Development of an imager with high time resolution optical photon counter

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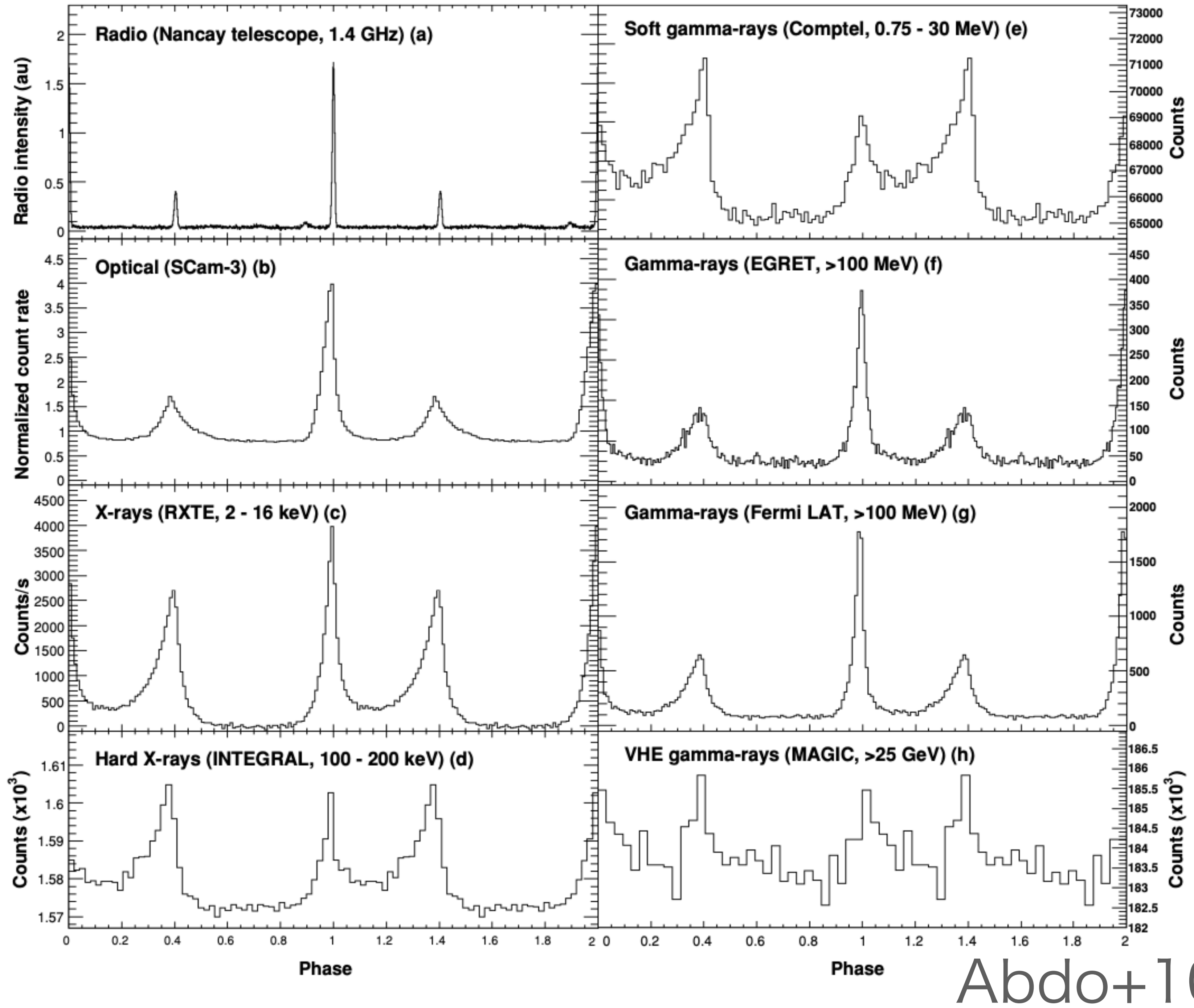
Research of Fast time scale optical phenomena

Example of target：GRP of Crab Pulsar

Crab pulsar

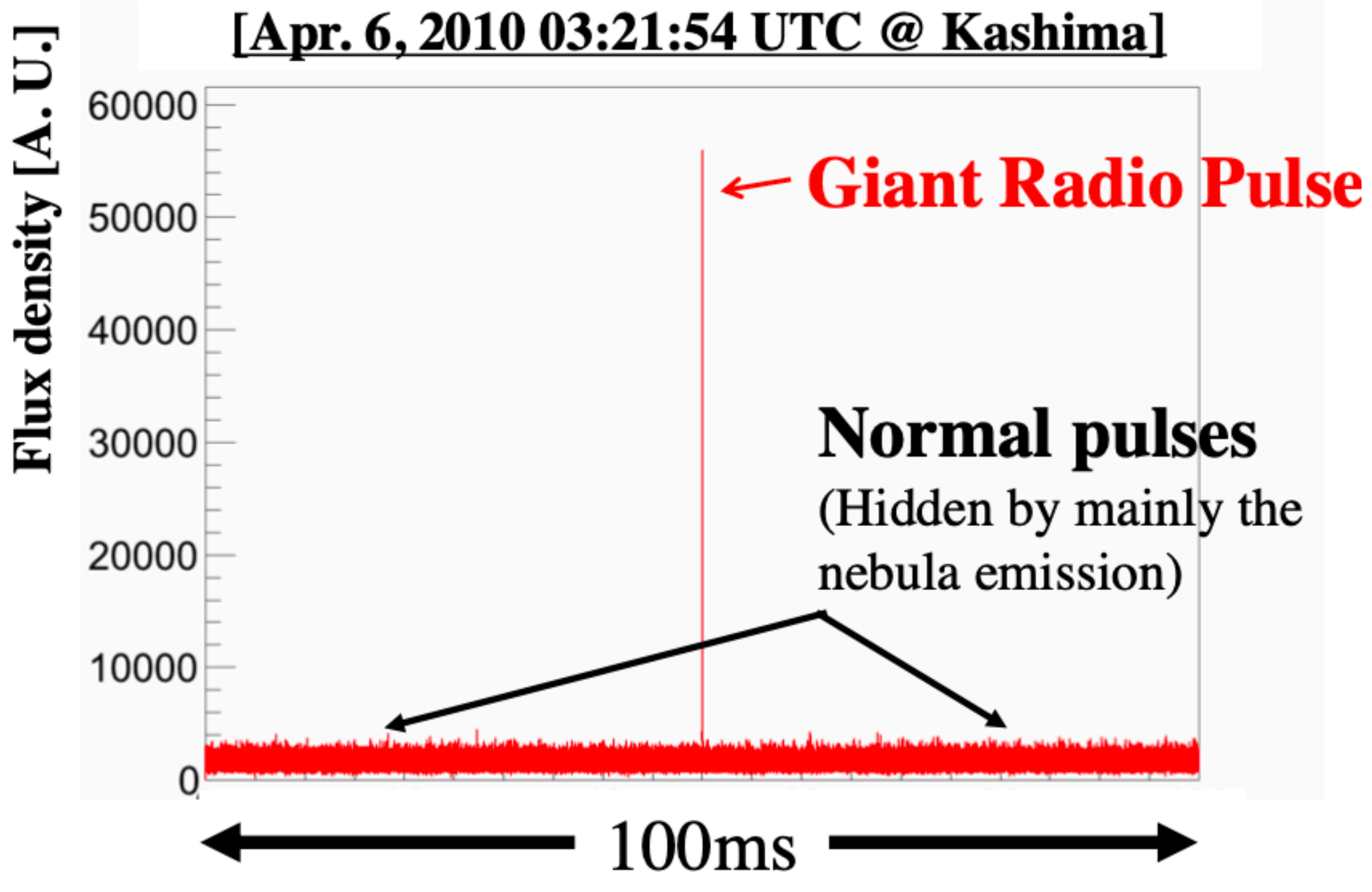
- Rotation period: P ~ 34 ms
- Persistent periodic emission



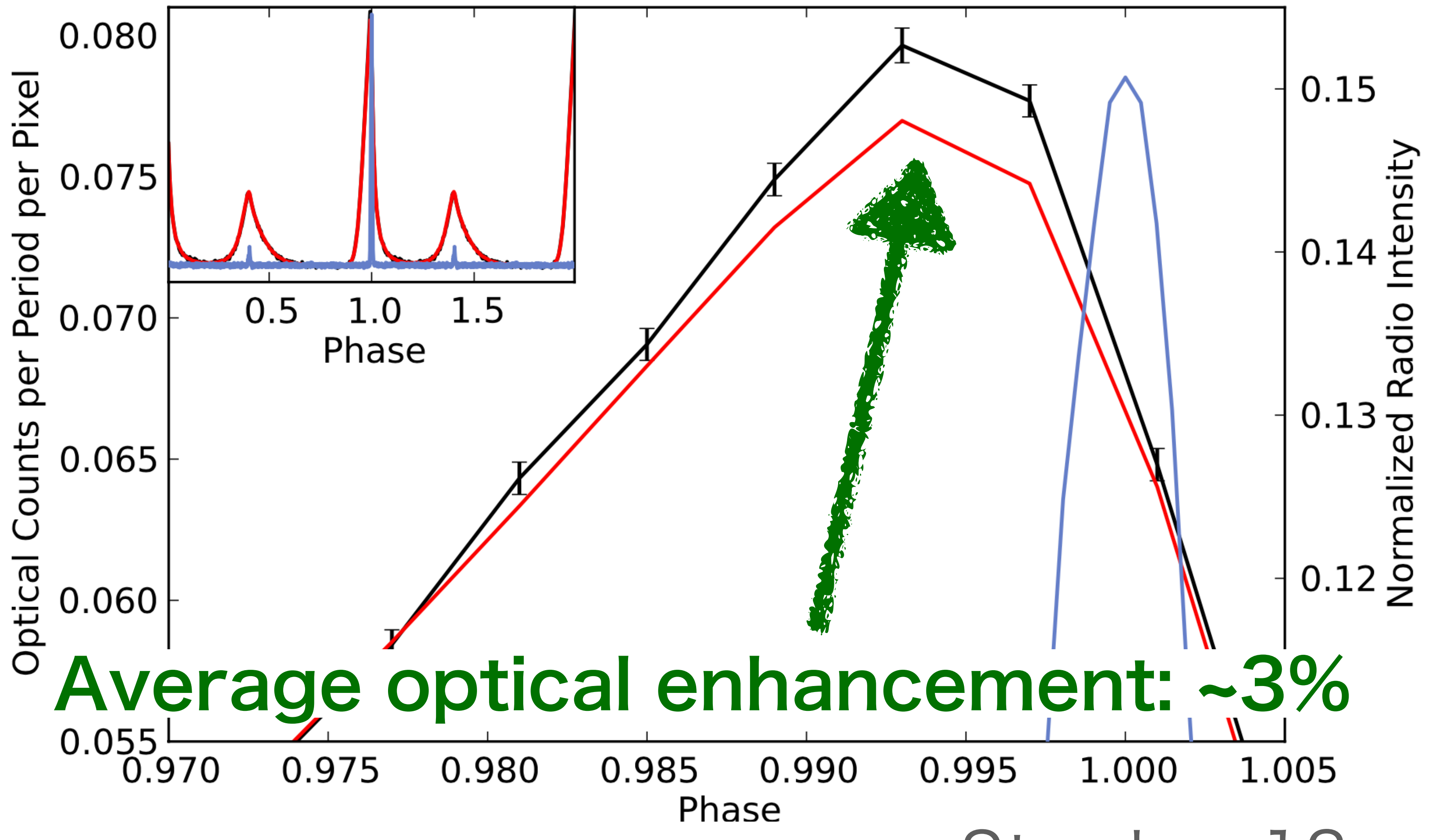
Abdo+10

Giant Radio Pulse (GRP)

- GRP: transient giant radio pulse (**ns-us**)
- Optical emission enhancement detected during GRPs



Mikami+15



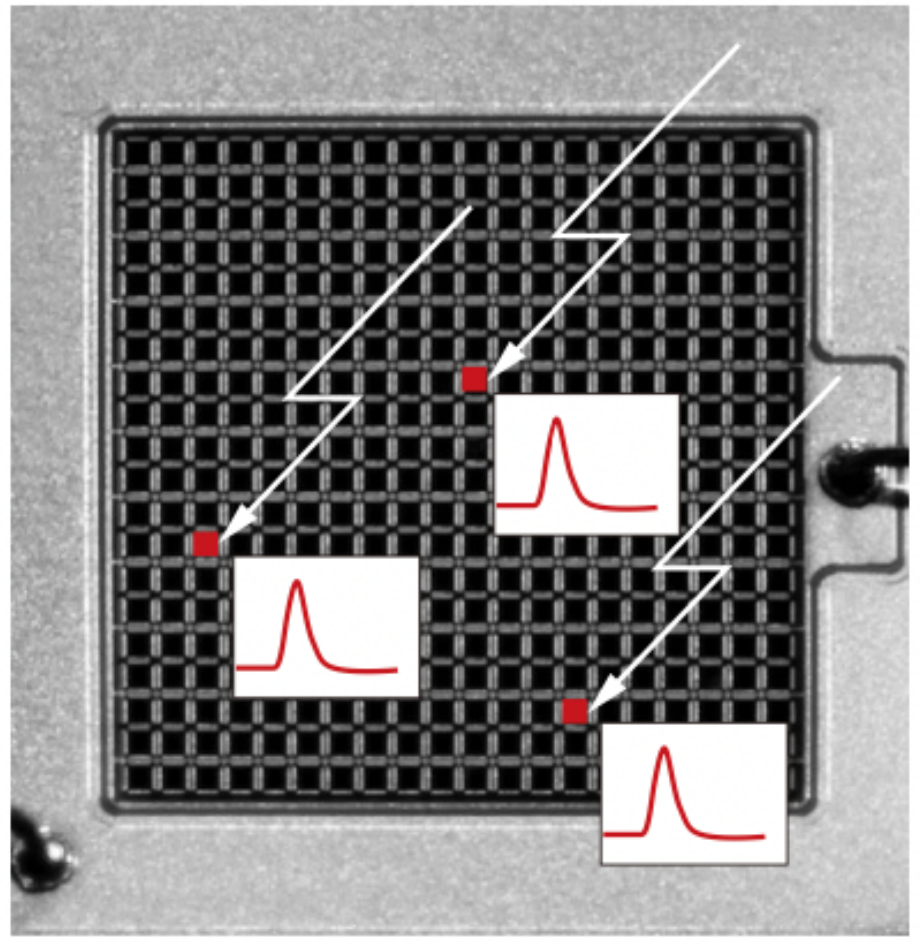
Strader+13

GRP emission mechanism is unrevealed → More multi-wavelength observations are needed

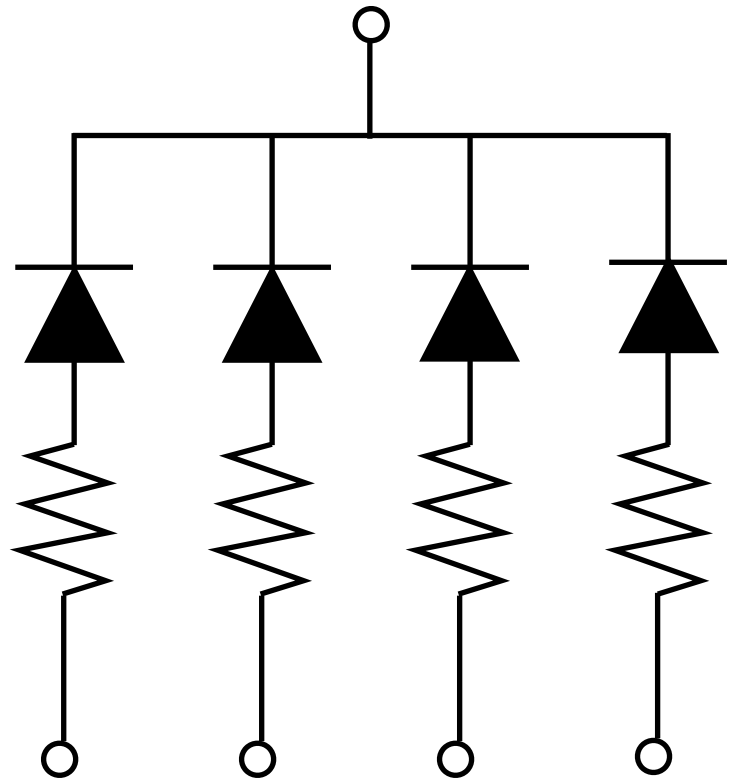
We need high sensitivity and high-time resolution optical photon detector!

Imager of MPPC-based Optical photoN counter from Yamagata

We use MPPC **customized** for astronomical observation



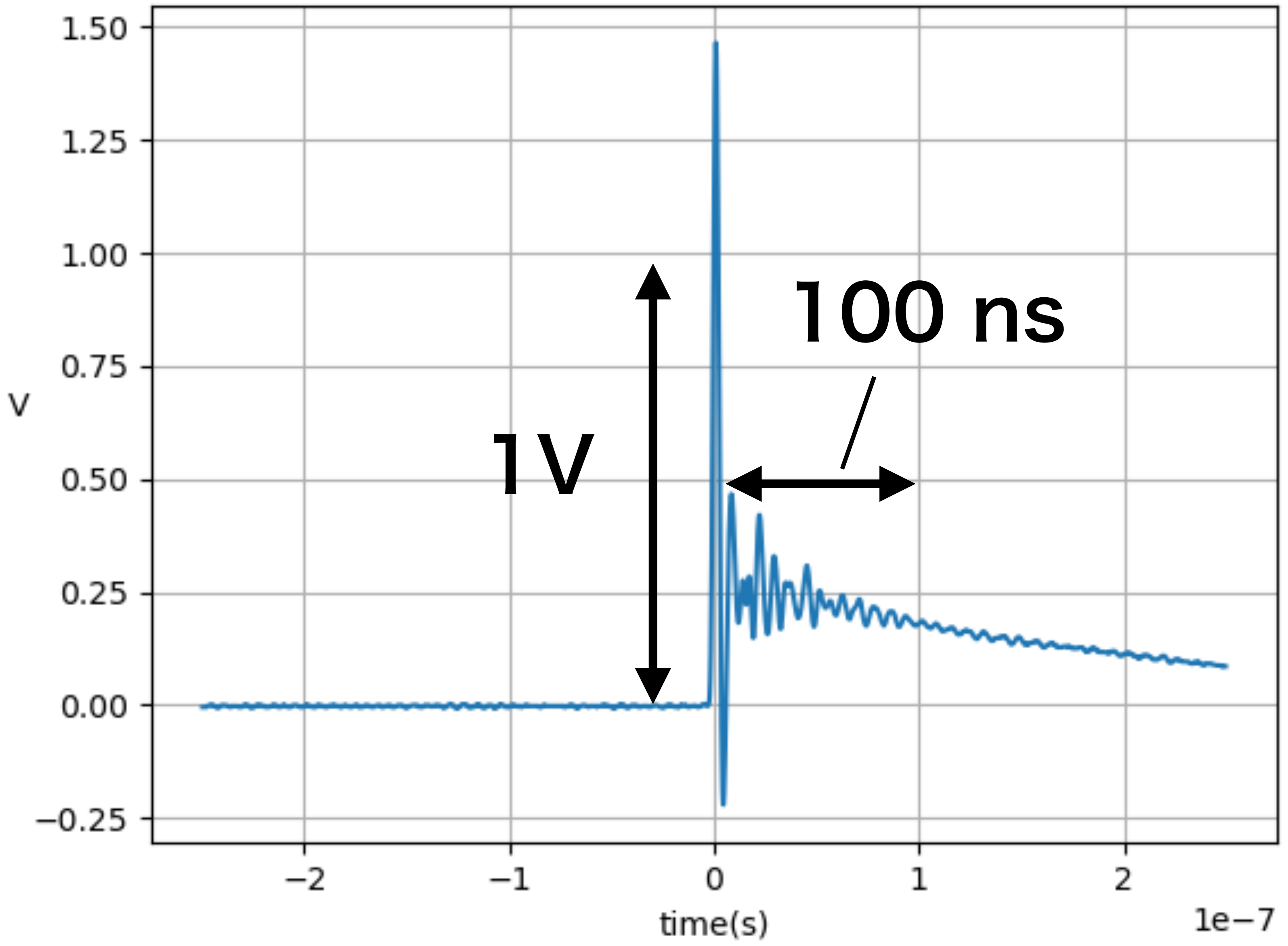
Images credit: Hamamatsu

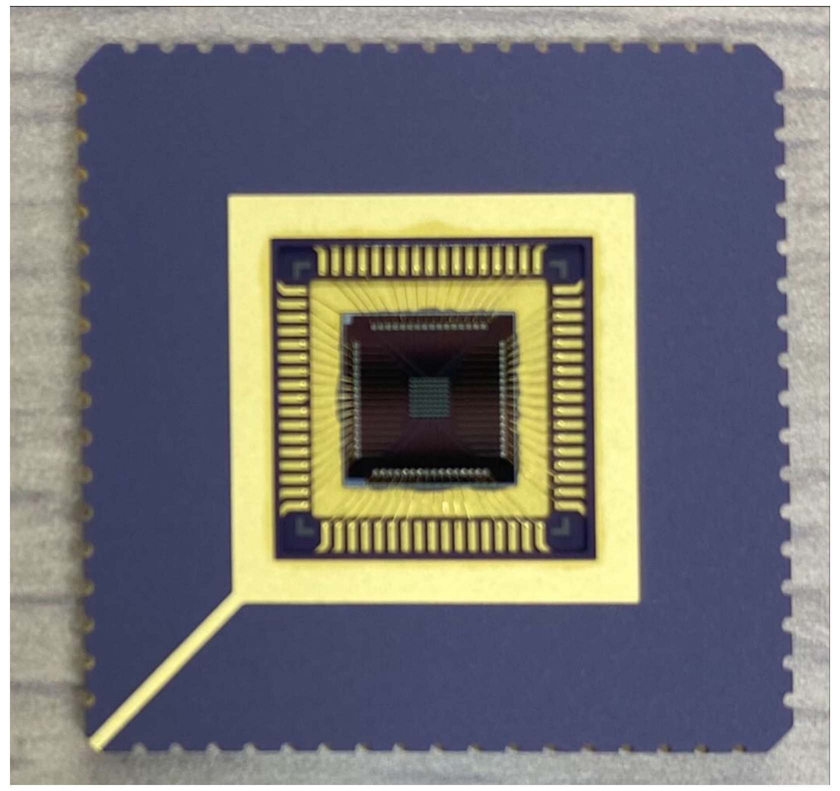


Geiger APD pixel

quenching resistar

pix by pix readout = GAPD array





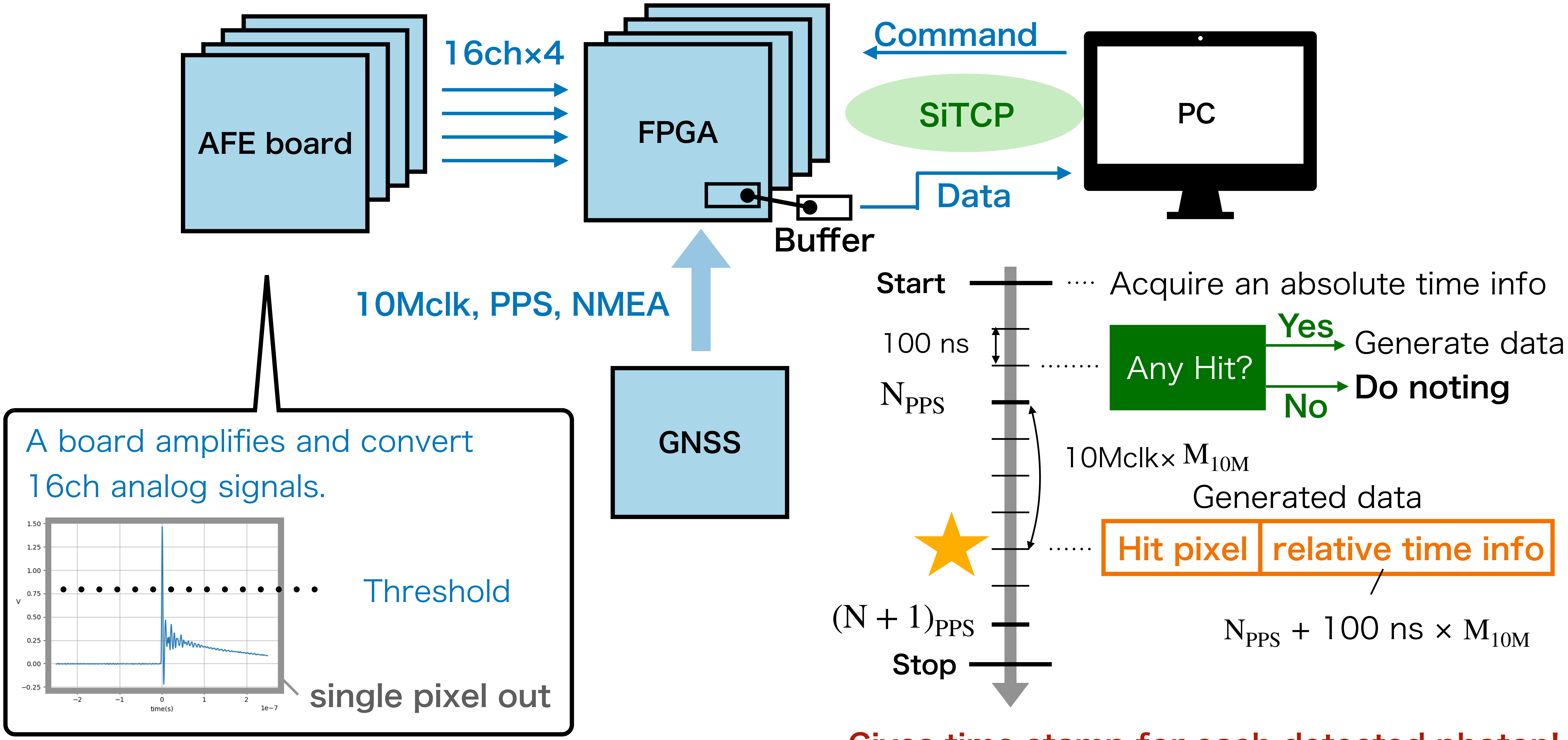
Multi-Pixel Photon Counter

- 8 × 8 arrays = 64 pixels
- pixel sizes: □100, 150, and 200 um
- Max PDE: ~70% @480 nm

Features

- Each pixel is read out **independently**
- Sensitive to a **single photon**
- **High S/N**

System configuration of IMONY



Gives time stamp for each detected photon!

Observation at the Seimei Telescope

We performed observations with the 3.8 m Seimei Telescope in 2023 and 2024.

2023.9

GNSS reception test

2023.10 Kino (23B-O-0004)

Test observation

Target

- Crab pulsar
- Other optical objects

2024.2 Kino (24A-K-0018)

Main observation

Target: Crab pulsar

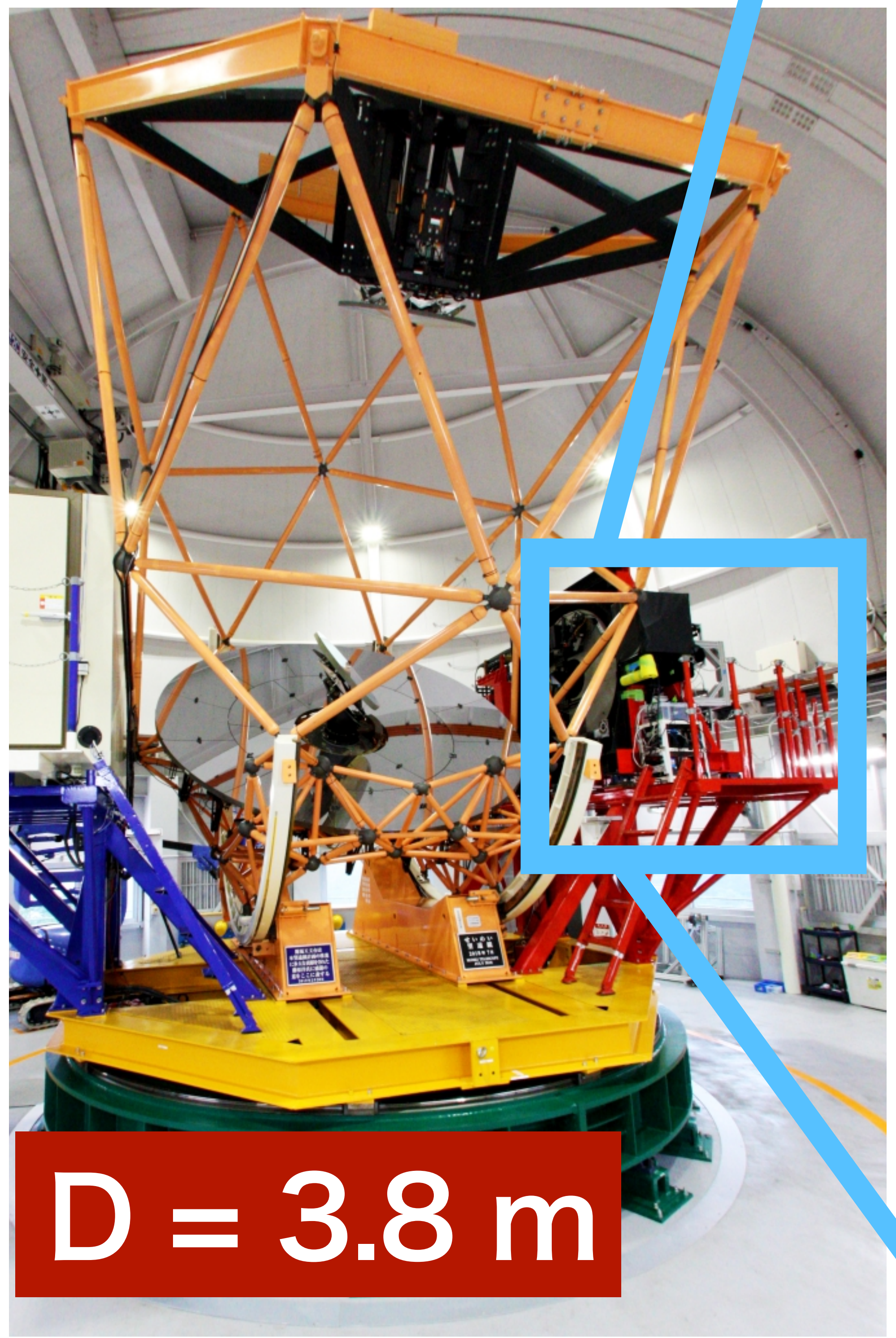
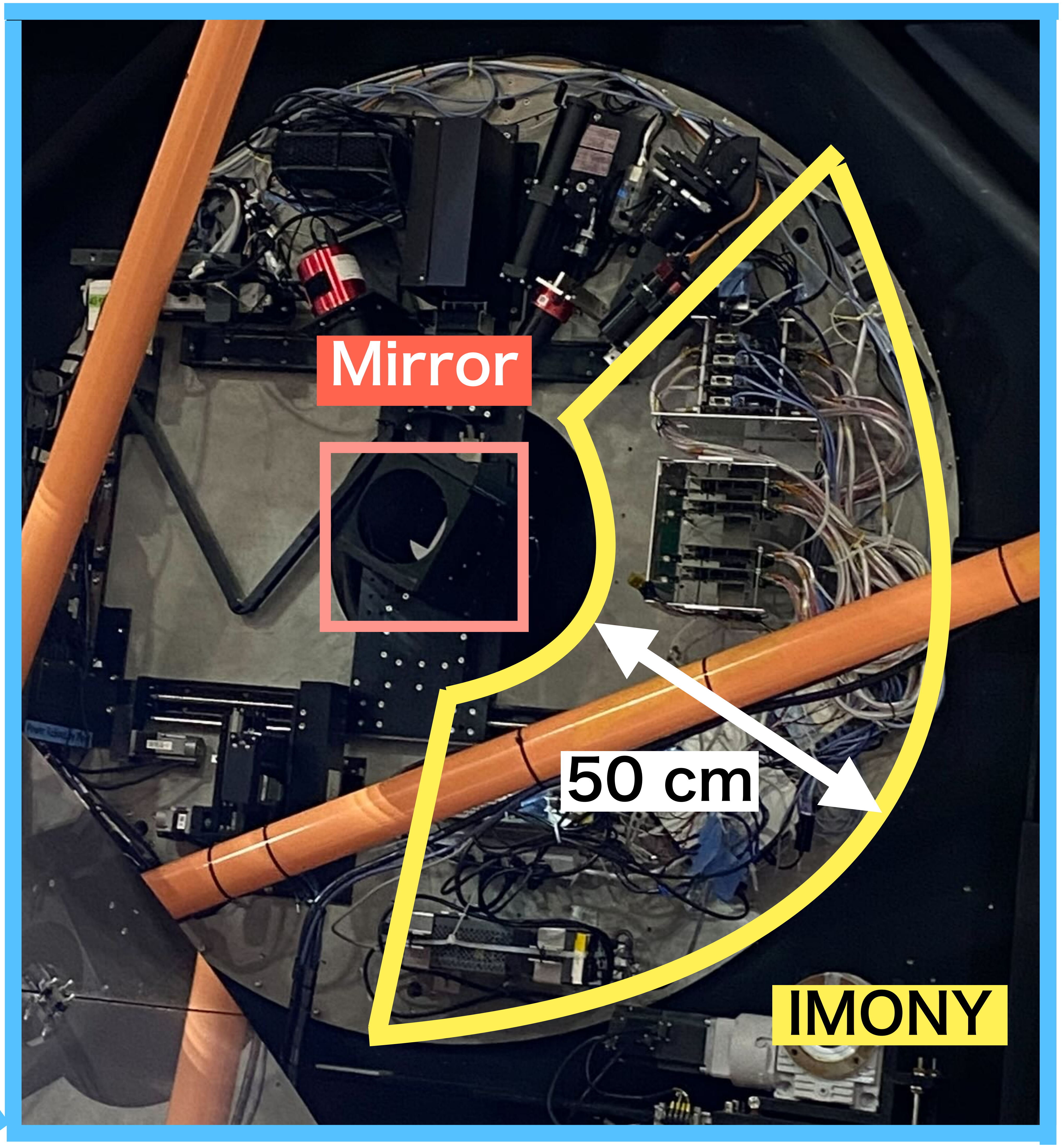
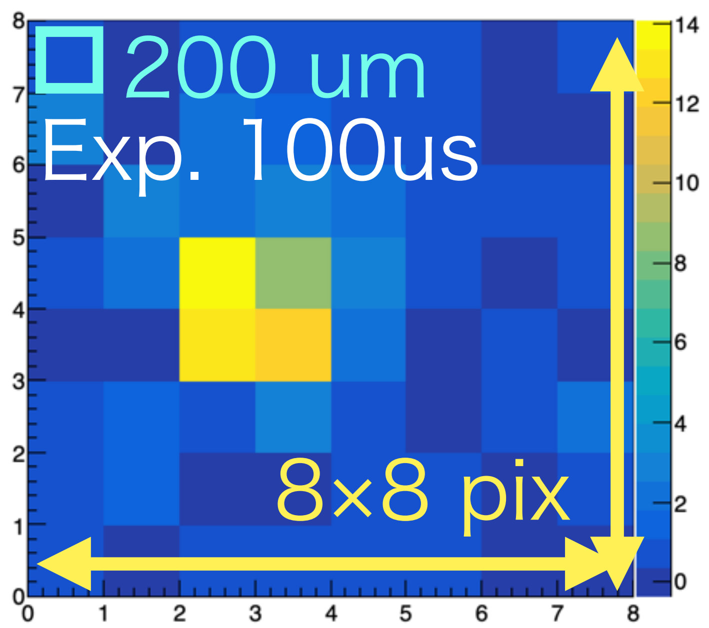


Image credit:
Okayama observatory



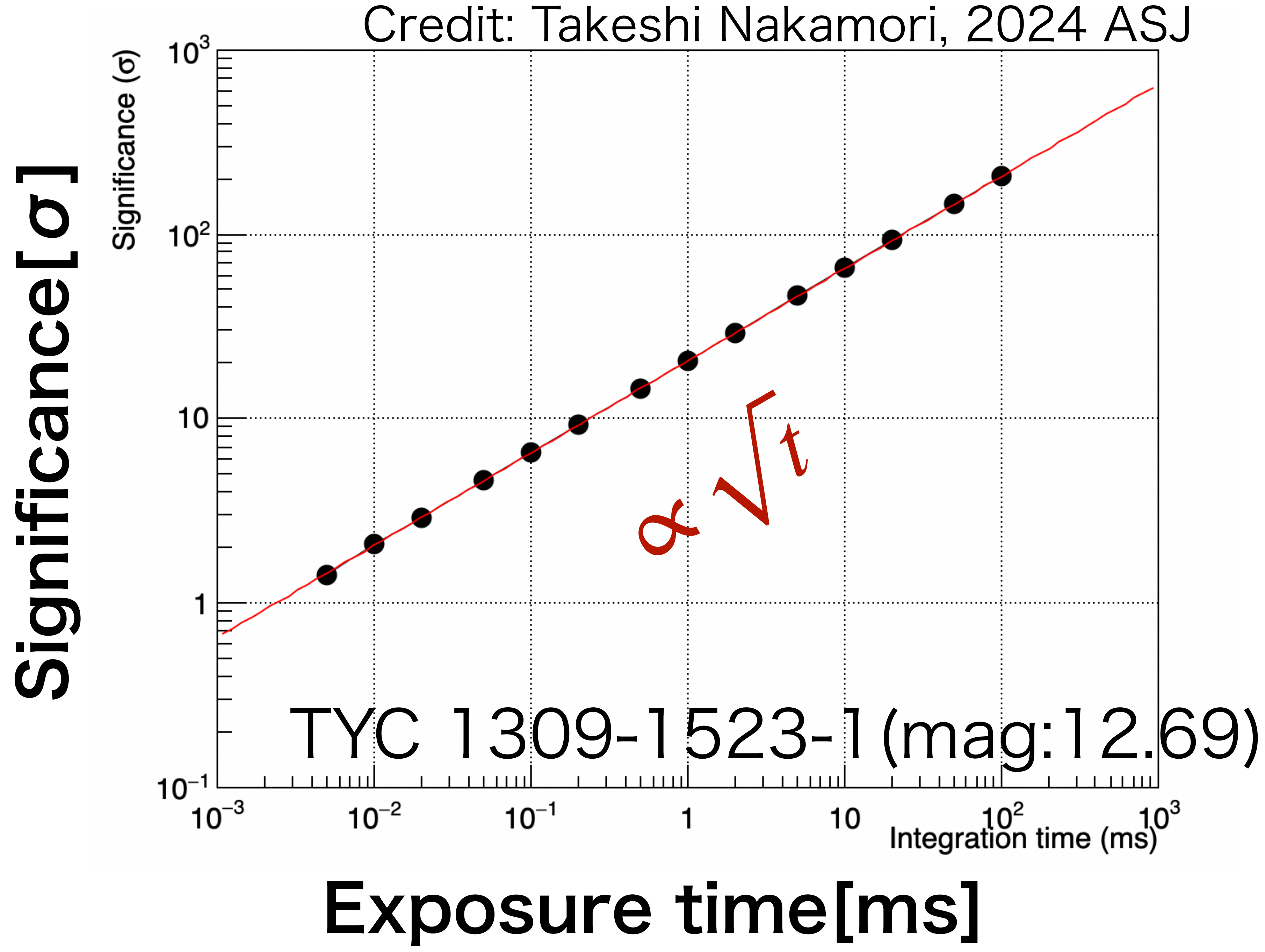
Estimated sensitivity of IMONY

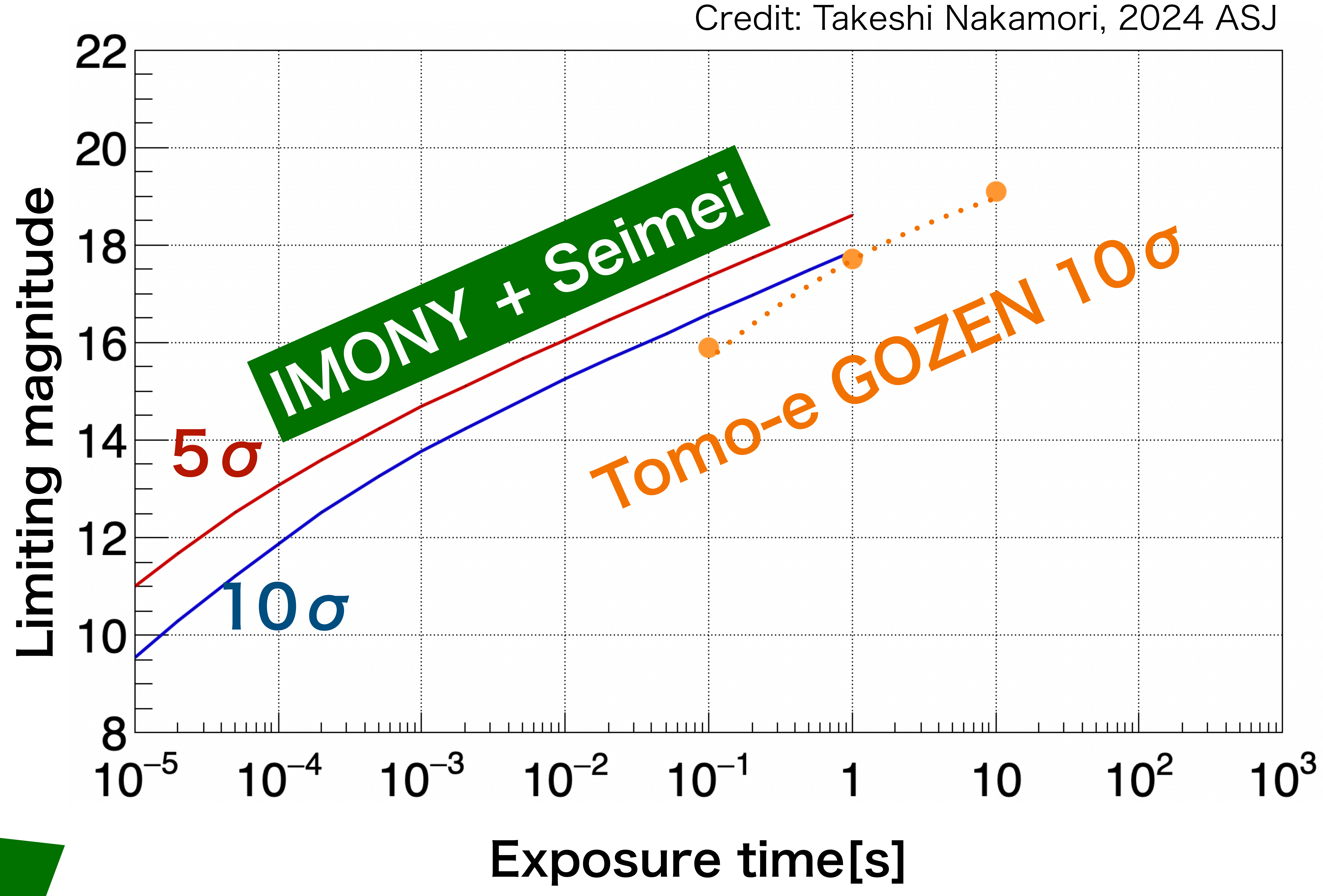


Using a lc data (Vmag = 12.69) , calculate significance of source count

↓

Integrate the number of count with exposure time





Photometric calibration
→ **Poster by Mana Hasebe**

Crab observation result @Seimei

Periodic emission

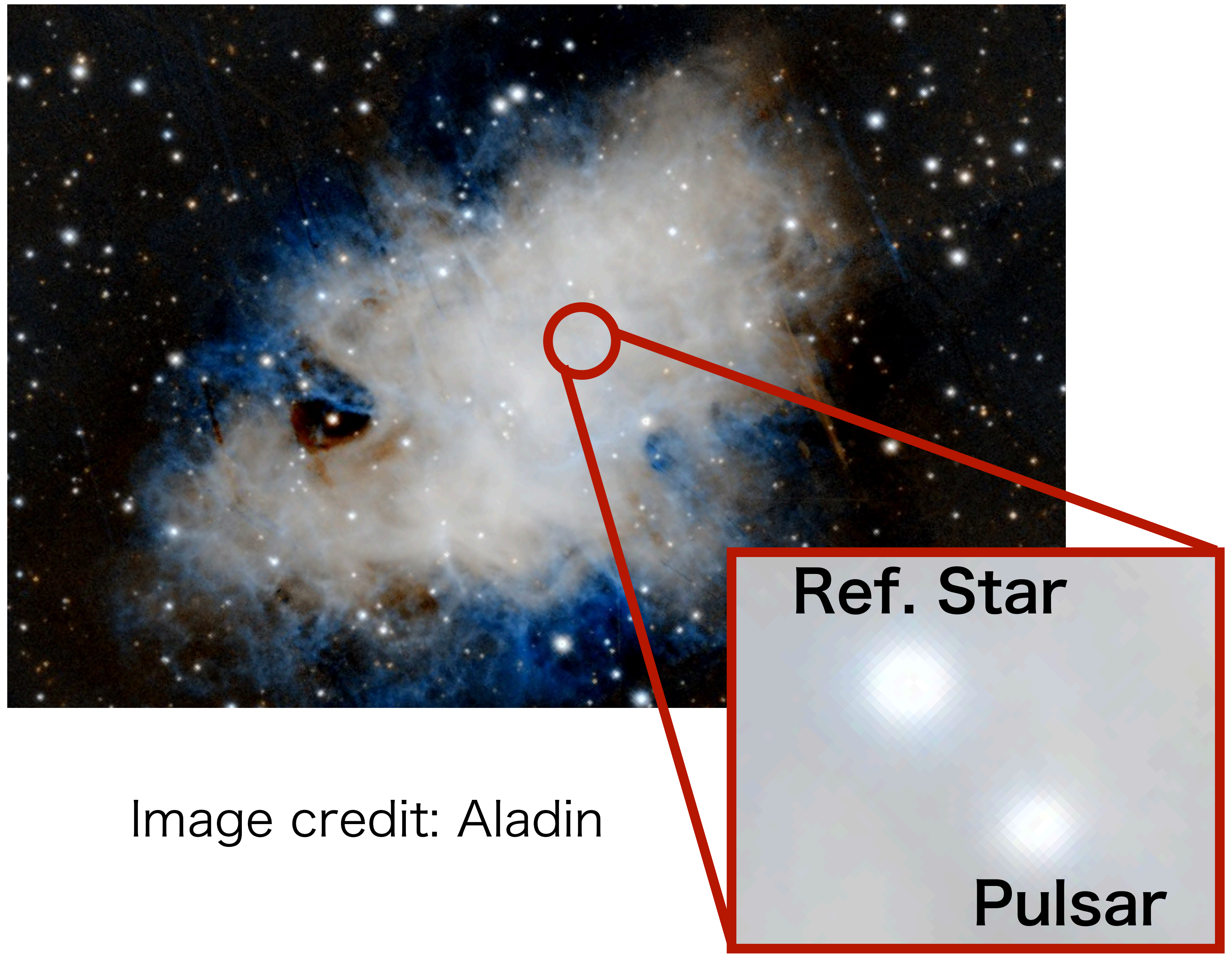


Image credit: Aladin

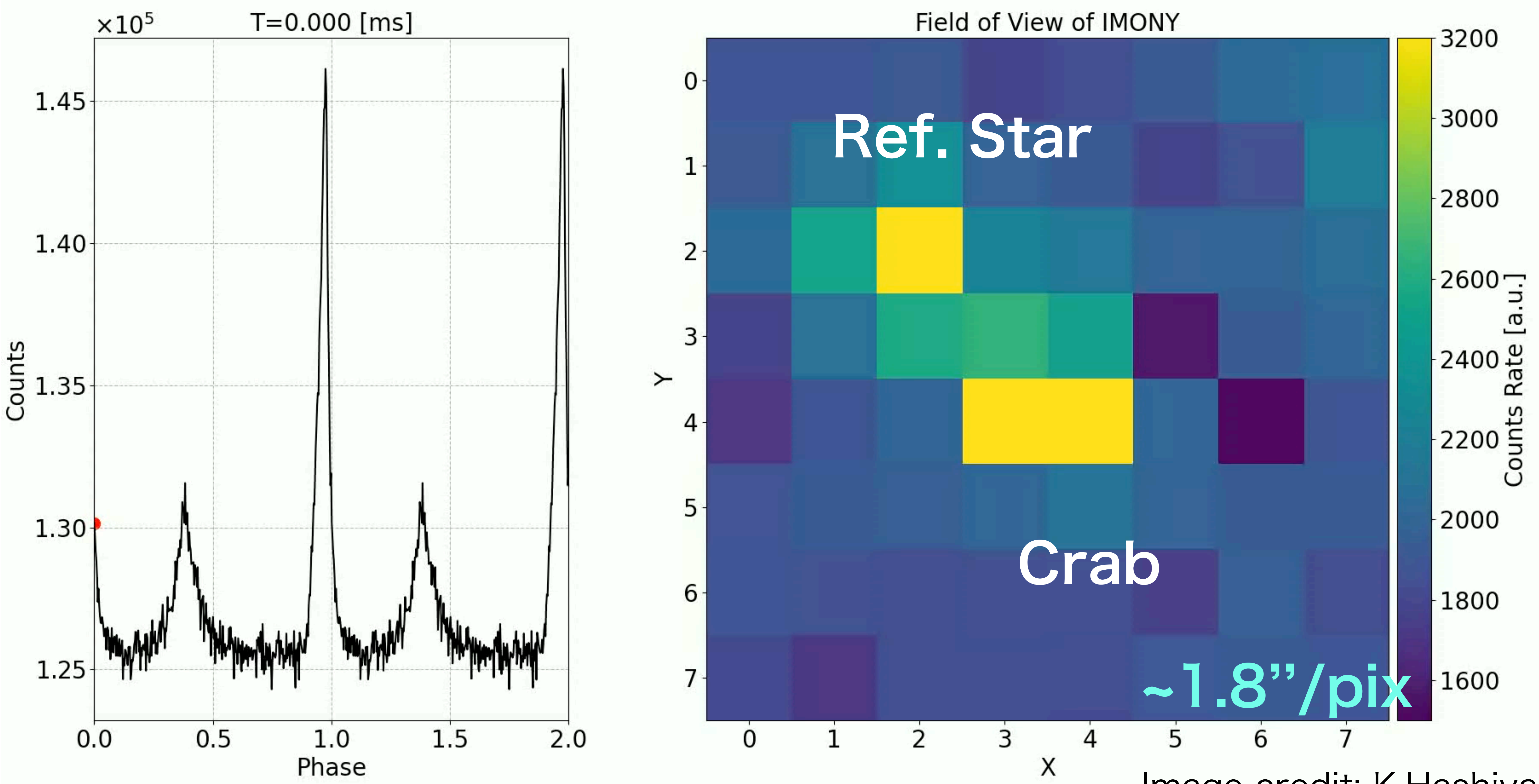
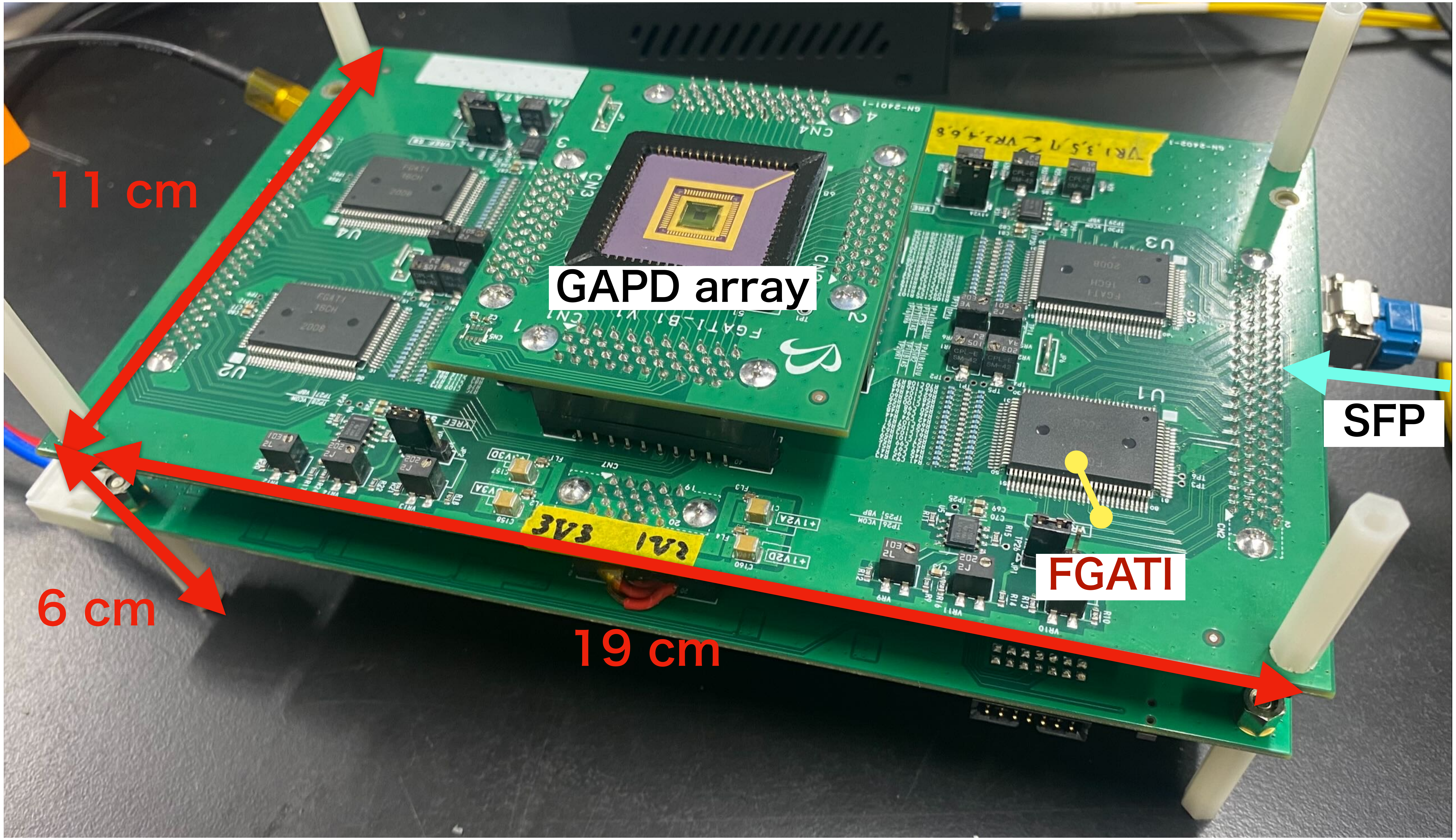


Image credit: K.Hashiyama

Remaining issues

- Large number of components in the system → **take a lot of time to mount on telescope**
- Unstable contact between board-to-board wiring→ **observations are sometimes interrupted**
- Installing and removing from the telescope each time→ **cause deterioration or damage**

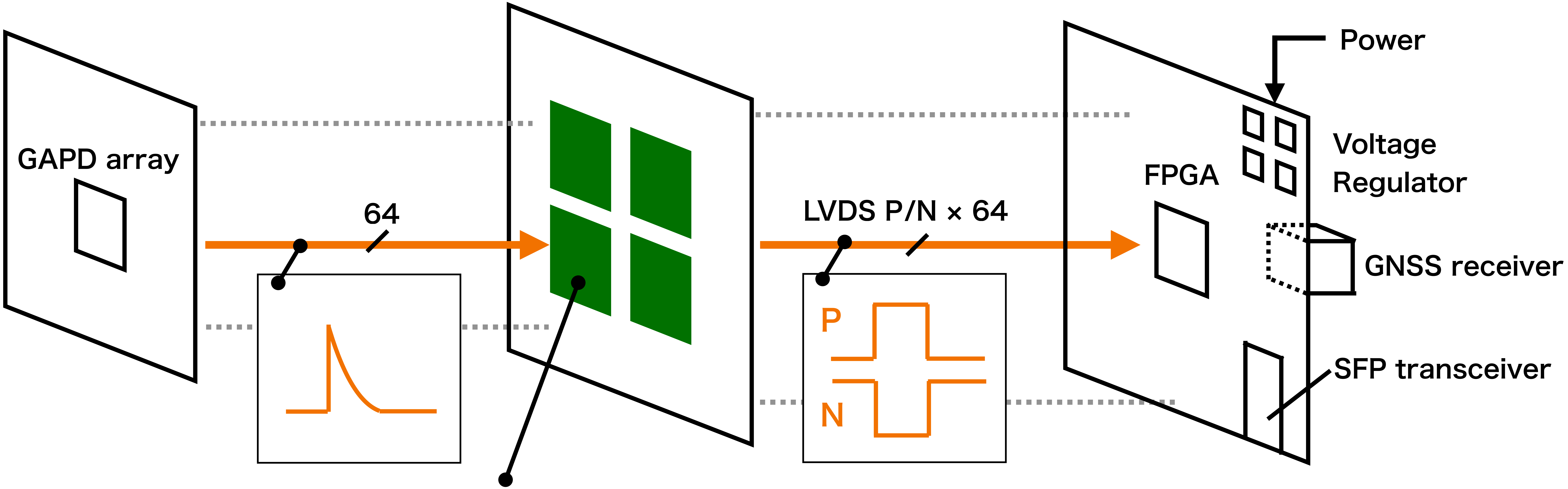
A picture of new system



Development of a new system with ASIC

We developed new boards to unify AFE boards and FPGAs in April of 2024.

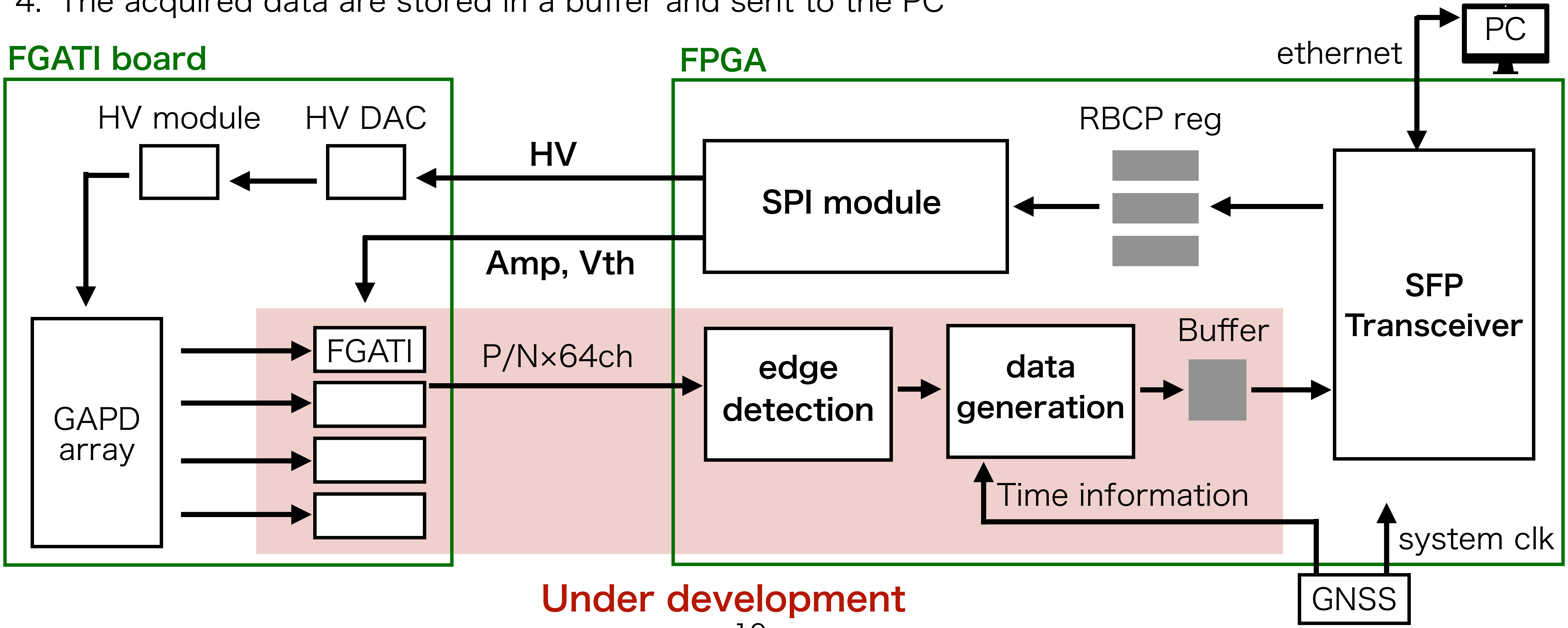
We applied **ASIC 'FGATI'** developed by KEK Open-It.



FGATI : general-purpose ASIC for MPPC readout
amplifies analog signal and converts into the timing pulse for 16ch analog signal (LVDS out)

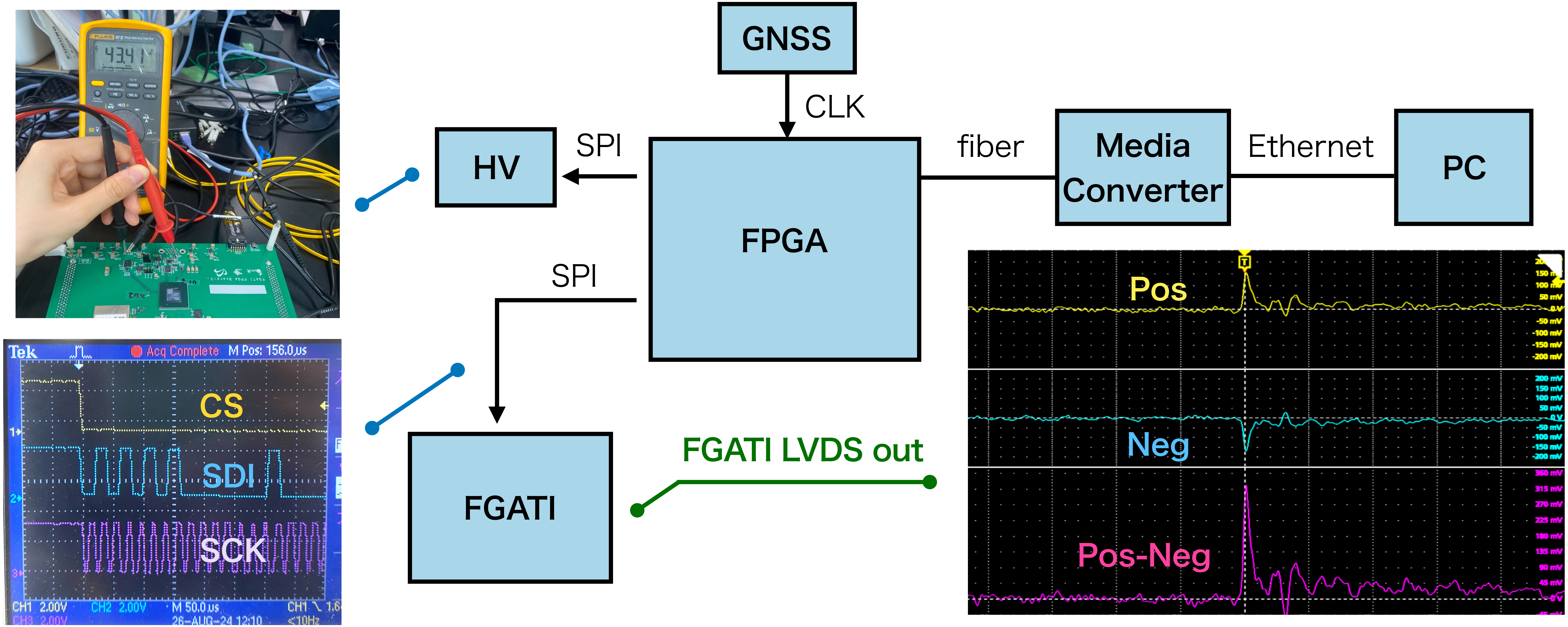
Structure of module operation

1. FPGA runs with GNSS clk and receives commands from the PC via ethernet
2. HV and FGATI are controlled by SPI
3. When FPGA detects photon hit, hit_pixel and photon arrival time information are combined
4. The acquired data are stored in a buffer and sent to the PC



Under development

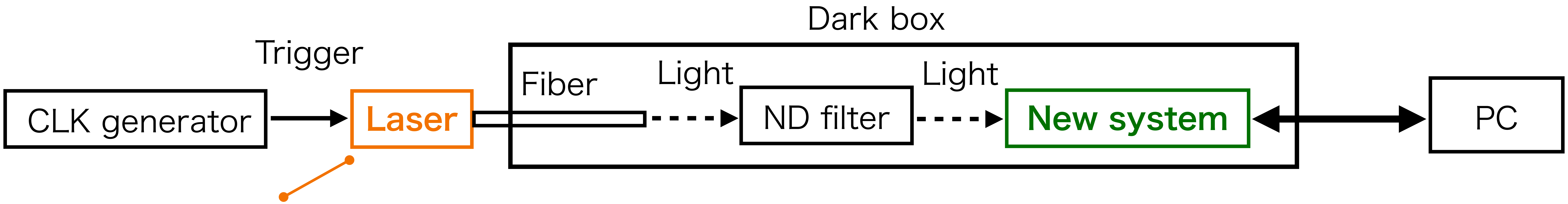
Functions test of the new system



We added following functions by FPGA coding and tested.

Data transfer, SPI control, threshold setting by FGATI

Observation of periodic ps-laser light emission

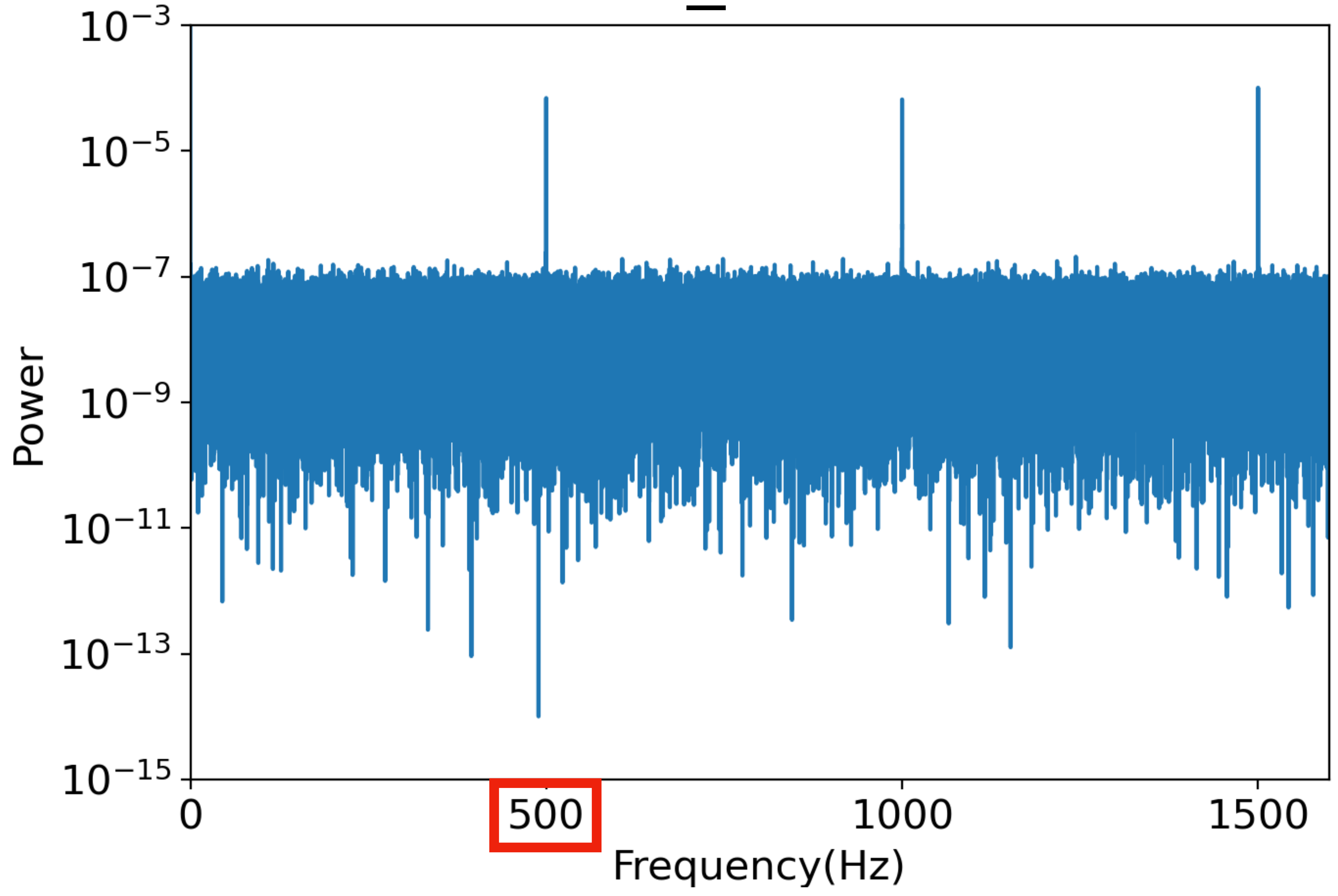


λ: 405 nm

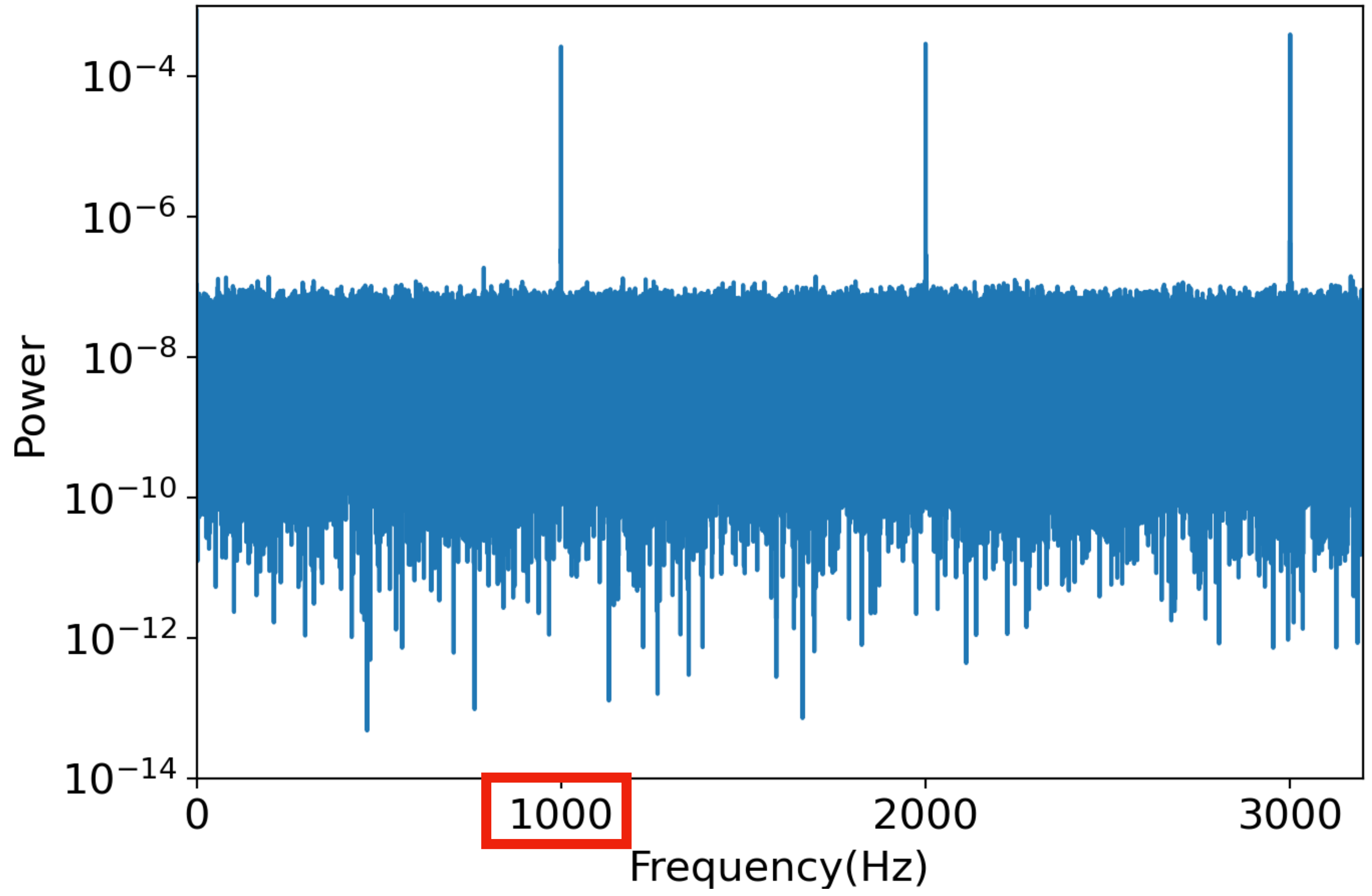
Δt: FWHM ~80 ps

Inome +19

ch57_ 500Hz



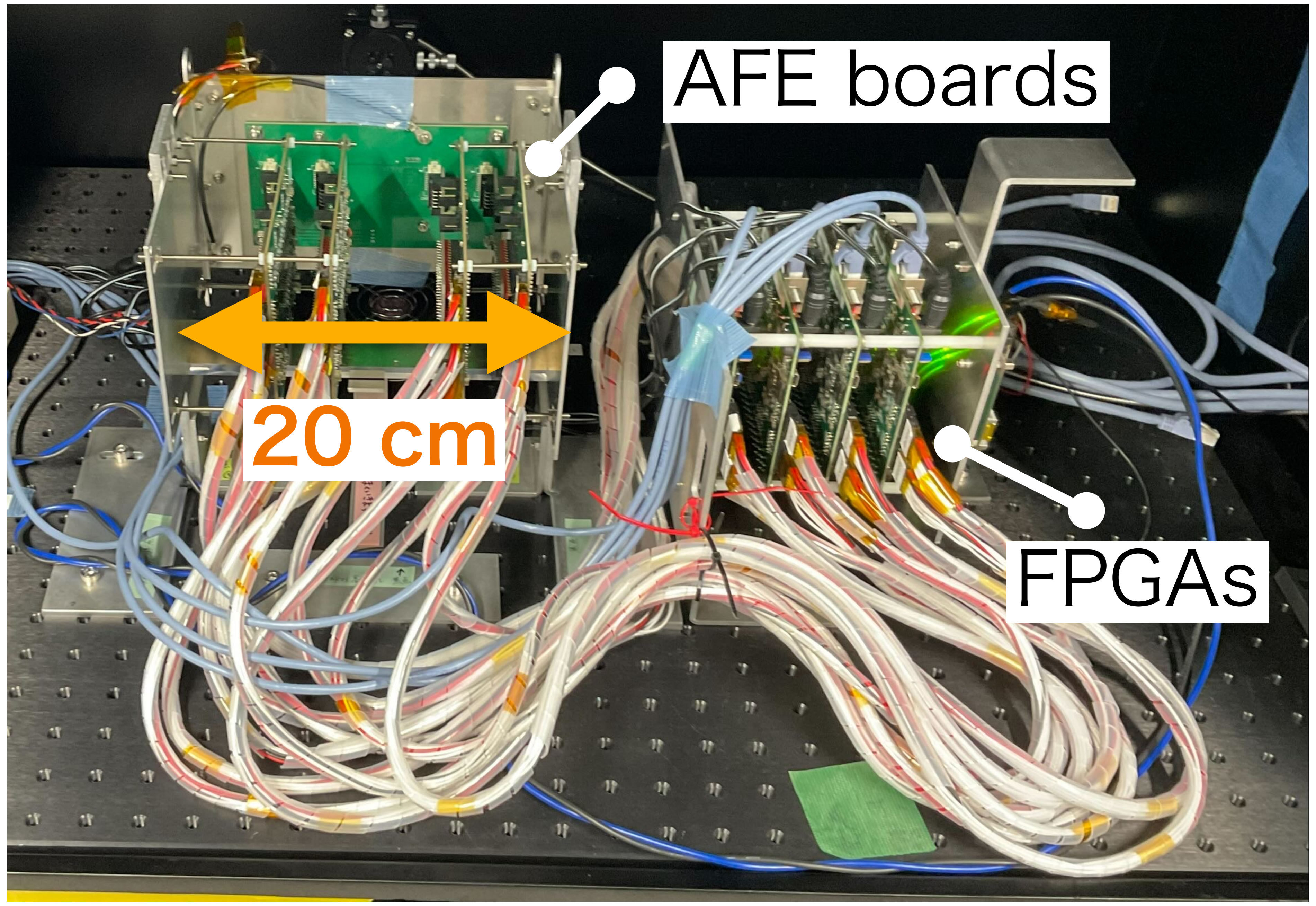
ch57_ 1 kHz



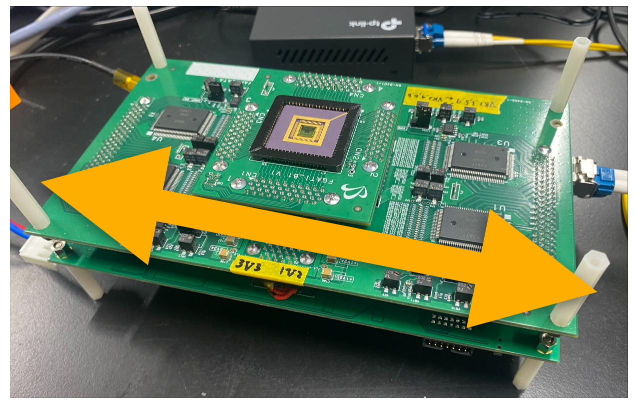
The new system observed lasers beams at two different frequencies (500 Hz and 1 kHz).
We confirmed that some channels can recognize the periodic pulses.

Future prospects

Current version



New version



20 cm

Our new system has a much more compact readout system.

The compact system allows us to observe various **occultation phenomena**.
In addition, we aim to adapt IMONY to **multi-color camera**

Summary

IMONY is a photon counting imager system with high sensitivity and high-time resolution

Our target is fast time scale optical phenomena like **GRPs of Crab pulsar**

We successfully detect a periodical emission of Crab pulsar

- We can also obtain images of stars (8×8 pixels, □200 um)
- We found system issues to solve : **unstable wiring and large number of components**

We are developing a new system using ASICs

- We applied **FGATIs**, which is one of **ASICs**, developed by KEK Open-It
- FGATI amplifies analog signal and converts into the timing pulse (16ch/board)

Future plans

- Using the new system, **we will observe neutron stars and compact objects**
- **Compactness** of the new system will be useful→aiming for **portability and multi-color cameras**

Backup

Photon detection efficiency vs Wavelength