Optical Systems and Focal Plane Cameras for the Cherenkov Telescope Array

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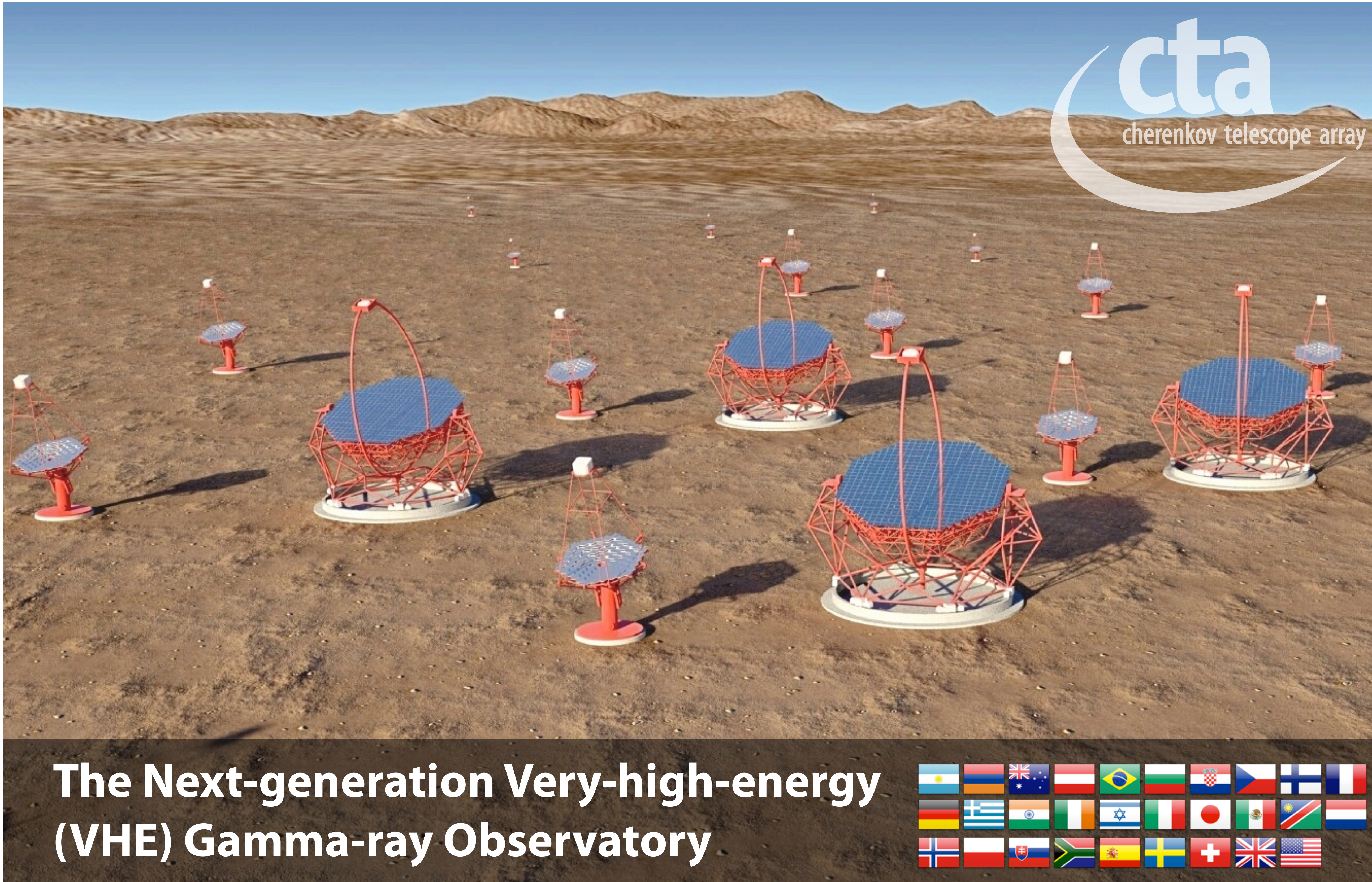
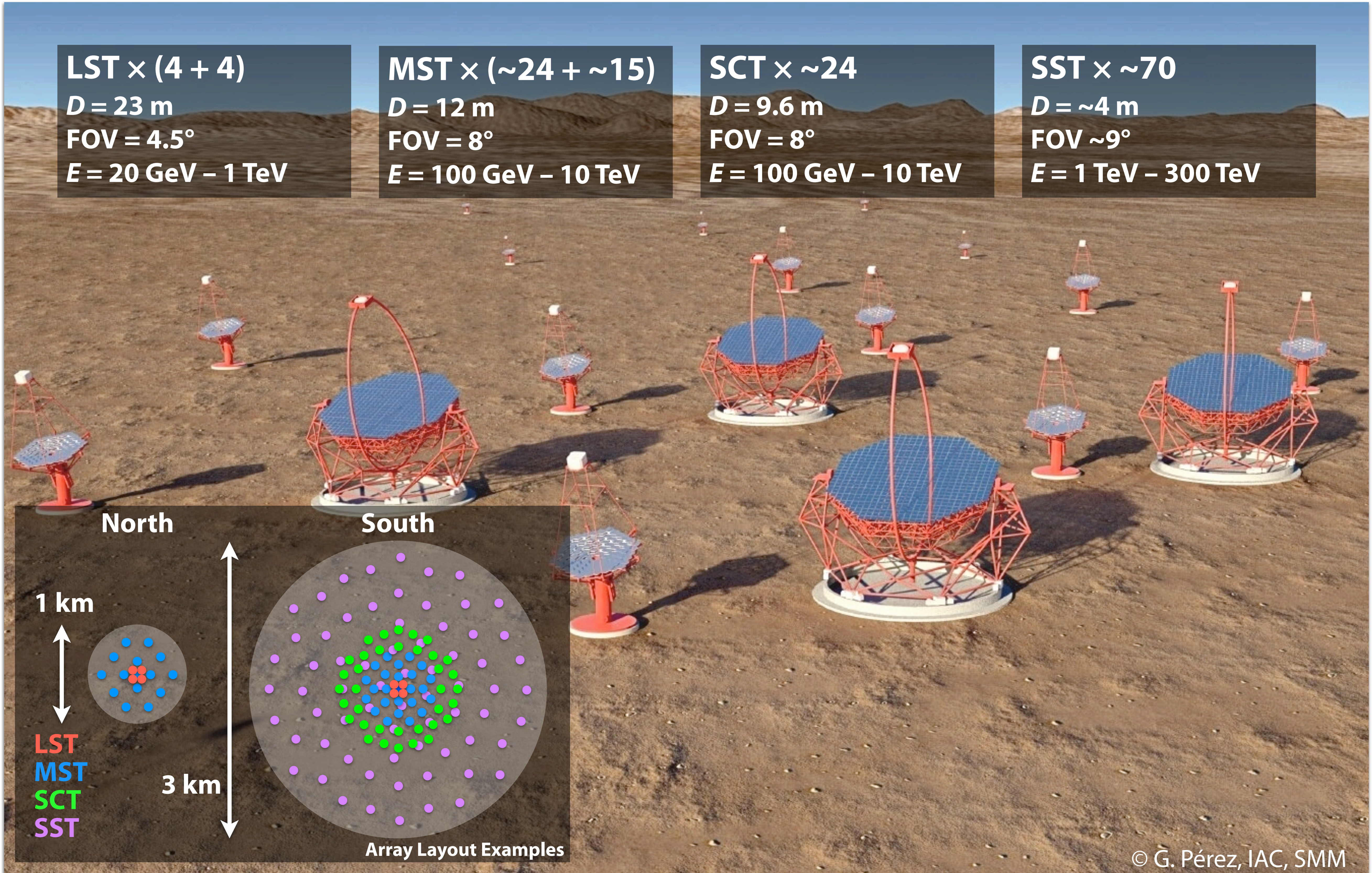
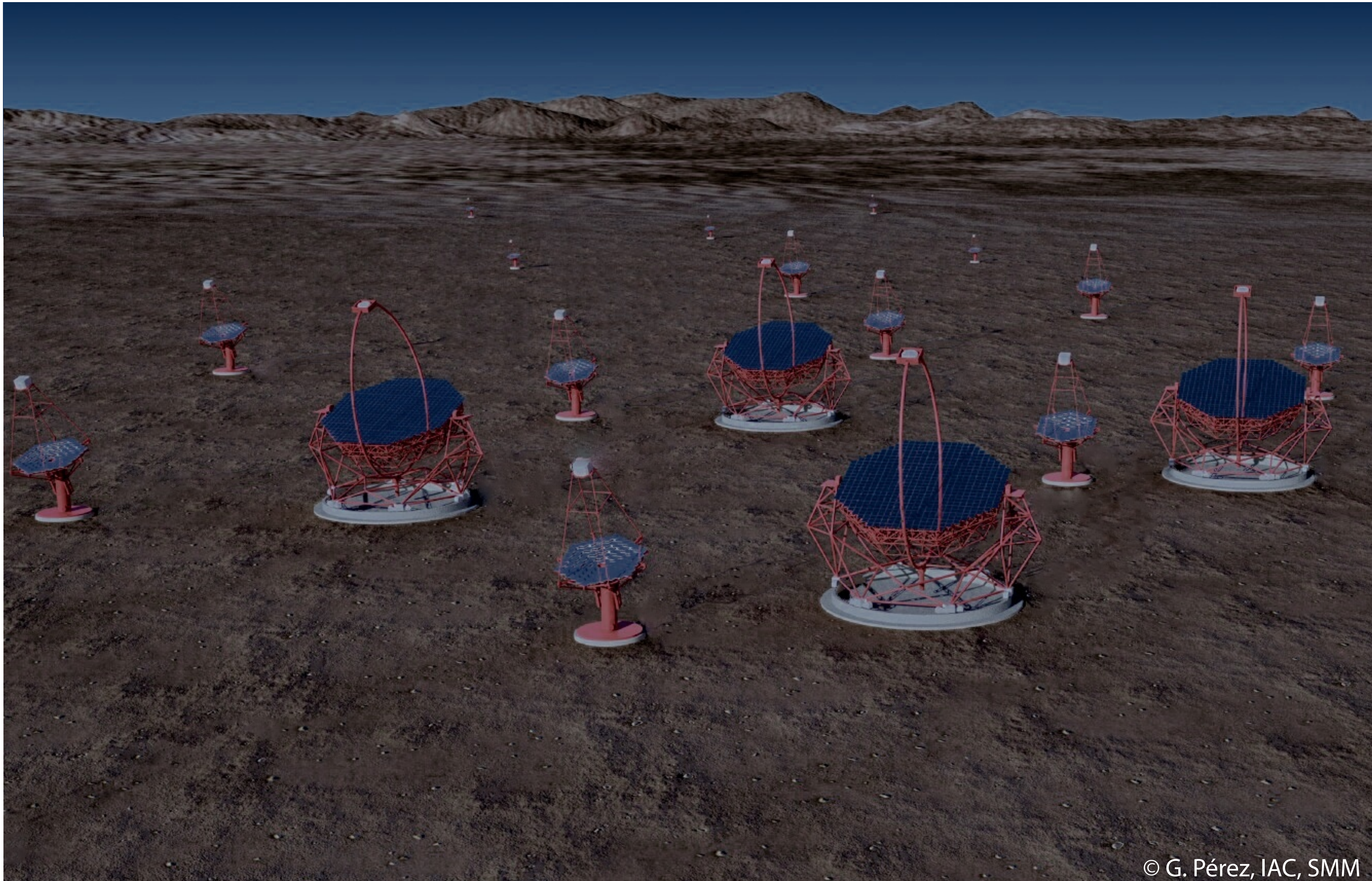
Cherenkov Telescope Array (CTA)



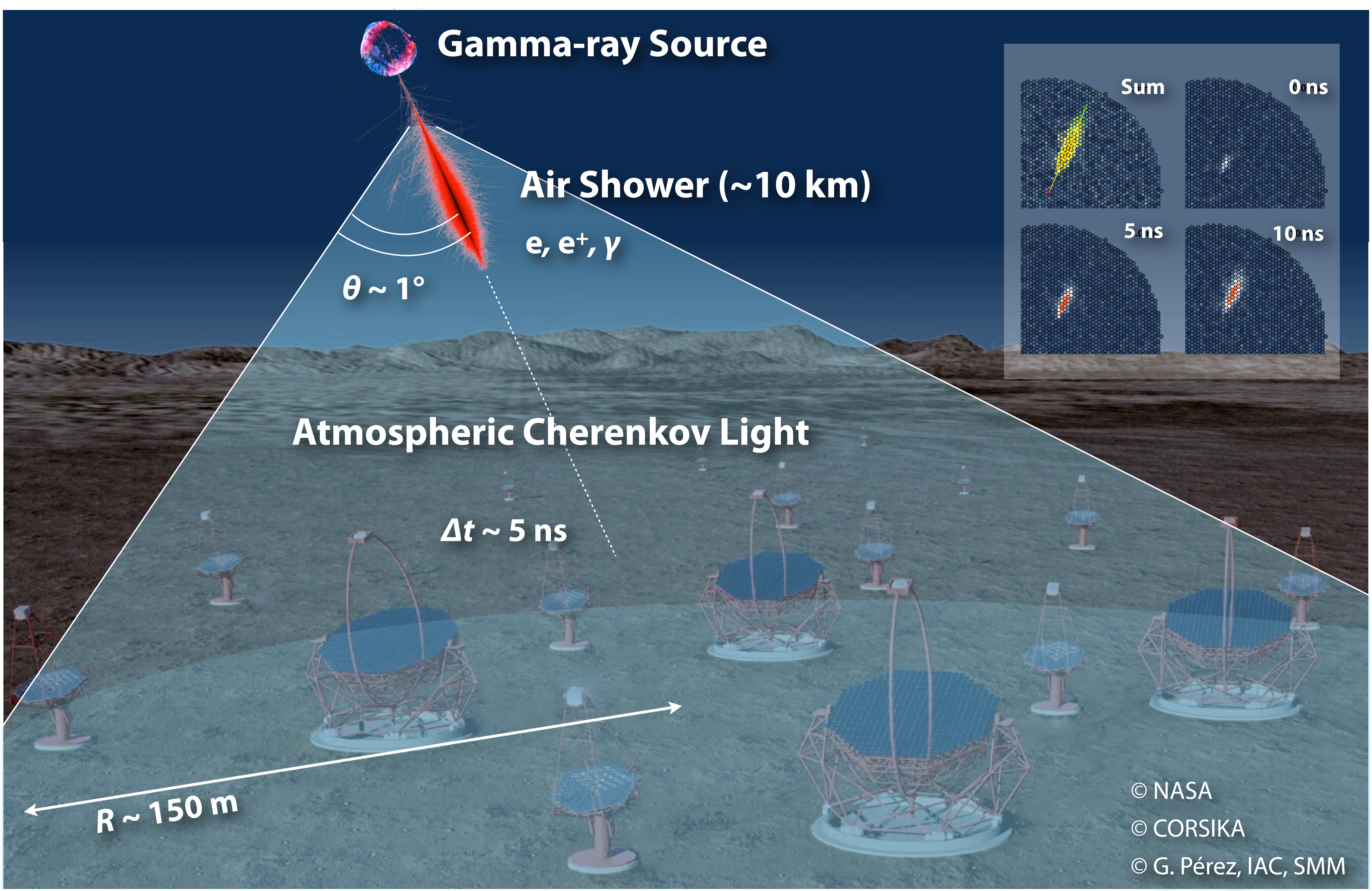
A Mixed Array of Four Different Telescopes



Detection Technique of VHE Gamma Rays



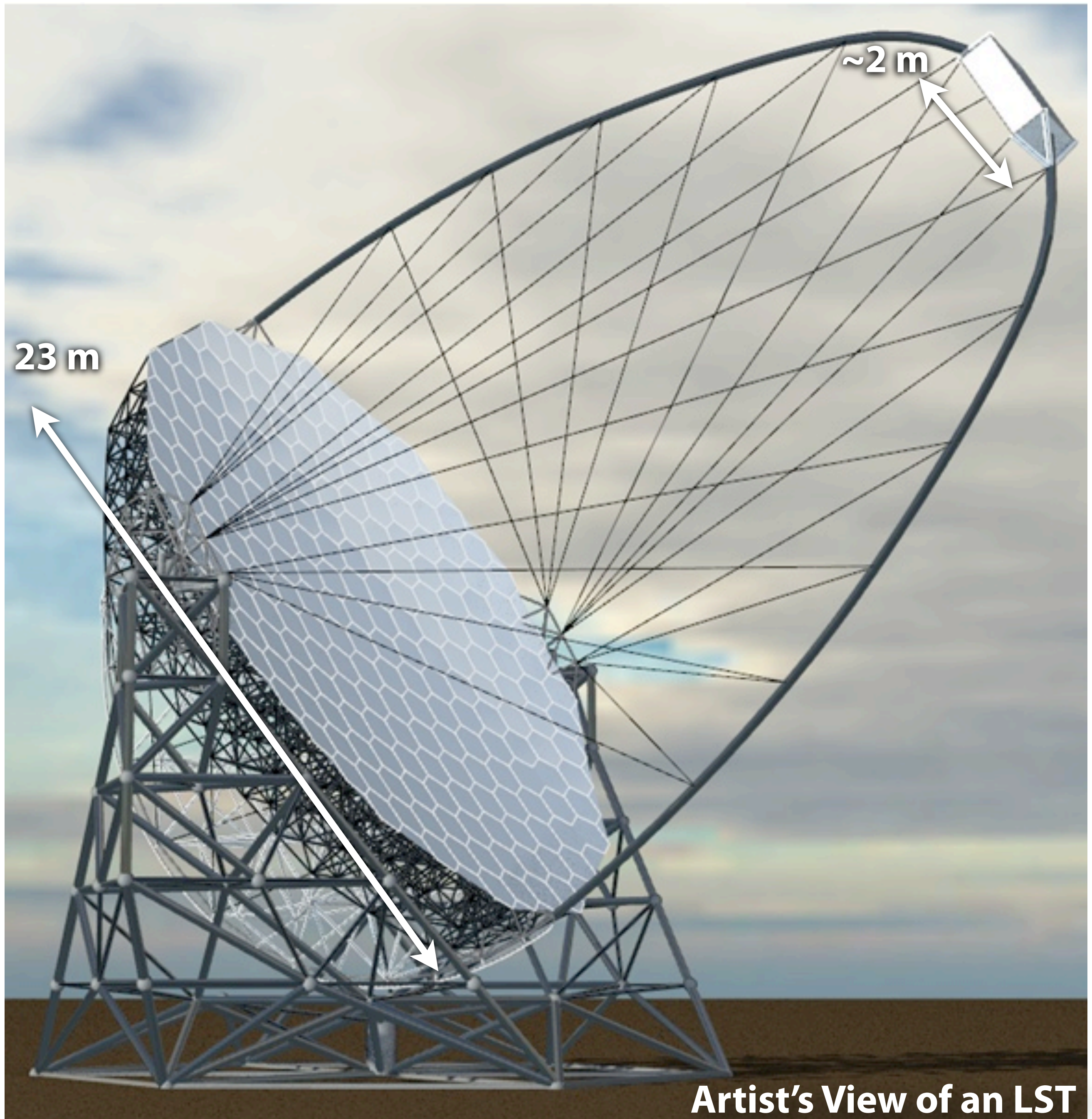
Detection Technique of VHE Gamma Rays



The Basic Elements of the Cherenkov Telescope Array

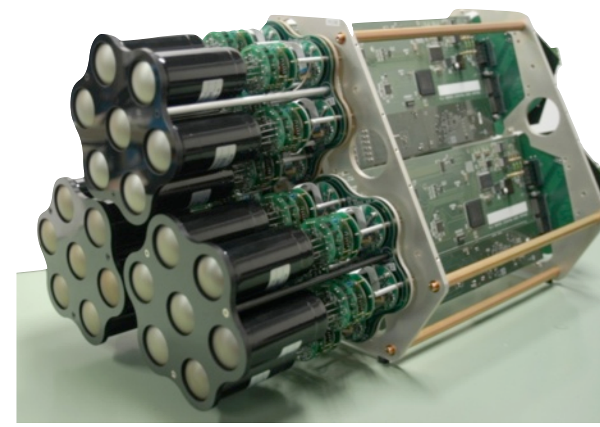
- A large primary mirror with segmented facets
  - Collect as many as photons possible to achieve a low energy threshold
  - Less expensive (a factor of 0.01 compared to astronomers' telescopes)
  - Can reduce coma aberration in Davies-Cotton systems
- Optical system
  - Parabolic system for LSTs to avoid timing spread of arrival photons
  - Davies-Cotton system for MSTs and/or SSTs to achieve wide FOV of ~8°
  - Schwarzschild-Couder system (primary and secondary mirrors) for SCTs and/or SSTs to high resolution of ~0.05° over wide FOV of ~8°
  - Time spread < ~1 ns
- Camera
  - Pixel size of ~0.1° (Cherenkov event image size ~ 1° × ~0.5°)
  - Fast and UV sensitive photodetectors (PMTs or SiPMs), some are AC coupled
  - Analog to digital conversion, fast signal sampling ~0.25 to 1 GHz, & trigger

Large-Sized Telescopes (LSTs)

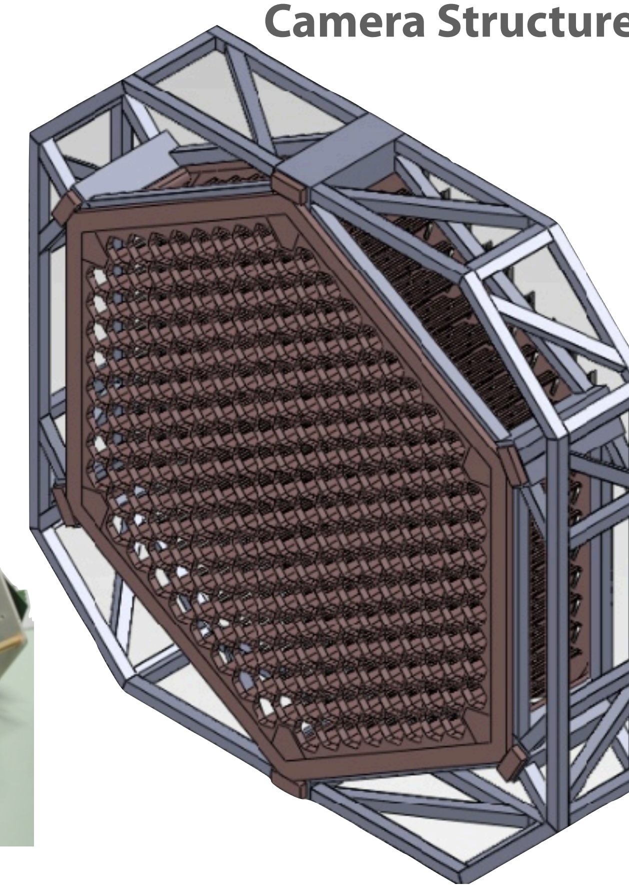


Artist's View of an LST

Camera Prototype

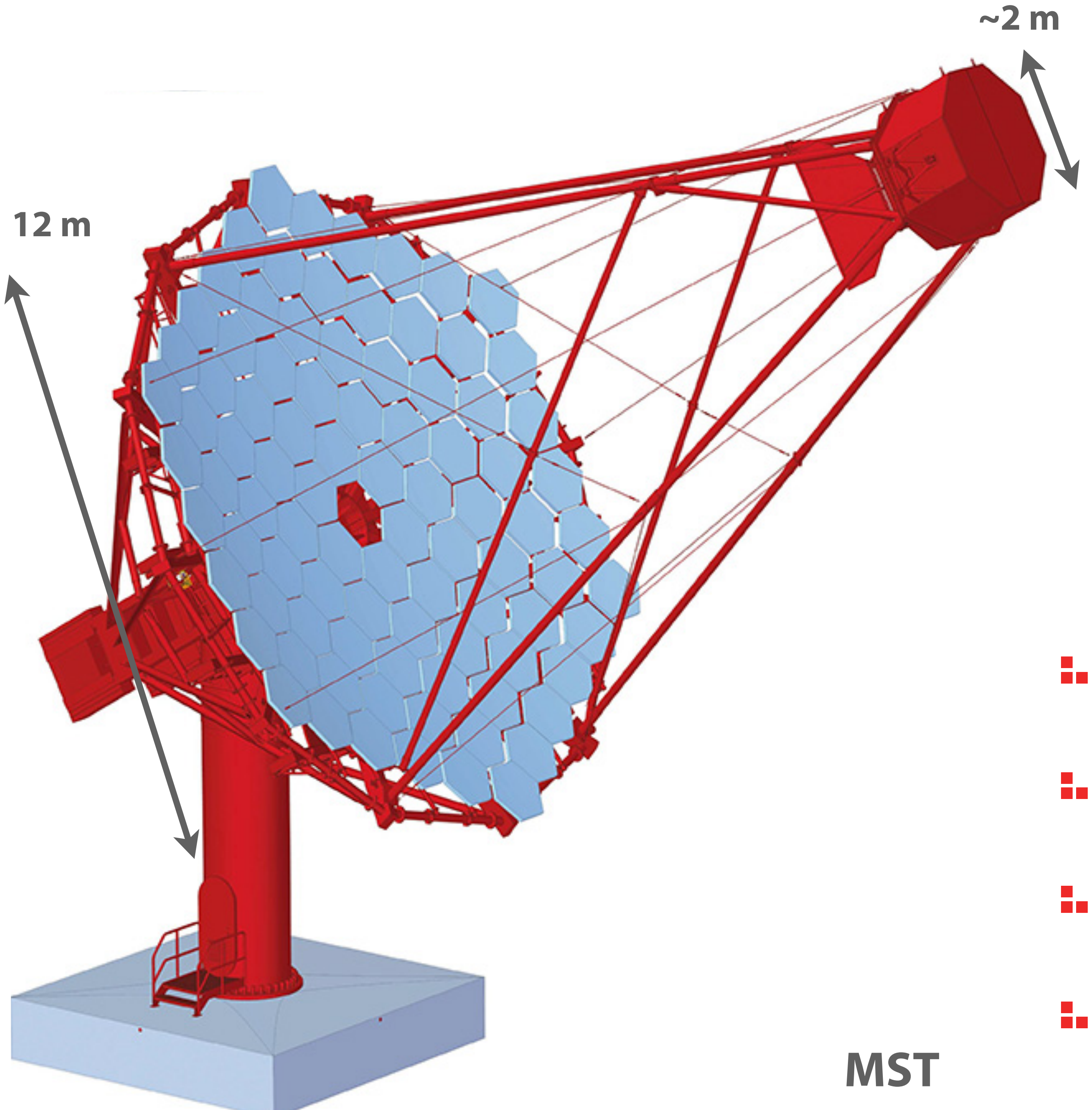


Camera Structure

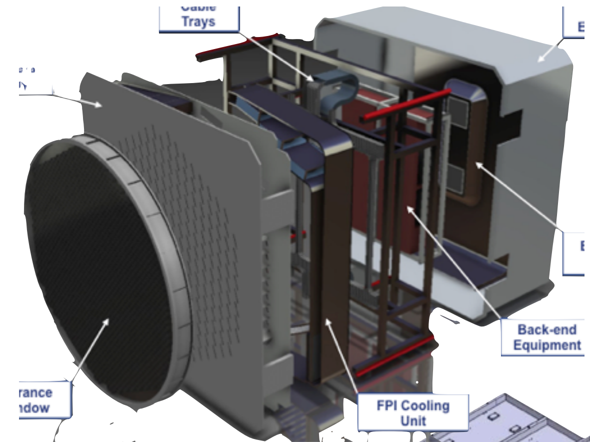


- Segmented parabolic mirror
- $f = 28$ m, $D = 23$ m, FOV = 4.5°
- Pixel = 50 mm (× 1,855 PMTs)
- PSF_{D80} = ~ 0.05 – 0.2° (pix = 0.1°)
- 1 optical system and 1 camera designs

Medium-Sized Telescopes (MSTs)

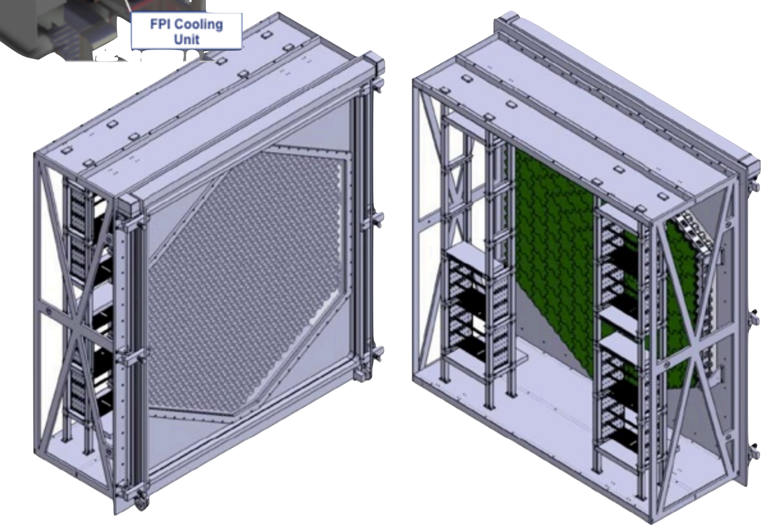


MST



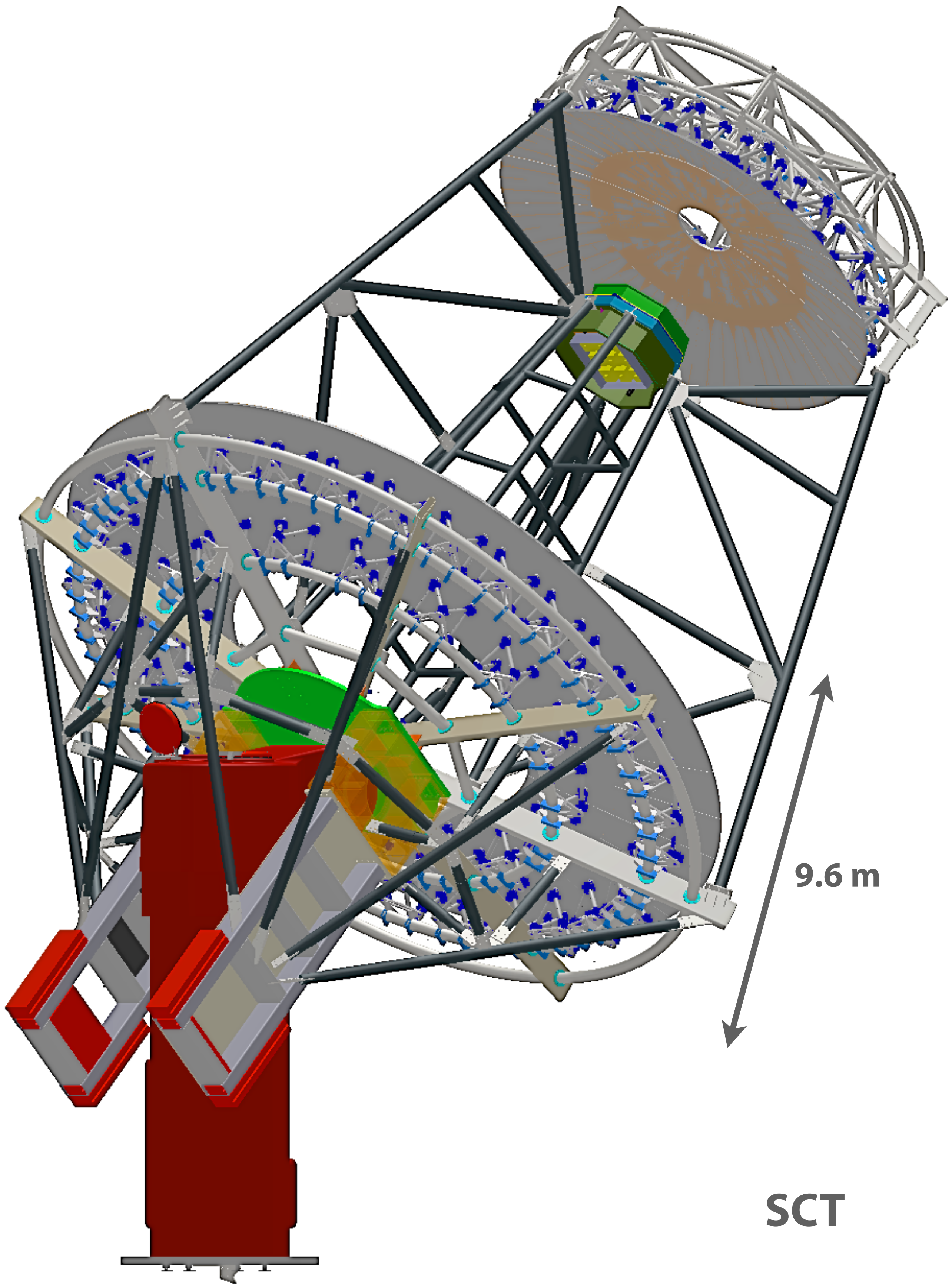
Nectar Cam

FlashCam

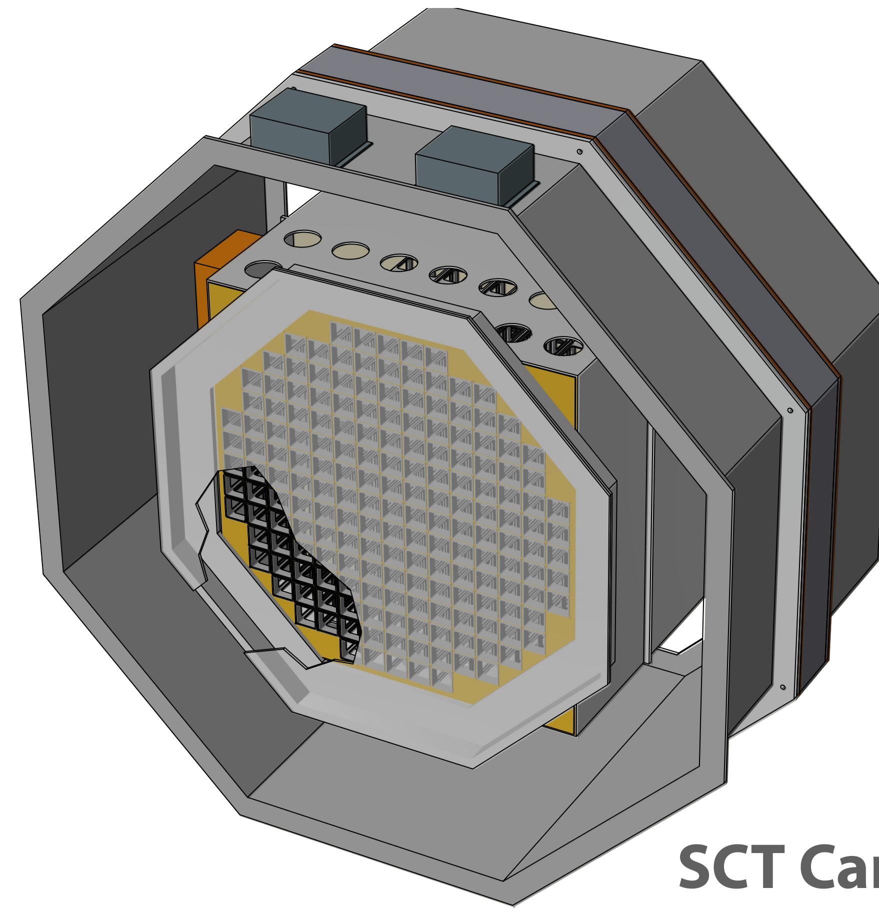


- Davies-Cotton optical system
- f = 16 m, D = 12 m, FOV = 8°
- Pixel = 50 mm (× ~1,800 PMTs)
- PSF_{D68} = ~0.08 – 0.2° (pix = 0.18°)
- 1 optics and **2** camera designs

Schwarzschild-Couder Telescopes (SCTs)



SCT

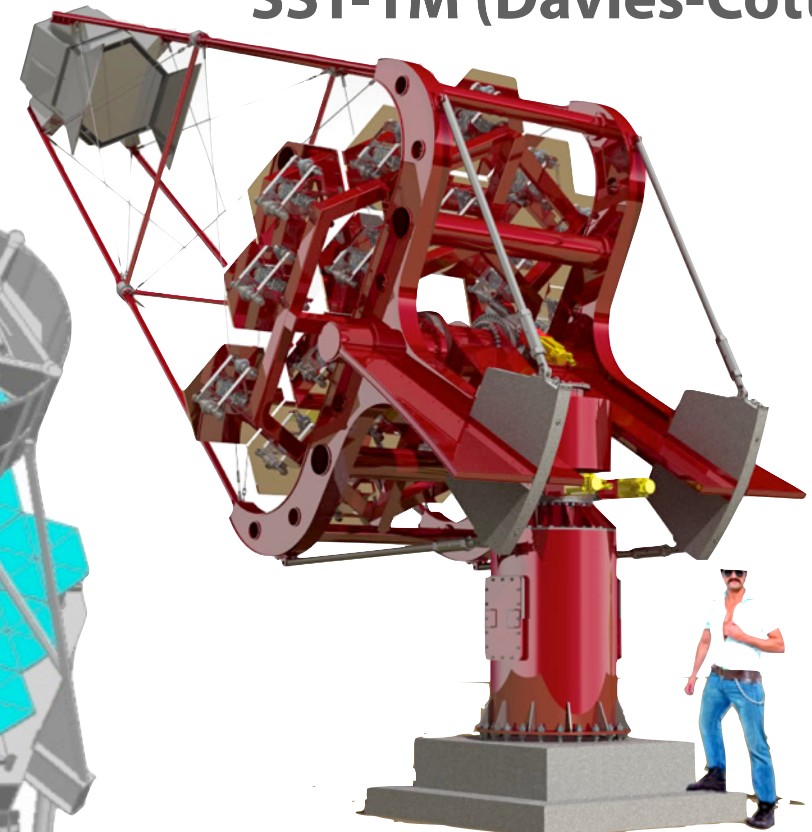


SCT Camera

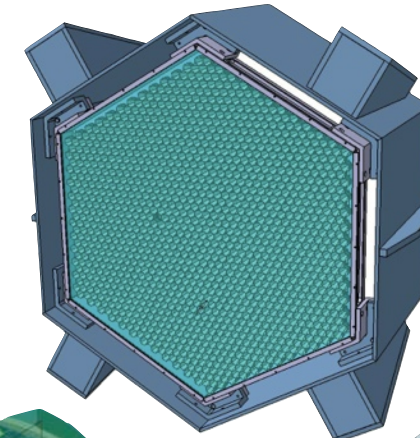
- Schwarzschild-Couder optics
- $f = 5.6$ m, $D = 9.6$ m, FOV = 8°
- Pixel = 6 mm (× 11,328 SiPMs)
- PSF_{D68} = ~0.04 – 0.08°(pix = 0.06°)
- 1 optics and 1 camera designs

Small-Sized Telescopes (SSTs)

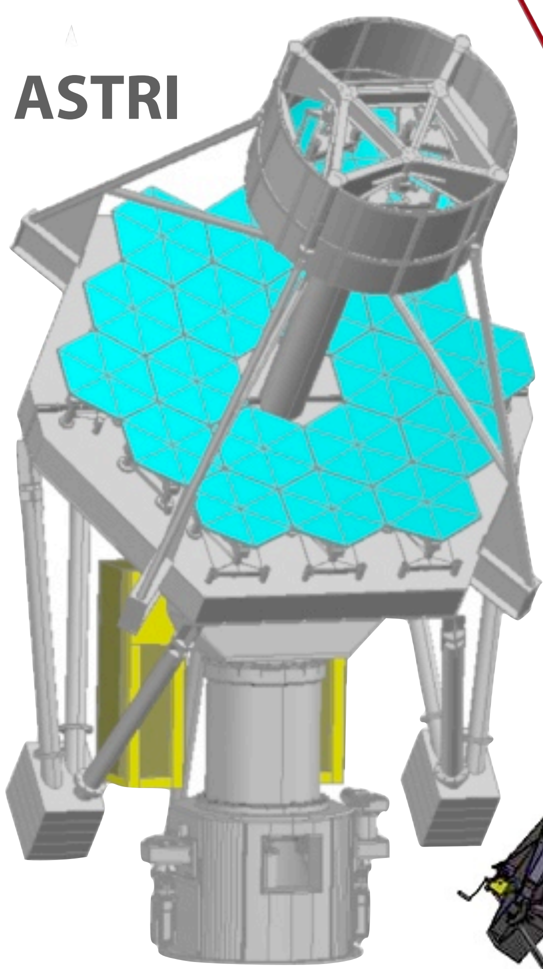
SST-1M (Davies-Cotton)



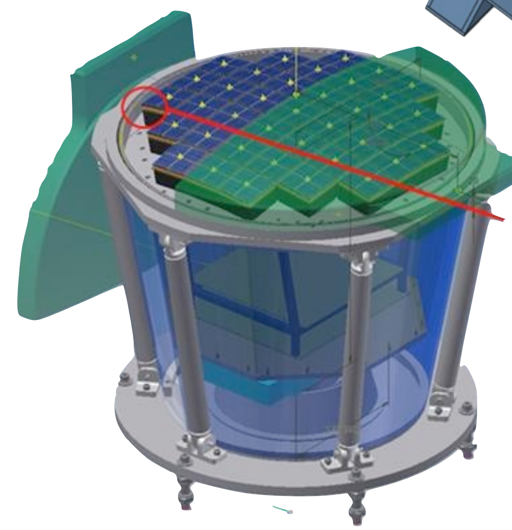
SST-1M Cam



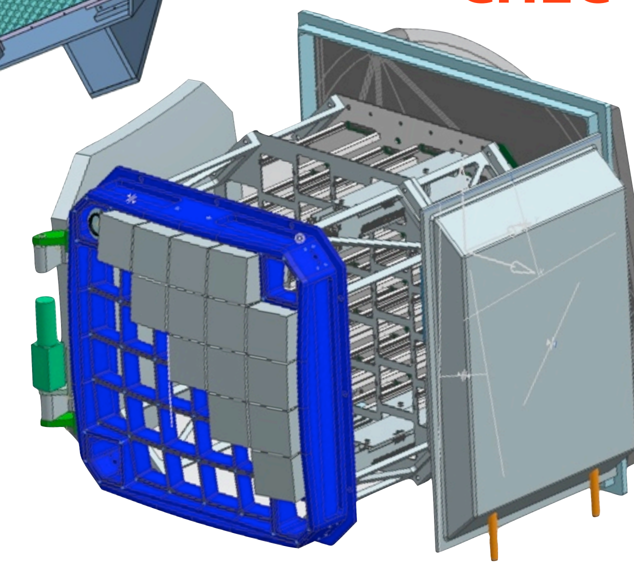
ASTRI



ASTRI



CHEC

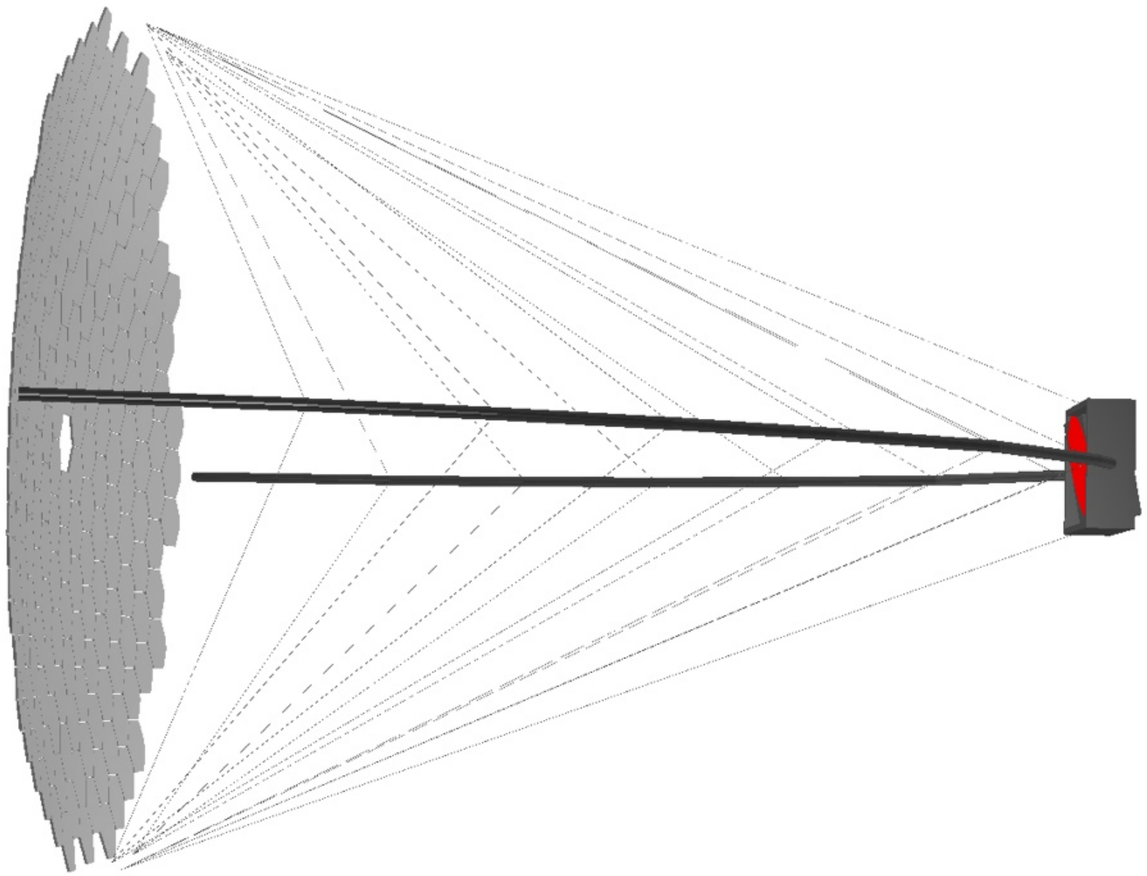


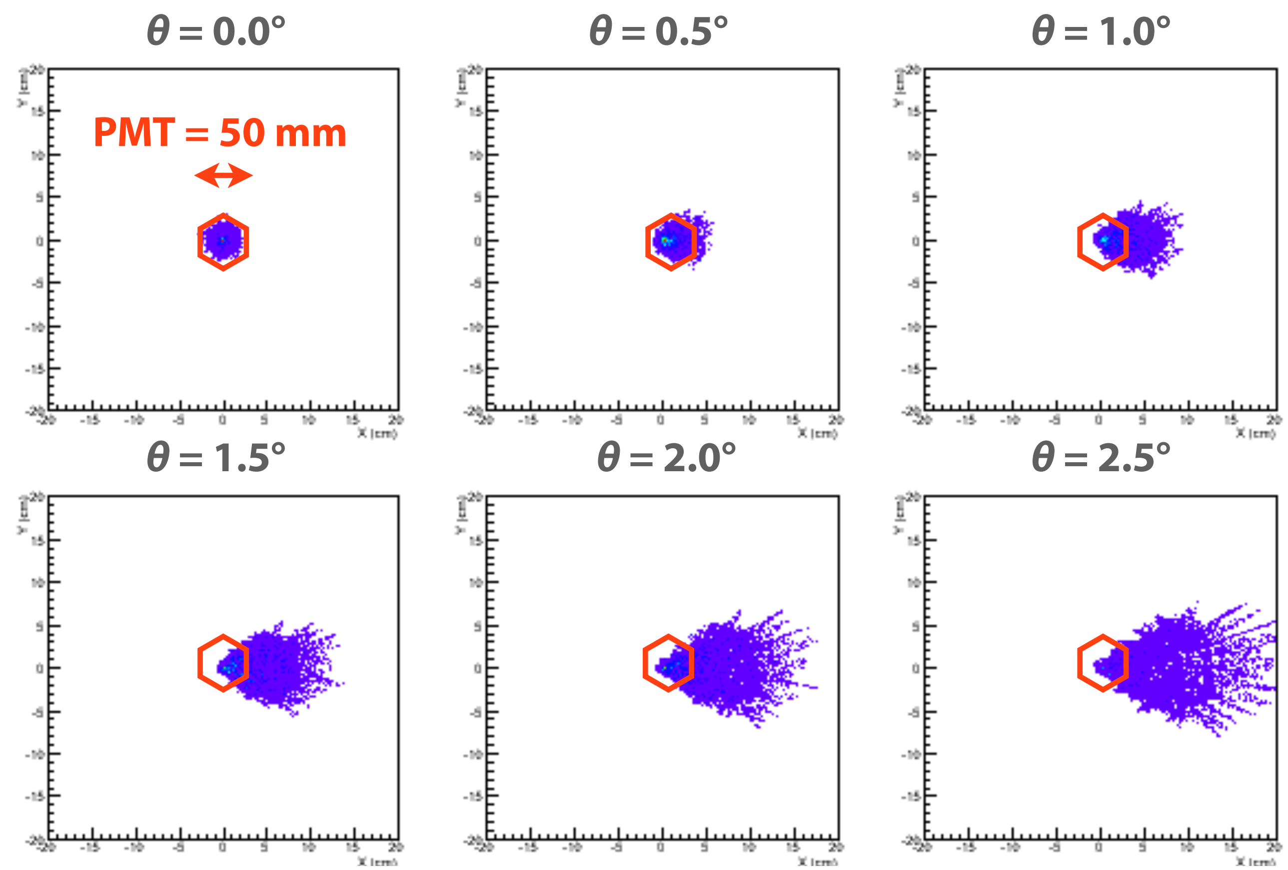
SST-GATE

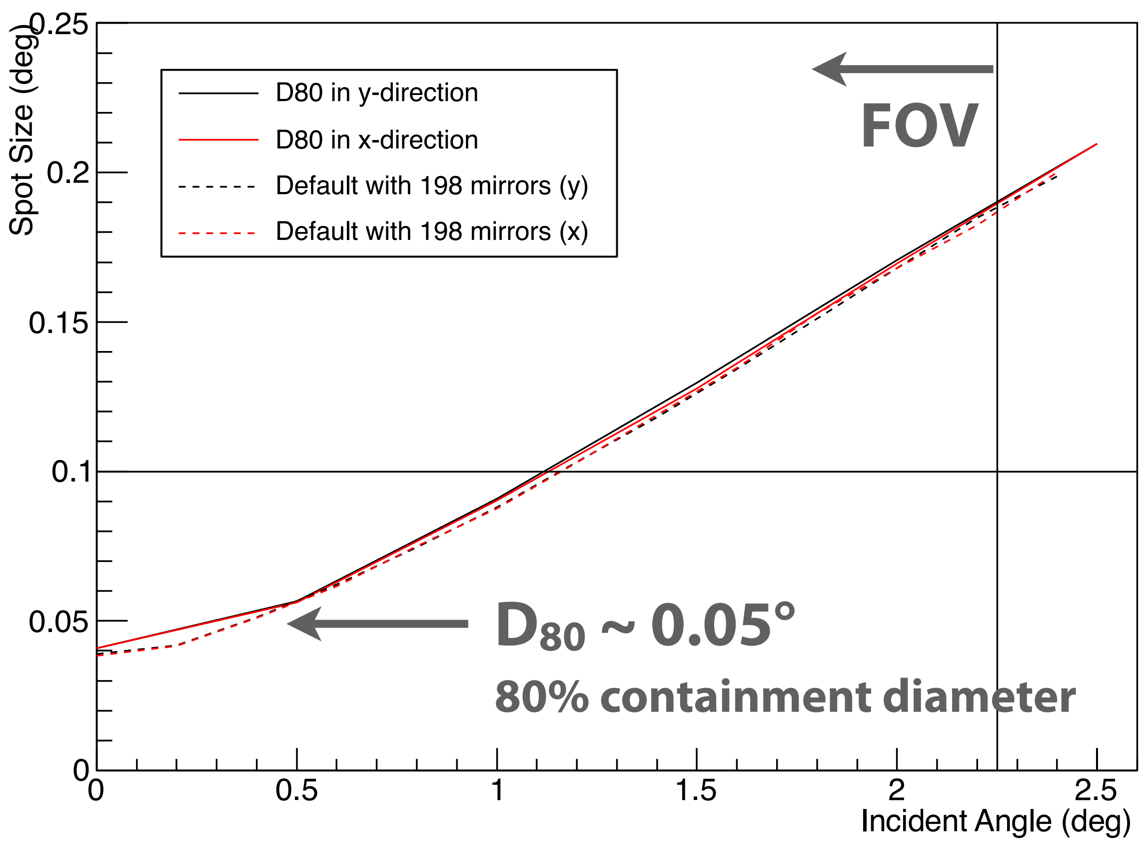
- Davies-Cotton or Schwarzschild-Couder optical system
- f = 5.6 or 2.15 m, D = 4 m, FOV = ~9 – 10°
- Pixel = 24.4 mm or ~6 mm (1307 or ~2000 SiPMs)
- PSF = ~0.4° or ~0.05 – 0.15° (pix = 0.25° or ~0.15°)
- **2** optics and **3** camera designs…

The LST Optical System

Simulation with ROBAST by Koji Noda (MPI)

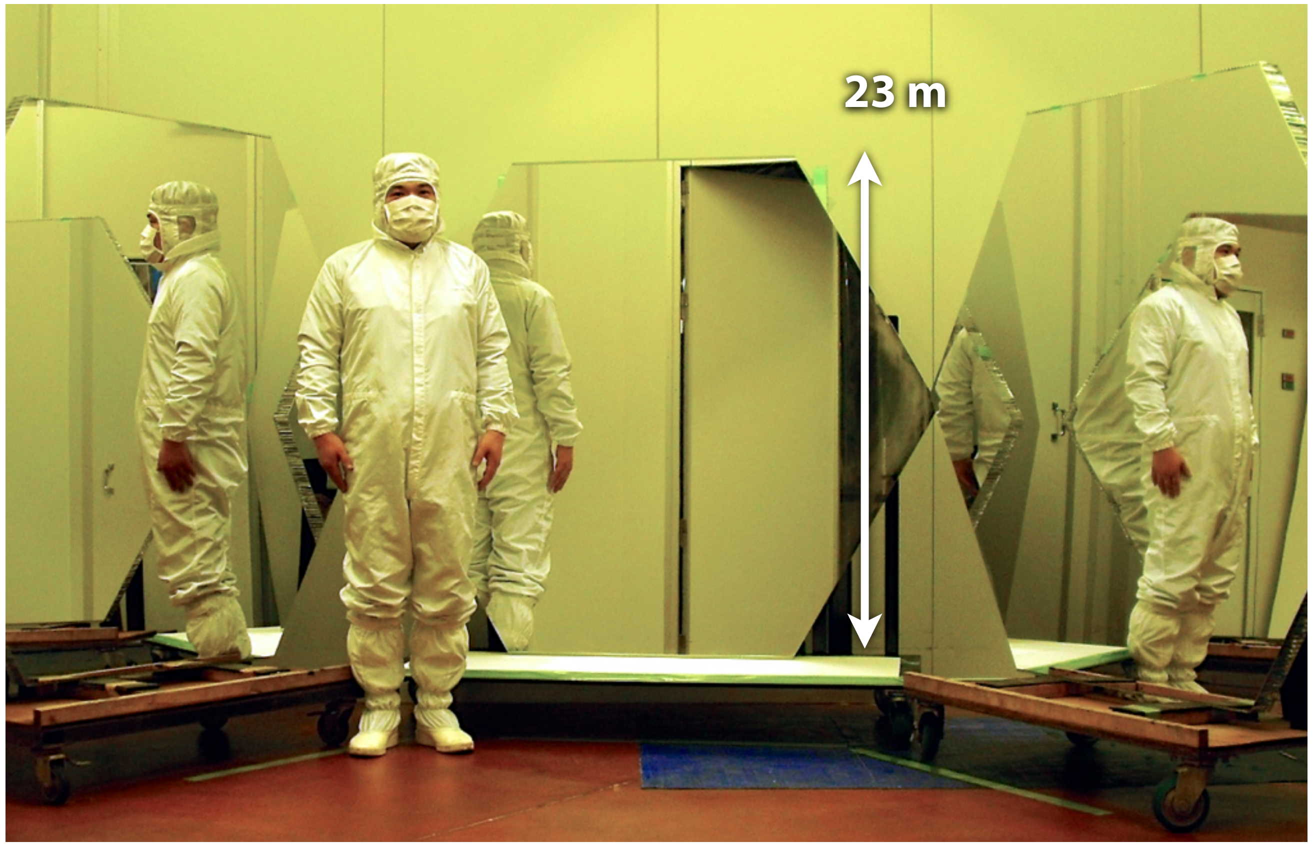




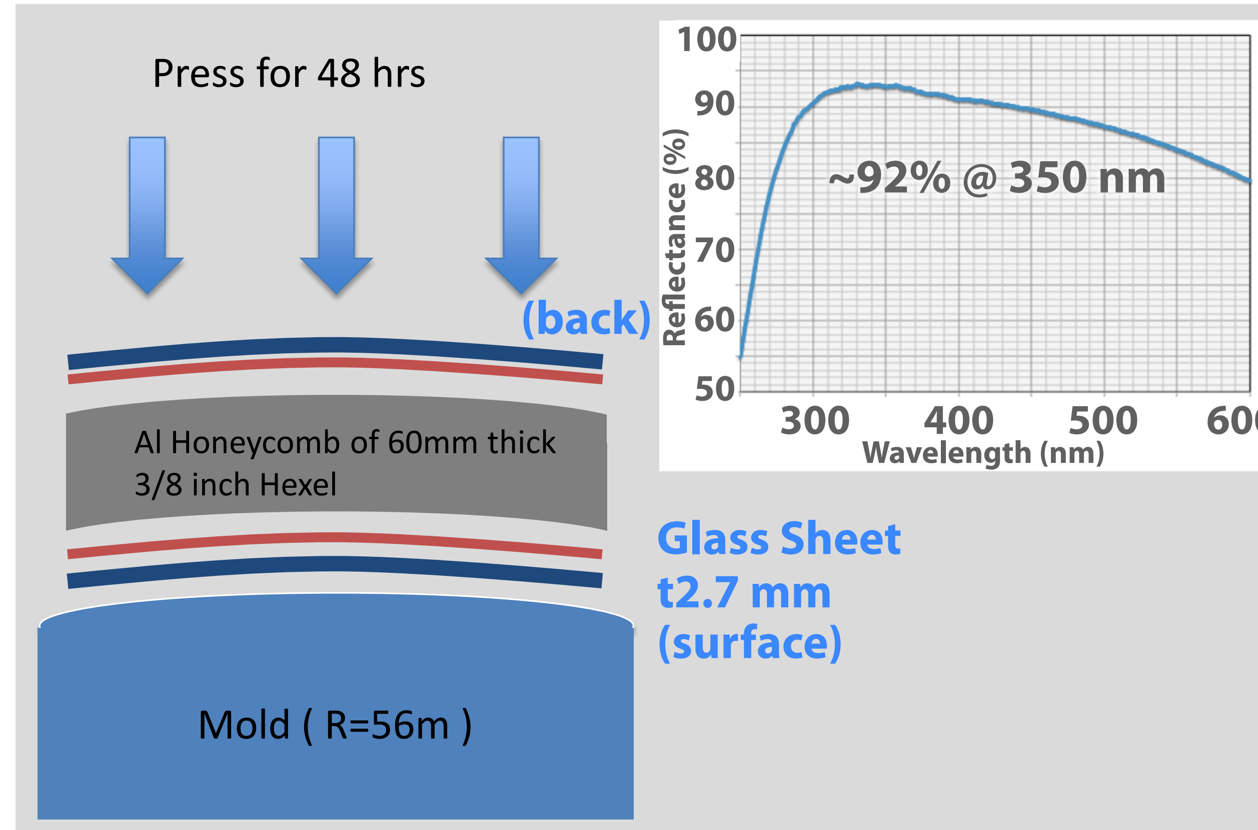


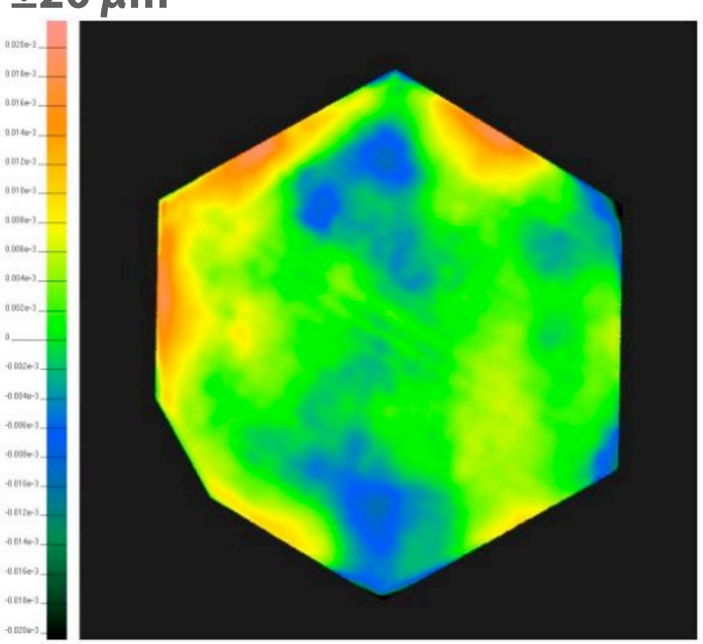
- 198 spherical segmented mirrors (387 m²)
- The on-axis performance is the best, as the system is parabolic
- Large coma aberration may be problematic if we put a HBT detector at the camera edge

LST Mirrors

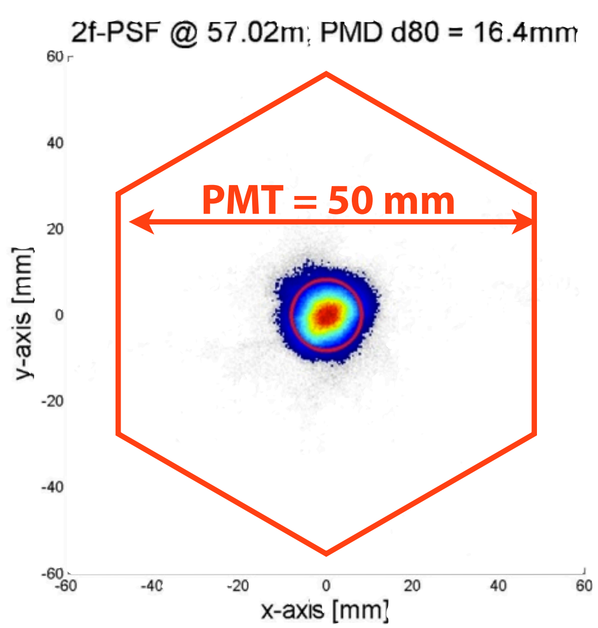


Cold Slumping Technique





Deviation from a Sphere

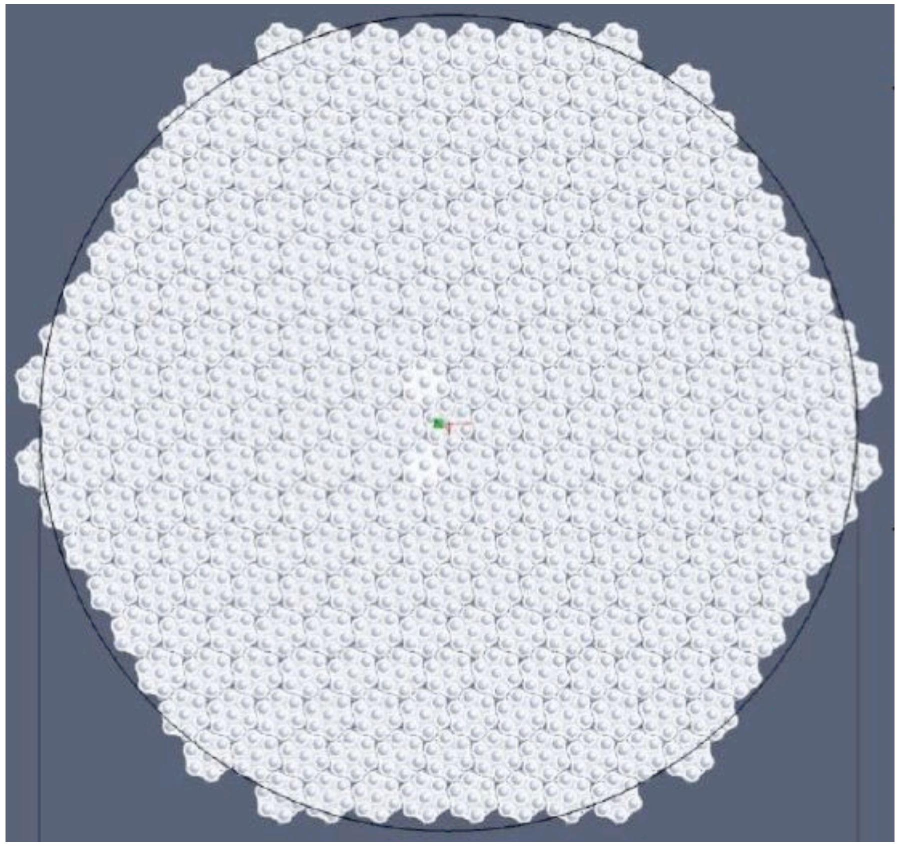


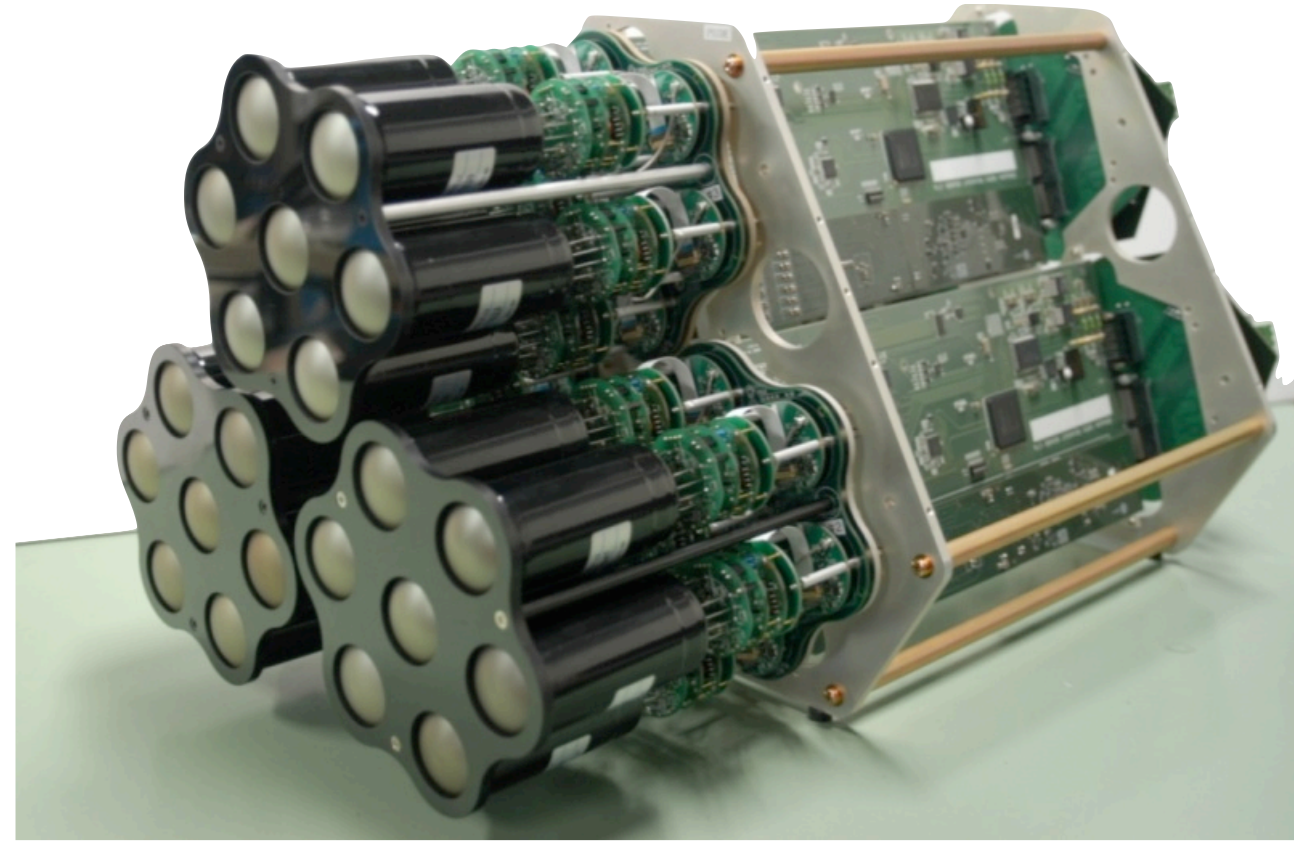
PSF by Ray Tracing

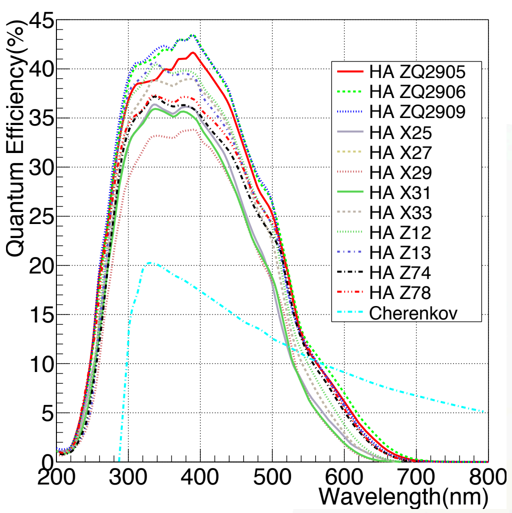
by Hironori Baba et al. (Ibaraki)

- Production with the cold slumping technique and sputtering
- The mirror surface quality is checked with the Phase Measuring Deflectometry (PMD) method
- Measured and simulated PSF sizes are quite nice ~20% of a pixel

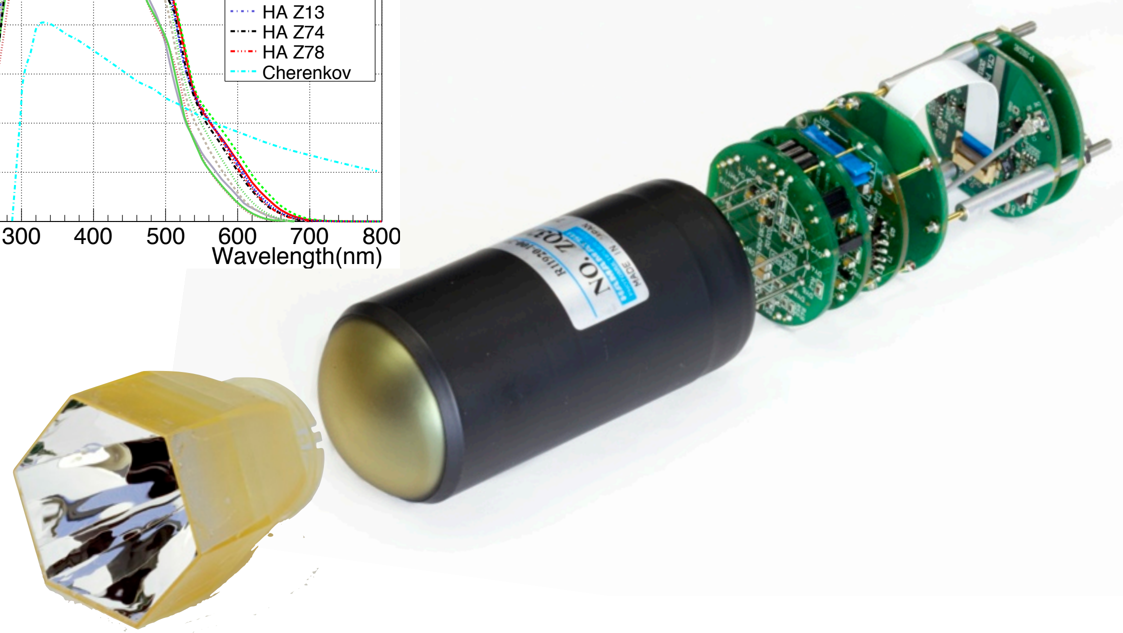
The LST Camera





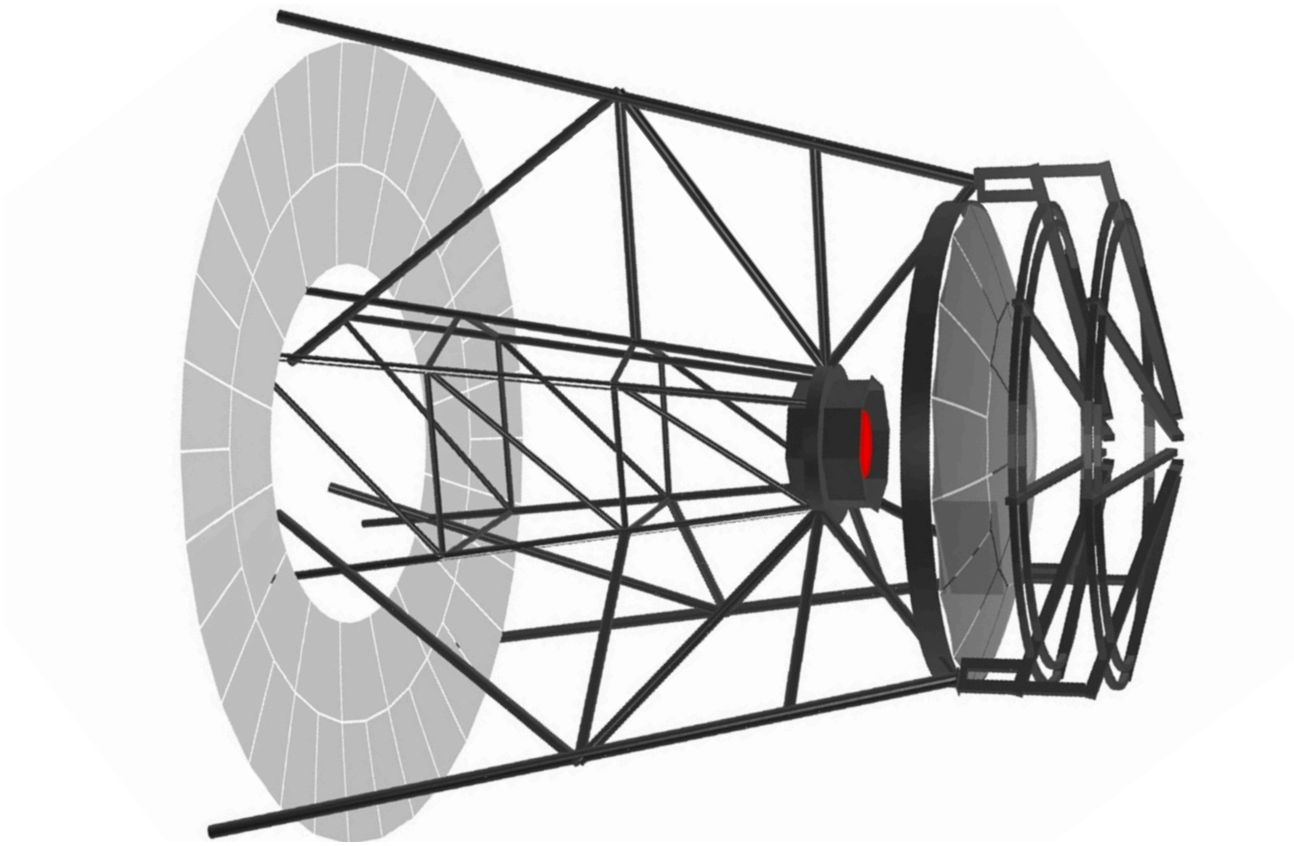


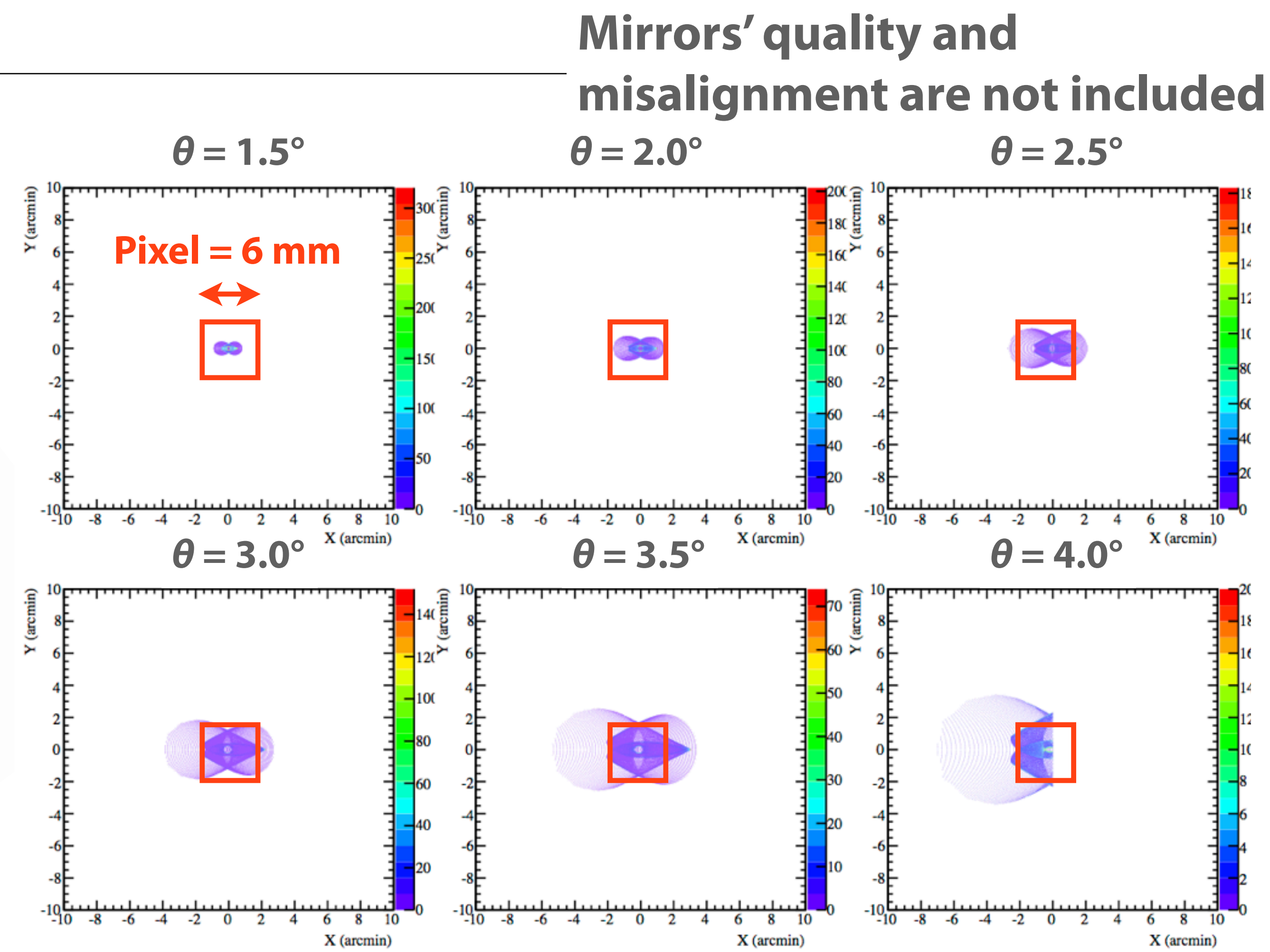
Eff. QE >40% @ 400 nm

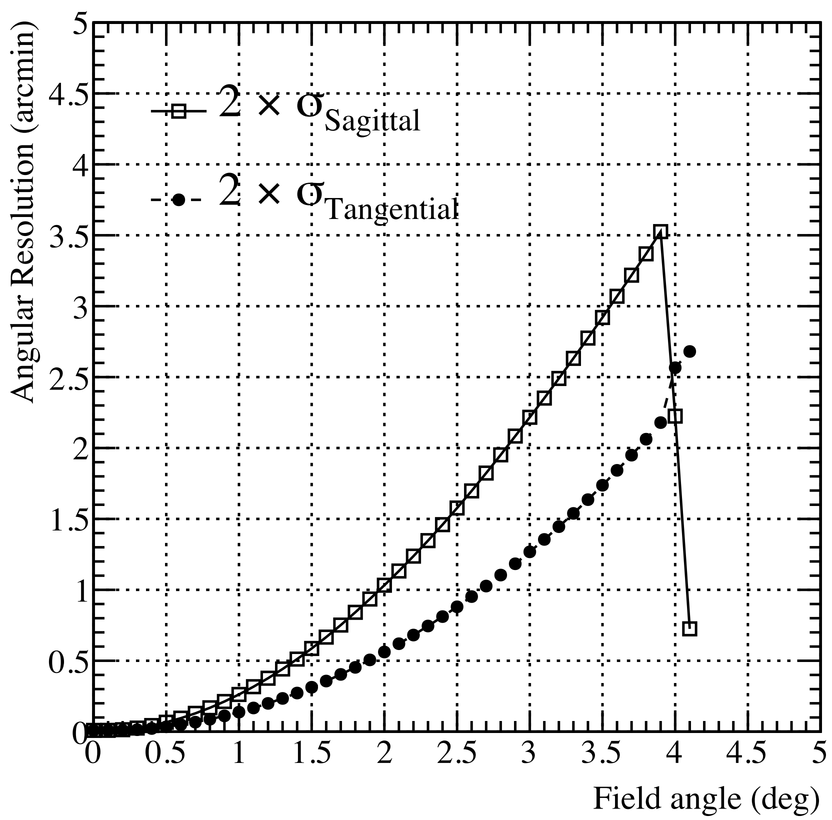


- 1,855 PMTs (UV sensitive)
- Digitizes PMT waveforms at 1 GHz, but continuous recording is not possible
- May be possible to install a dedicated detector at the center
  - Needs strong requests before finalizing the design!

The SCT Optical System

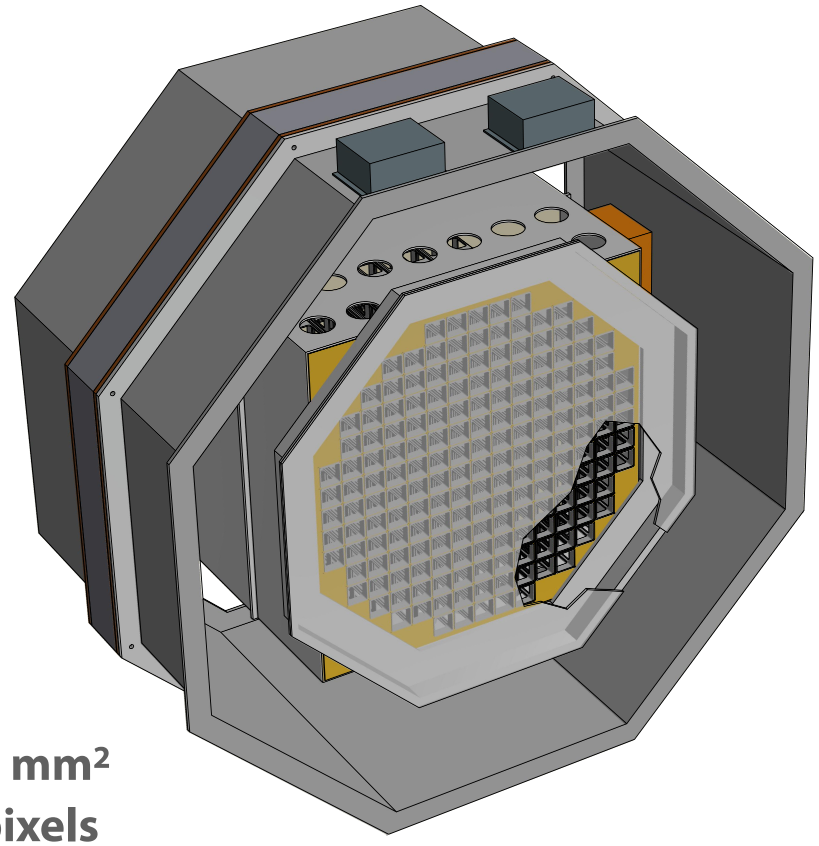




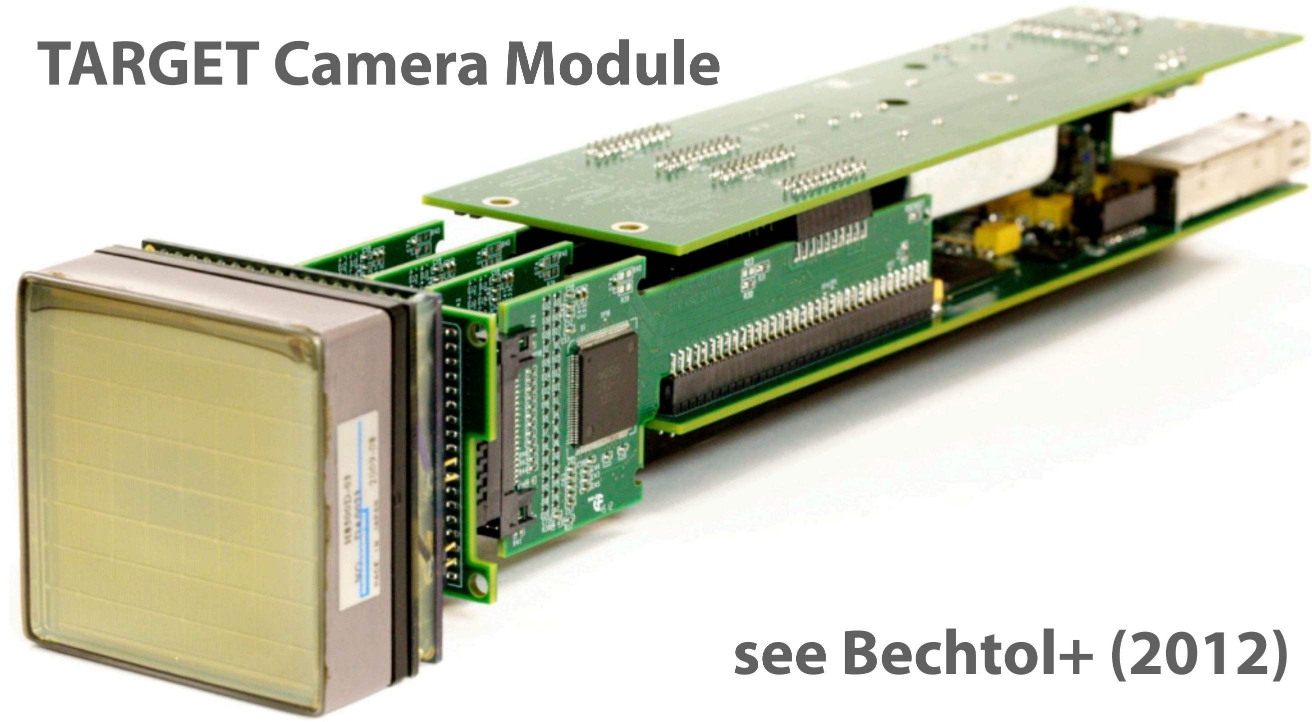


- The first optical system with a secondary mirror in gamma-ray astronomy
- 48 and 24 segmented aspherical mirrors for the primary and the secondary, respectively
- PSF will be dominated by the mirrors' quality and misalignment, so it will be more uniform over the FOV ~0.05 – 0.1°

The SCT Camera

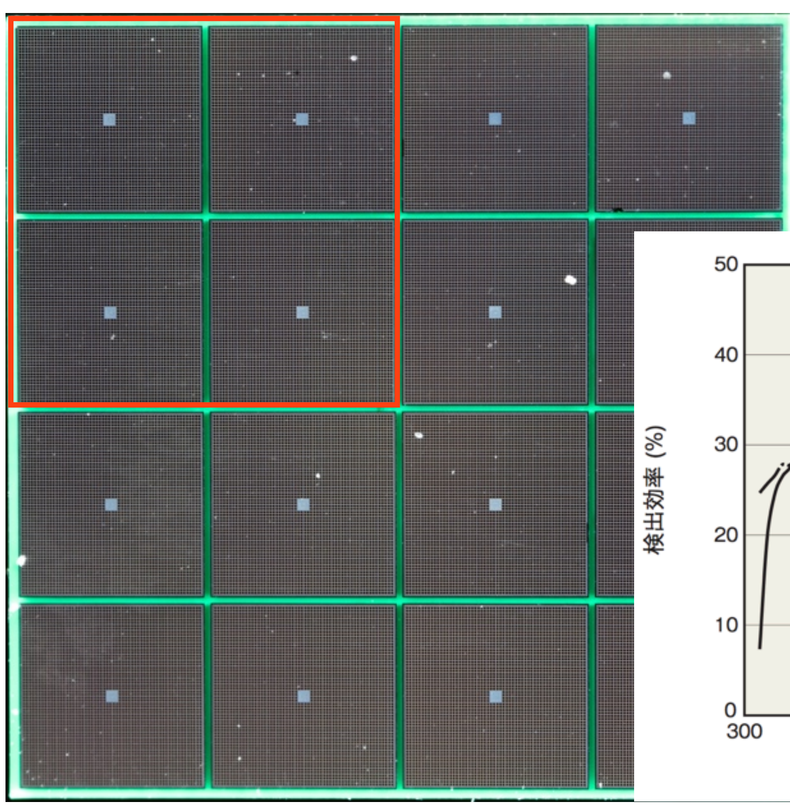


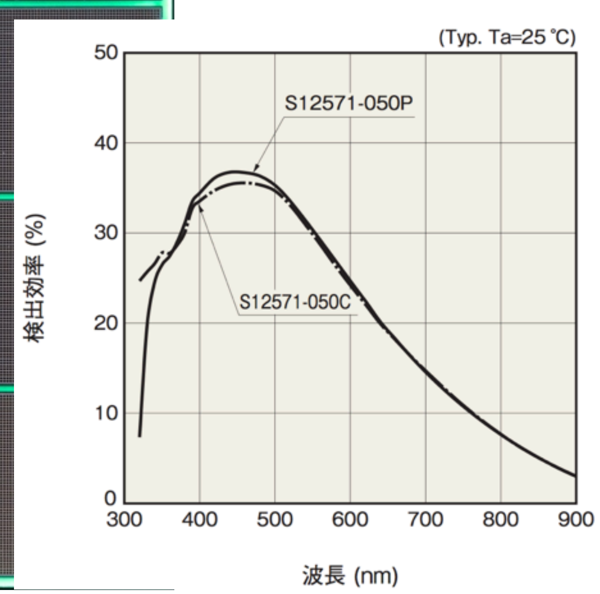
TARGET Camera Module



see Bechtol+ (2012)

3 × 3 mm²
× 4 pixels



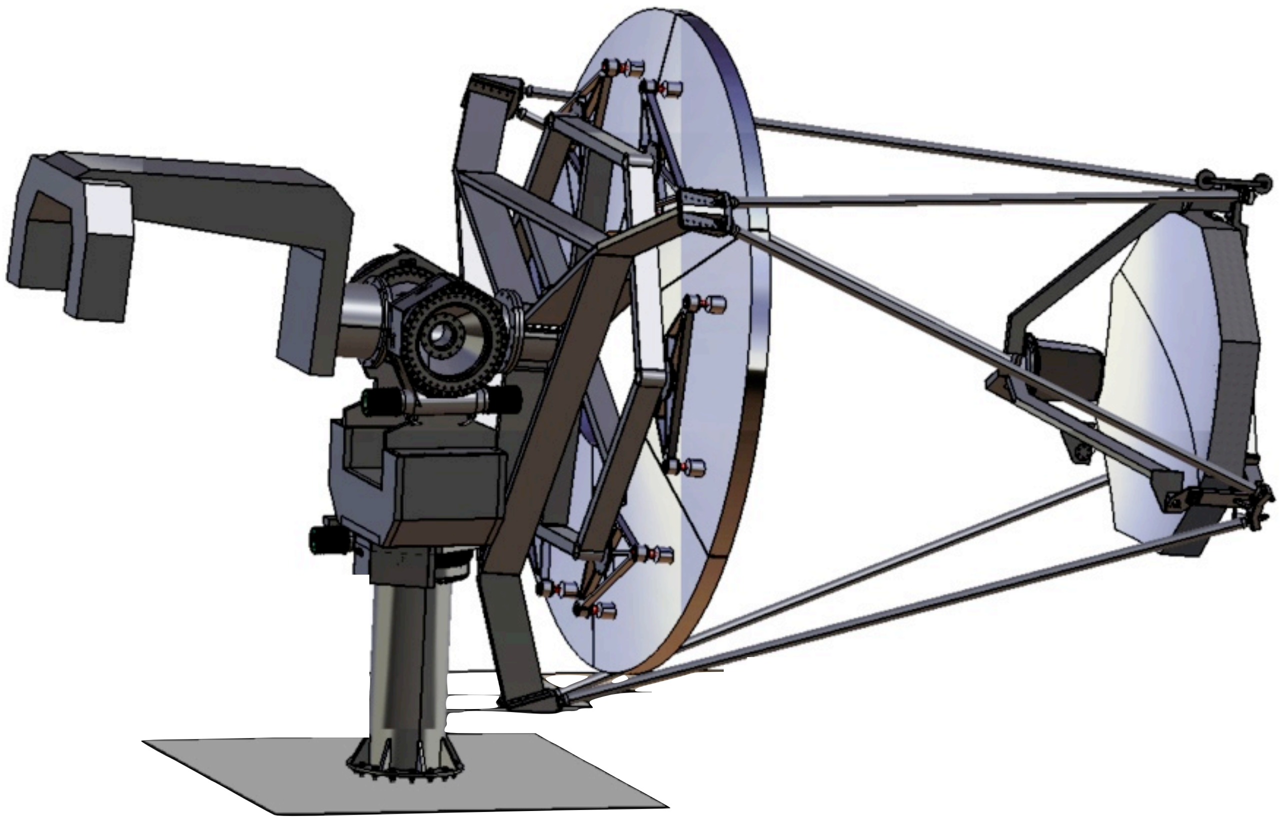


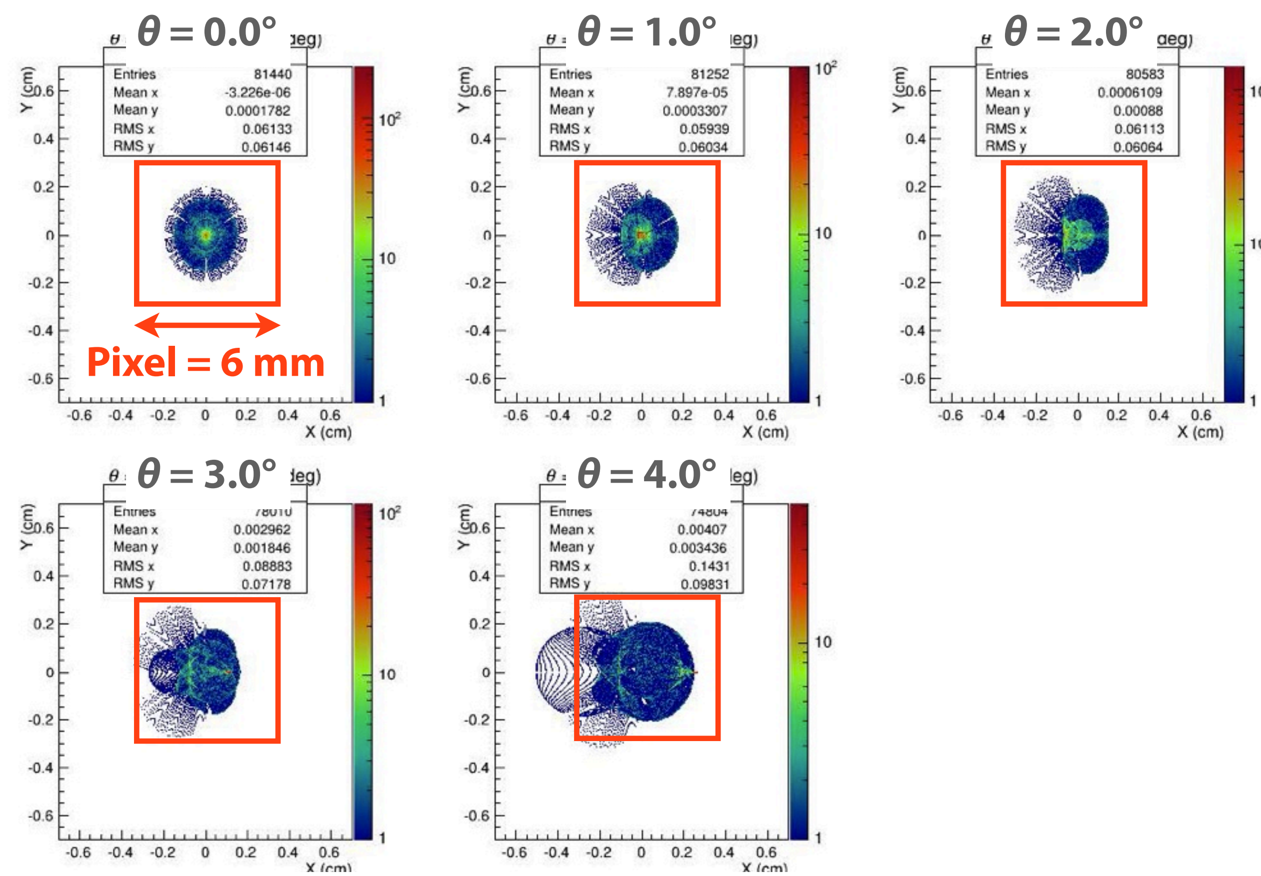
From Hamamatsu Catalog

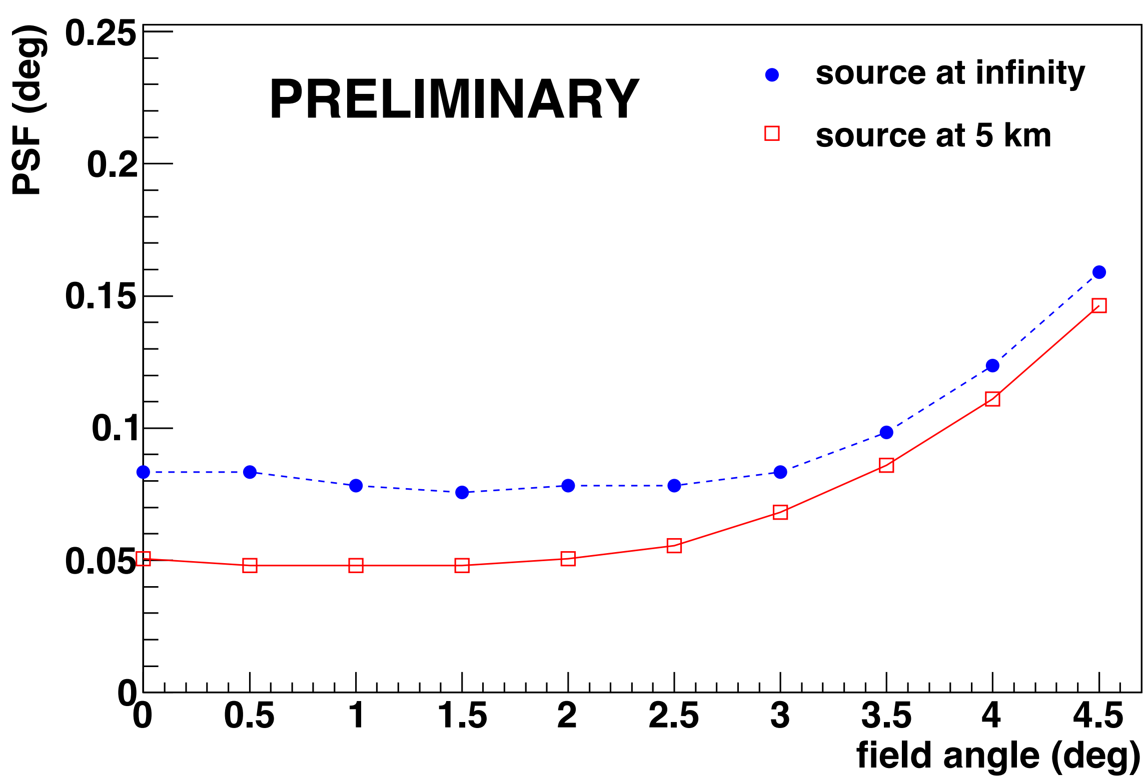
- 11,328 channels (× 4 SiPMs)
- Signal digitization is done by very compact and low power consumption camera modules (w/ TARGET ASICs)
- The camera center will be used for optics alignment and calibration

The SST-GATE Optical System

Simulation with ROBAST by Cameron Rulten (Obs. Paris)

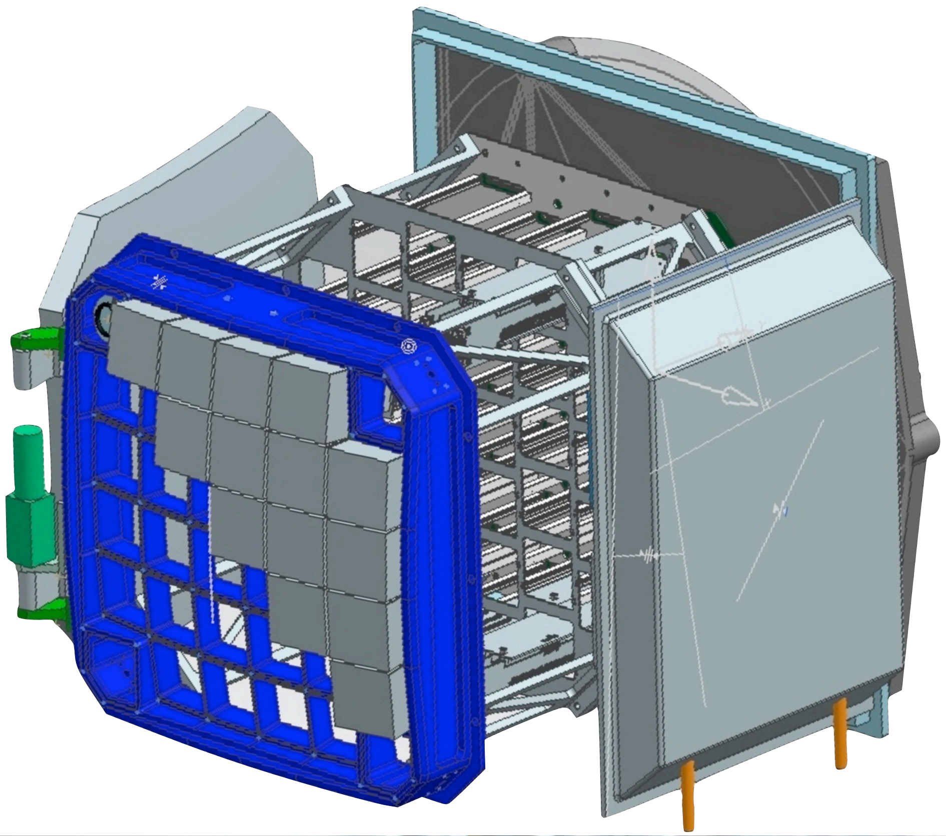


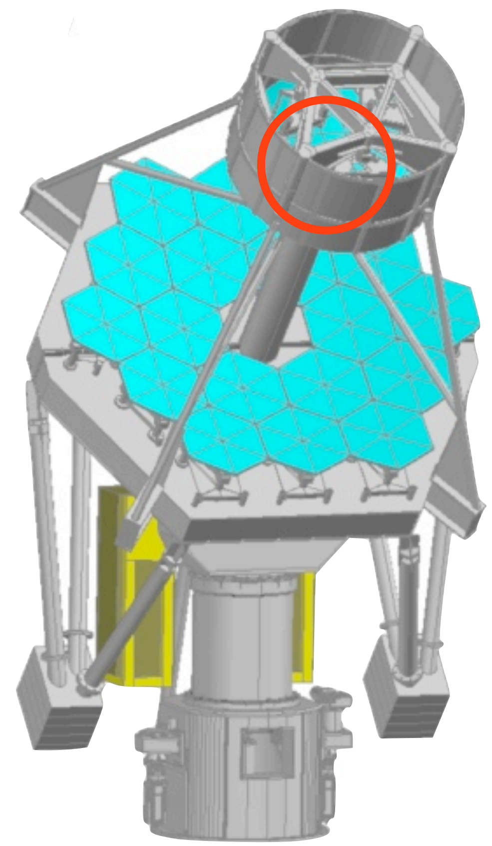


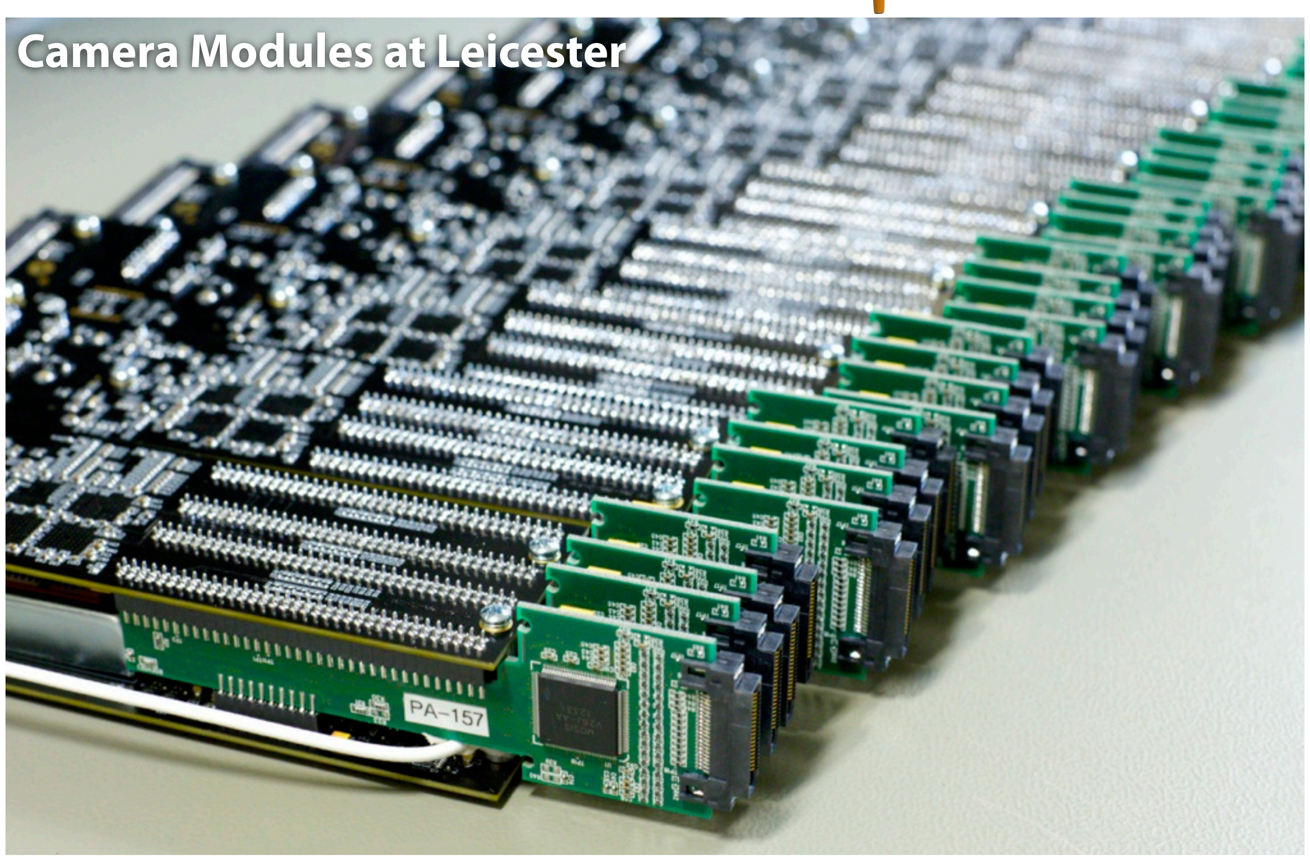


- One of three telescope designs, based on the Schwarzschild-Couder optical system
- 6 segmented primary mirrors, and a monolithic secondary
- ~0.05 – 0.15° over the FOV

Compact High-Energy Camera (CHEC) for SST

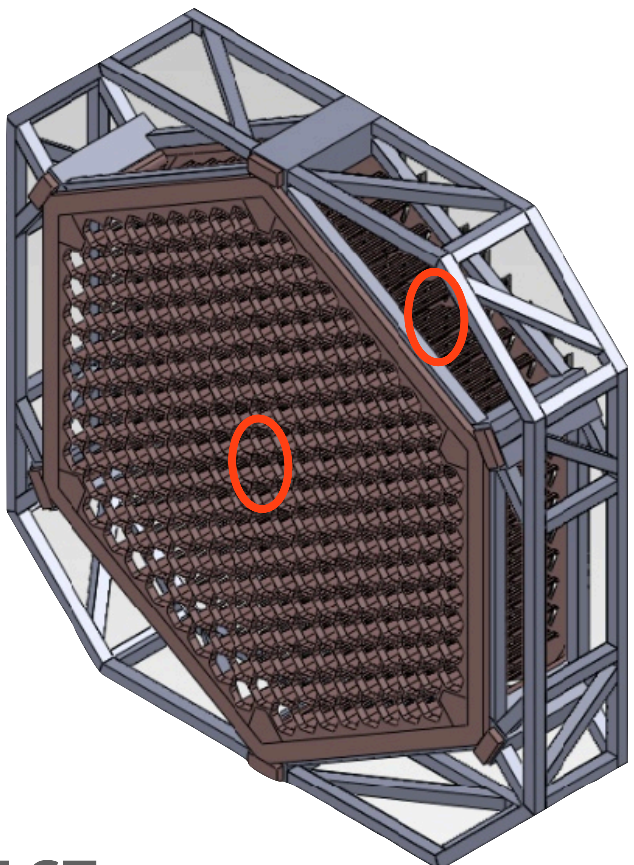




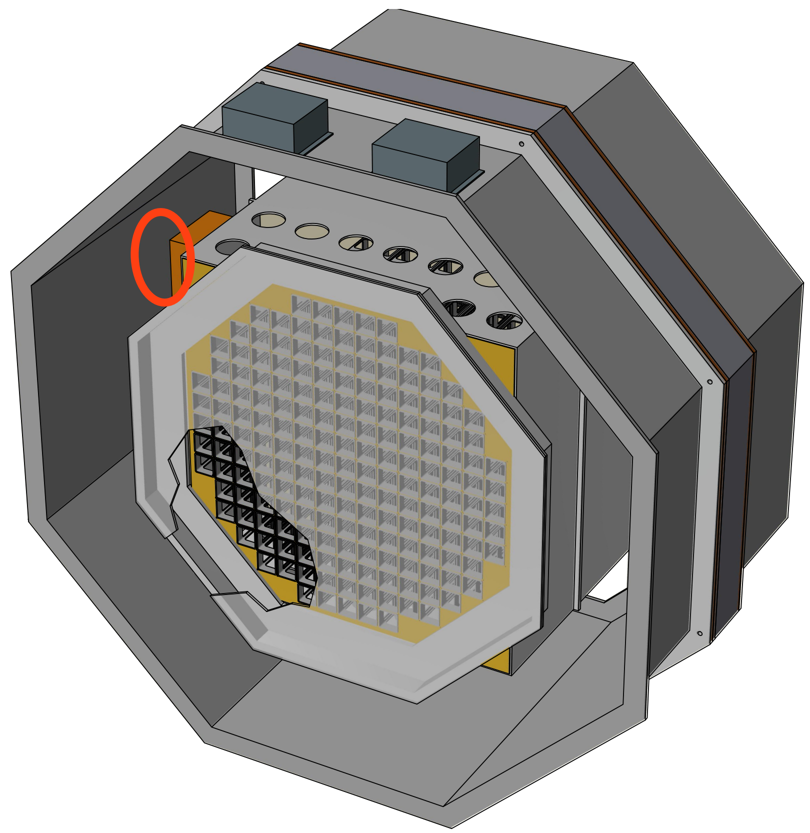


- Compatible with both the SST-GATE and ASTRI optical systems
- Sharing the common technologies with the SCT camera
- 2,048 channels (× 4 SiPMs)
- Again, it is difficult to put a dedicated detector for HBT interferometry

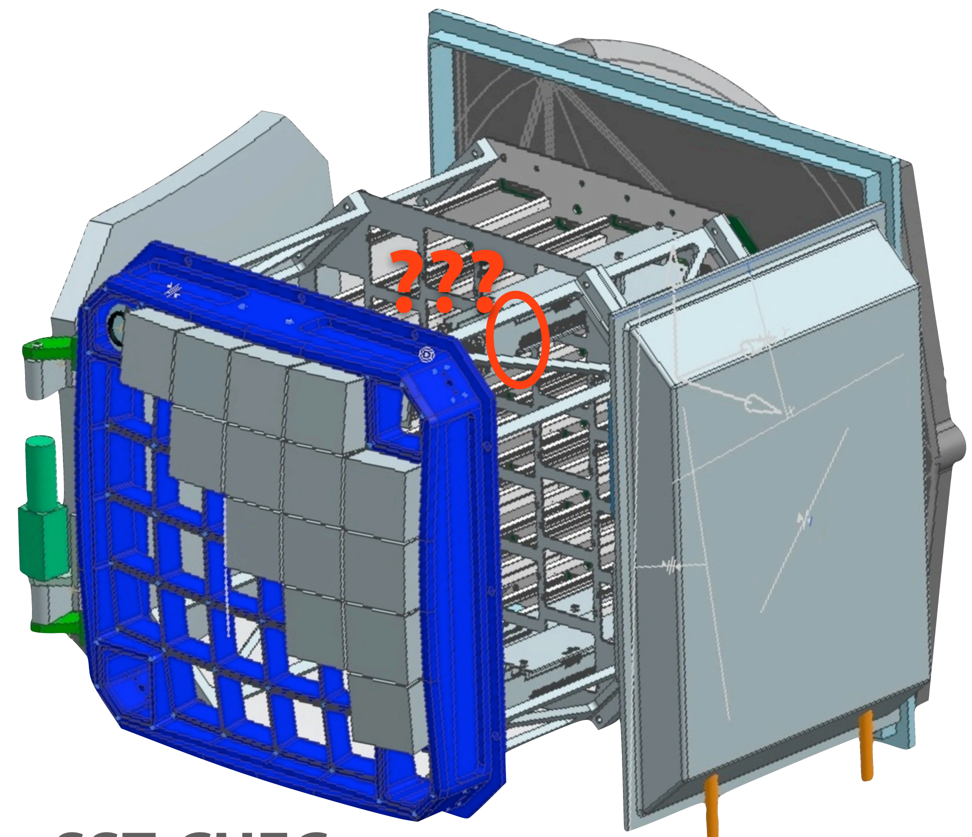
Where to Put Photodetectors for Interferometry?



LST



SCT



SST-CHEC

- LSTs and MSTs could have a dedicated photodetector at the centers of the cameras (but negotiations and feasibility study will be needed)
- SCT and CHEC cannot, because an individual camera module has 64 channels
- LST/MST/SCT have outskirts in the camera boxes, but the PSF is not excellent
- The photon incident angle distribution at the focal plane is 0 to ~25 deg for LST, ~30 to ~60 deg for SCT and SST

Summary

- Different designs of optical systems and cameras are being developed in CTA
  - LST (parabolic), MST (Davies-Cotton), SCT (Schwarzschild-Couder), SST (DC or SC)
  - Two and three cameras for MST and SST, respectively
- They are all sensitive to UV (300 - 500 nm)
- Typical PSF (D_{80}) is ~0.05 – 0.1° (on-axis)
- The default camera systems are of course designed only for gamma-ray astronomy
- Need feedback and requests for the CTA camera teams
  - Willing to provide you the specifications and parameters of CTA
  - It is not easy to replace a camera pixel with a dedicated detector after installation
  - We are finalizing camera designs!