COBAND
Cosmic Background Neutrino Decay Search

ISoNF2018

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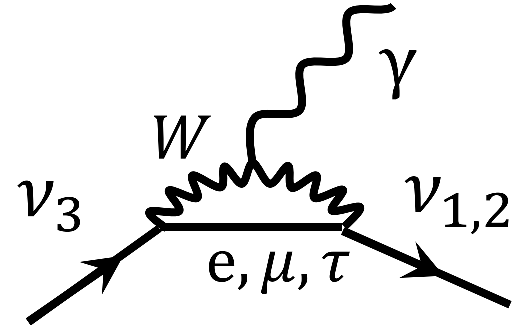
Yuji Takeuchi (TCHoU, University of Tsukuba)

on behalf of COBAND collaboration

Neutrino Decay

- Heavier neutrinos in mass-eigenstate (ν_2, ν_3) are not stable
  - $\nu_3 \rightarrow \nu_{1,2} + \gamma$



This process is highly suppressed in SM

➔Very sensitive to new physics (e.g. LRSM)

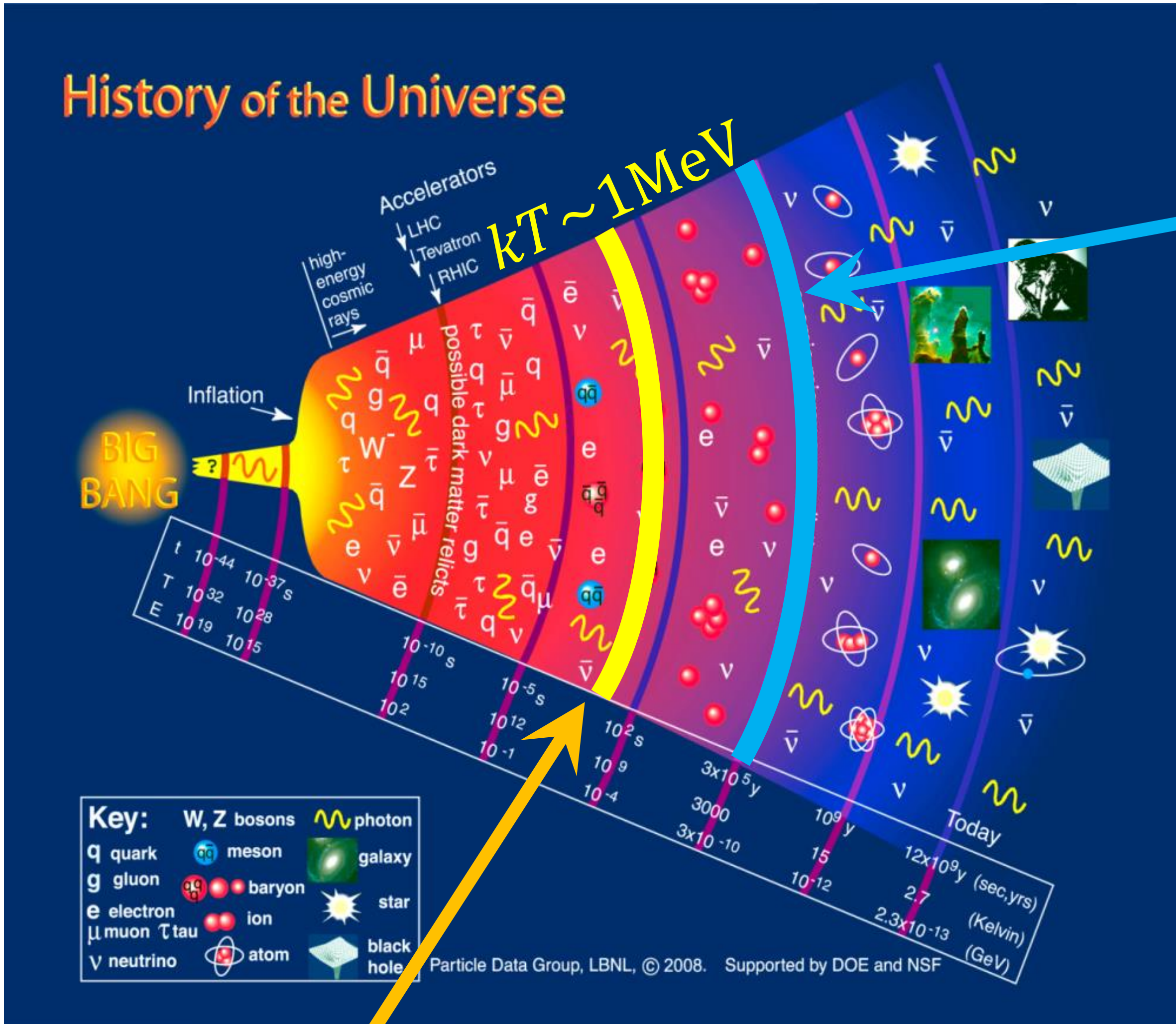
ν_3 Lifetime
for m_3=50meV

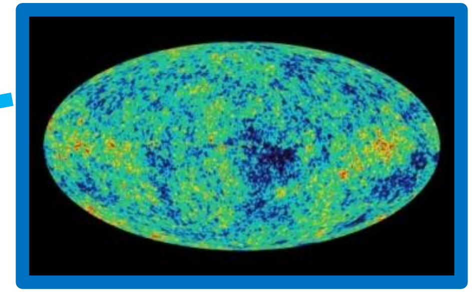
- Standard Model expectation: $\tau = O(10^{43})$ yrs
- L-R Sym. Model prediction: $\tau = O(10^{17})$ yrs

  for W_L-W_R mixing angle $|\zeta| \sim 0.02$
- Experimental lower limit: $\tau = O(10^{12})$ yrs

Also can get neutrino mass from photon energy: $m_3 = (m_3^2 - m_{1,2}^2)/2E_\gamma$

Cosmic neutrino background (CνB)





CMB

(=Photon decoupling)

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

$T_\gamma = 2.73\ K$

~380,000yrs after the Big Bang

CνB (=neutrino decoupling)

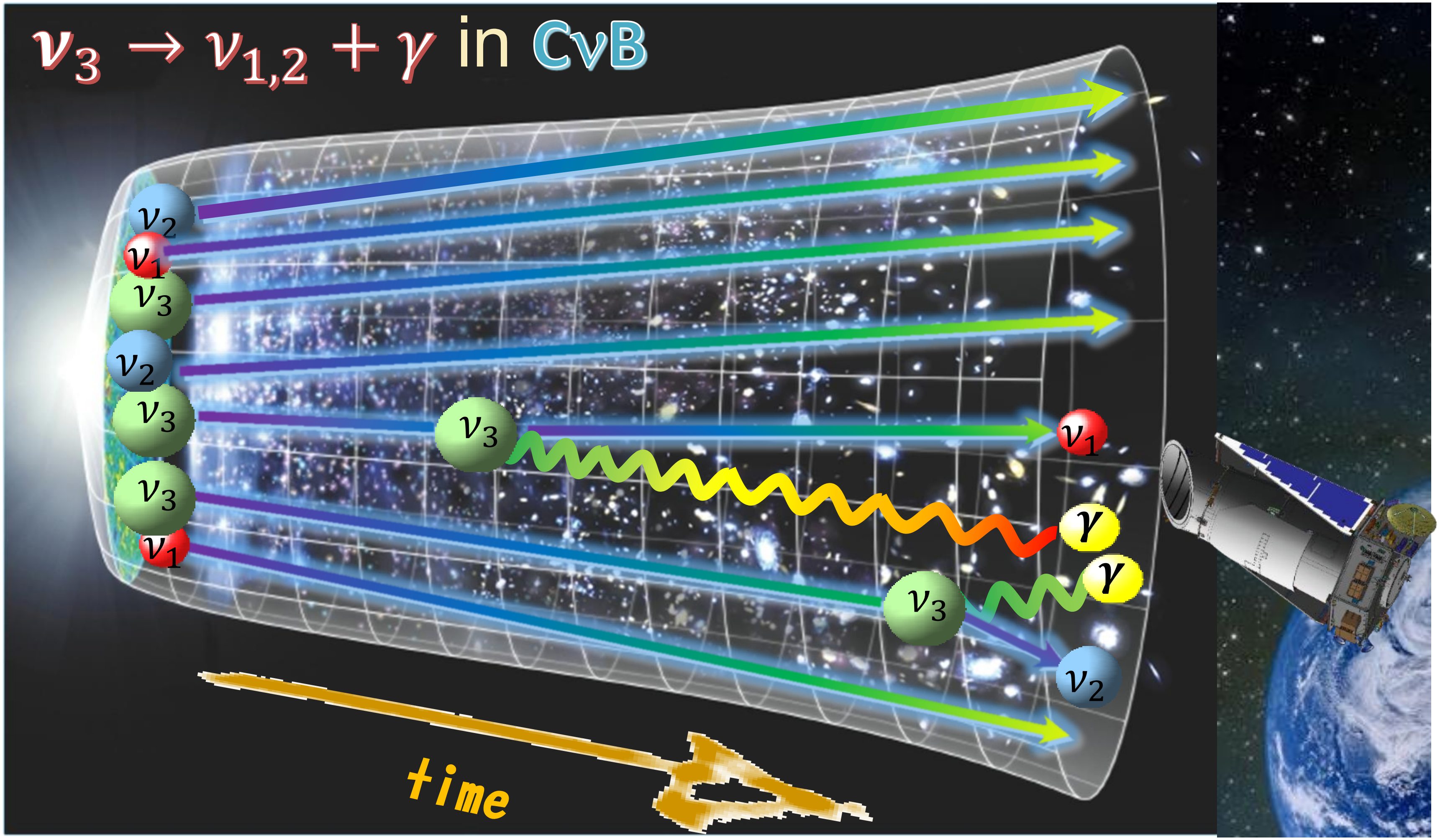
~1sec after the big bang

$n(\nu_3 + \bar{\nu}_3) \sim 110/\mathrm{cm}^3$

COBAND (COsmic BAckground Neutrino Decay)

Search for Neutrino decay in Cosmic background neutrino

➔To be observed as photons in neutrino decays

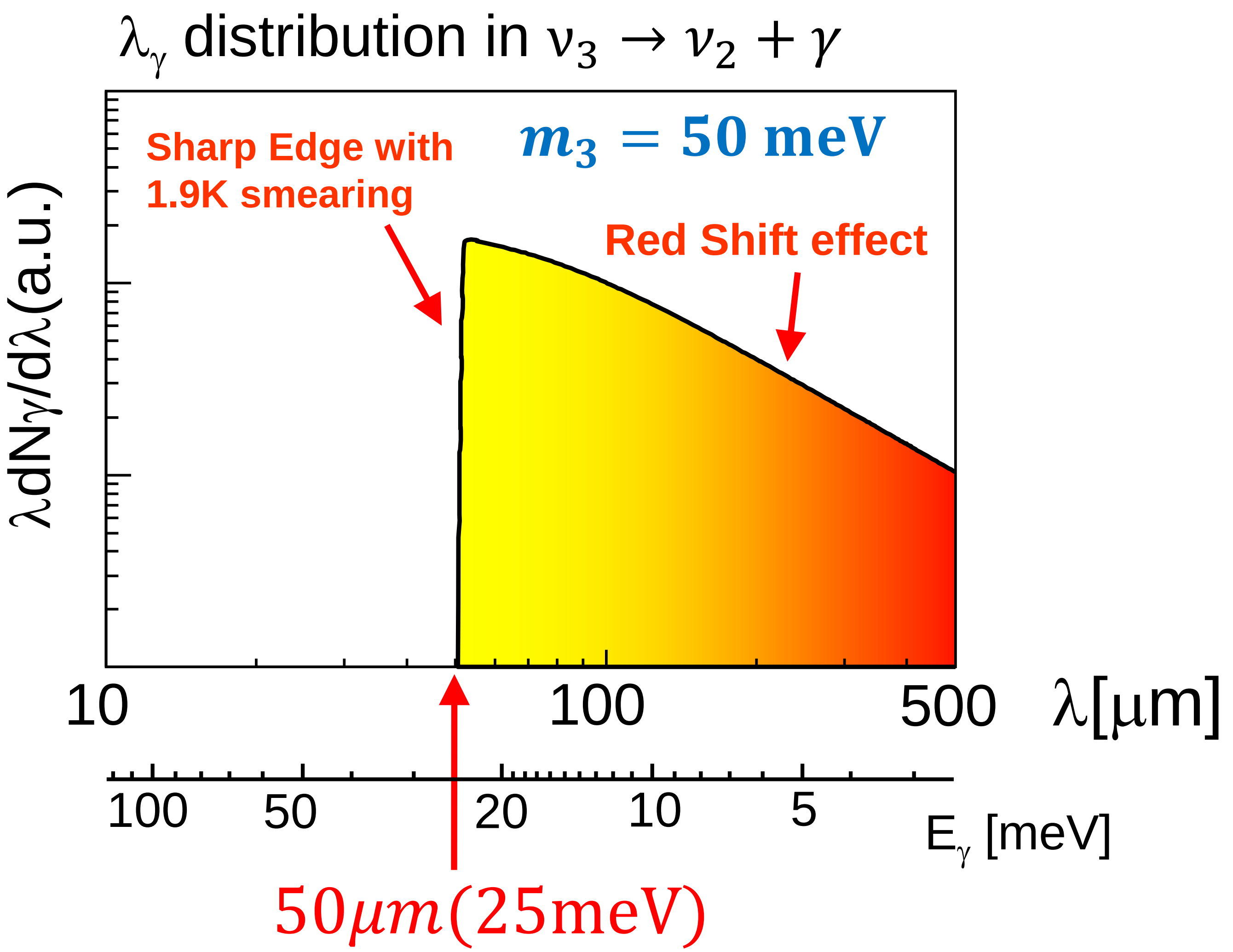


COBAND

COBAND Collaboration Members (As of Jul. 2018)

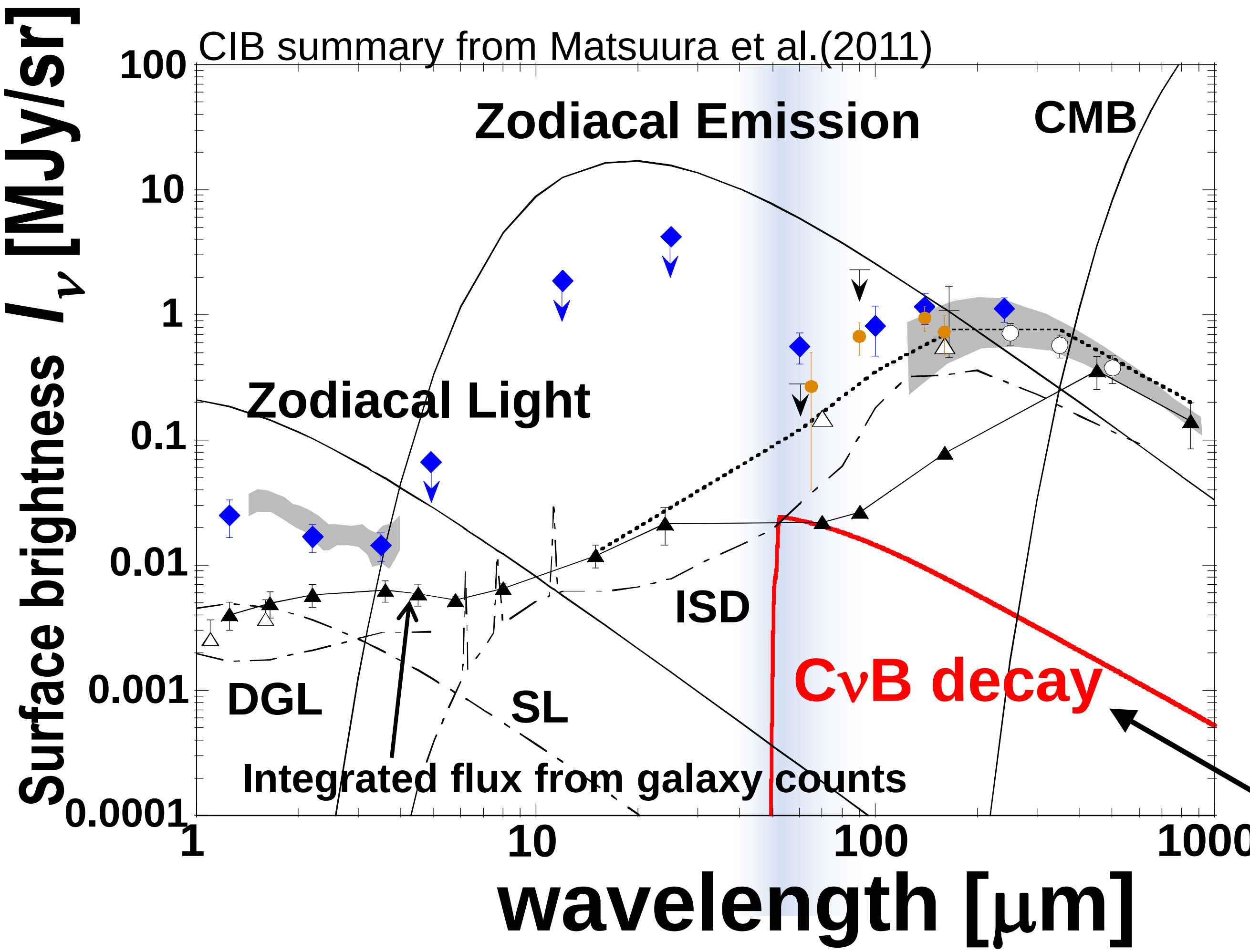
Shin-Hong Kim, Yuji Takeuchi, Takashi Iida, Kenichi Takemasa, Kazuki Nagata, Chisa Asano, Rena Wakasa, Akihiro Kasajima, Hironobu Kanno, Yoichi Otsuka (Univ. of Tsukuba),
Hirokazu Ikeda, Takehiko Wada, Koichi Nagase (JAXA/ISAS),
Shuji Matsuura (Kwansei gakuin Univ),
Yasuo Arai, Ikuo Kurachi, Masashi Hazumi (KEK),
Takuo Yoshida, Takahiro Nakamura, Makoto Sakai , Wataru Nishimura (Univ. of Fukui),
Satoru Mima (RIKEN), Kenji Kiuchi (University of Tokyo),
H.Ishino, A.Kibayashi (Okayama Univ.),
Yukihiro Kato (Kindai University),
Go Fujii, Shigetomo Shiki, Masahiro Ukibe, Masataka Ohkubo (AIST),
Shoji Kawahito (Shizuoka Univ.),
Erik Ramberg, Paul Rubinov, Dmitri Sergatskov (Fermilab),
Soo-Bong Kim (Seoul National University)

Expected photon wavelength spectrum from CνB decays



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**

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

$m_3 = 50\ \text{meV}$

We can identify the contribution from CνB decay!!

Requirements for the photo-sensor in COBAND experiment

Sensitive area of $100\mu m \times 100\mu m$ for each pixel

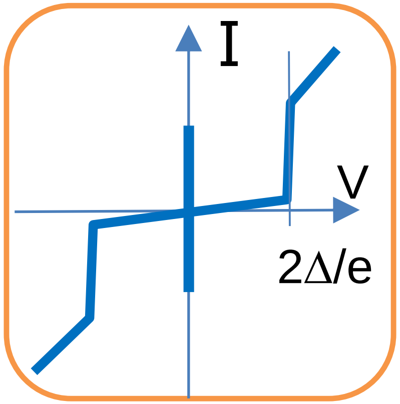
A spectrometer which can measure photon-by-photon energy at better than 2% resolution for a far-infrared photon around $\lambda=50\mu m$

OR

Combination between diffraction grating and multi-pixel array of the following photo-sensor pixels:

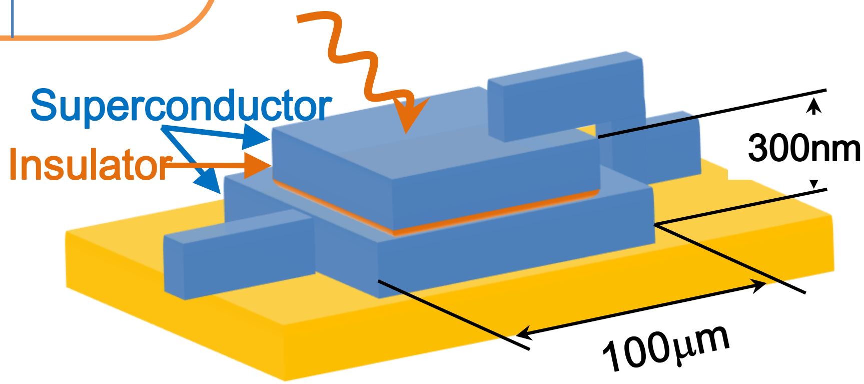
- Can detect single far-infrared photon around $\lambda=50\mu m$
- Dark count rate much less than expected real photon rate (300Hz)

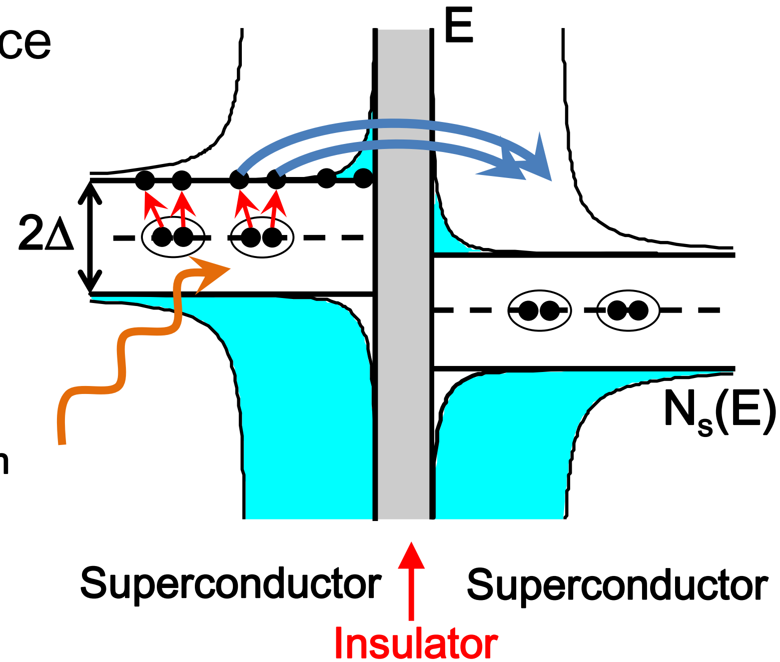
Superconducting Tunnel Junction (STJ)



Superconductor / Insulator /Superconductor

Josephson junction device



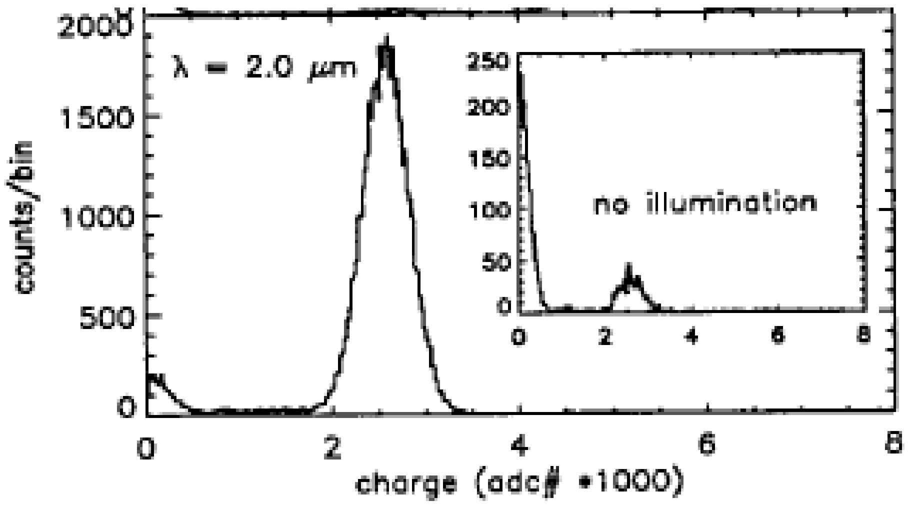


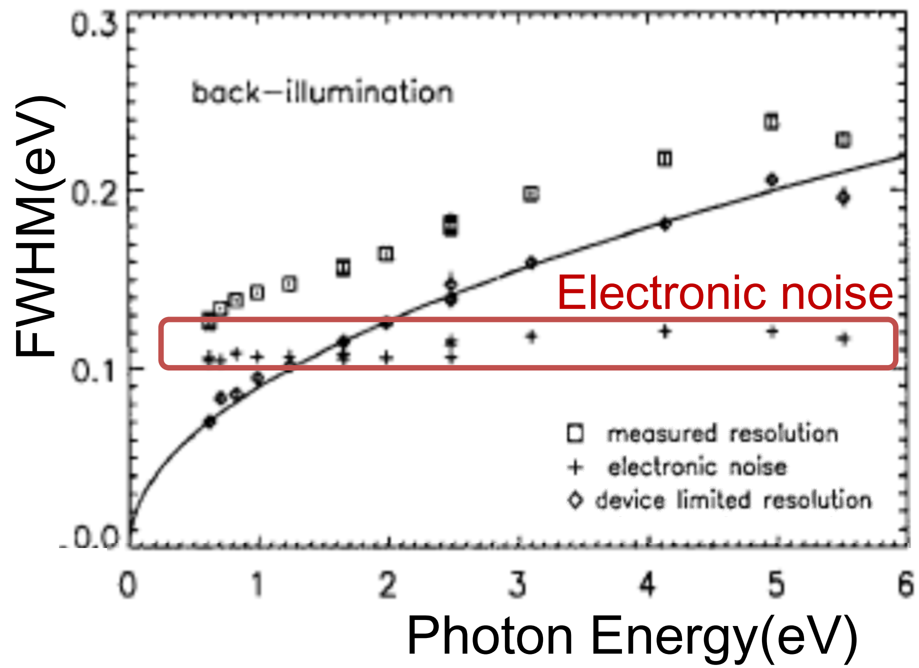
Δ: Superconducting gap energy

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 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.

STJ candidates

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

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

➔ Spectrum measurement without a diffraction grating

➔ Developing for a future satellite experiment

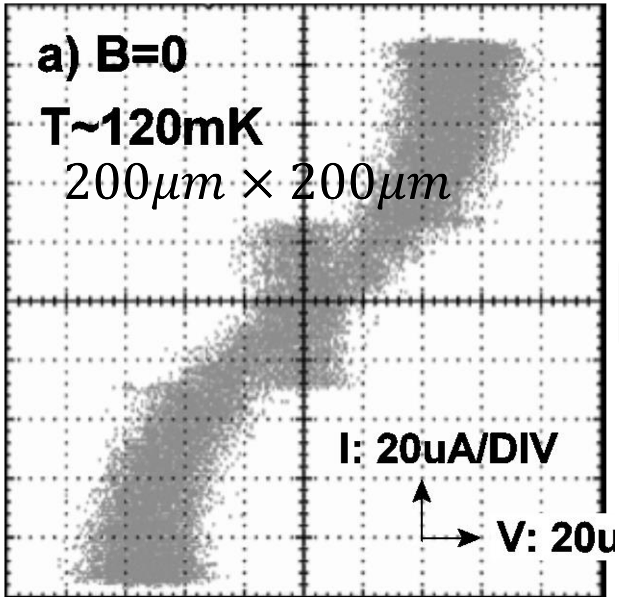
Nb/Al-STJ
- Well-established
  - Δ~0.6meV by the proximity effect from Al
  - Operation temperature <400mK
  - Back-tunnelling gain G_{Al}~10
- $N_{q.p.}$=25meV/1.7Δ×G_{Al}~ 250 σ_E/E~10% for E=25meV

➔ 25meV single-photon detection is feasible in principle

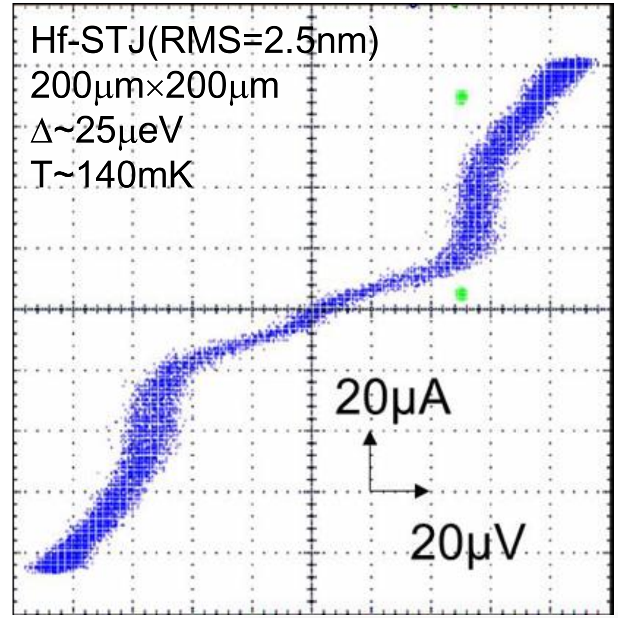
➔ Developing for the rocket experiment

Hf-STJ development

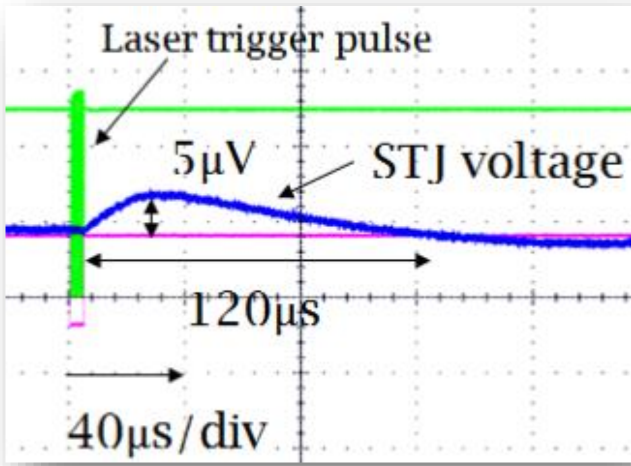
200μm sq. Hf-STJ in 2010



200μm sq. Hf-STJ in 2017



We successfully made a device with SIS in 2010, and reduce leakage and observe response to laser pulse in 2017, but need to suppress leakage further down to ~pA for practical usage.

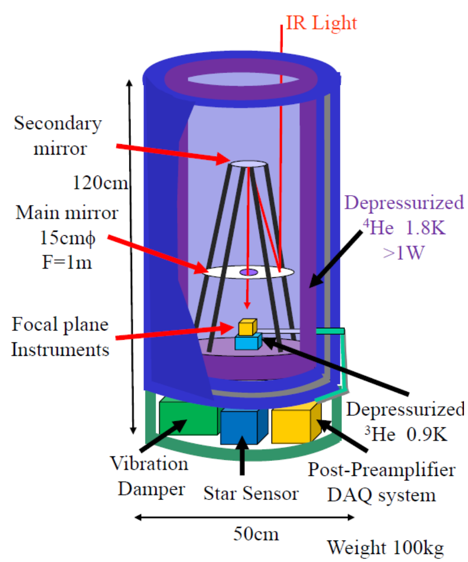


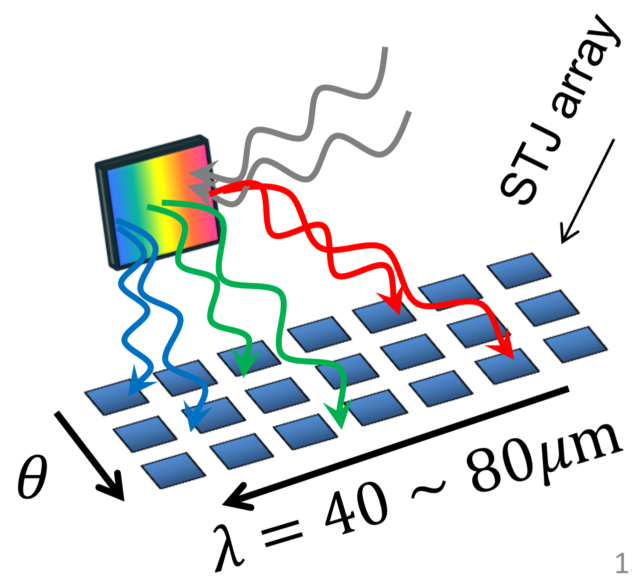
Proposal for COBAND Rocket Experiment

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

JAXA sounding rocket S-520

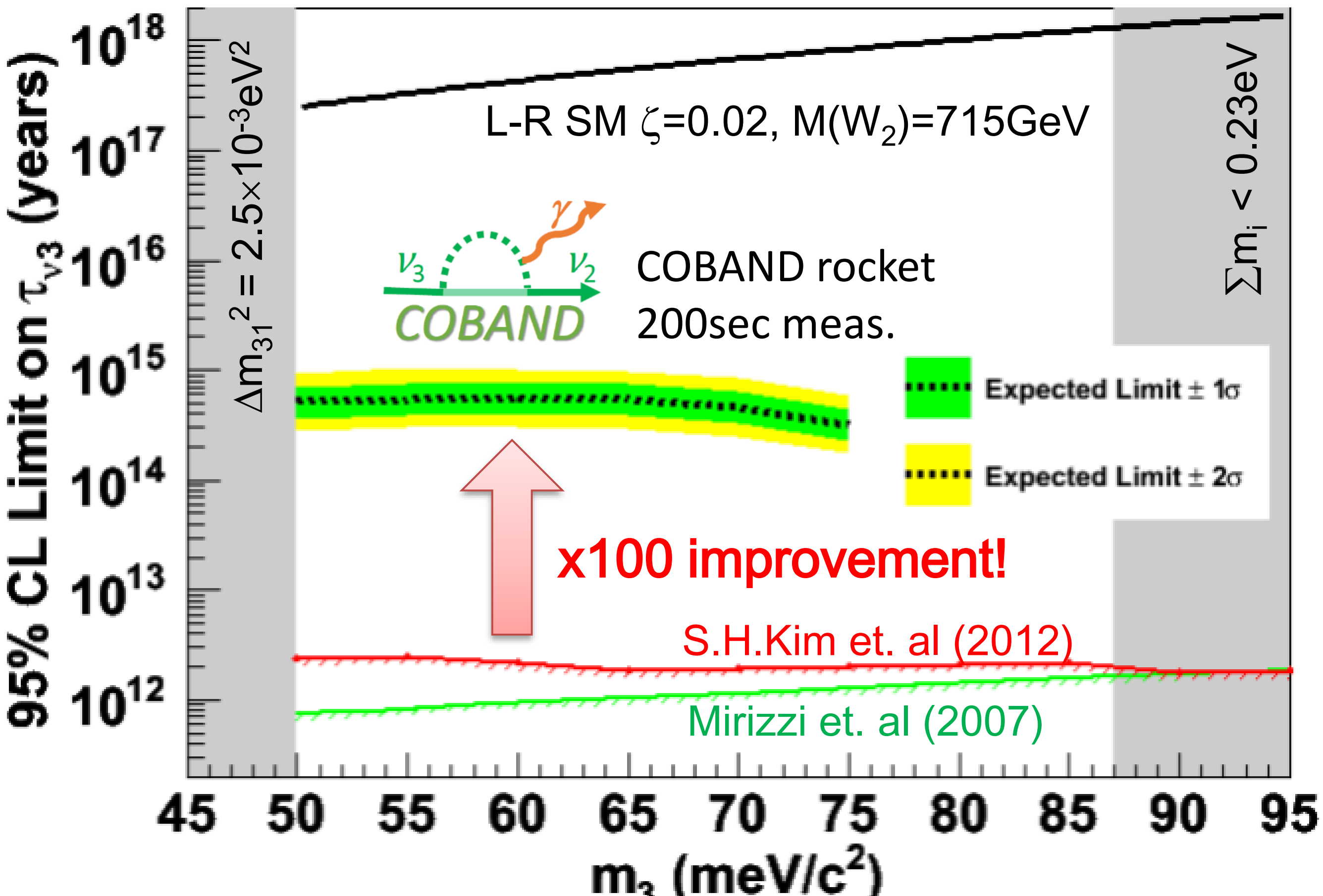
- Telescope with **15cm diameter** and **1m focal length**
- At the focal point, a diffraction grating covering **λ=40-80μm** and an array of photo-detector pixels of **50(λ) x 8(θ)** are placed.
- Each pixel has **100μmx100μm** sensitive area.





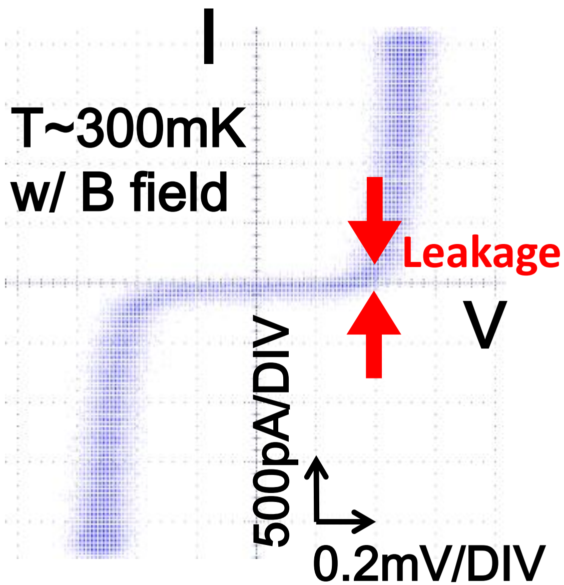
COBAND rocket experiment sensitivity

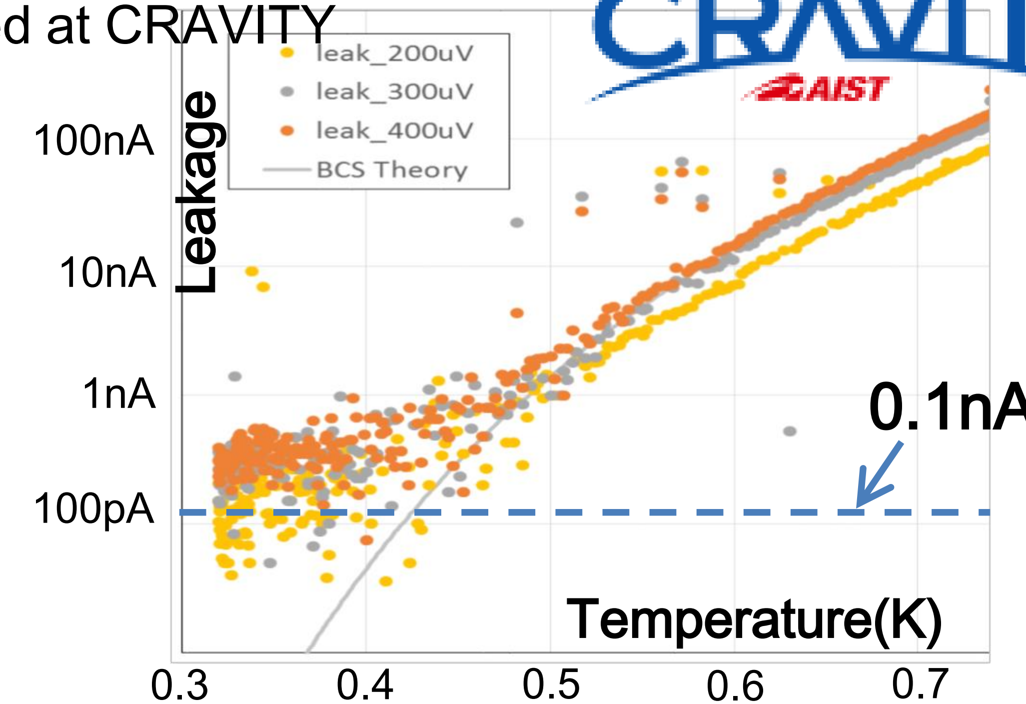
- 200-sec measurements with a sounding rocket
- 15cm dia. and 1m focal length telescope and grating in 40~80μm range
- Each pixel in 100μm×100μm×8×50pix. array counts number of photons



Nb/Al-STJ development at CRAVITY

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





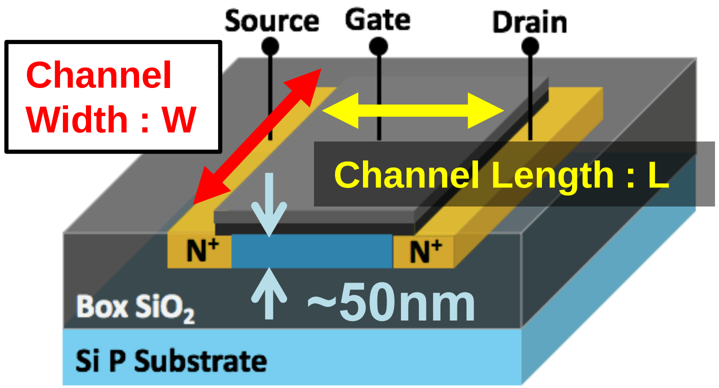
I_{leak}~200pA for 50μm sq. STJ, and achieved 50pA for 20μm sq.

➔ This satisfies our requirement!

Nb/Al-STJ fabricated at CRAVITY has potential to far-infrared single photon detection with a cryogenic amplifier which can be deployed in close proximity to the STJ.

FD-SOI-MOSFET at cryogenic temperature

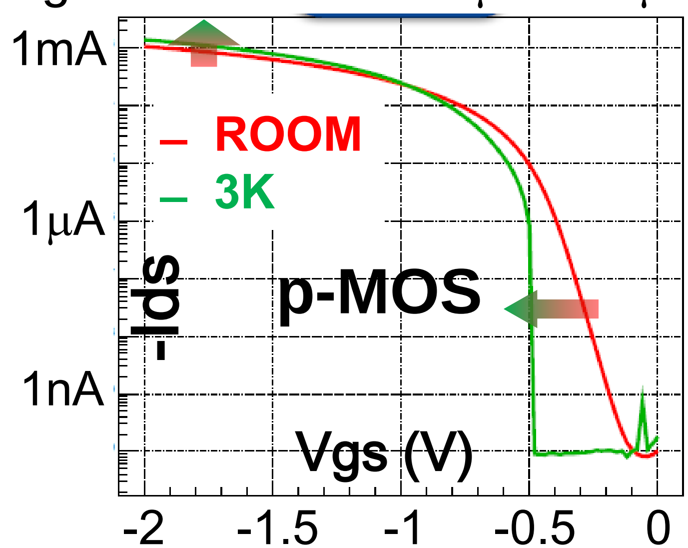
FD-SOI : **F**ully **D**epleted – **S**ilicon **O**n **I**nsulator

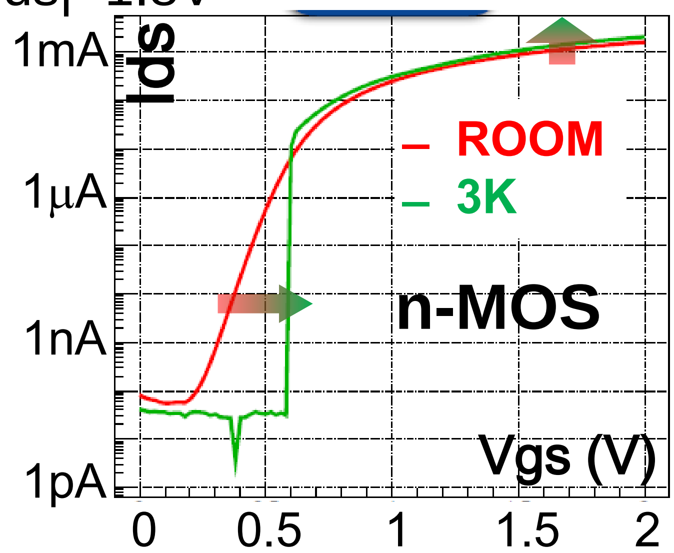


- Very thin channel layer in MOSFET on SiO_2
- No floating body effect caused by charge accumulation in the body
- FD-SOI-MOSFET is reported to work at 4K

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

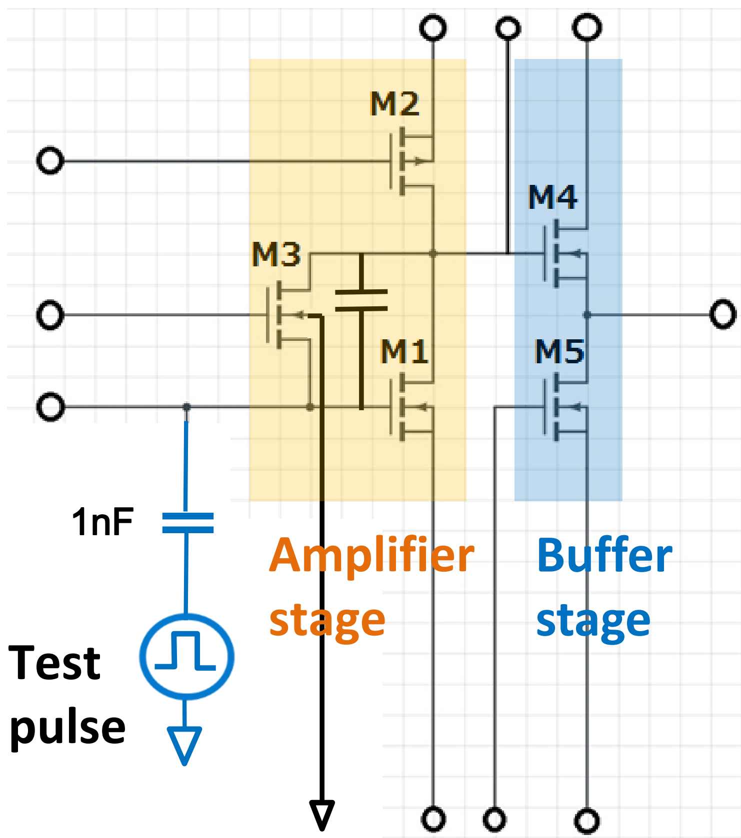
Id-Vg curve of W/L=10μm/0.4μm at |Vds|=1.8V

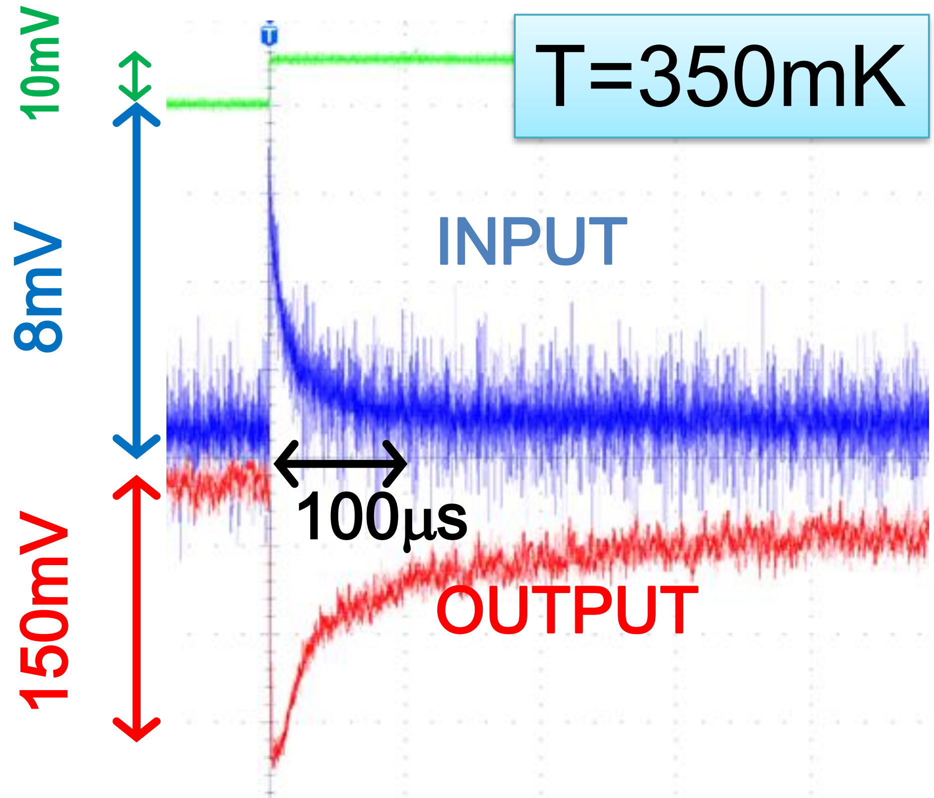




Both p-MOS and n-MOS show excellent performance at 3K and below.

SOI prototype amplifier for demonstration test

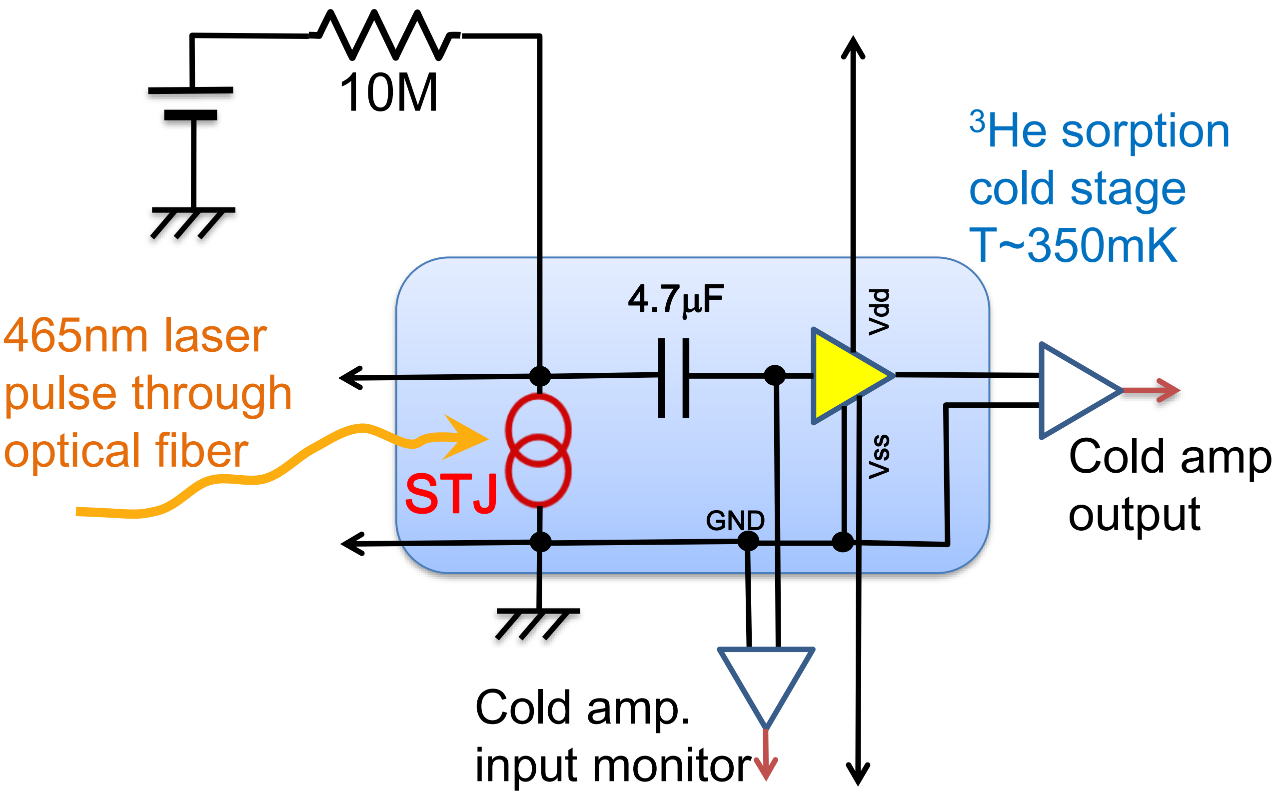


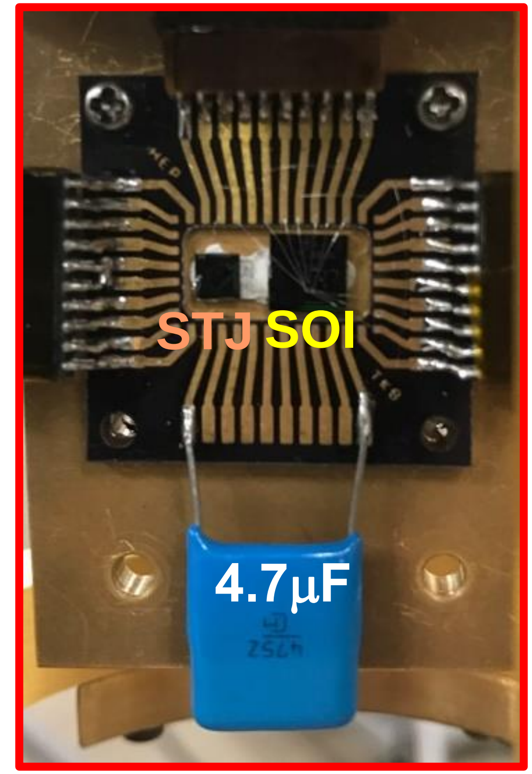


Test pulse input through C=1nF at T=3K and 350mK

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

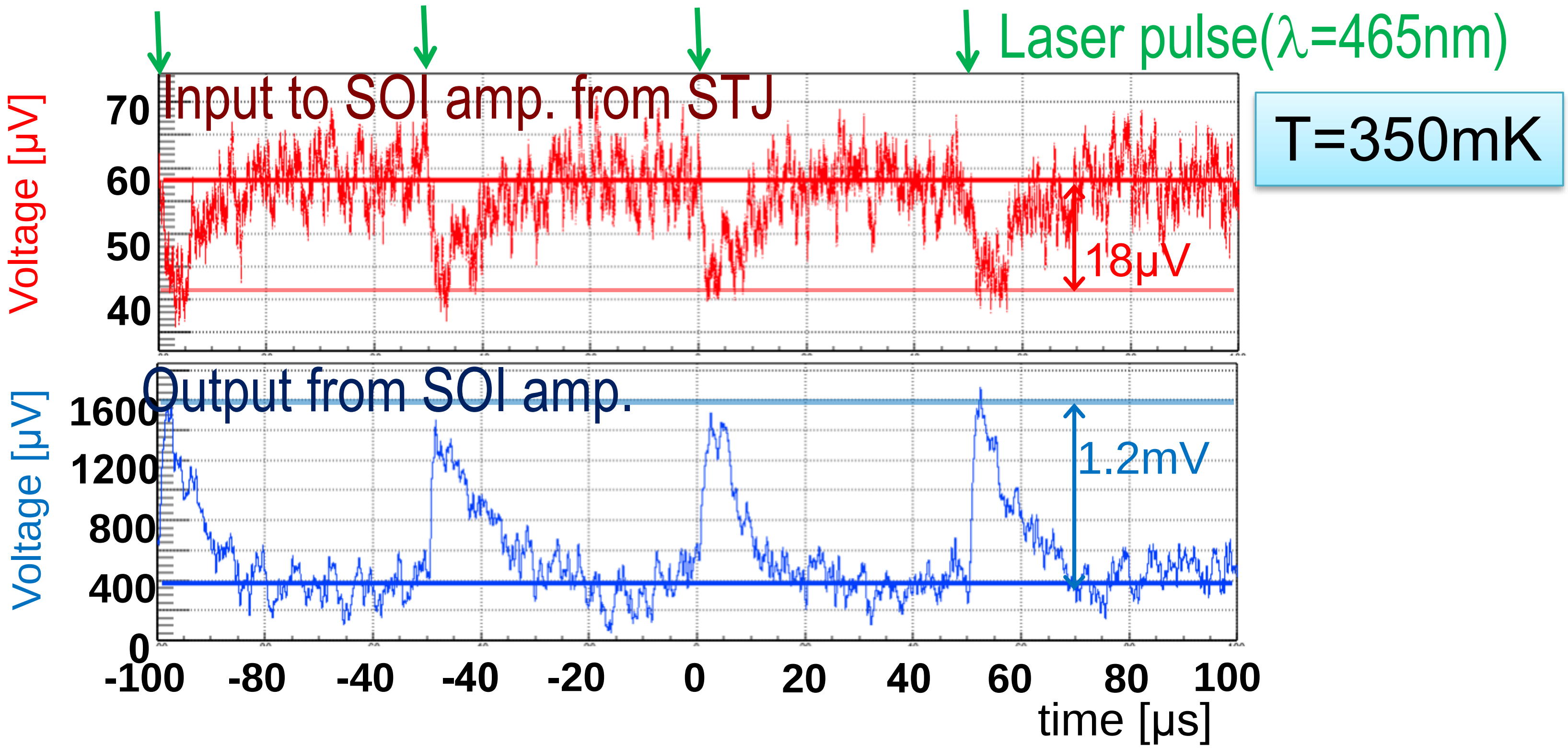
Amplification of STJ response to laser pulse on cold stage





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

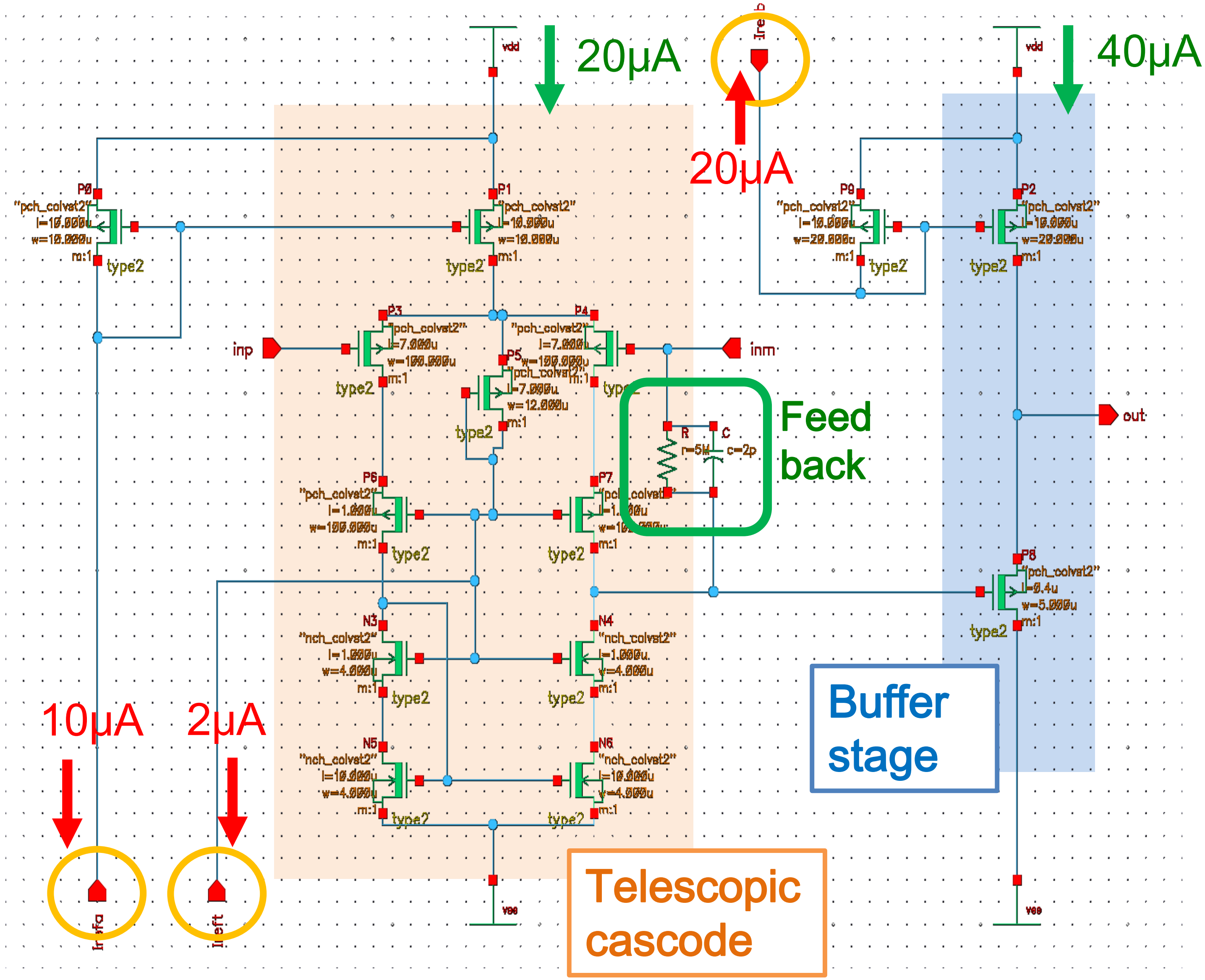
Amplification of STJ response to laser pulse on cold stage



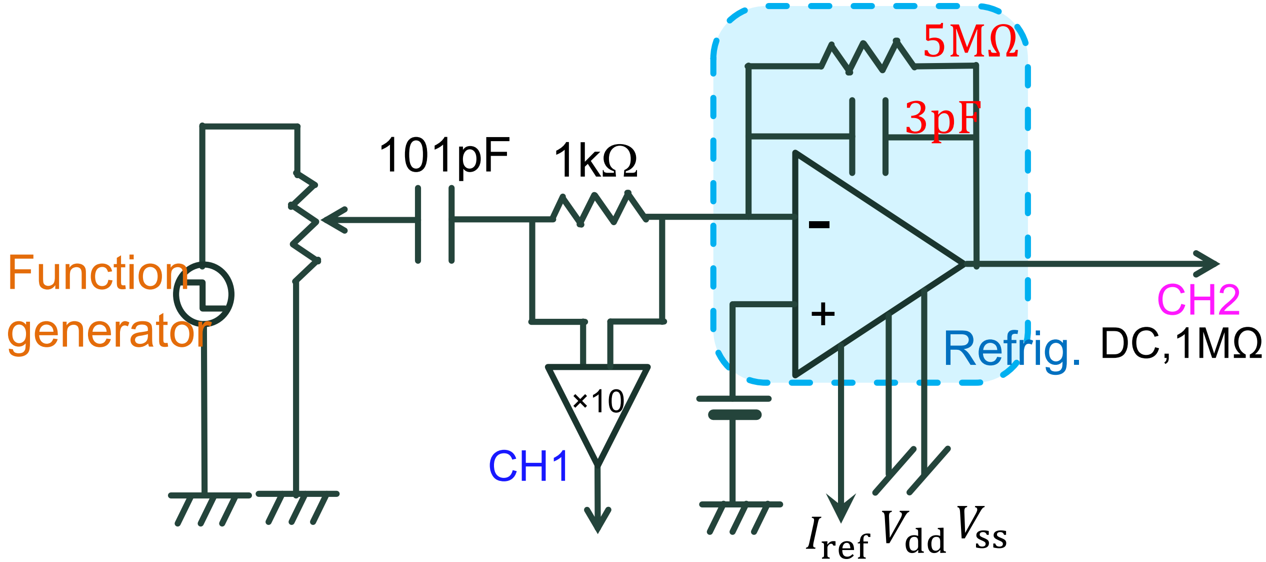
Demonstrated to show amplification of Nb/Al-STJ response to laser pulse by SOI amplifier situated close to STJ at T=350mK

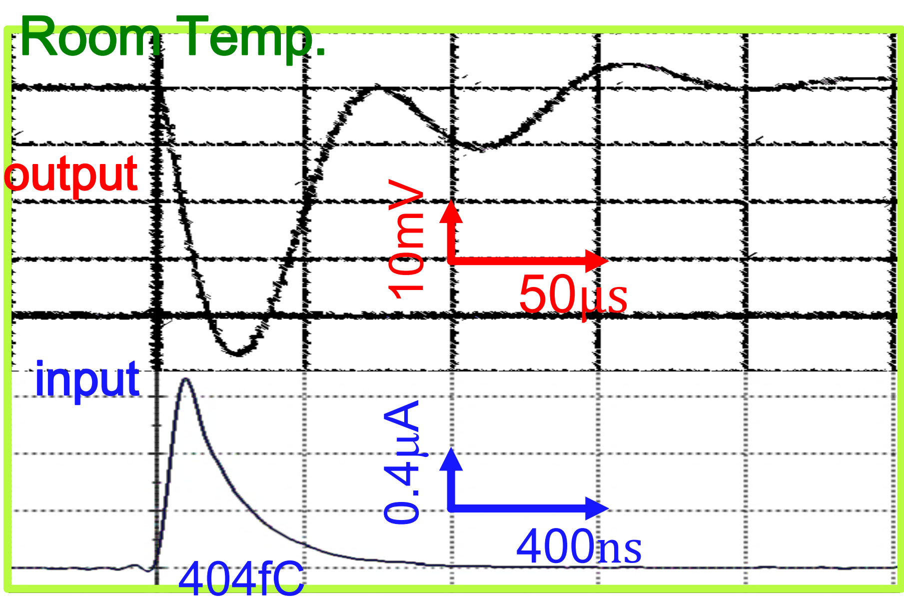
Development of SOI cryogenic amplifier for STJ signal readout is now moving to the stage of design for practical use !

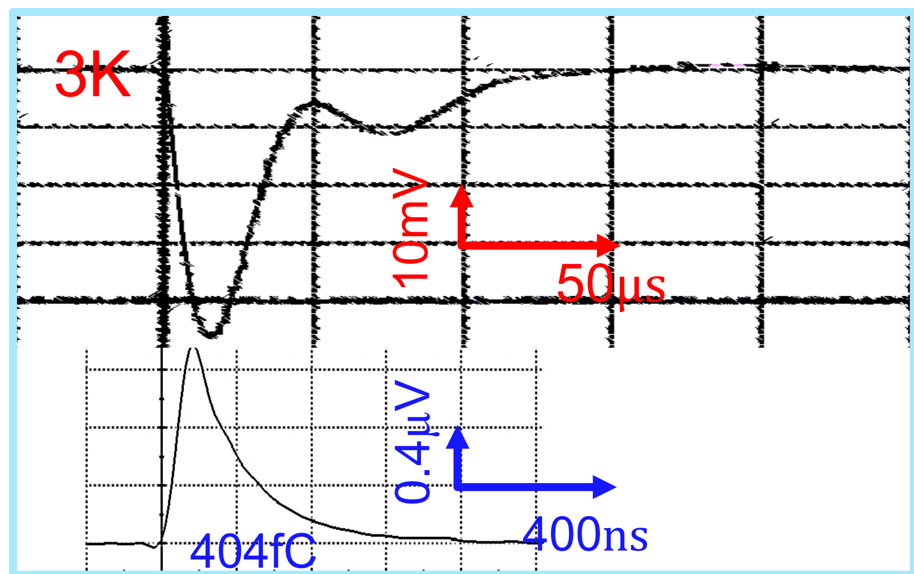
Charge sensitive amplifier



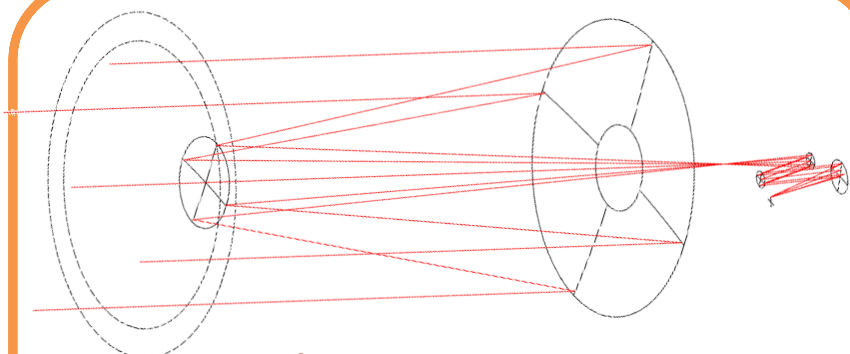
Response to charge injection



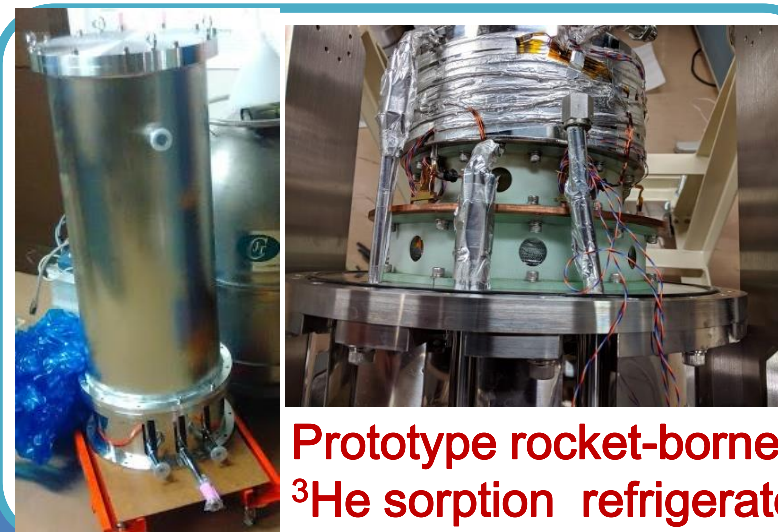




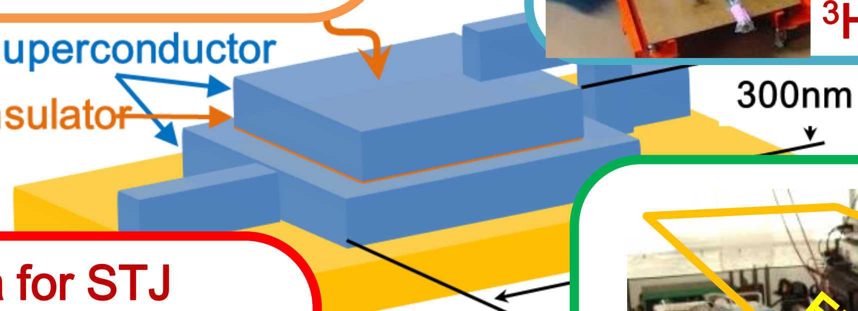
Other R&D components for COBAND rocket experiment



Design of Telescope optics

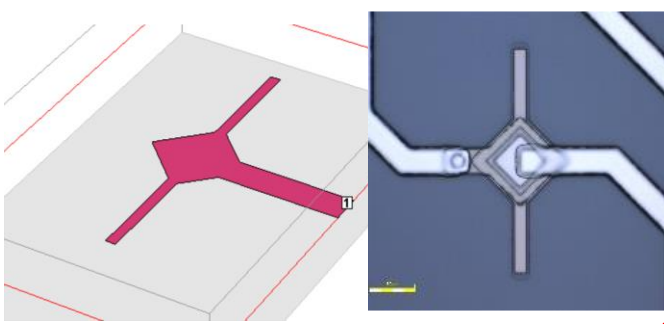


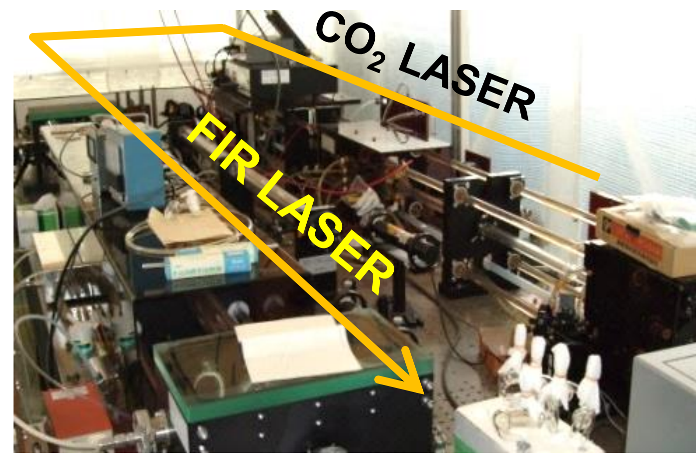
Prototype rocket-borne ^{3}He sorption refrigerator



Design of antenna for STJ

Coupling of STJ with FIR photon





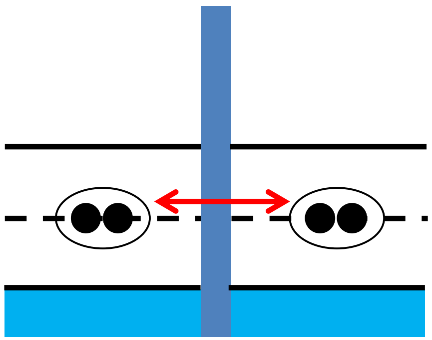
FIR laser for STJ calibration

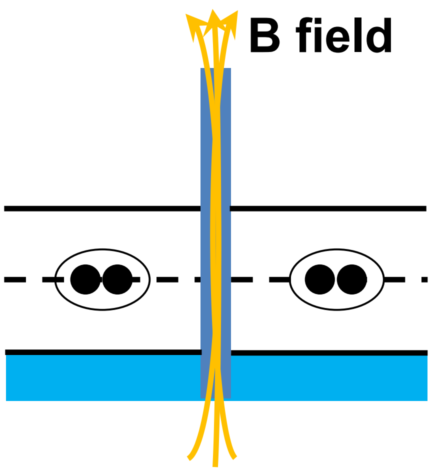
Summary

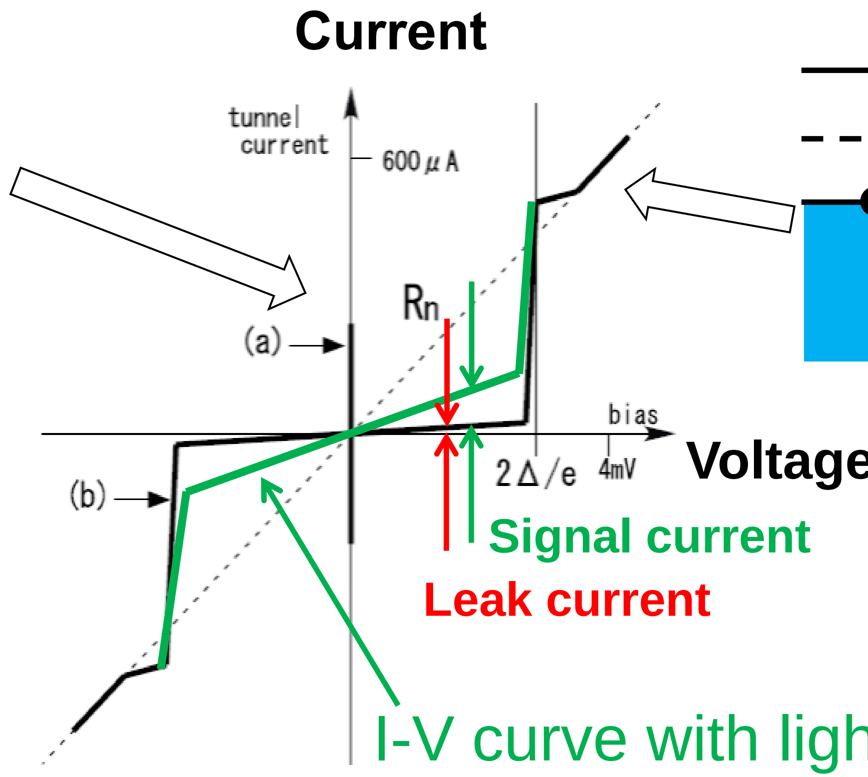
- We propose a sounding rocket experiment to search for neutrino radiative decay in cosmic neutrino background, followed by a future satellite experiment .
- Nb/Al-STJ array with a grating for the rocket experiment.
  - Demonstrated STJ signal amplification by a prototype SOI amplifier at T~350mK
  - Now we design and develop SOI cryogenic amplifier for practical use
- Hf-STJ is under development for future satellite 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.

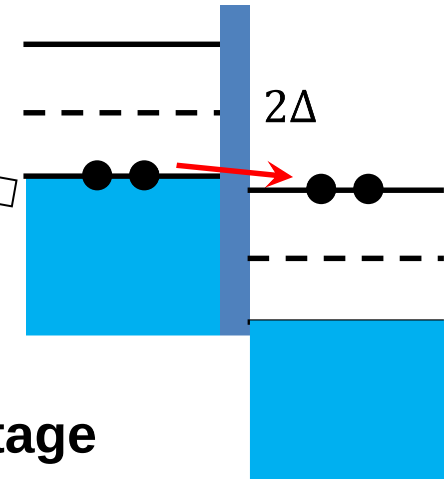
Backup

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