Cherenkov Cameras for Future Gamma-Ray and Neutrino Observations

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The 3rd annual conference of
Transformative Research Areas (A), "Multimessenger Astrophysics"

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B01: Introduction

多粒子宇宙観測技術の開発による新たな「眼」の獲得

https://multimessenger.jp/en/core_projects/#b01

B01 Acquisition of new “eyes” by developing multimessenger observation technologies

We will develop space- and ground-based celestial high-energy gamma-ray detectors and neutrino detectors by combining our shared expertise in high-energy astrophysics, which includes photon detectors, semiconductors, application-specific integrated circuits, and Monte Carlo simulations. Our goal is to expand the energy coverage and improve the sensitivity for the future advancement of multimessenger astronomy. Additionally, our public research funding program welcomes detector proposals that go beyond existing gamma-ray or neutrino detector ideas.

PI (TeV)

Akira Okumura
Institute for Space–Earth Environmental Research (ISEE), Nagoya University, Jr. Associate Professor

me

Co-PI (MeV)

Yasushi Fukazawa
Graduate School of Advanced Science and Engineering, Hiroshima University, Professor

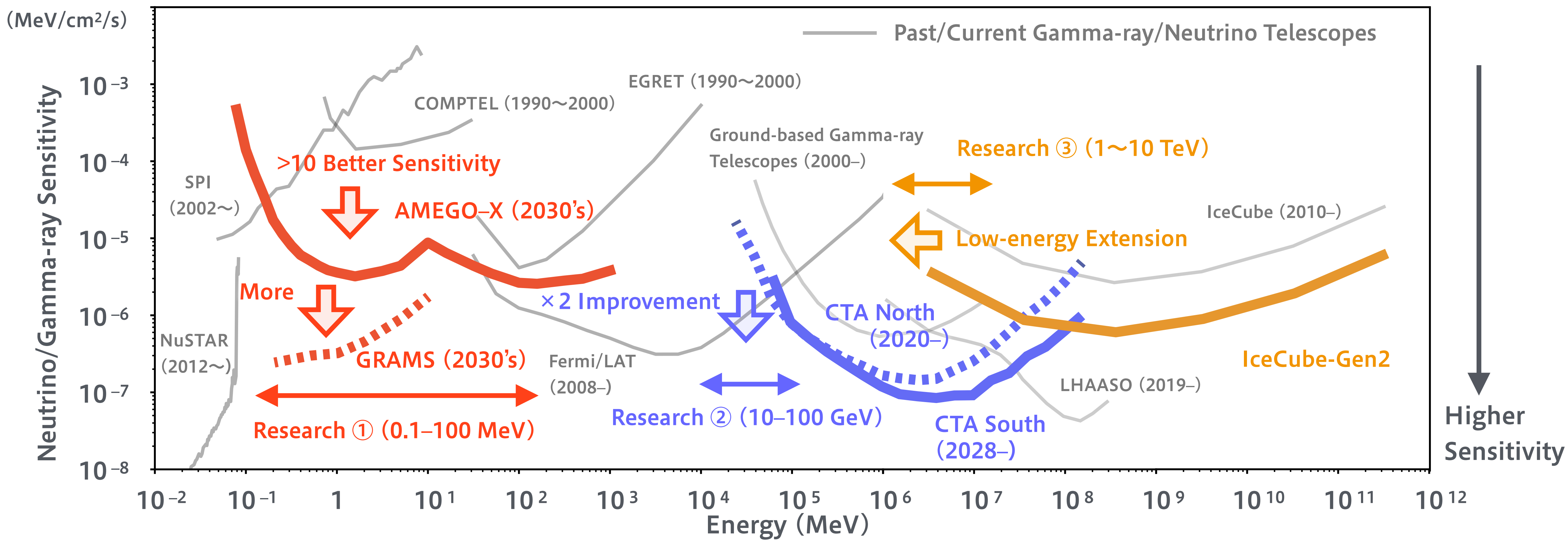
See talks by A. Roy and H. Tajima

Co-PI (ν)

Yoshiki Tsunesada
Institute of Science, Osaka Metropolitan University, Professor

See talk by T. Ishii

Wide High-Energy Coverage by “Particles”

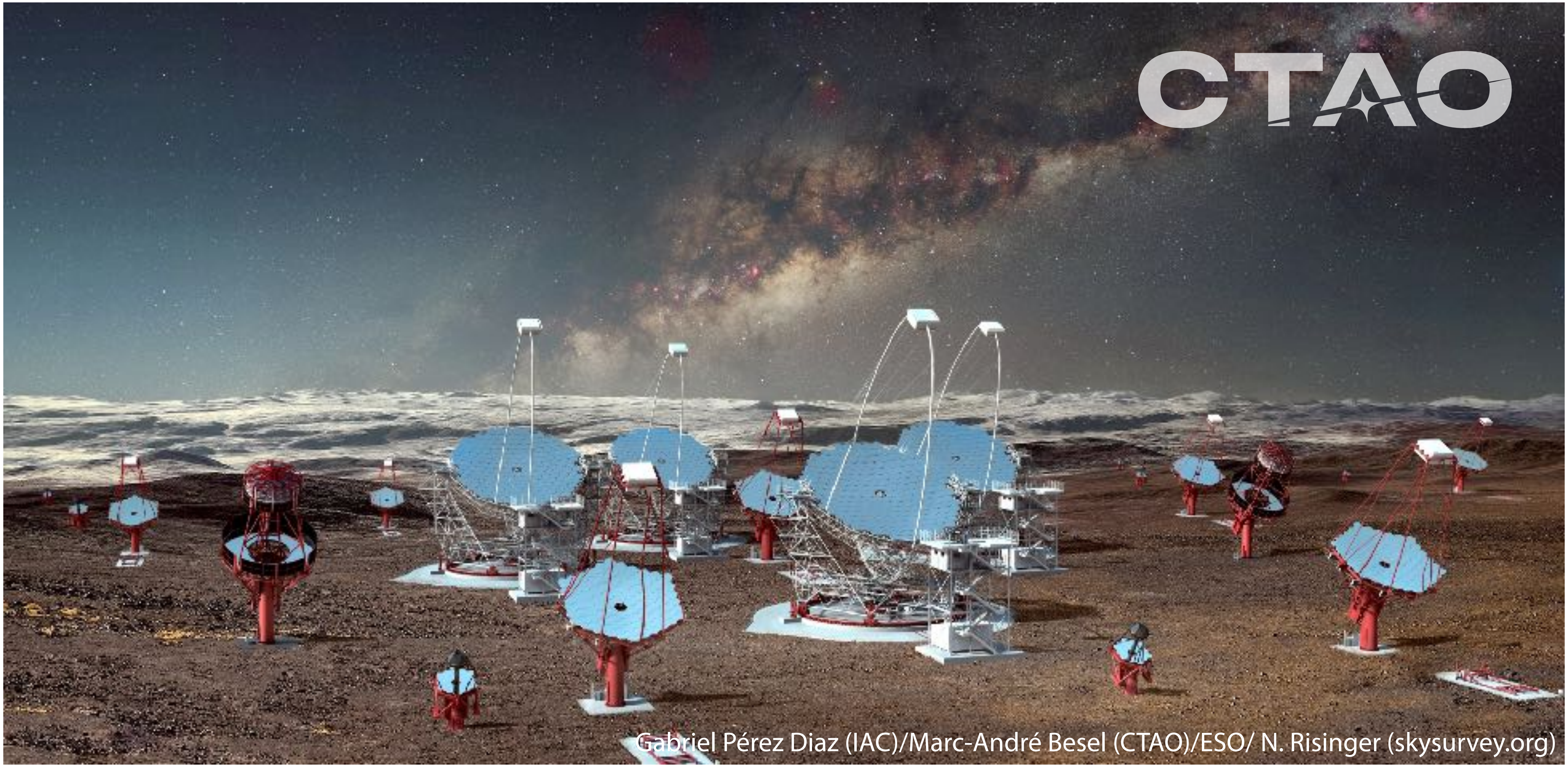


- **Neutral** keV/MeV/GeV/TeV/PeV regions are covered by different techniques and by gamma rays and neutrinos
- Res. (1) MeV Gamma (Fukazawa@Hiroshima), (2) CTA LST (Okumura@Nagoya), and (3) IceCube (Tsunesada@OMU)
- Need to **fill the sensitivity gaps** and to **extend the energy coverages** for future multimessenger astrophysics (2030–)

Cherenkov Cameras using Silicon Photomultipliers (SiPMs)

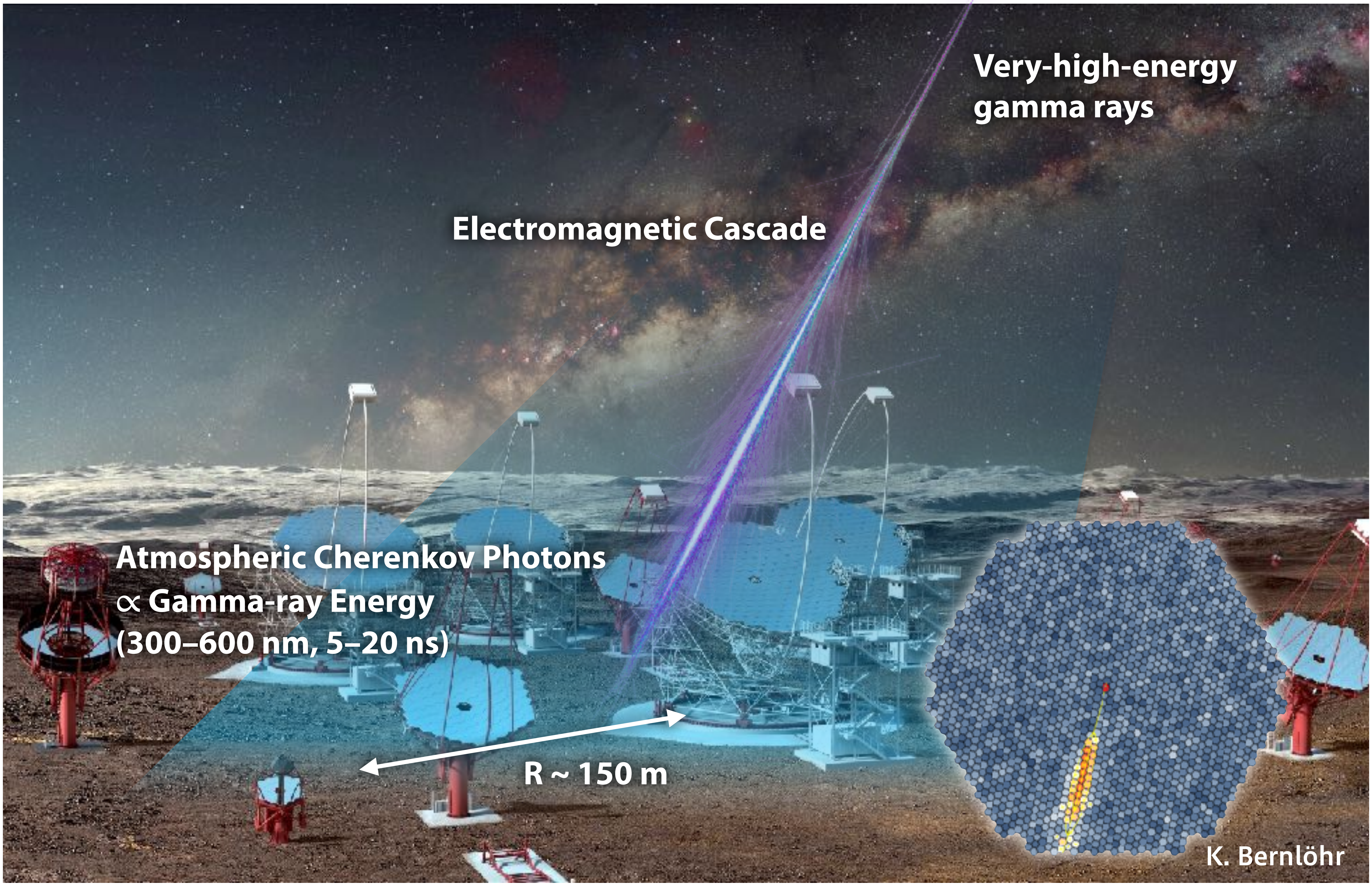
- Small-Sized Telescopes (SSTs) of the Cherenkov Telescope Array Observatory (CTAO) (2020s)
- Future upgrade of Large-Sized Telescopes (LSTs) of CTAO (in 2030s?)
- Further SiPM and wide-FOV optics application for earth-skimming neutrinos

Cherenkov Telescope Array Observatory (CTAO)

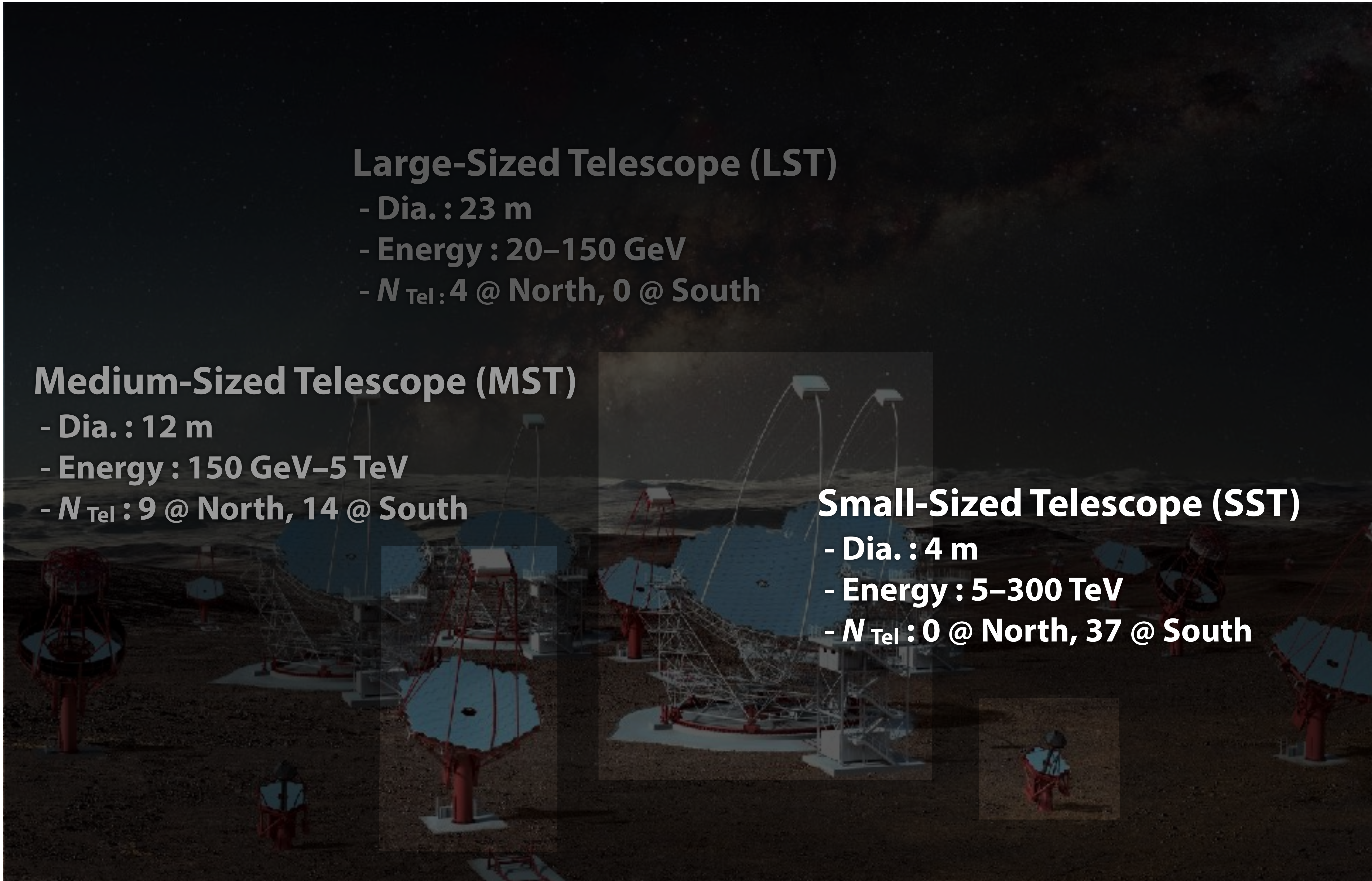


- Next-generation ground-based gamma-ray observatory with ×10 better sensitivity
- Covering 20 GeV–300 TeV with 3 telescope designs
- High angular resolution of 0.02–0.05° above 10 TeV

Cherenkov Telescope Array (CTA)

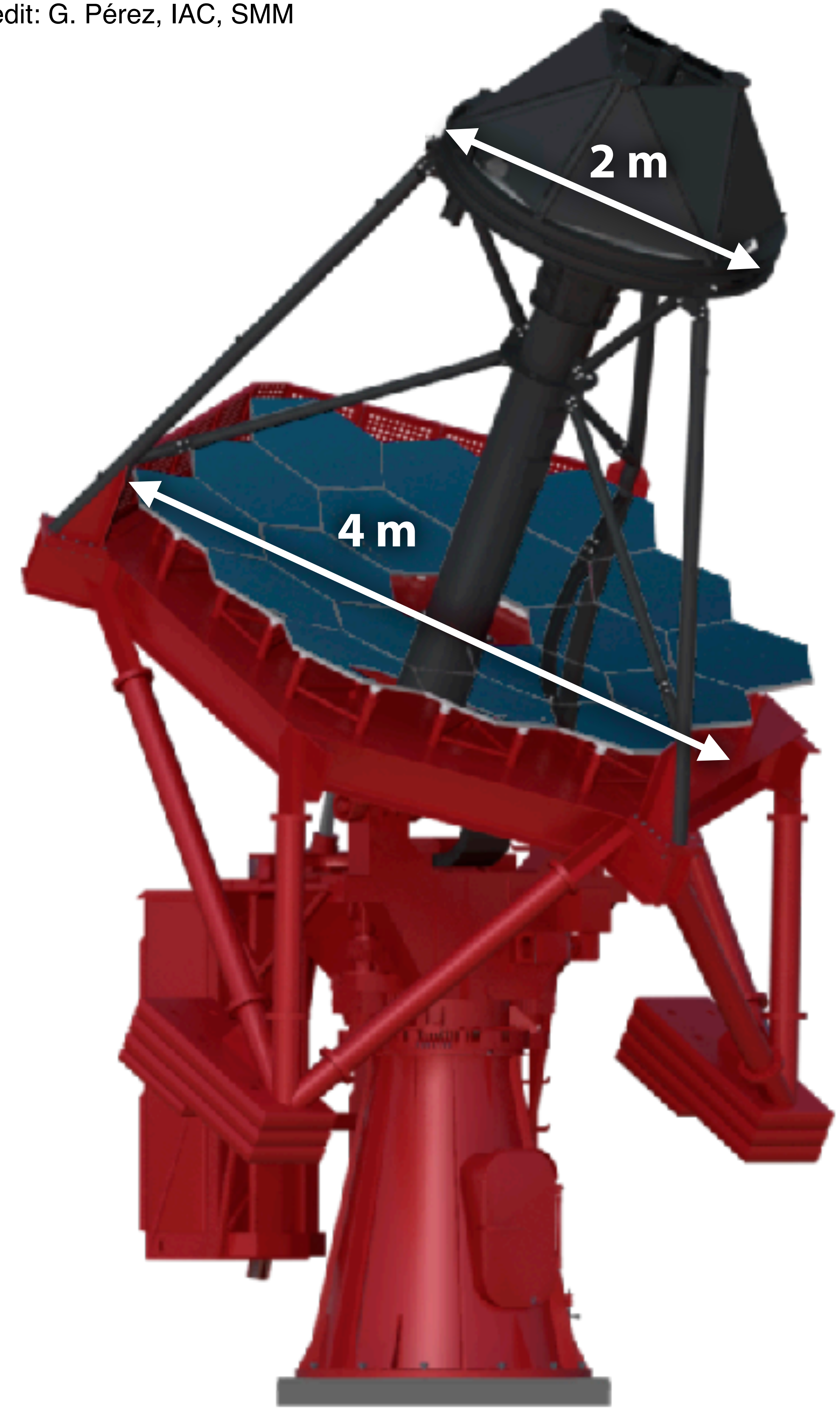


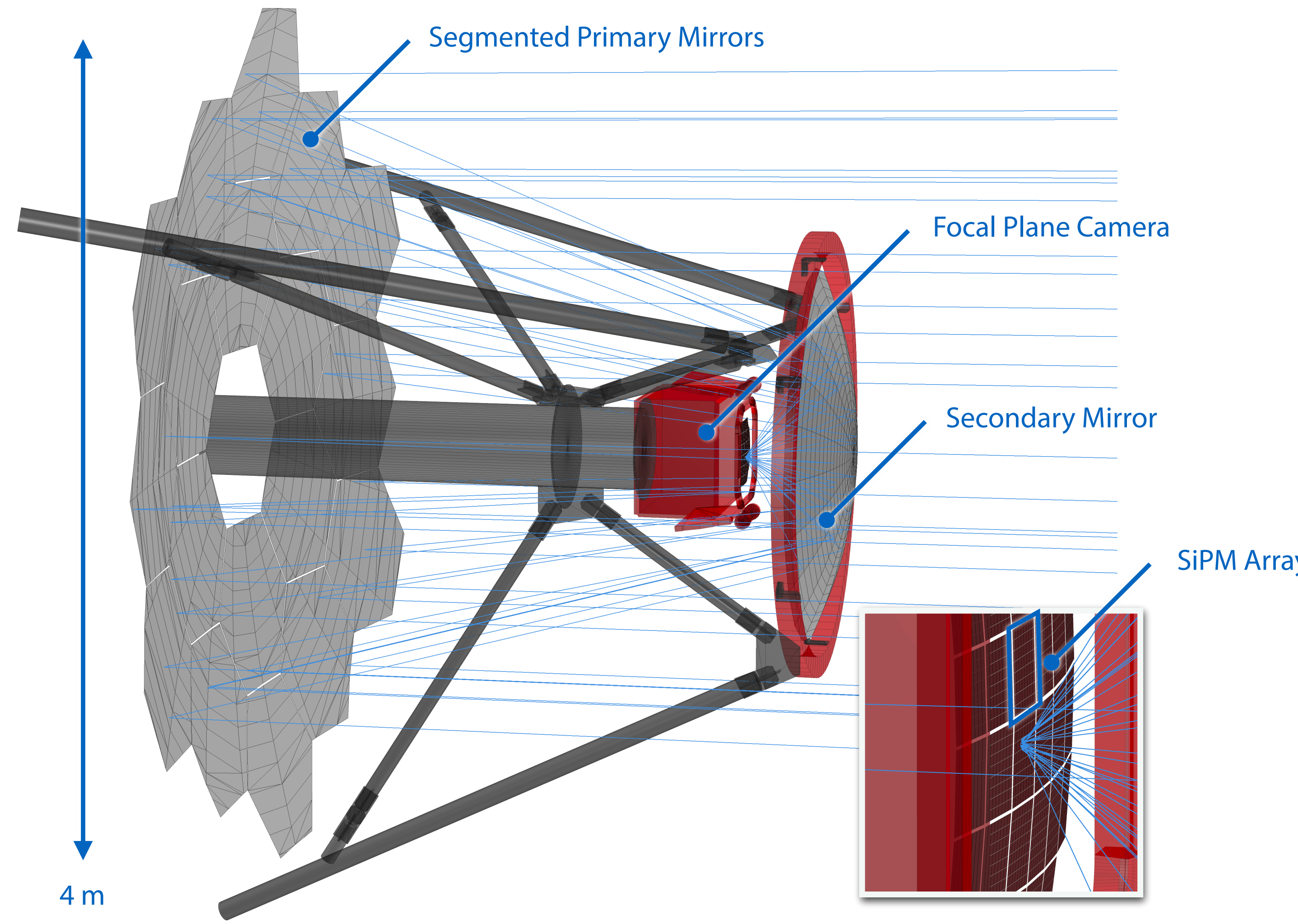
Cherenkov Telescope Array (CTA)



Small-Sized Telescopes (SSTs)

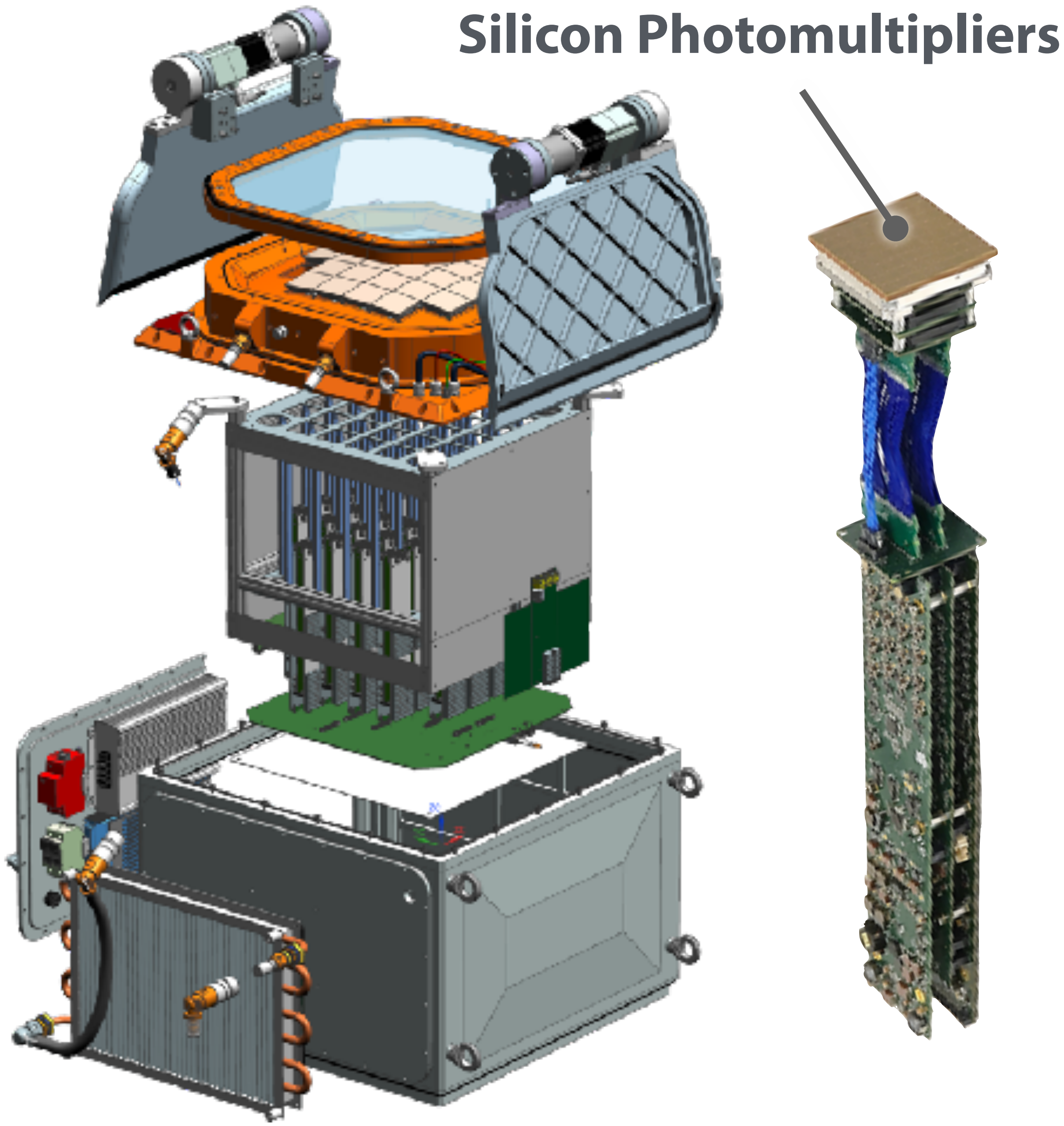
Credit: G. Pérez, IAC, SMM





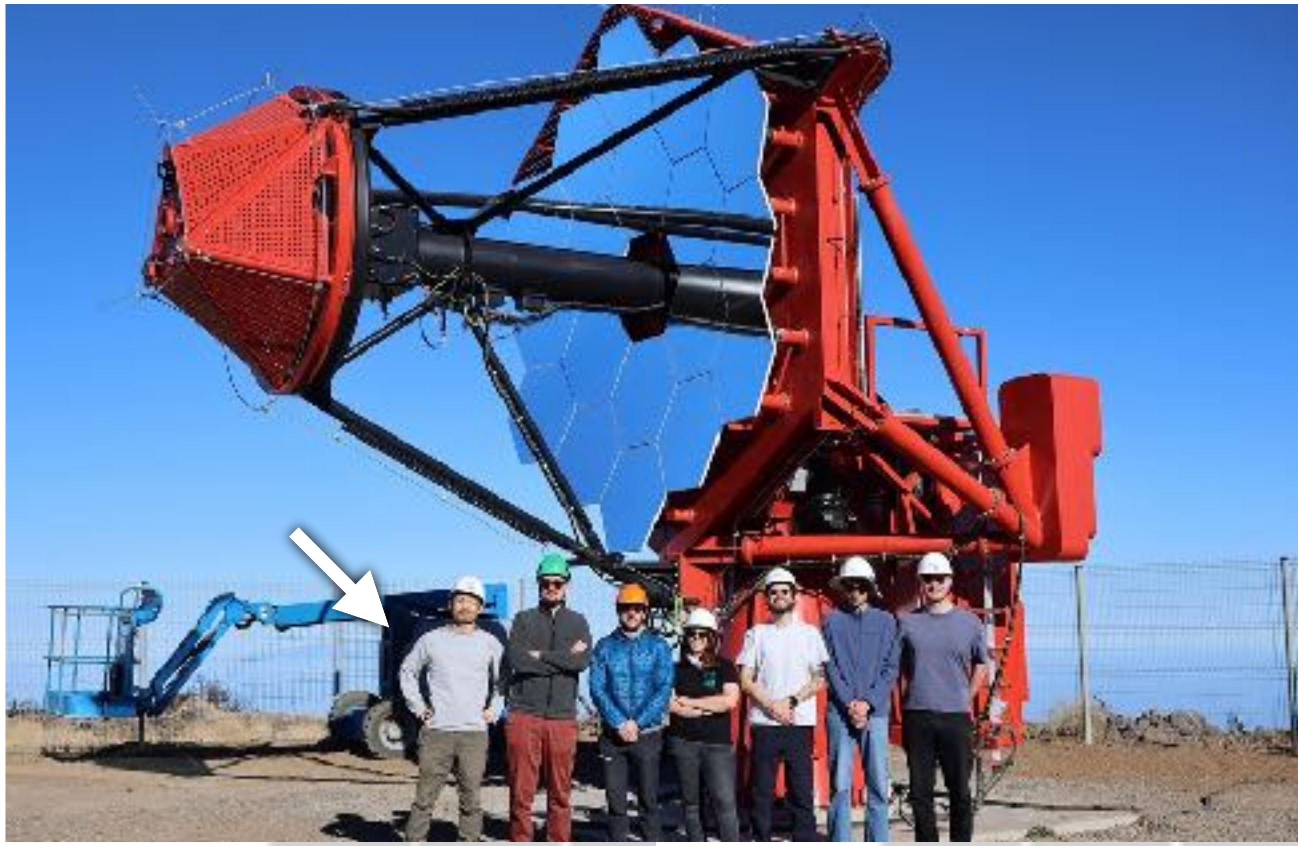
- PeVatron search is the main physics
- Schwarzschild–Couder optical system
  - 4 m aspherical primary mirrors (segmented)
  - 2 m monolithic secondary mirror (monolithic)
  - ~0.15° PSF diameter over ~9° FOV
- Compact focal-plane camera
  - 2048 silicon photomultiplier (SiPM) pixels
  - 32 × 64-ch camera modules with dedicated ASICs

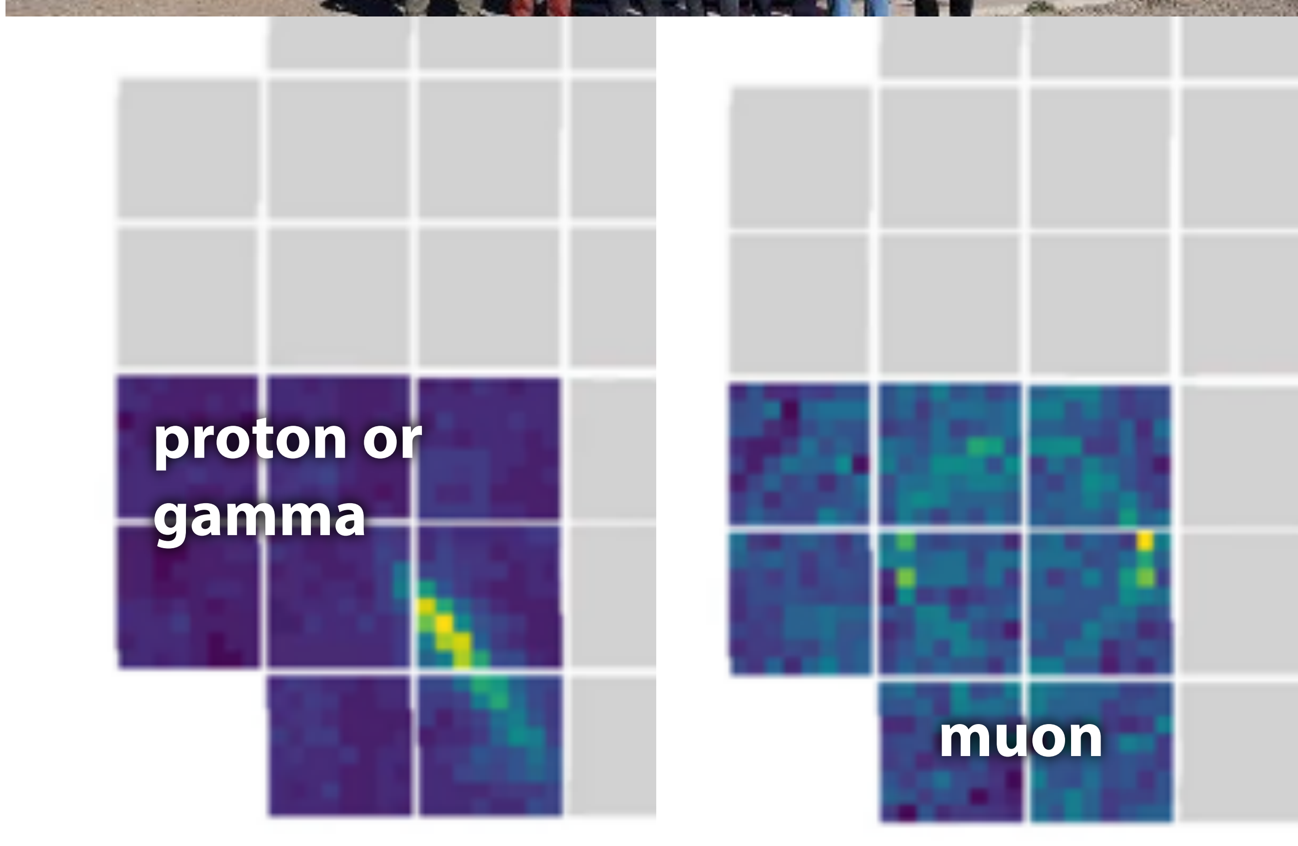
Integration of Quarter SST Camera at MPIK, Feb 2025



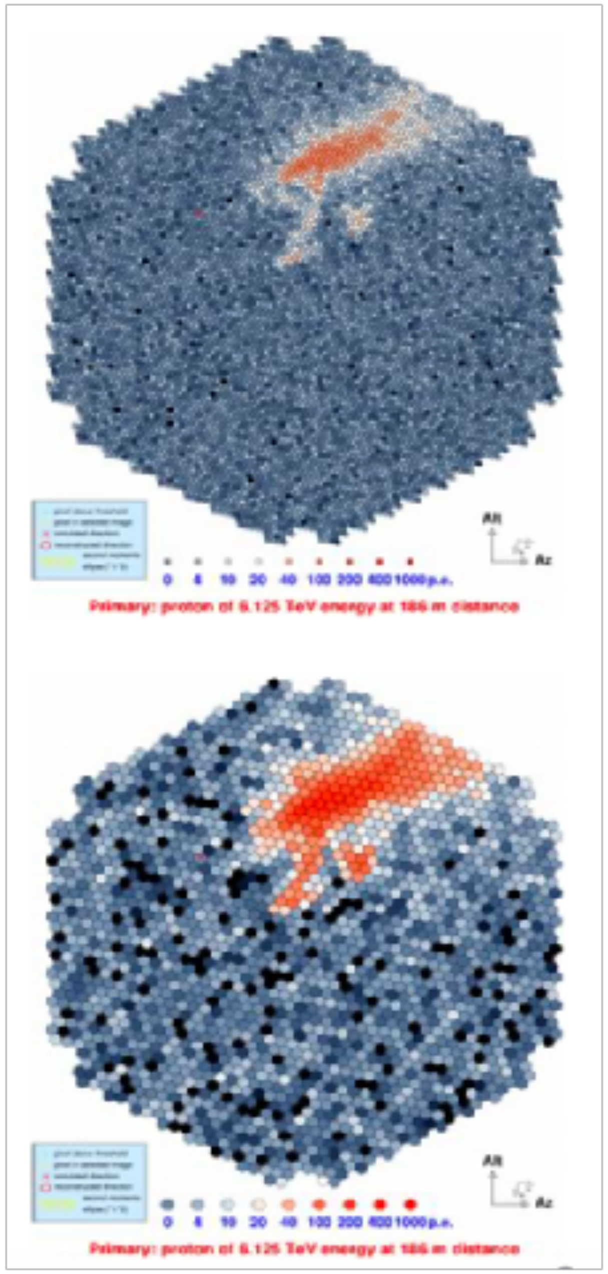
- Currently working on a quarter camera for final debugging of the whole system
- The next steps are an engineering camera and mass production in 2026 and later
- CTAO southern site is gradually being developed now

Test Observation Campaign at Teide Observatory, July 2025

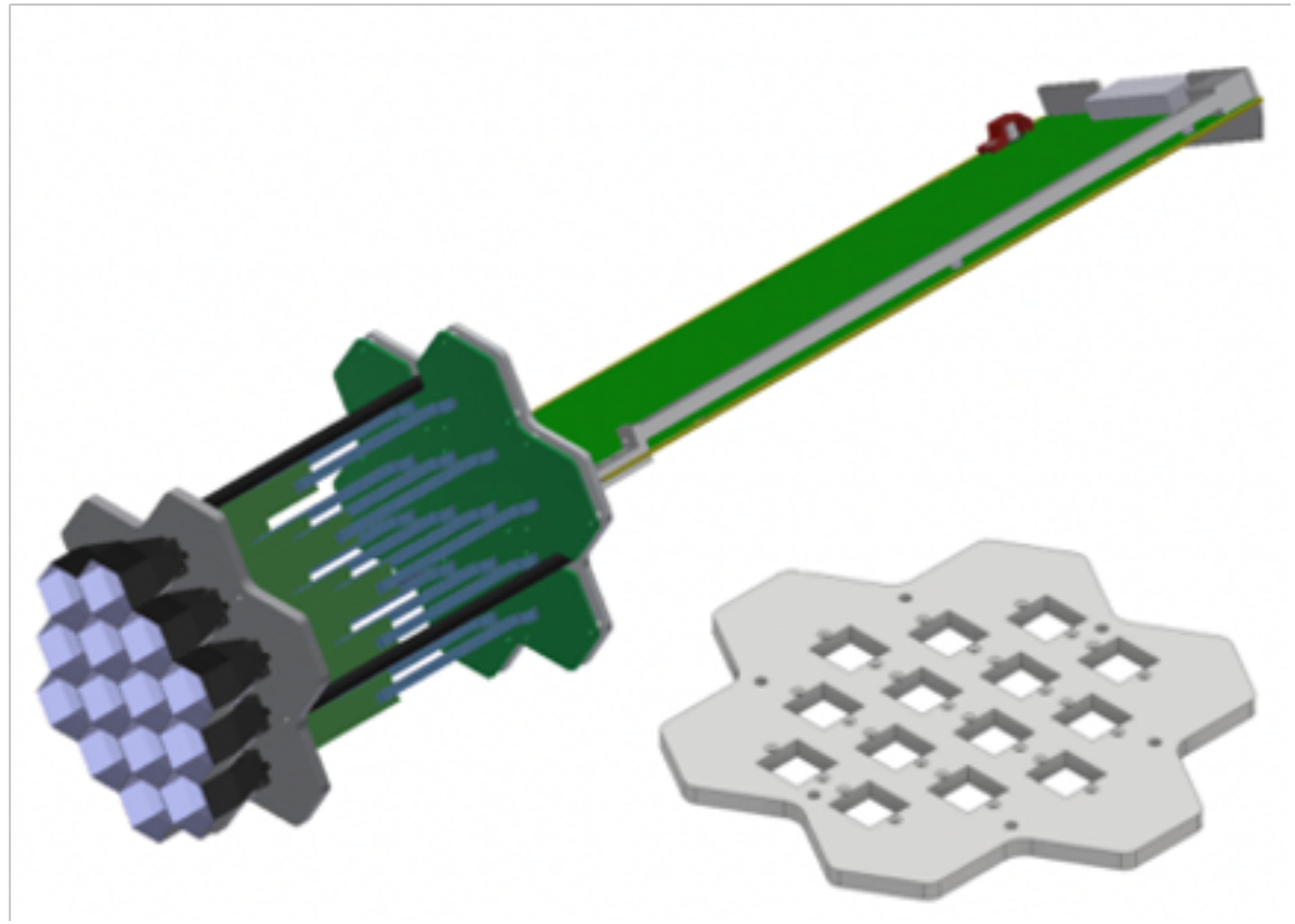




SiPMs for CTA LSTs



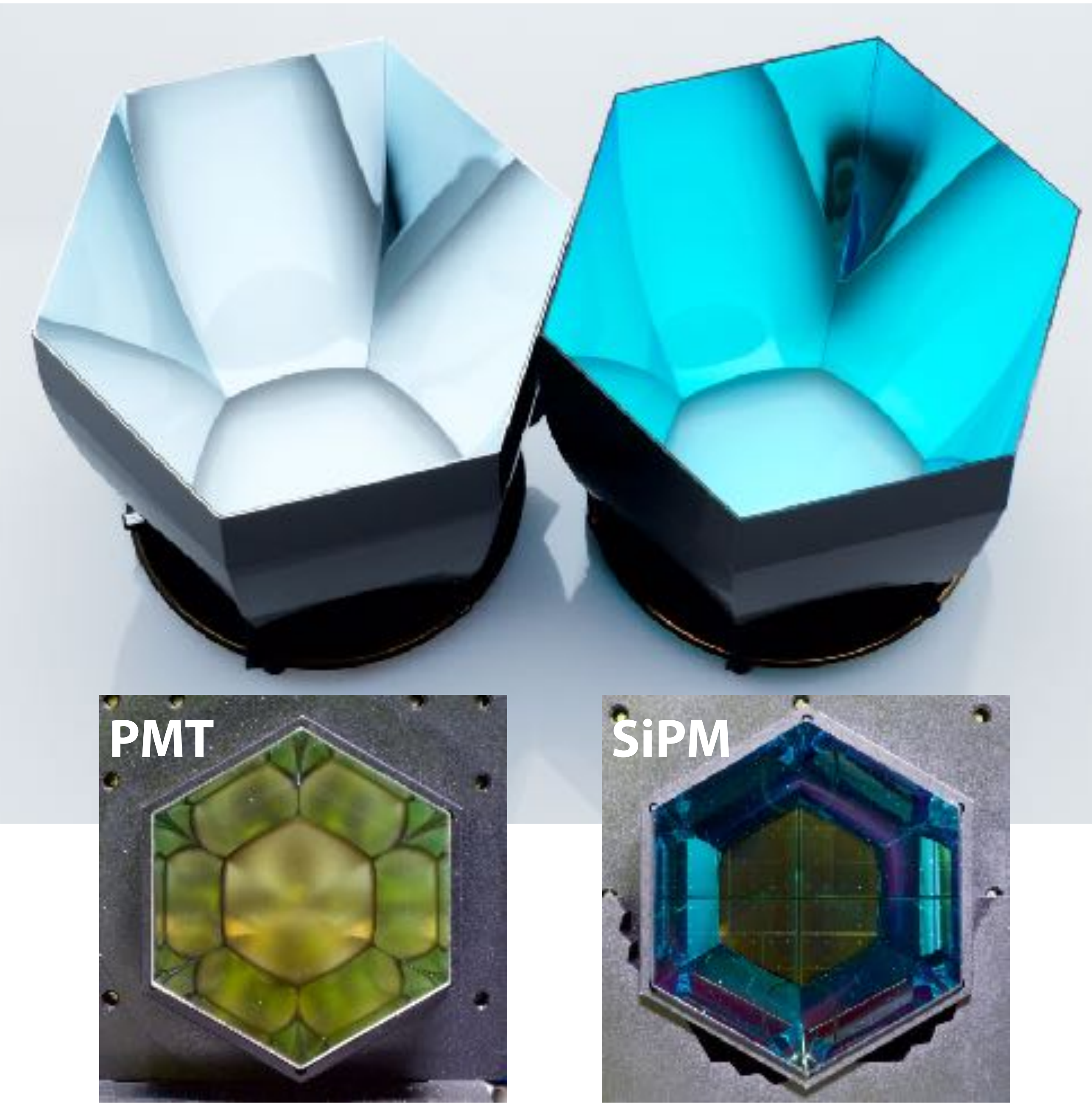
with T. Saito (ICRR), T. Yamamoto (Konan)

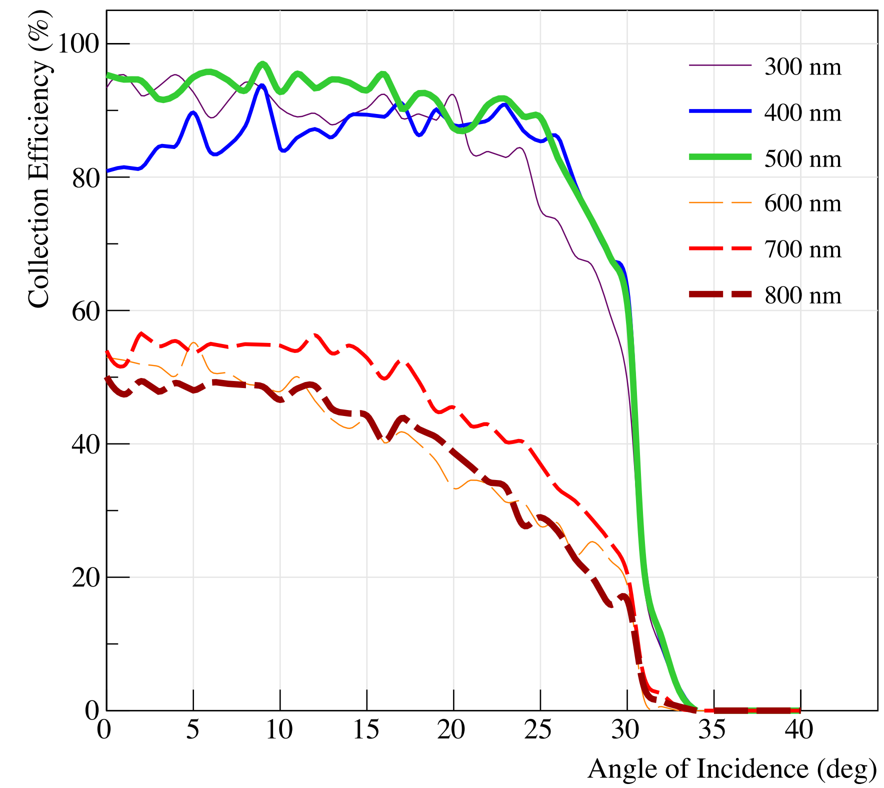


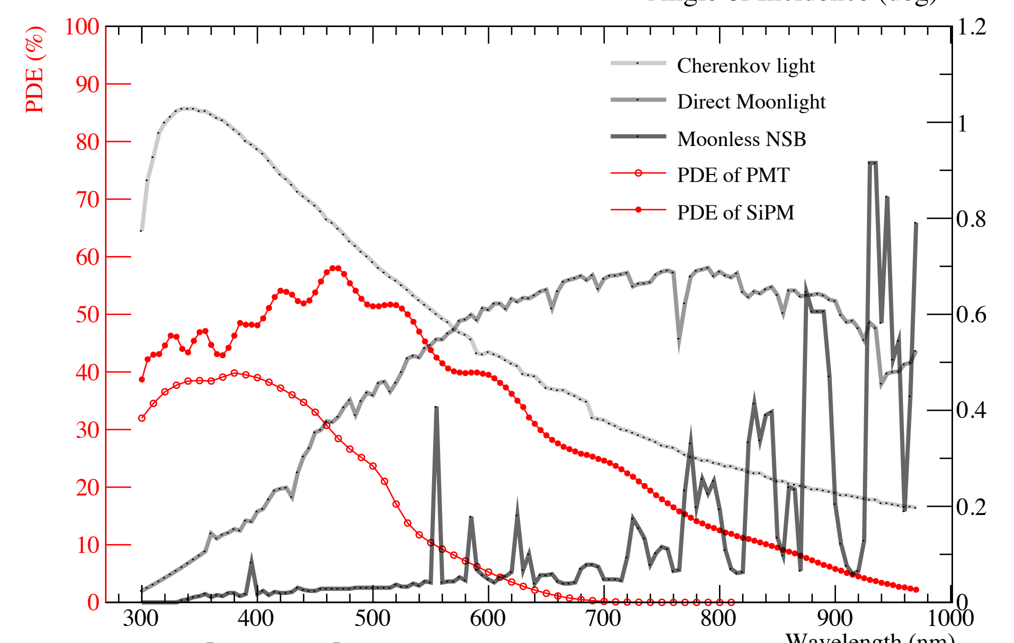
- Compact pixelization will fully exploit the LST optics resolution and improve the signal to noise ratio
- Better angular resolution for gamma-ray events is expected
- Highly tolerant against

Okumura et al. (2023)

Multilayer Coating on Winston Cones



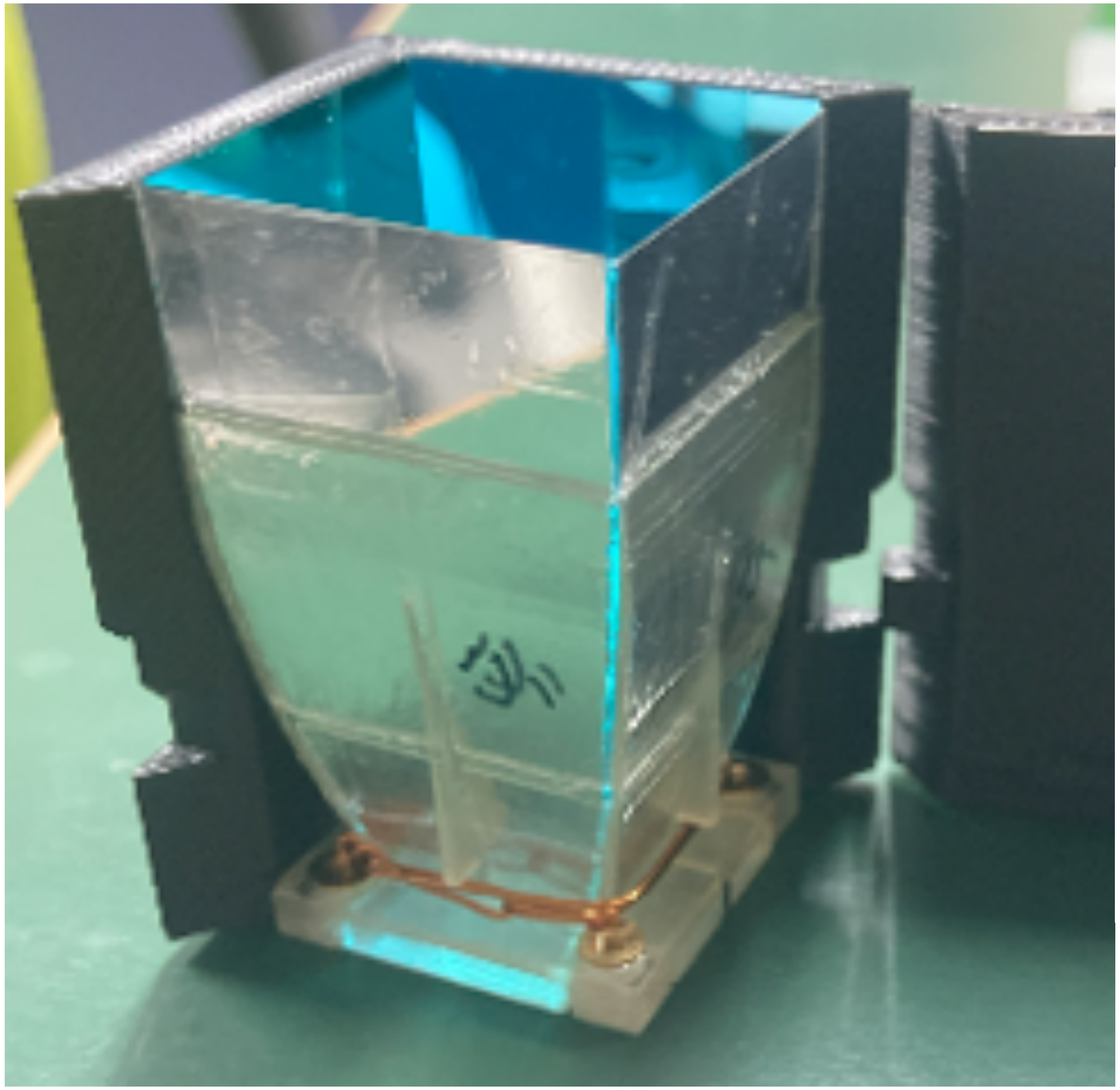


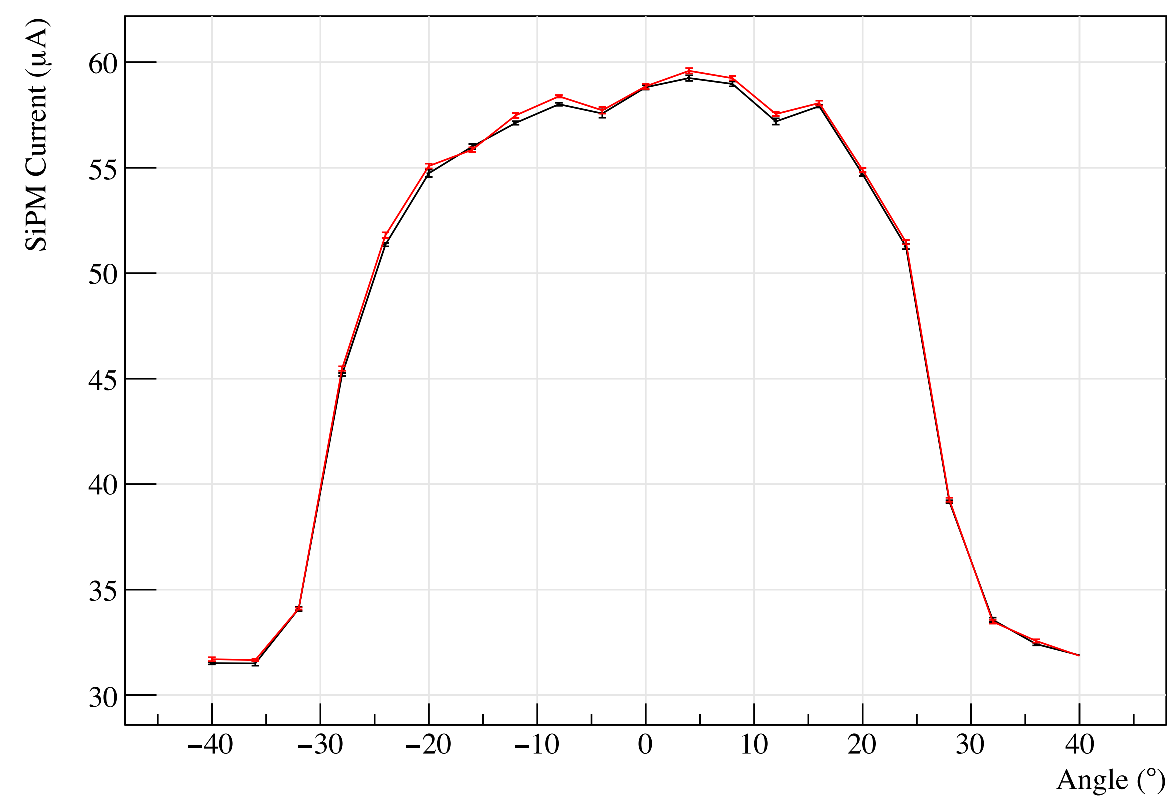


- SiPMs will bring better PDE and tolerance against bright moon
  → Lower energy threshold, longer observation time, and finer pixels
- Novel absorptive 8-layer coating achieved by additional thin (~10 nm) Al layer

Prototype Performance Study

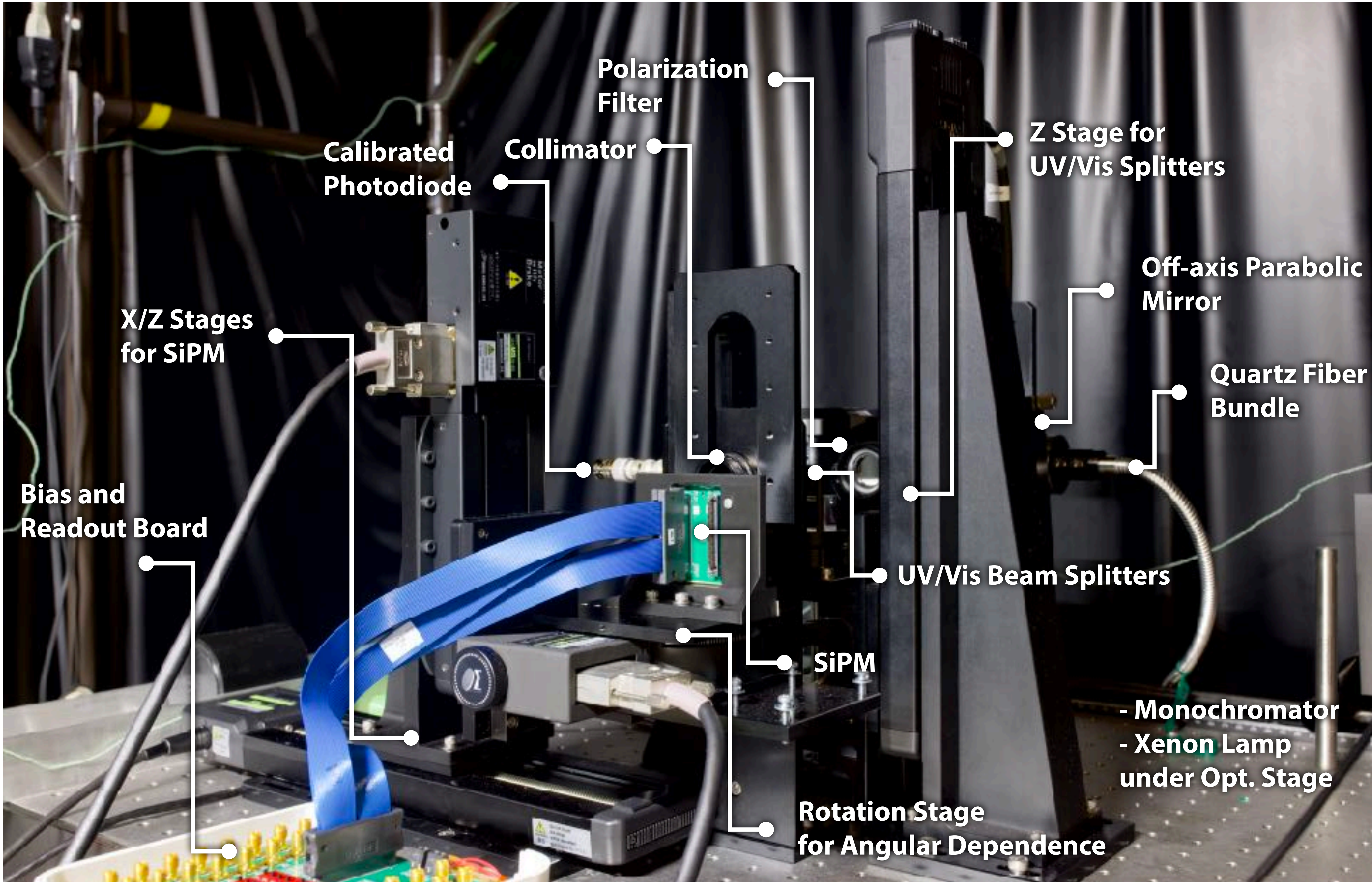
M. Mizote (Konan U.)





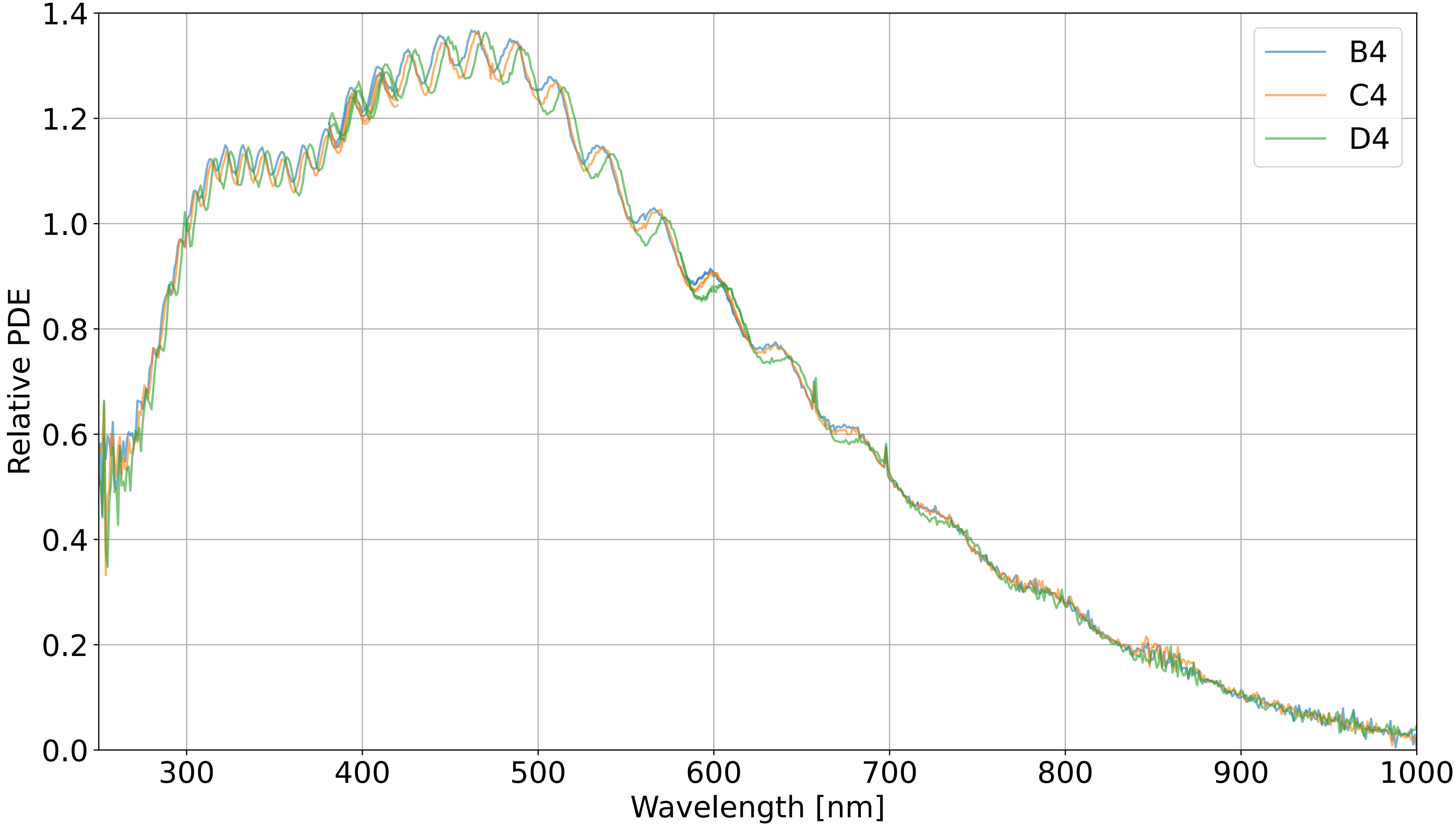
- Square prototype cones were produced using 3D printer in FY2024
- Multilayer coating on thin glass sheets
- Tentative design will be optimized for plastic injection molding

PDE Measurement System @ Nagoya



Tentative Relative PDE (SST SiPMs)

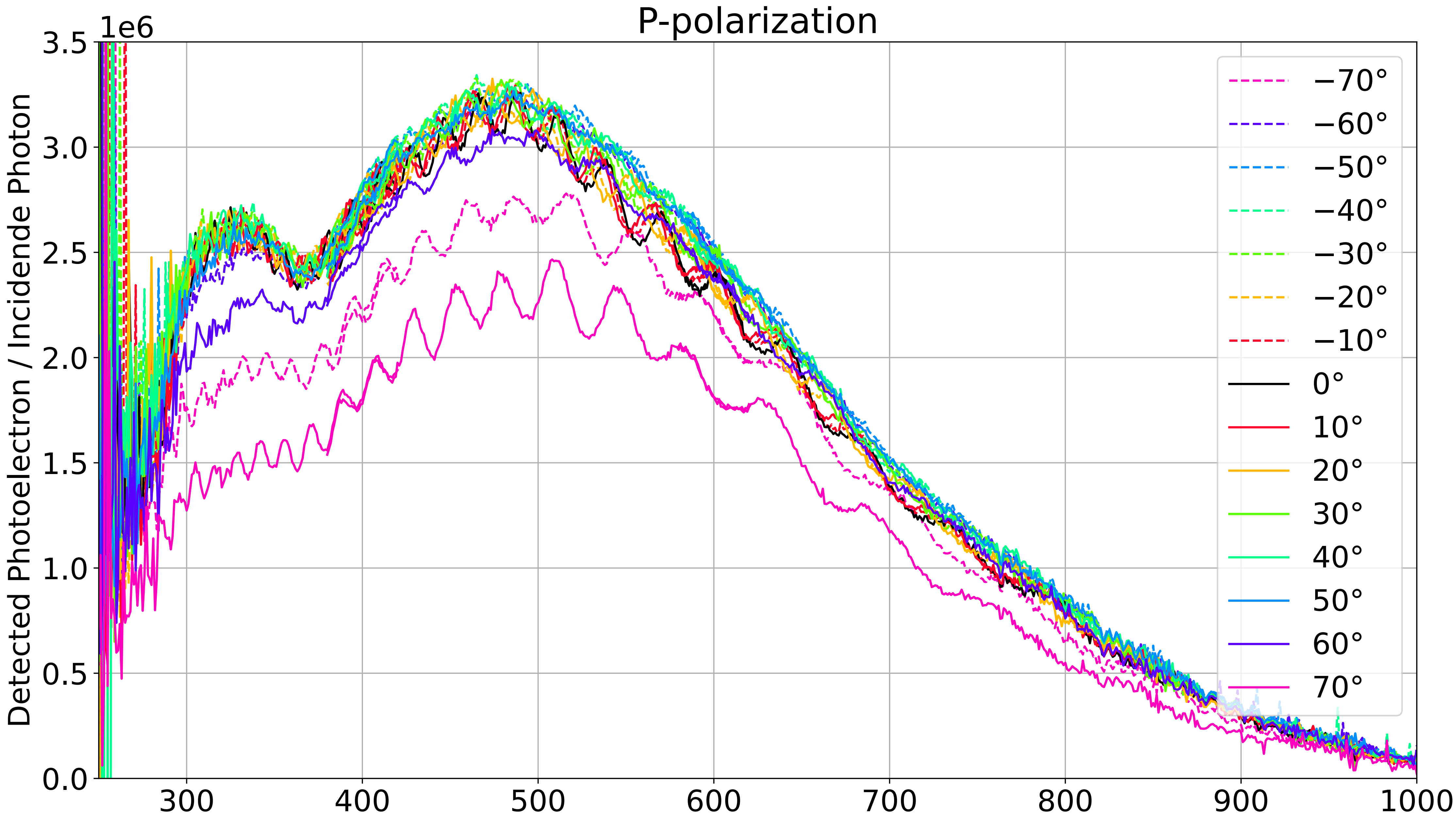
by Daichi Ando (Nagoya)



- Measured at ~10 channels with overvoltage of 3 V
- Slight ch-by-ch difference is seen
- Absolute PDE to be measured after more calibration

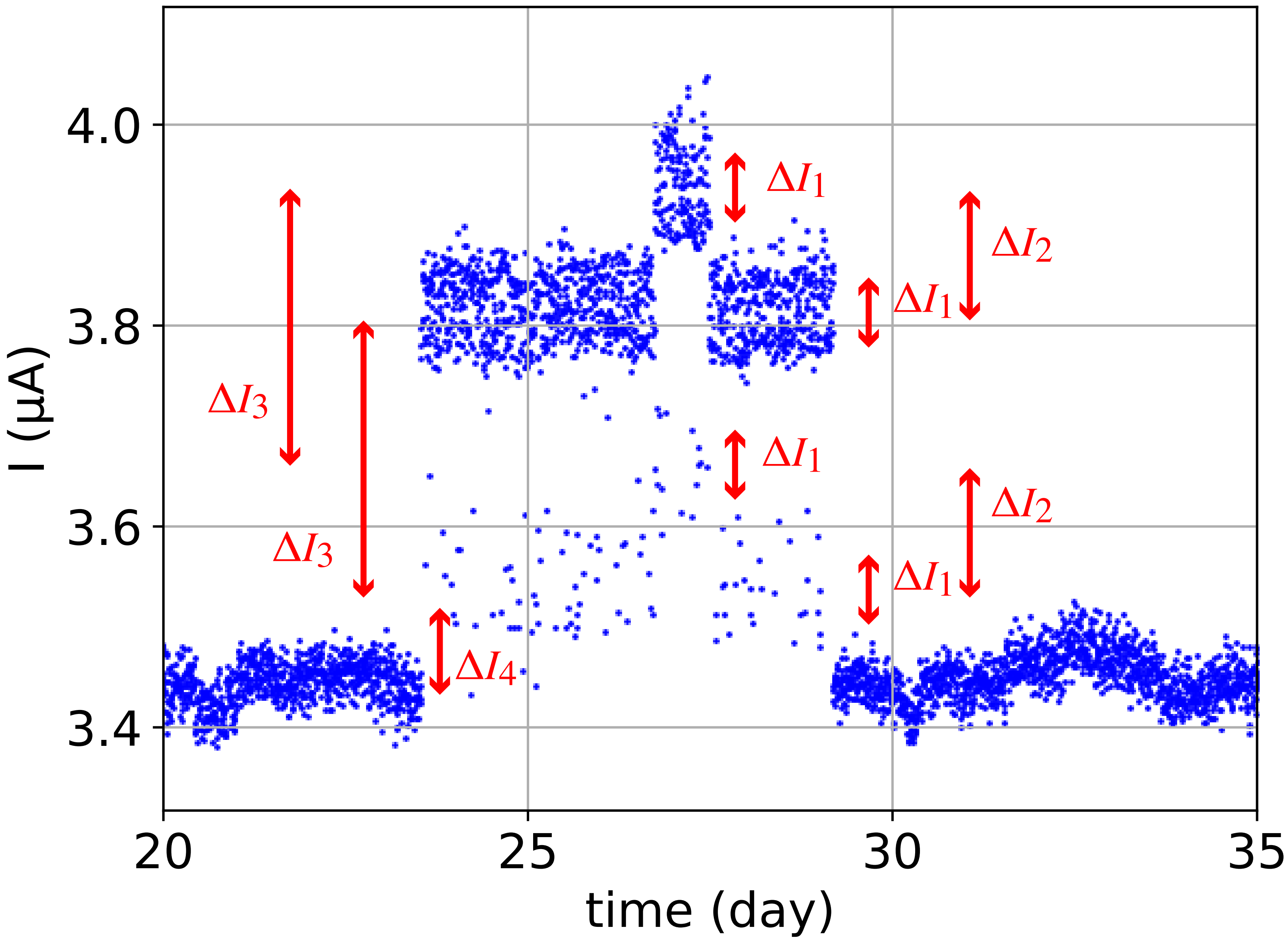
Angular Dependence

by Daichi Ando (Nagoya)



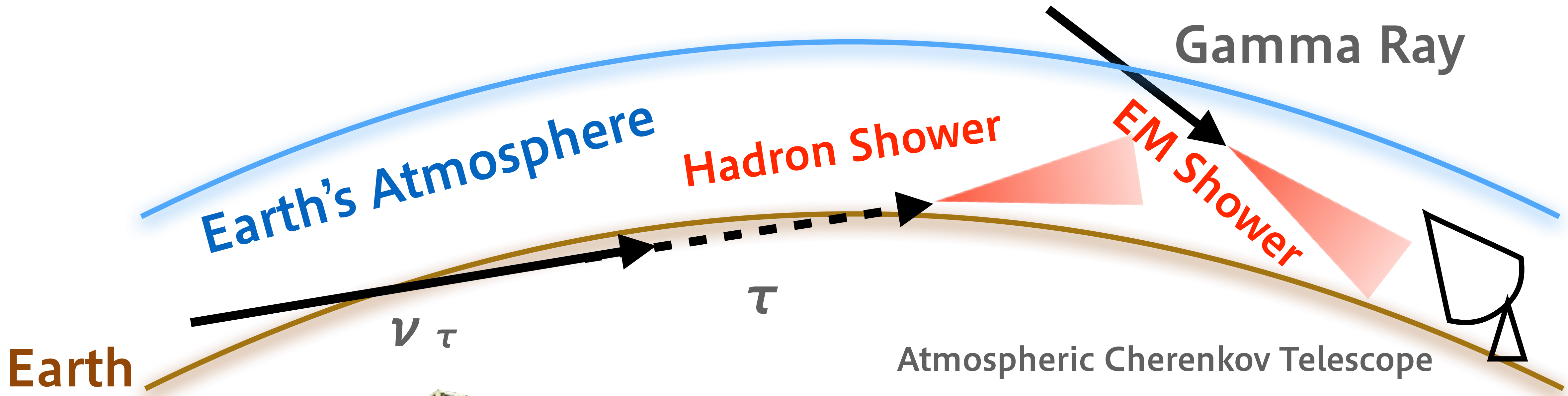
Instability of SiPM Dark Current

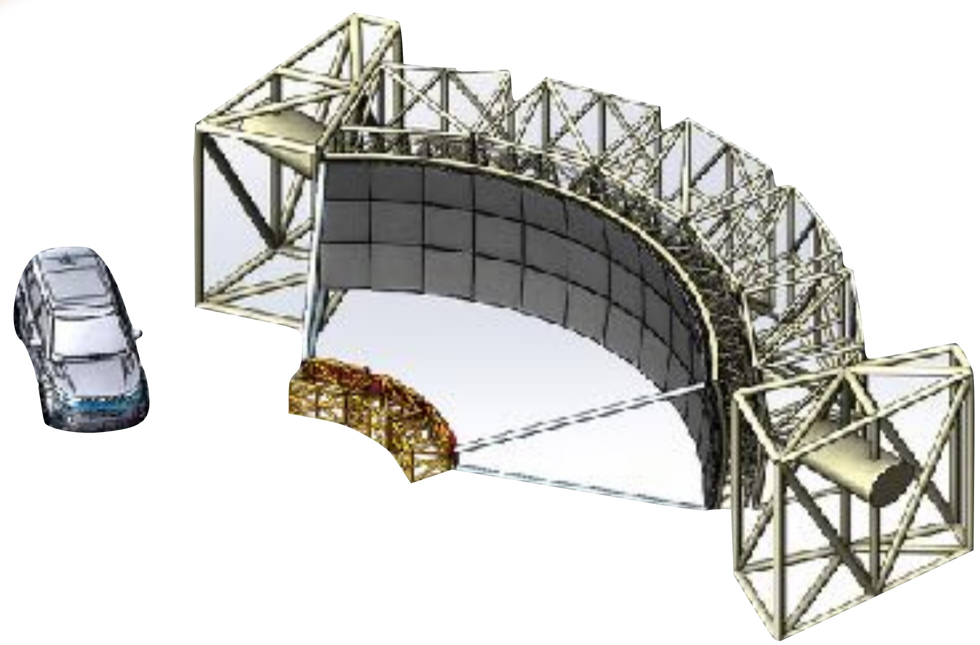
Kawarasaki et al. (2025)

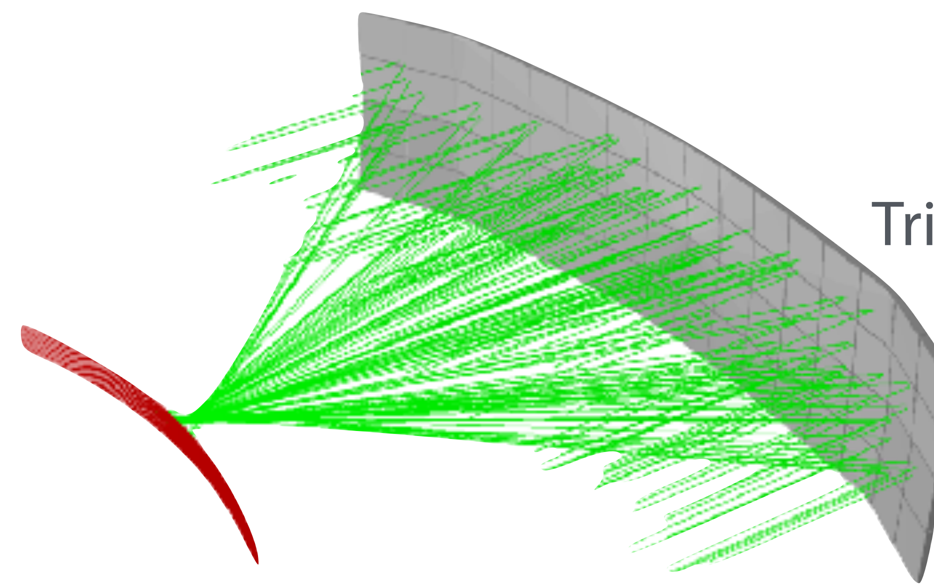


- Long-term stability needs be checked before SST construction
- Dark current instability with hour to week time scale was discovered but negligible for SST
- Accelerated reliability test under high humidity condition is so far so good

Earth Skimming Neutrinos







Trinity Colab.

- Other types of neutrino telescopes can extend the capability
- Except for IceCube, there are only several GRAND (radio) members in Japan
- Wide FOV optics, Winston cones, and SiPMs can be used for
- Cherenkov detection is well matured technique but limited duty cycle and FOV

Summary

- Slowly but CTAO SSTs will follow the advanced other telescopes in 2020s
- Future SiPM camera upgrade is under investigation by Japan, Switzerland, etc
- SiPM characterization is actively conducted at Nagoya University for CTAO SSTs and LSTs
- Use of SiPM cameras in neutrino observations is expected