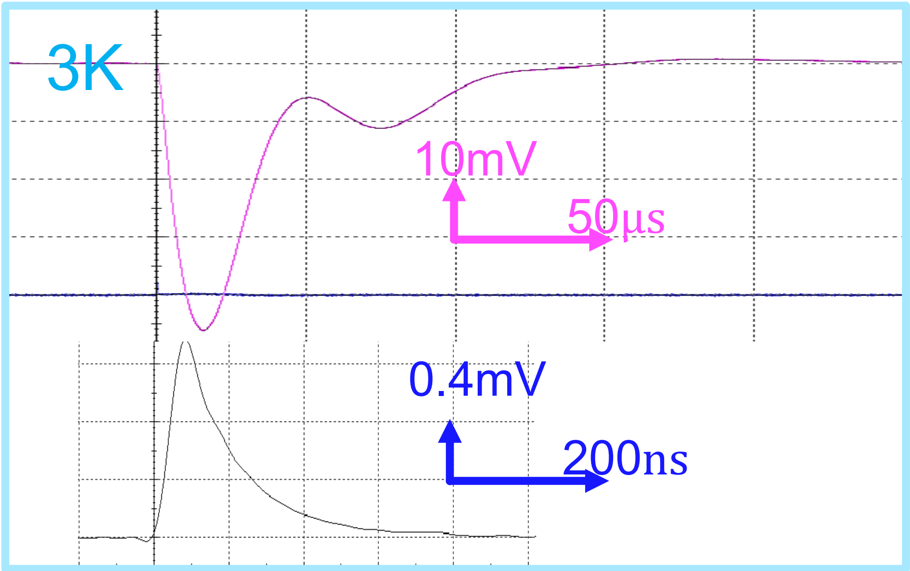
Charge sensitive amplifier



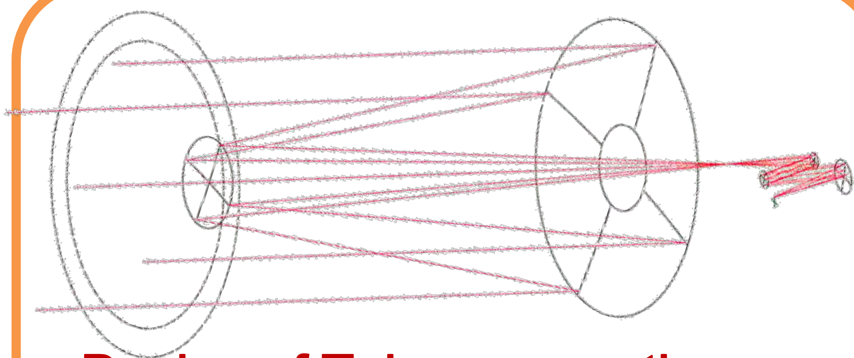
Response to charge injection



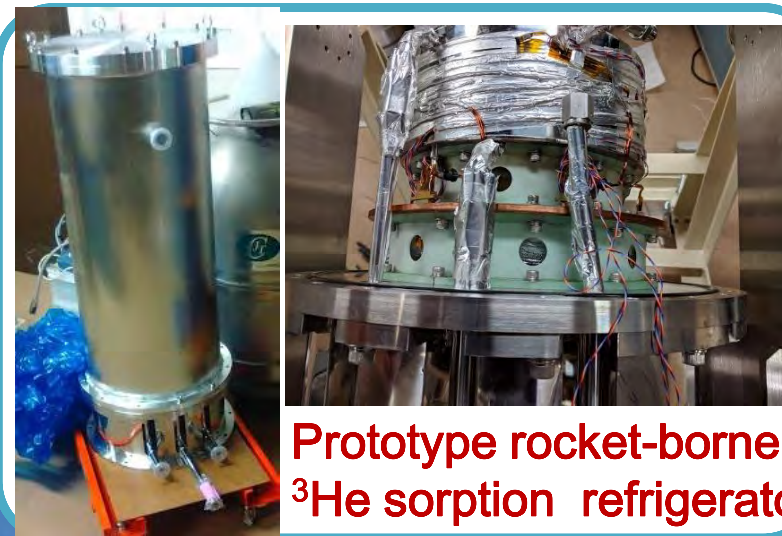




Other R&D components for COBAND rocket experiment



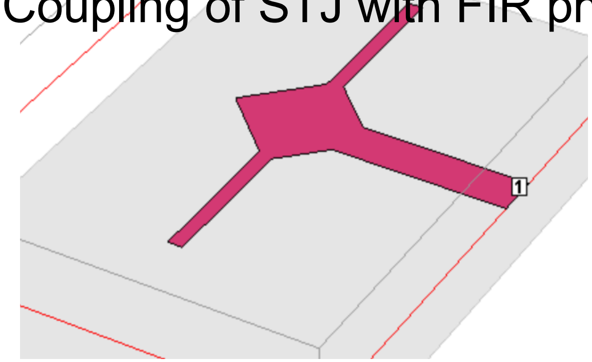
Design of Telescope optics

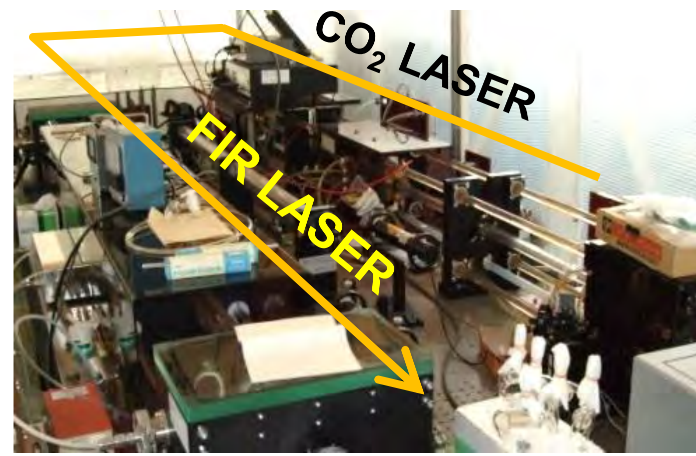


Prototype rocket-borne ^3He sorption refrigerator

Design of antenna for STJ

Coupling of STJ with FIR photon





FIR laser for STJ calibration

Summary

- We propose a sounding rocket experiment to search for neutrino radiative decay in cosmic neutrino background, followed by a future satellite experiment .
- Nb/Al-STJ array with a grating for the rocket experiment.
  – Demonstrated STJ signal amplification by a prototype SOI amplifier at T~350mK
  – Now we design and develop SOI cryogenic amplifier for practical use
- Hf-STJ is under development for future experiment
- Development of telescope optics, STJ with antenna, rocket-borne refrigerator, and FIR laser source for STJ calibration are on going as well toward rocket experiment.

Backup

Noise Equivalent Power (NEP) Requirements for the photo-detector

- Neutrino decay ($m_3 = 50$ meV, $\tau_\nu = 10^{14}$yrs): I_ν=25kJy/sr @ λ=50μm

$$P_{ND} = 25\ kJy/sr \times 8 \times 10^{-8} sr \times \pi(15cm/2)^2 \times \Delta\nu$$
$$= 3.3 \times 10^{-20} W/8pix$$

- Zodiacal emission: I_ν=8MJy/sr @ λ=50μm

$$P_{ZE} = 1.1 \times 10^{-17} W/8pix$$

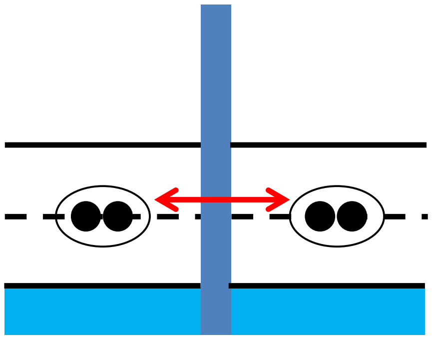
- Shot noise in P_{ZE} integrated over an interval Δt
  - Fluctuation in number of photons with energy ϵ_γ: $\sqrt{\epsilon_\gamma P_{ZE} \Delta t}$

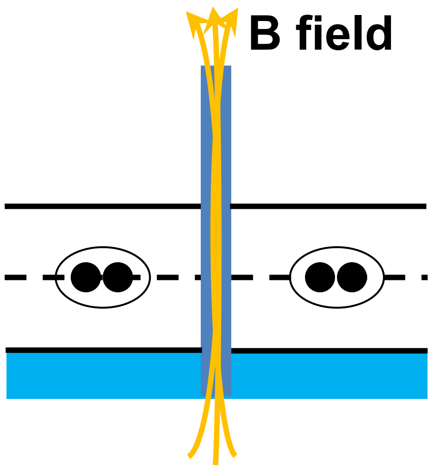
$$\frac{NEP}{\sqrt{2\Delta t}} \times \Delta t \ll \sqrt{\epsilon_\gamma P_{ZE} \Delta t} \ll P_{ND} \Delta t$$

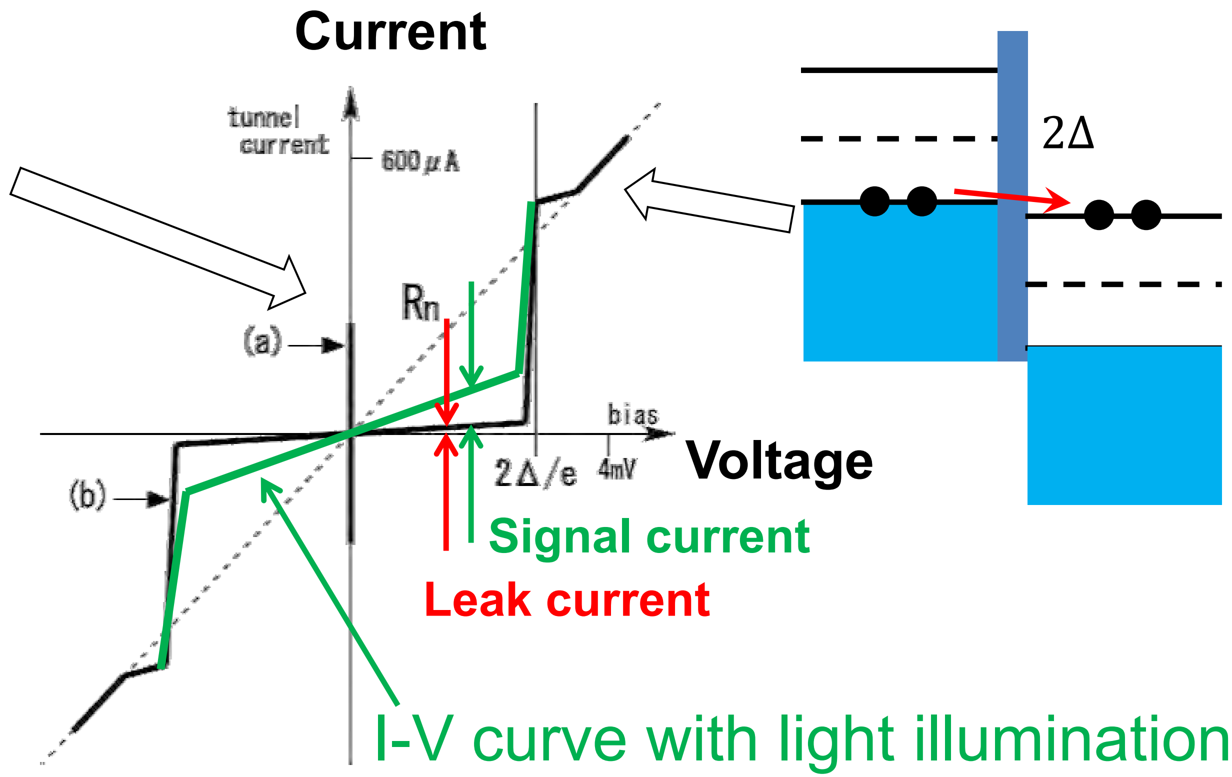
➔ Δt>200sec

➔ NEP $\sim O(10^{-20})\ W/\sqrt{Hz}$ for 1pix

STJ current-voltage curve







Tunnel current of Cooper pairs (Josephson current) is suppressed by applying magnetic field

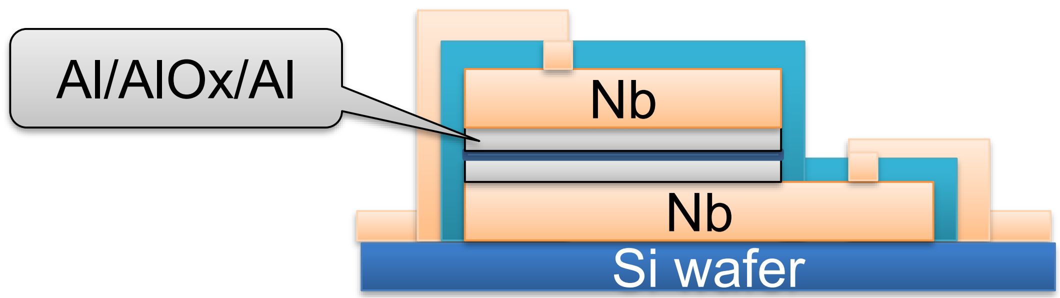
Optical signal readout

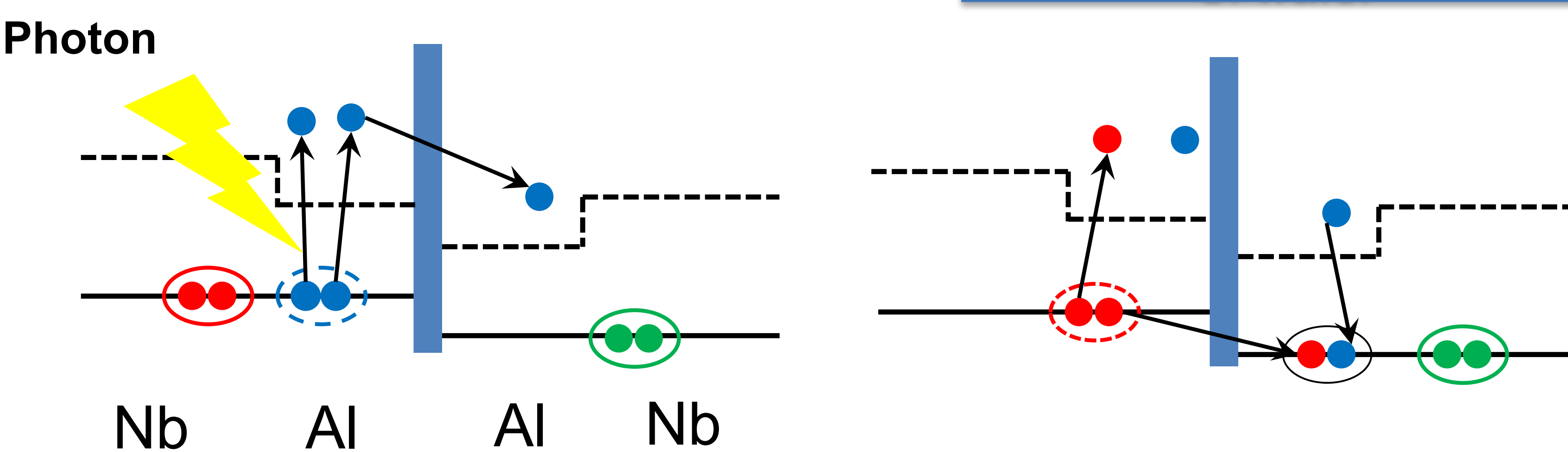
➔ Apply a constant bias voltage (|V|<2Δ) across the junction and collect tunneling current of quasi particles created by photons

✓ Leak current causes background noise

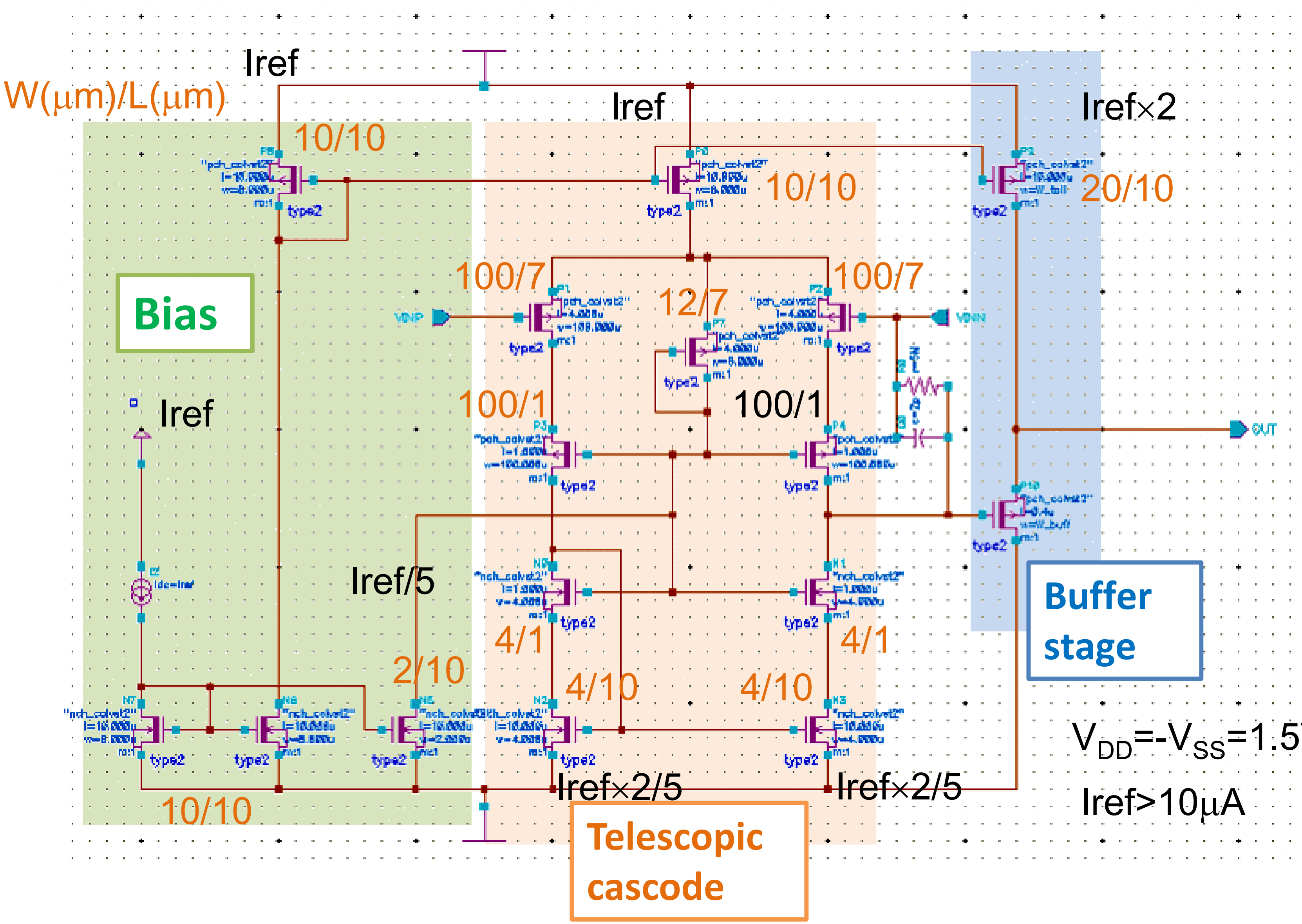
STJ back-tunneling effect

- Bi-layer fabricated with superconductors of different gaps $\Delta_{Nb} > \Delta_{Al}$ to enhance quasi-particle density near the barrier
  - Quasi-particle near the barrier can mediate multiple Cooper pairs
- Nb/Al-STJ   Nb(200nm)/Al(70nm)/AlOx/Al(70nm)/Nb(200nm)
- Gain: ～10





Charge sensitive amplifier



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

Iref>10μA