Performance of Radiation-Damaged SiPM at Low Temperature (100 K)

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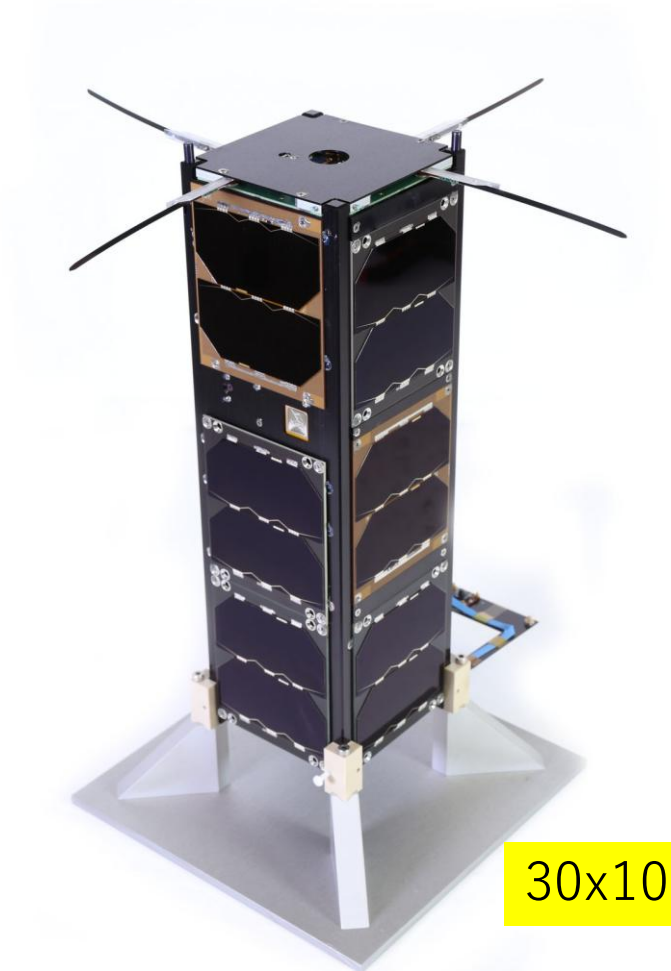
GRBAlpha

10x10x10 cm^3 1.2 kg

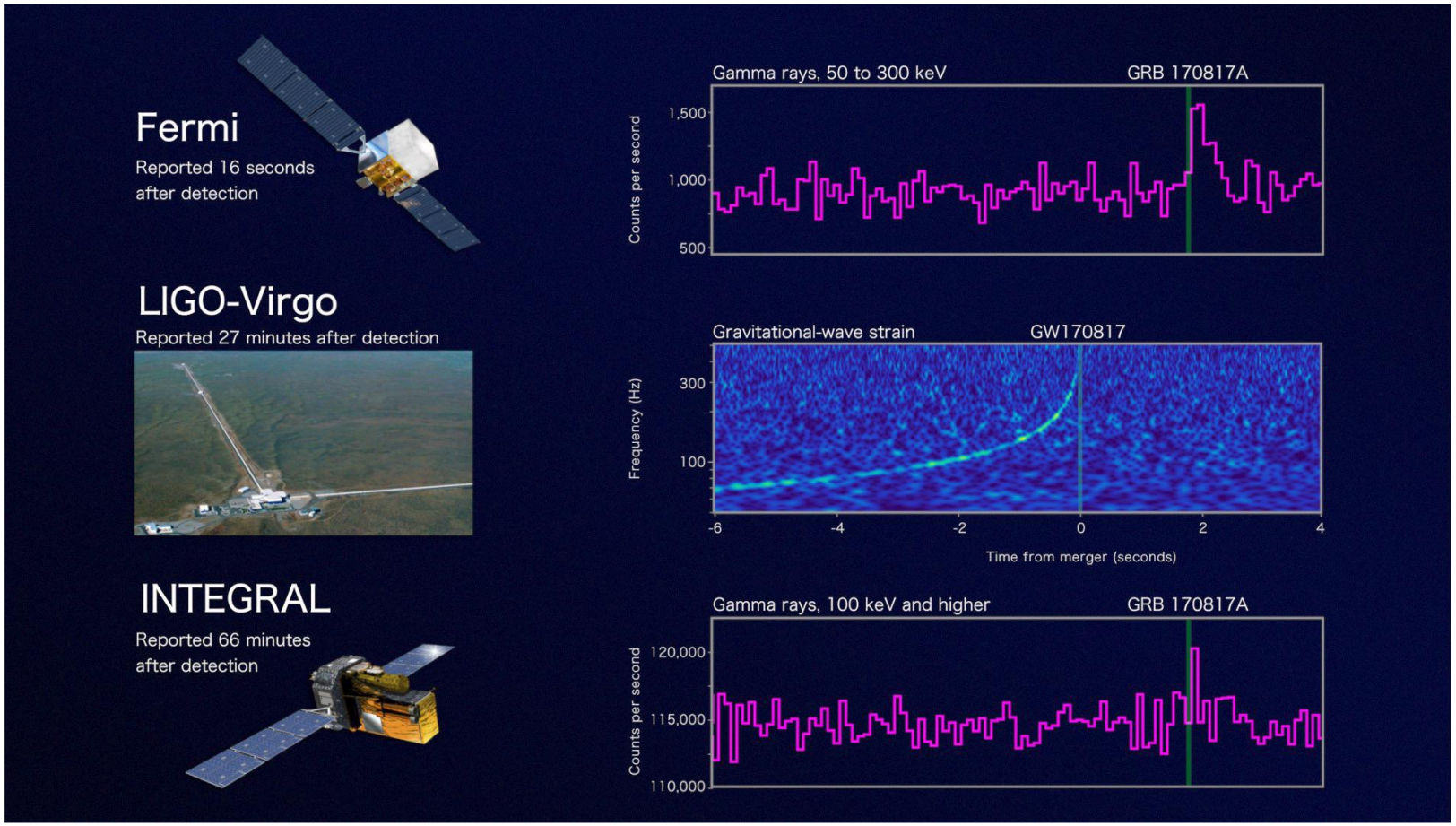
VZLUSAT-2



30x10x10 cm^3 3.9 kg

Multi-messenger astronomy with all-sky observations

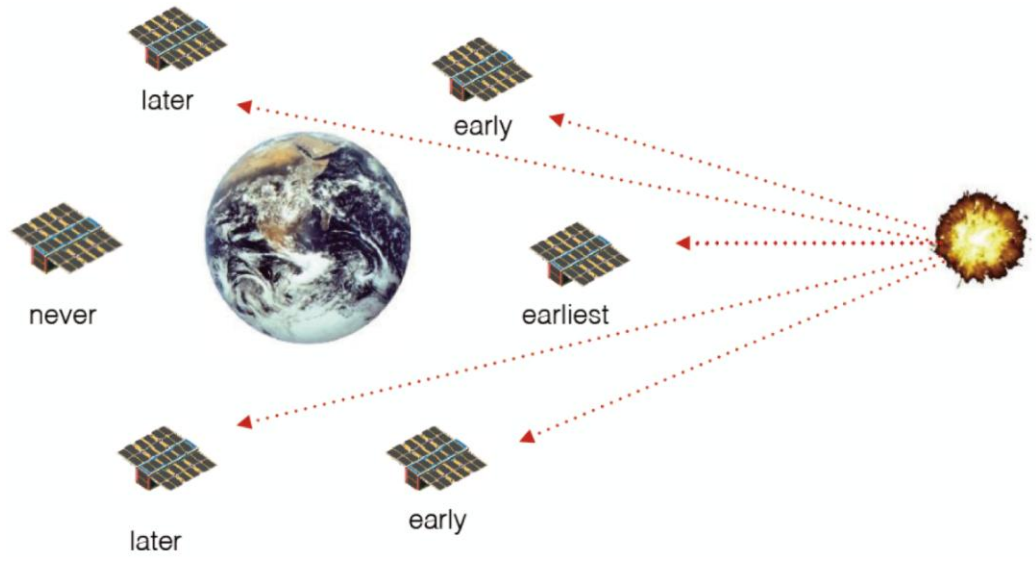
- LIGO/Virgo detected several Gravitational Wave (GW) sources
- GW170817/GRB170817A :
  Counterpart detection confirmed a open of the “GW astronomy era”
- More sample required by “All-sky/Always/Location” gamma-ray observations
- CubeSats constellation could be a solution => **CAMELOT mission**

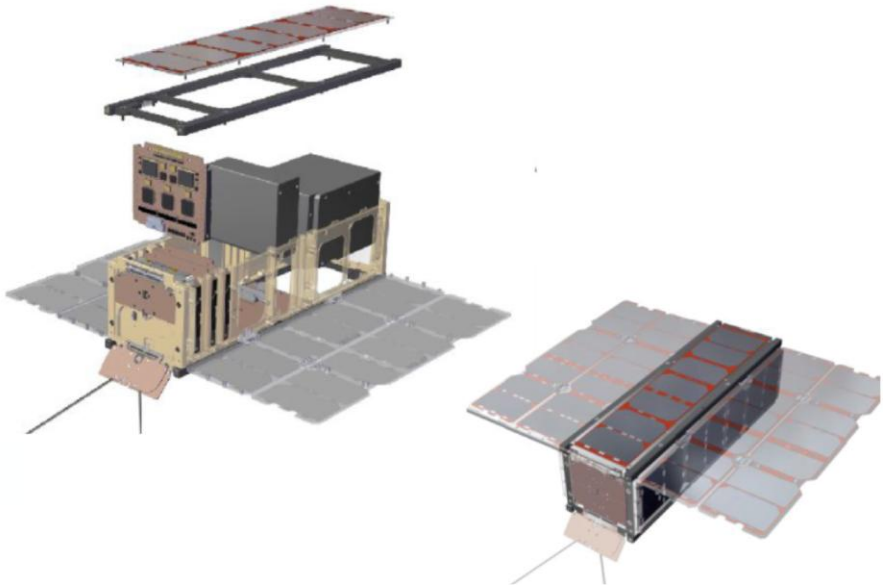


CAMELOT: Cubesats Applied for MEasuring and LOcalising Transients

PI: Norbert Werner (Masaryk University, Czech)

Werner SPIE 2018
Ohno SPIE 2018





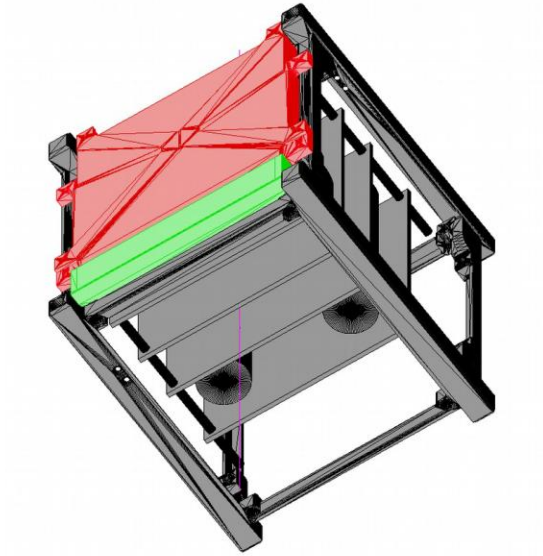
- Dozen CubeSat constellation ⇒ all-sky coverage
- Localization by photon arrival time

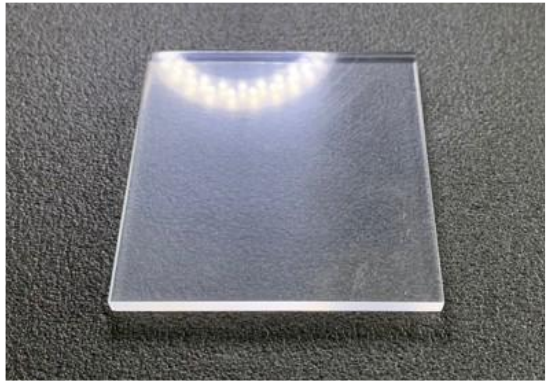
The number of signals determines the timing/localization accuracy.
⇒ Detectors with Large effective area (with lower threshold)

SiPMs for Small Satellites (CubeSats)

Small size (<1 cm), Low operational voltage (<~50 V), high gain

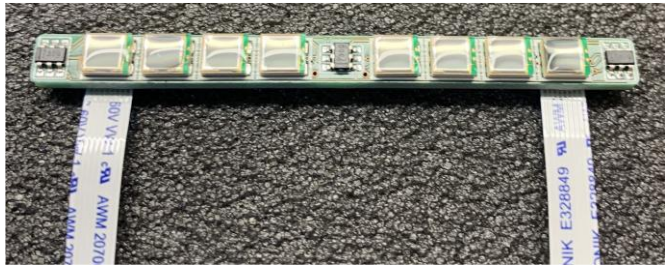
GRBAlpha (1U CubeSat, 10x10x10 cm3): 1 unit. **VZLUSAT-2** (3U) has 2 units.



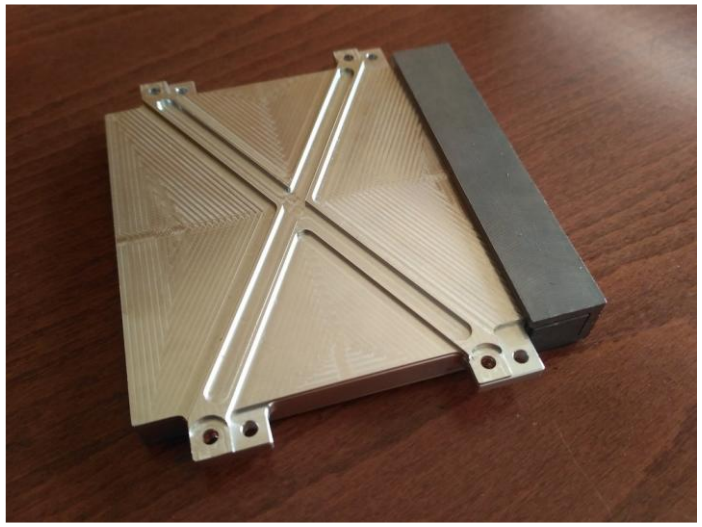


CsI(Tl) scintillator
7.5x7.5x0.5 cm3

Wrapped with ESR reflector



2 readout channels
of 4 MPPCs (S13360-3050PE)



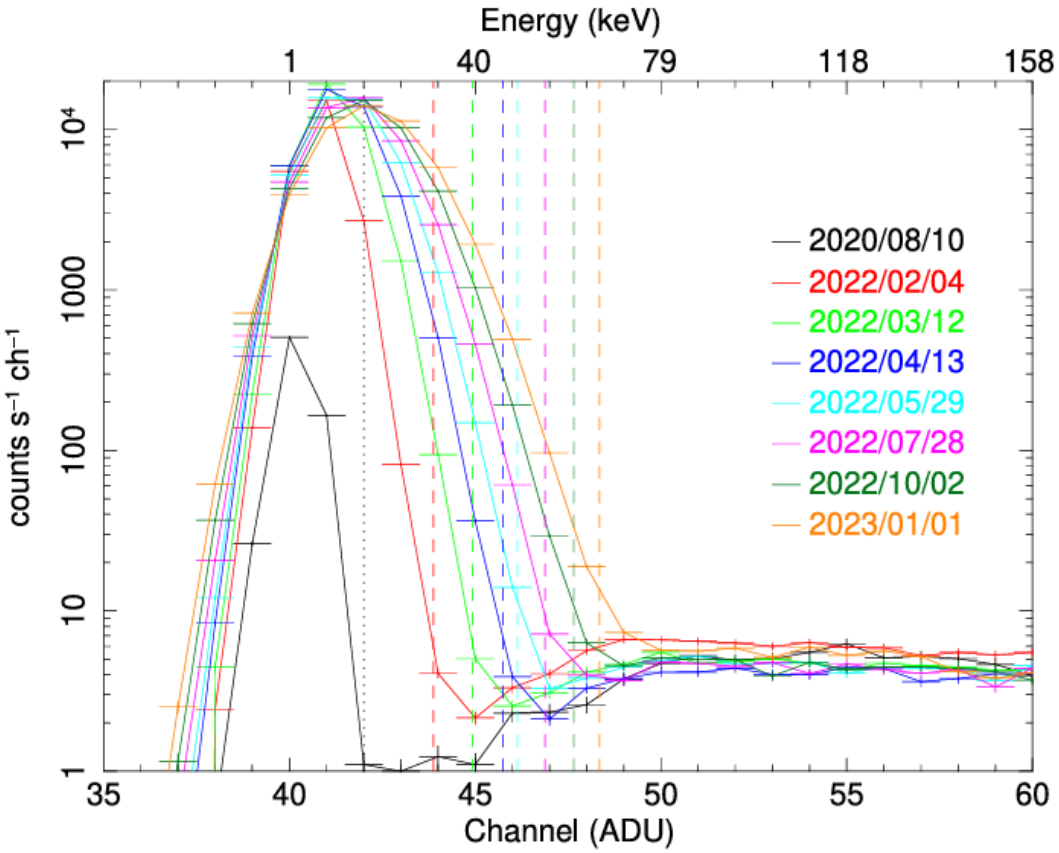
2.5mm Pb-Sb alloy shield
to reduce radiation damages for MPPCs

Radiation Damage of SiPM in orbit (550-470 km)

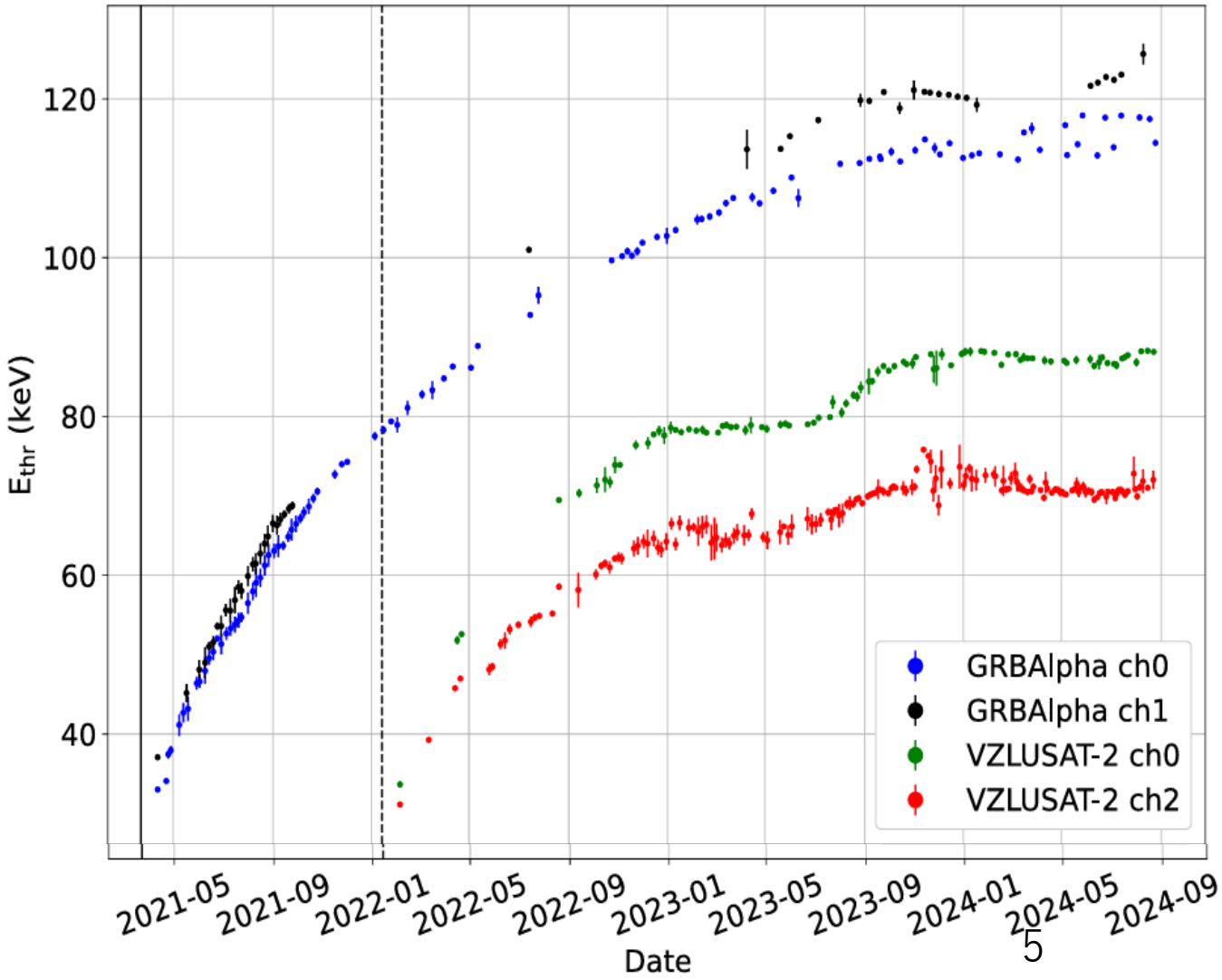
Ripa+2025

Dose rate: 0.1-1 krad (1-10 Gy)/year

Noise spectra of GRBAlpha



Trend of low-energy threshold



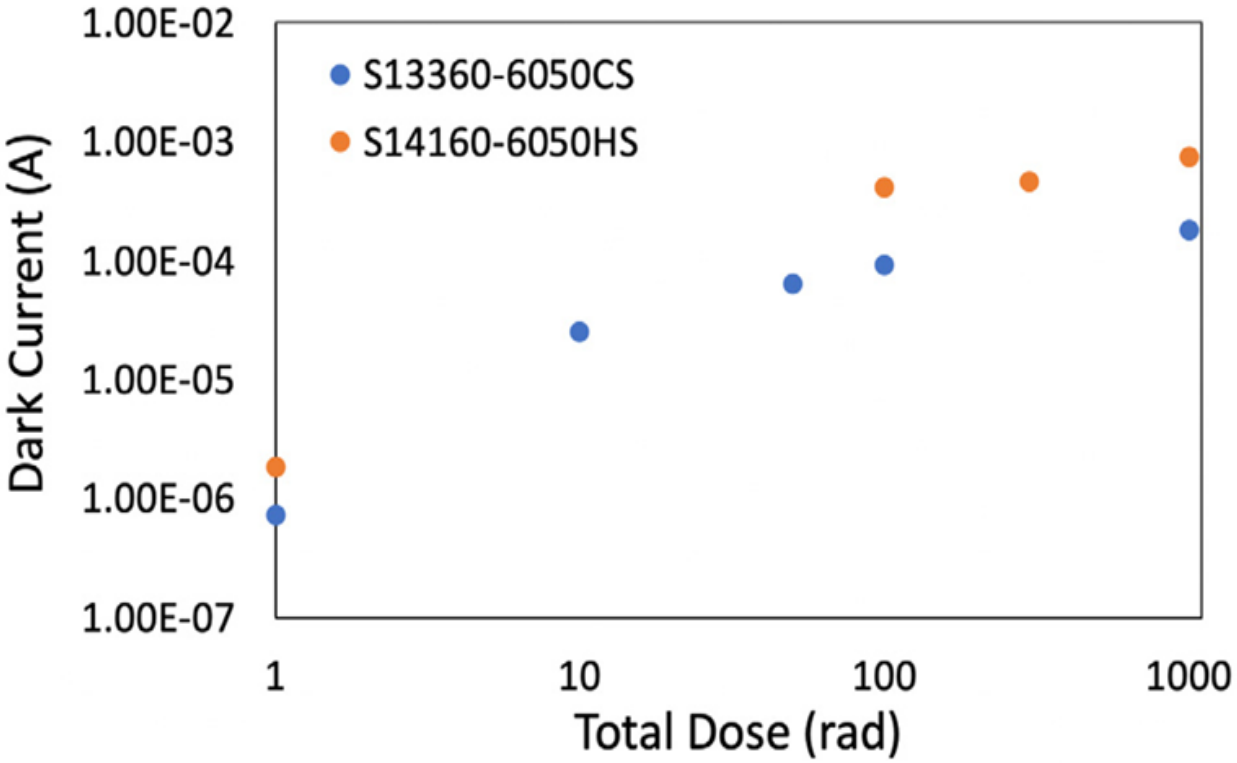
Previous studies of Radiation Damaged SiPM

Hirade+2021, Morishita+2024

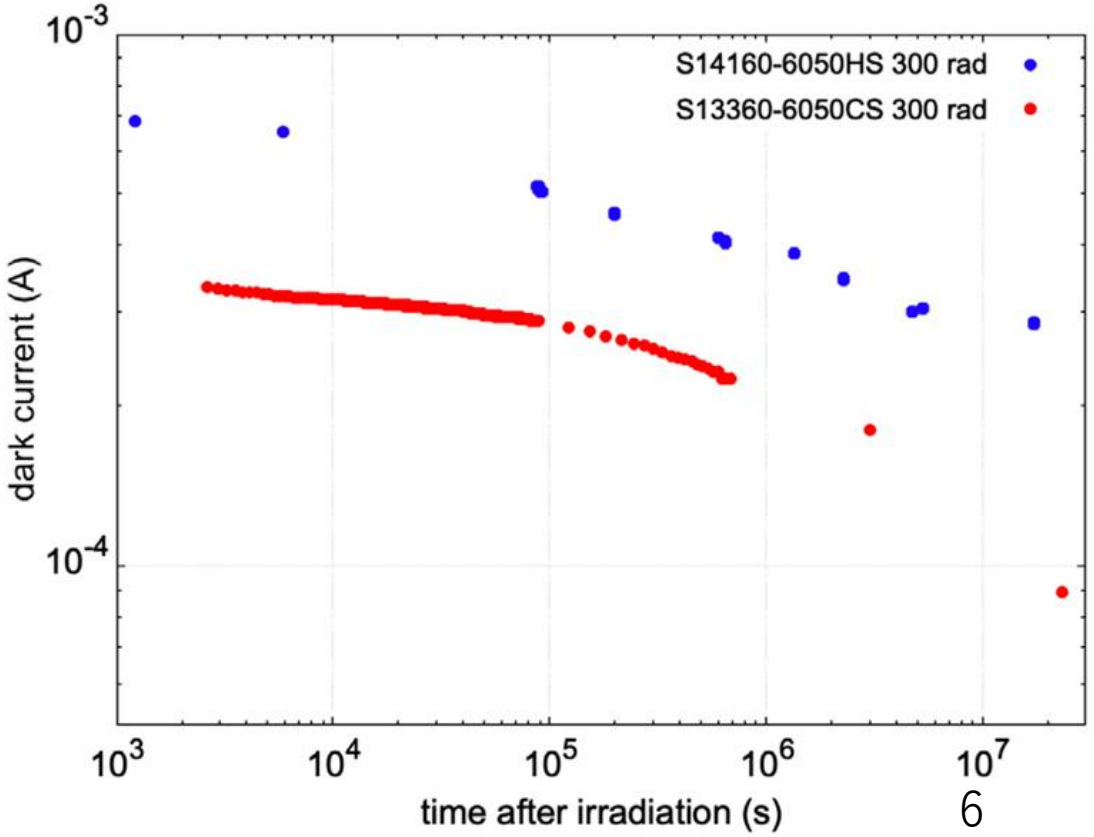
- **Different types** (S13360, S14160)
- **Annealing**
- **Coincidence** of multi-SiPMs
- **Fast shaping time**

Each recovery: by a factor
⇔ the initial damage is 2-3 orders of magnitudes.

Noise increase by radiation damage



Annealing at room temperature over 1 year

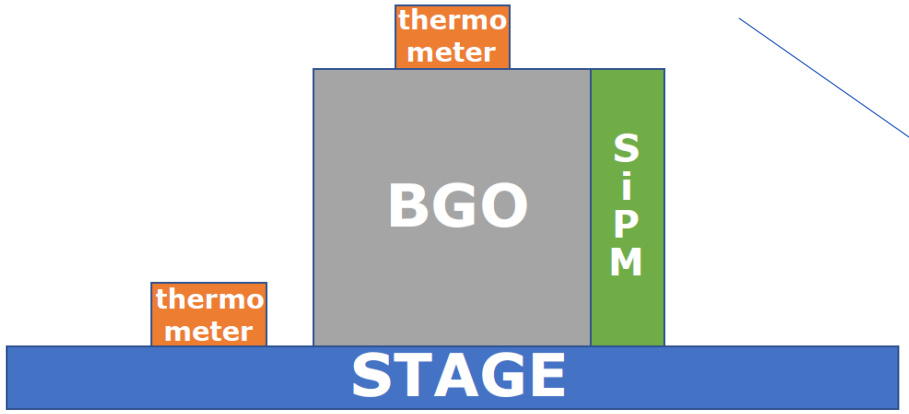


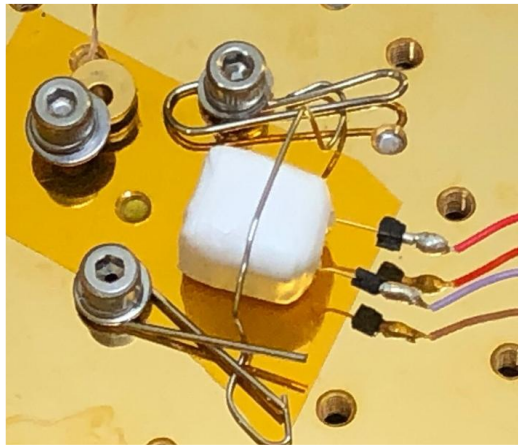
(This time) Measurement at Lower Temperature

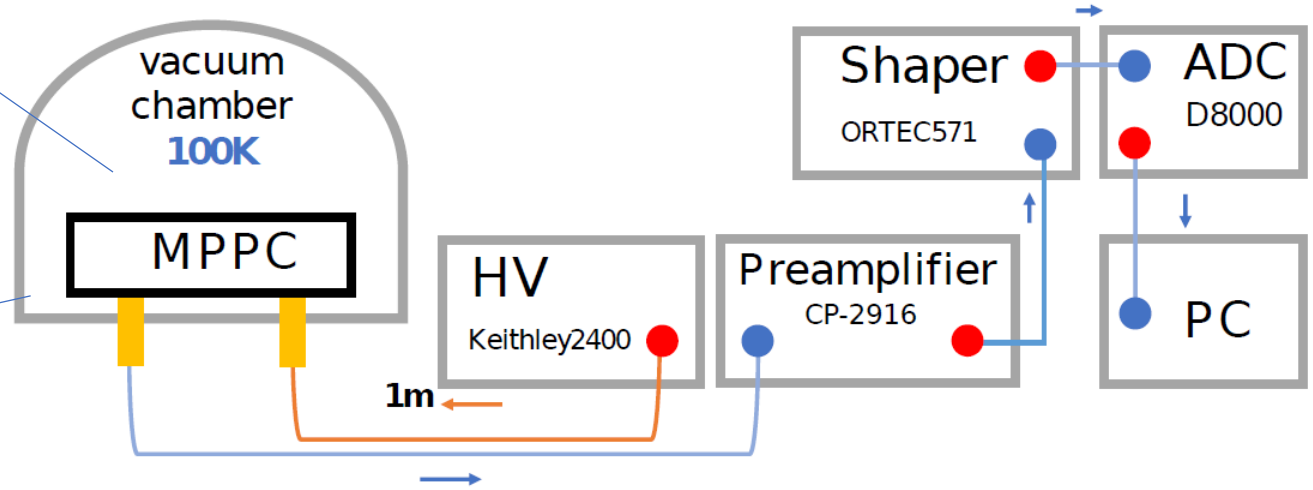
MPPC: S13360-6050CS

200 MeV protons: 1 krad (1.71 x 10^{10} protons/cm2 = 1.69 × 10^{10} 1 MeV n_{eq})

1cm^3 BGO scintillator

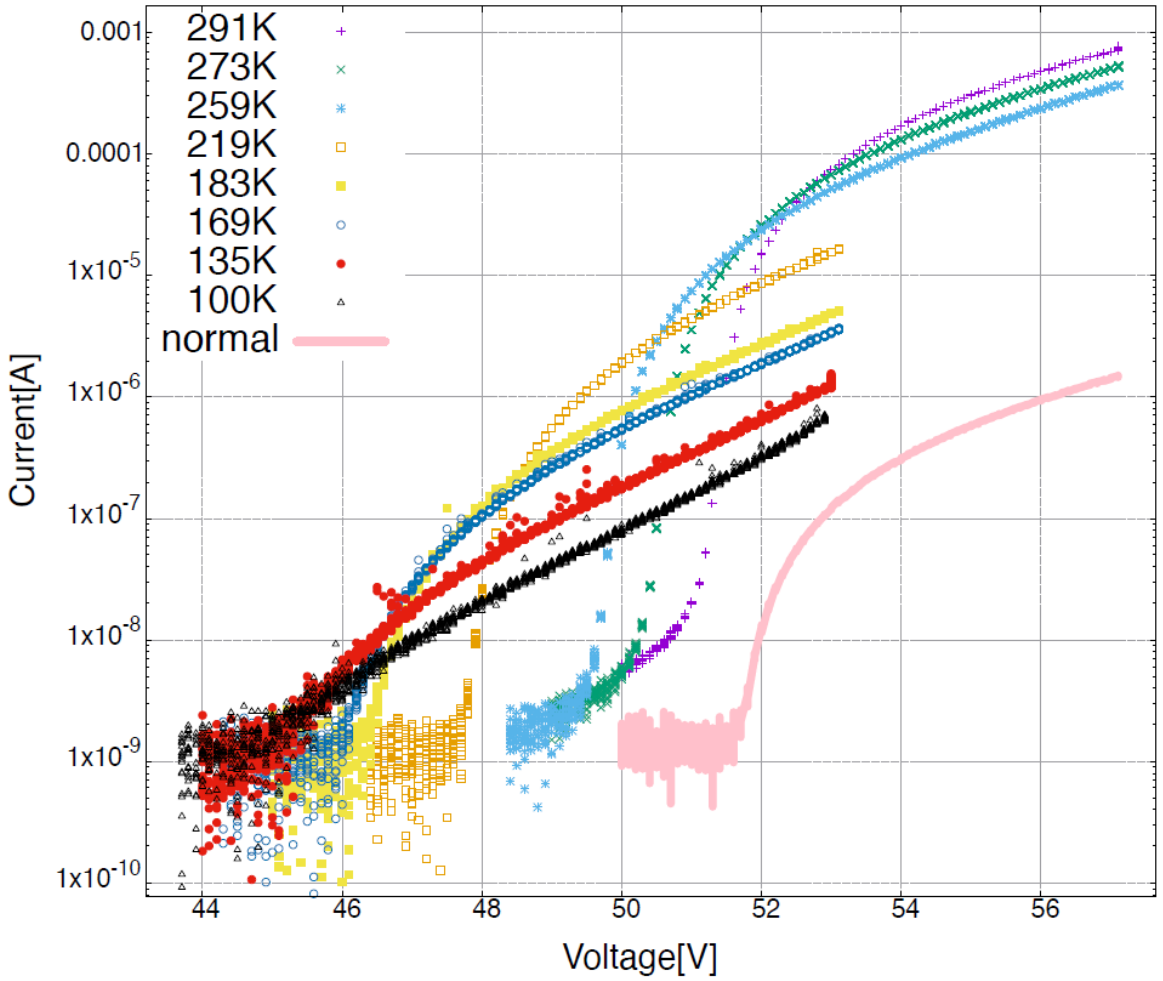




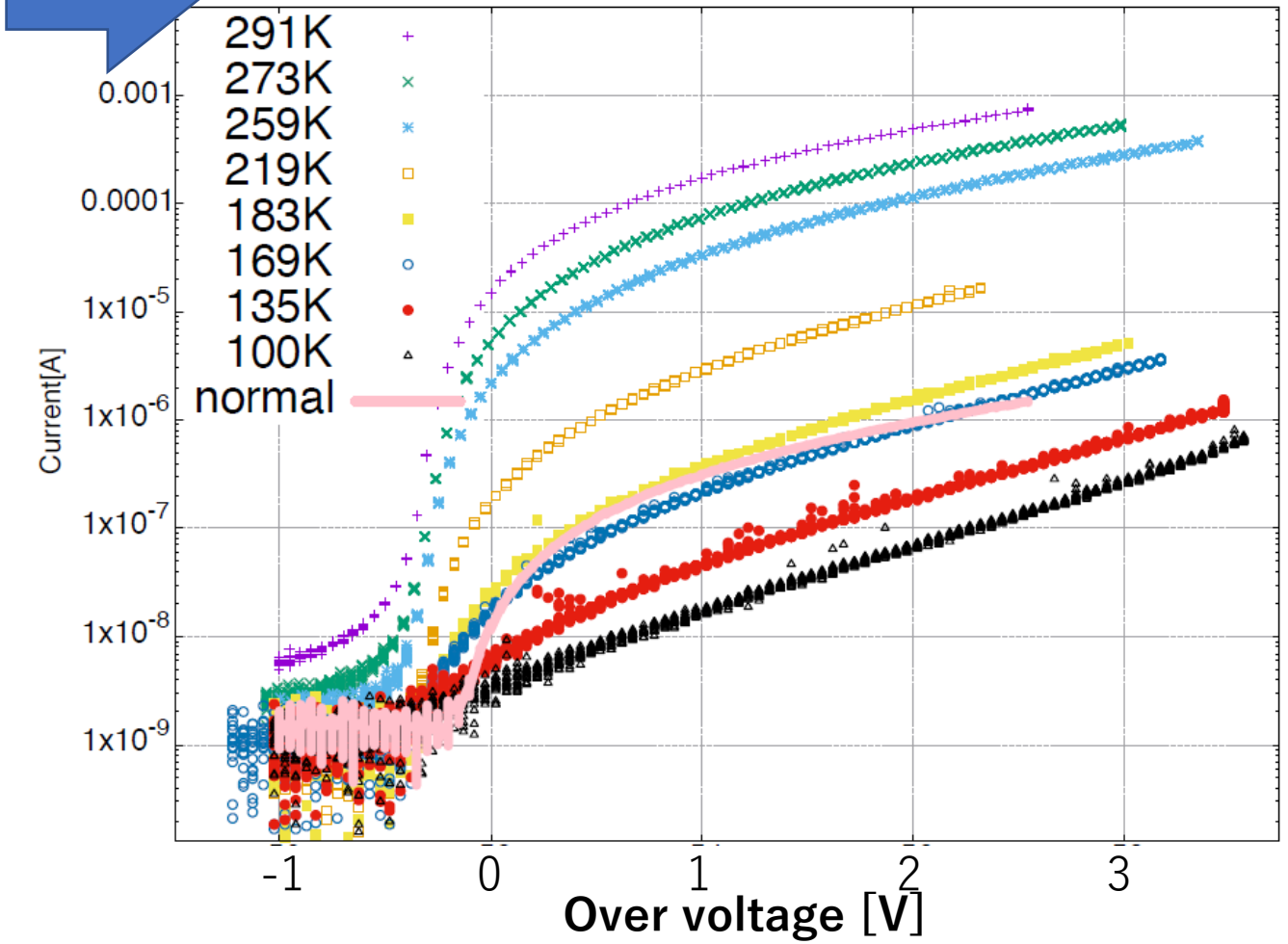


Performance at Lower Temperature: Noise Current

Raw measurements



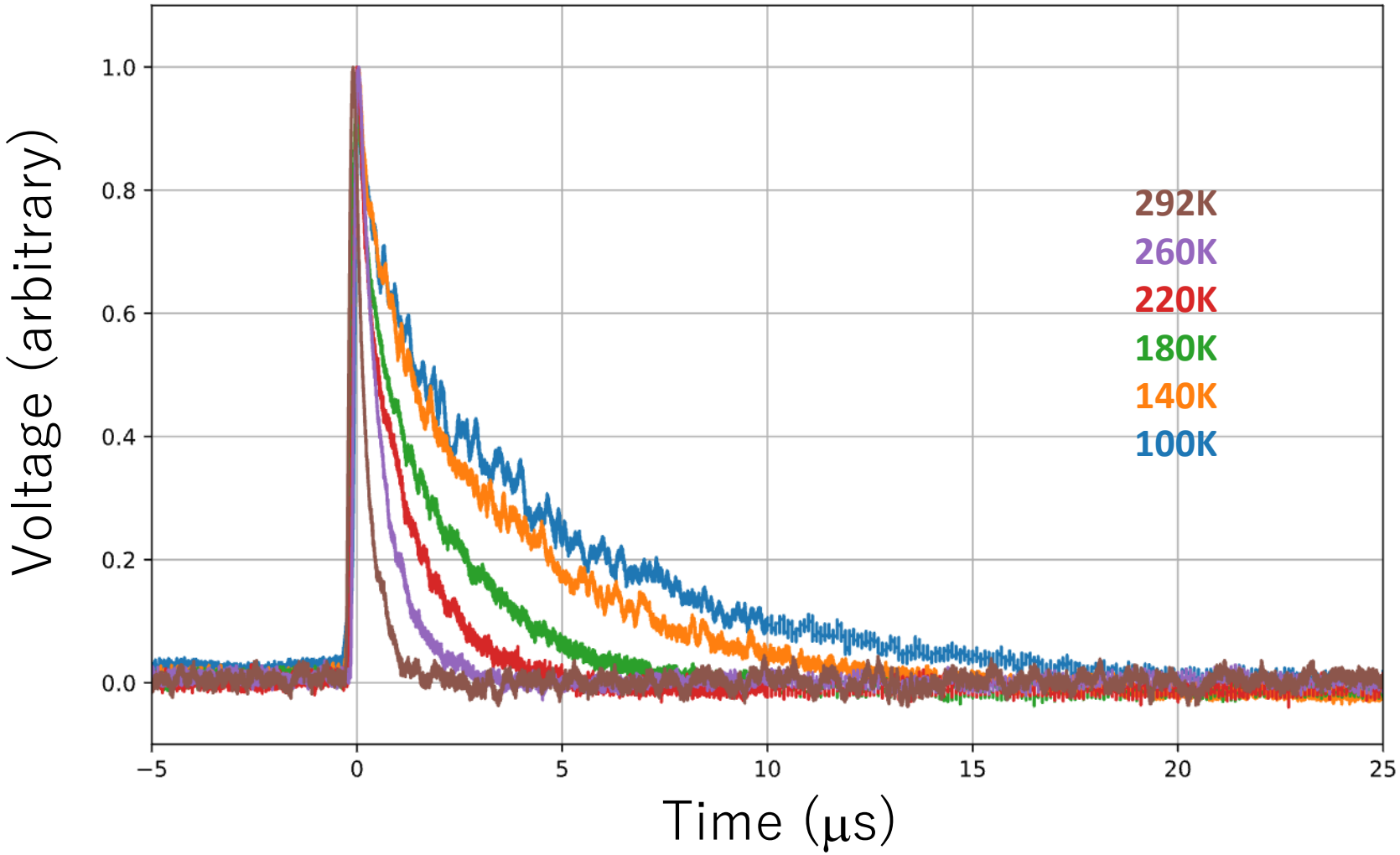
After normalized by over voltage



Even for damaged SiPM, the noise decreased following the temperature.

(e.g., At 170-180K, the noise returns to the original/normal level.)

Pulse shape of BGO scintillator

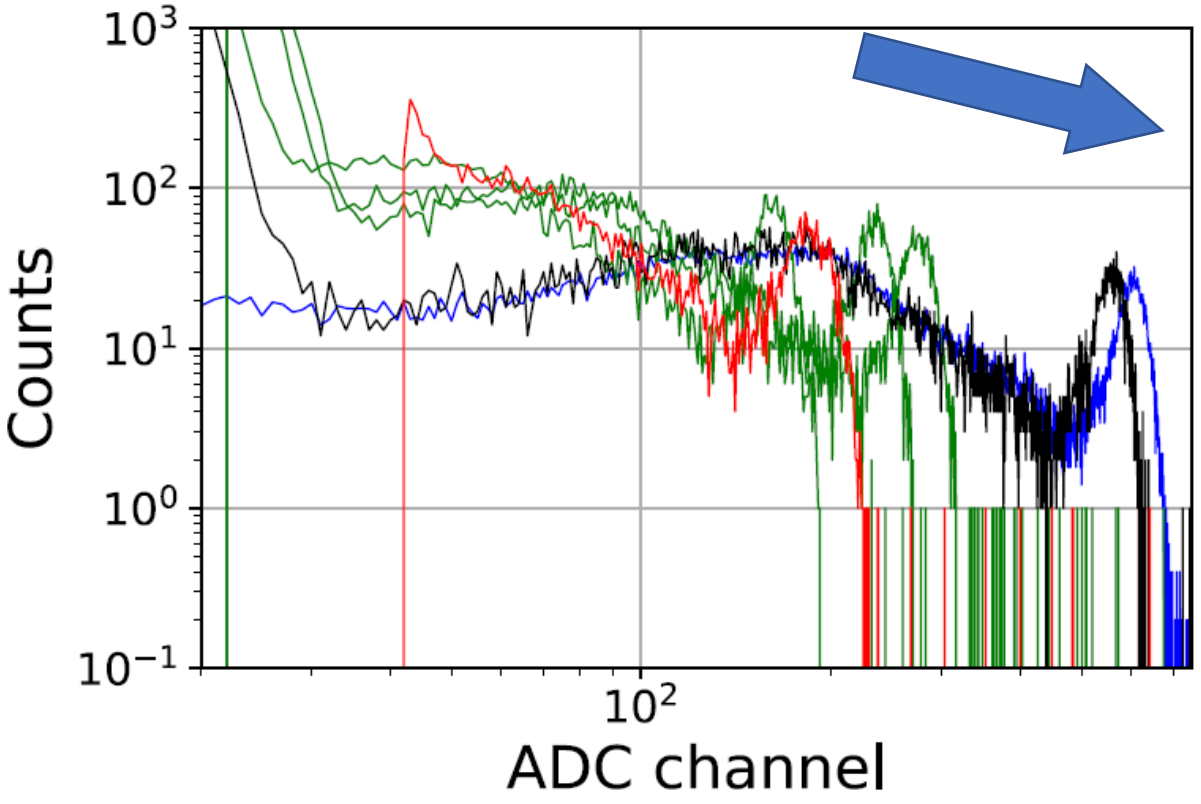


At the lower temperatures, the decay time of BGO becomes longer.
=> We adjusted the shaping time between 0.5-3 us.

Performance at Lower Temperature: Energy Spectra (BGO)

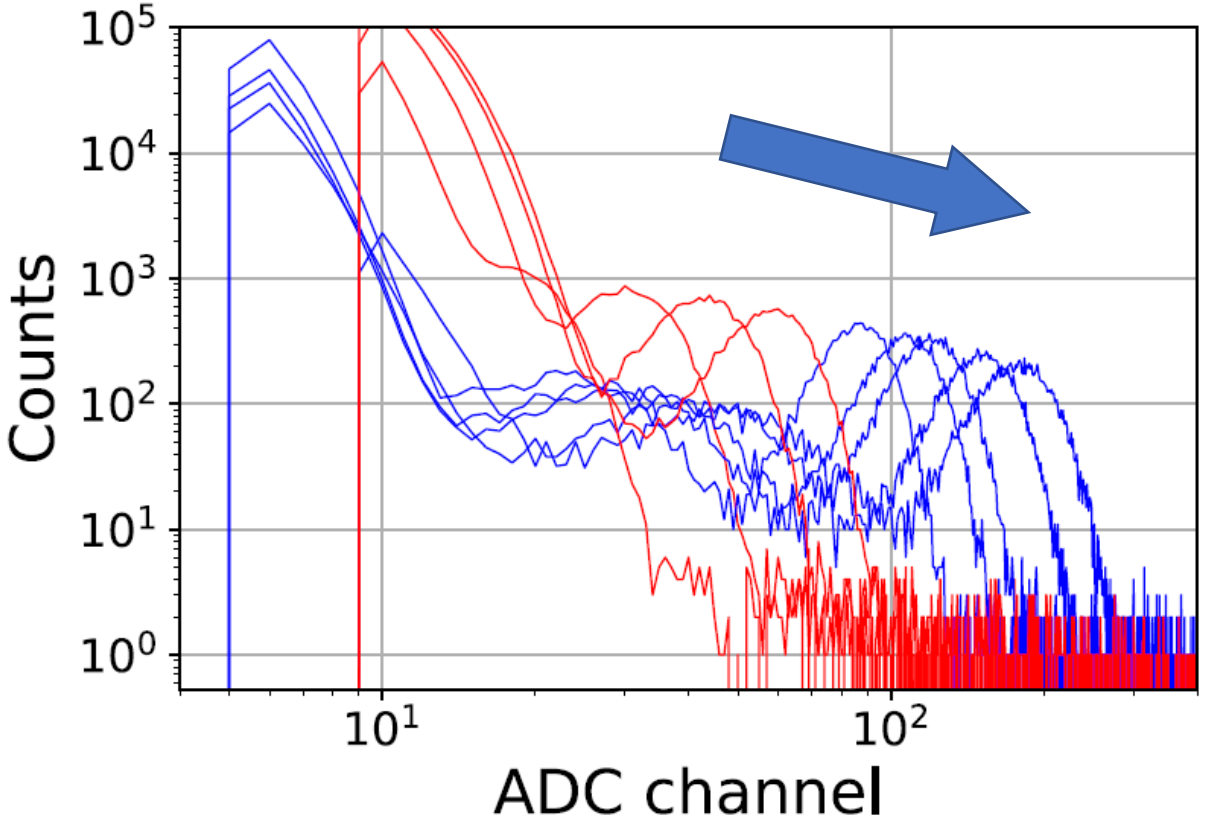
Shaping time: 0.5 μs (292K), 1 μs (>260 K), 2 μs (260-180 K), 3 μs (<180 K)
<= including temperature dependency of BGO itself.

292 K (room) – 100 K (137Cs)



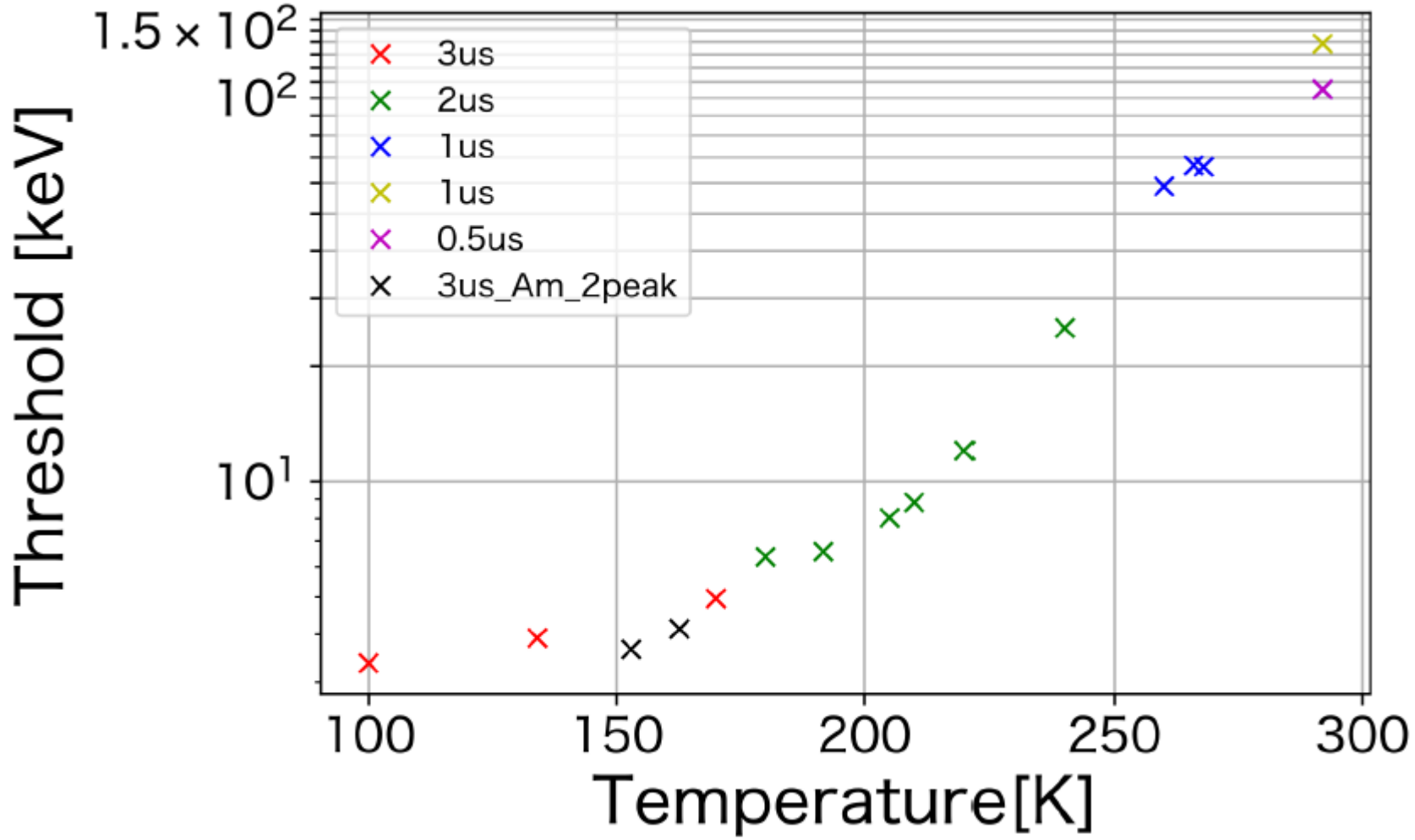
(Blue) 100 K, 46.5 V, (black) 233 K 50.5 V
(green) 265 K, 268 K, and 273 K with 51.5 V
(red) 292K, 52.5 V

253 K – 100 K (241Am)



(Blue) 100 K to 187 K with 49.5 V
(red) 225 K to 253 K with 50.5V.

Performance at Lower Temperature: Energy Threshold (BGO)

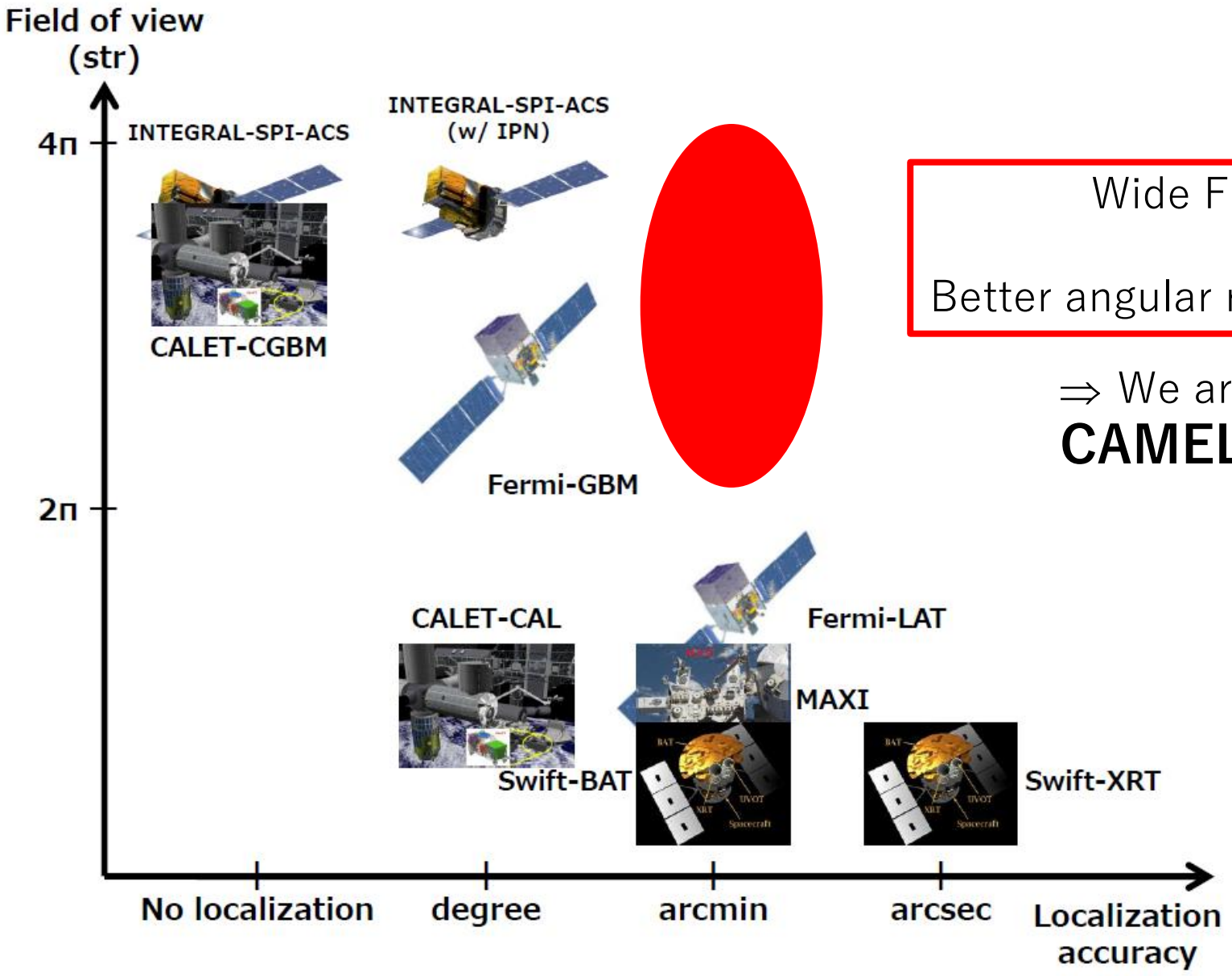


As lower the temperature, the energy threshold becomes the lower.
(Below 150K, the electric noise dominates in this setup.)

Conclusions

- SiPMs (MPPCs) are used for scintillator detectors of small satellites (CubeSats).
- Due to radiation damage on orbit, the dark noise increases.
  ⇒ the low-energy threshold degrades.
- This time, we measured radiation-damaged SiPM at lower temperature (100 K).
- As the temperature decreases, it is confirmed that
  - Dark current decreases (at 170-180 K, it returns to the original/normal level).
  - With BGO scintillator, the low-energy threshold also improves.
- **When SiPMs are used in liquid Argon (Nitrogen, Xenon, Helium) detectors, the effect of radiation damages could be negligible.**
- **Improving radiation tolerance is still essential for normal-temperature detectors.**

Current gamma-ray sky surveys

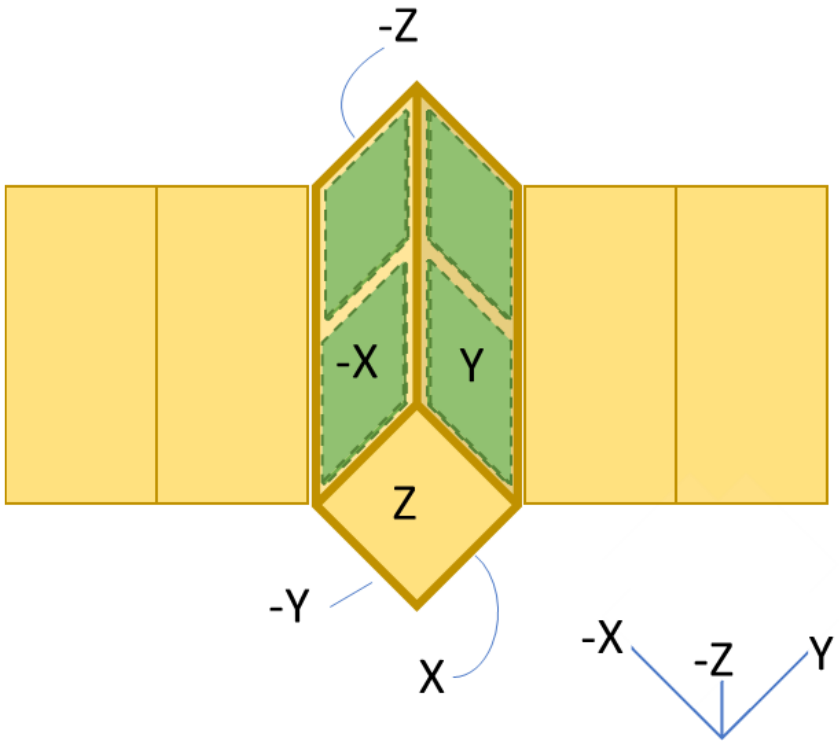


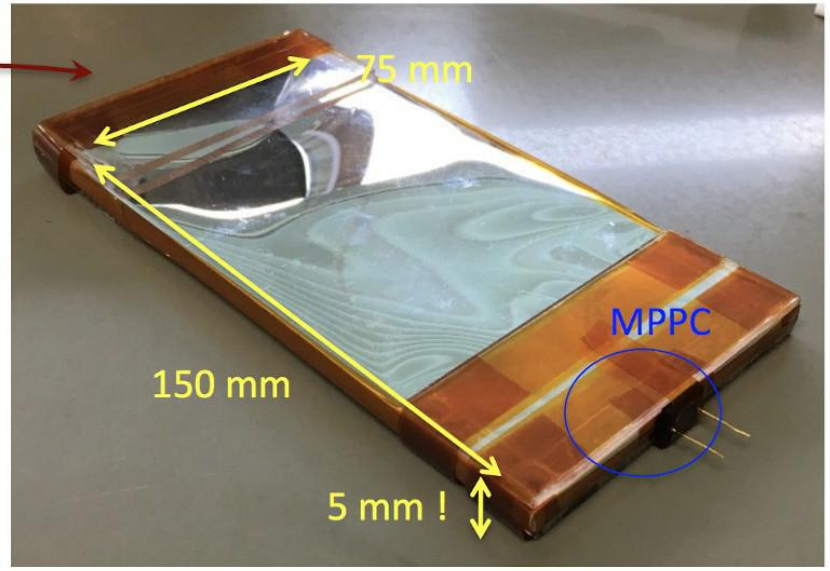
Wide FOV （$>2\pi$）
+
Better angular resolution (<degree)

⇒ We are developing
CAMELOT mission

CAMELOT detector: Flat scintillator + SiPM (MPPC)

Werner SPIE 2018





・To maximize the effective area, the detectors based on CsI scintillators and Multi-Pixel Photon Counters (MPPC) will occupy two lateral extensions
(8.3 cm x 15 cm x 0.9 cm x 4)

・The large and thin detectors with small readout area are challenging

・The read out of the CsI detectors with MPPC has been evaluated in the lab.

・The system provides a large light yield, compact readout area and relatively low operational voltage.