# **Building the SSTs of** CTAO & the Dutch role R. White (MPIK) CTA-KM3NeT Community Day 8 September 2025





























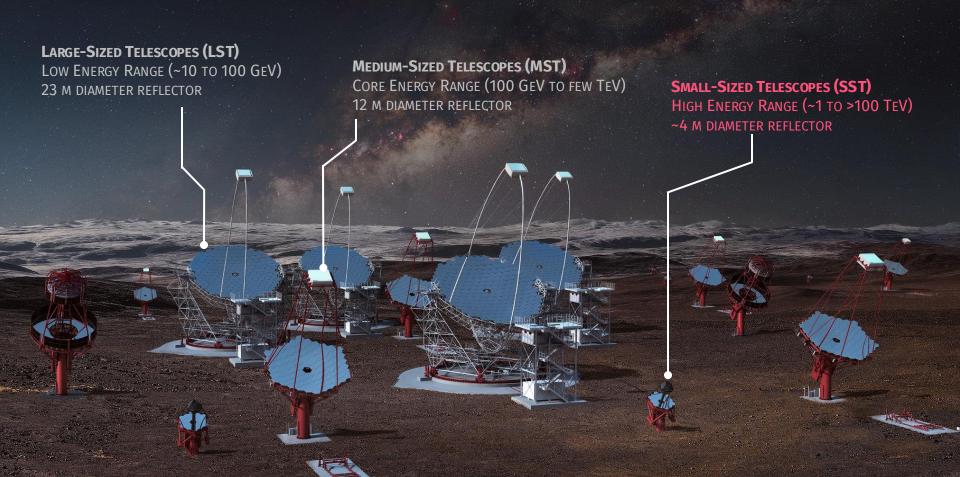












#### **Motivation**



#### Why do we need SSTs?

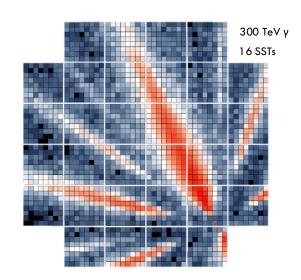
- High energy showers are rare, implying large area coverage needed
- Angular resolution & background rejection improve as more telescopes record the same shower, implying large field of view / close spacing

The (12m) MSTs are too expensive to cover the required area (& can not be spaced further apart due to limited field of view)

→ We need a dedicated telescope design for the highest energies

#### SST Design Drivers

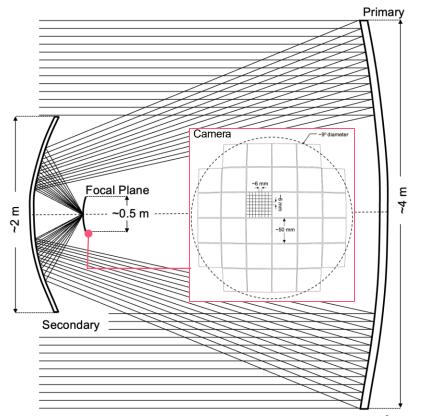
- Sensitivity → Large Area → Many telescopes → Low cost structure
- High Energies → Bright showers → We don't need MST reflector size
- Ang. Resolution / background rejection → Large impact distances
  - → Wide field of view → many pixels → low cost individual pixels
  - → Large time gradients → digitisation in wide window

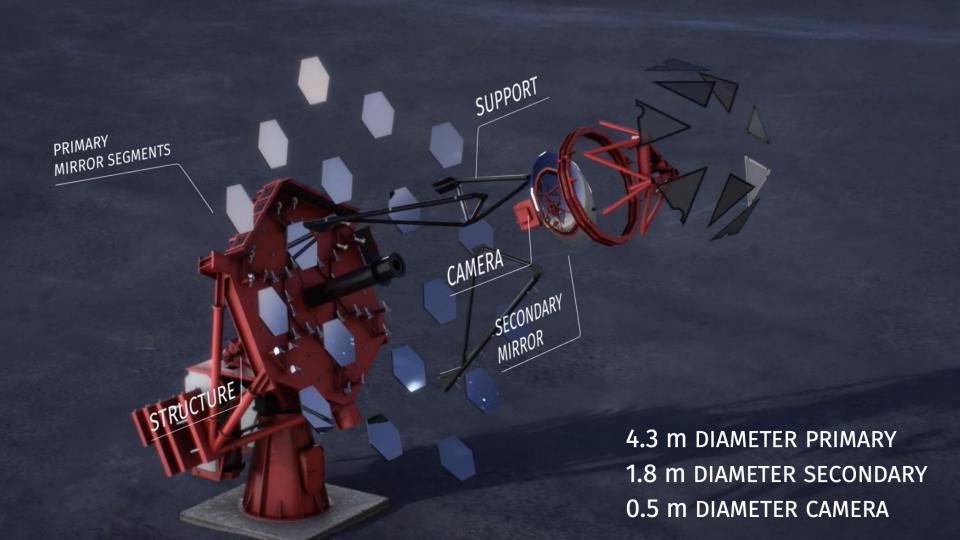


#### **SST Concept**



- A dual-mirror design was chosen for the SST
- Advantages
  - Reduces off-axis aberrations
    - 9º FoV becomes feasible
  - Reduces the plate scale:
    - Cheaper photosensors
    - The camera becomes 0.5 m across
- Challenges
  - Complex mirror shapes
  - Curved focal plane
  - Sensitive to misalignment
  - Readout channel density

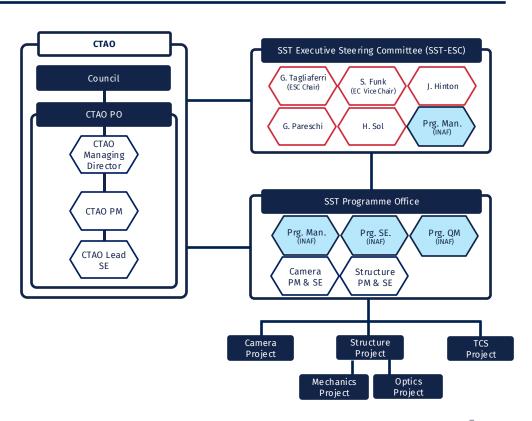




#### The SST Programme



- Established to provide SSTs as an In-Kind Contribution to CTAO
  - 37 42 SSTs
  - Software
  - Documentation
- Overseen by the SST ESC
  - PI / Chair: G. Tagliaferri (INAF)
- Executed by the SST Programme Office
  - Prg. Manager: A. Troi (INAF)
- Contains projects for
  - Structure (INAF + CNRS)
  - Telescope Control Software (INAF)
  - Camera (see next slide)

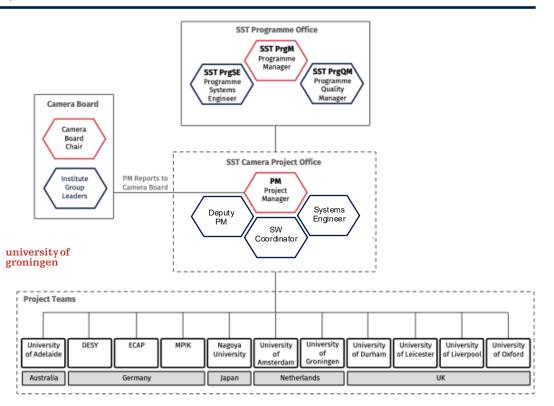


#### **The SST Camera Project**

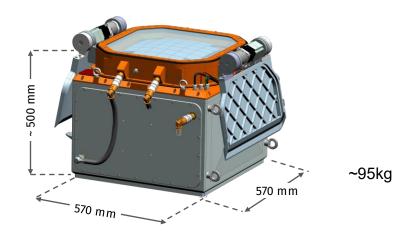


- Camera Board
  - Institute representatives
  - NL:
    - UvA (J. Vink)
    - Groningen (A. Baryshev)
- Camera Project Office
  - Project Manager:
    - R. White (MPIK)
  - Deputy Project Manager:
    - C. Duffy (Groningen)
  - Systems Engineer:
    - G. Giavitto (DESY)
  - Software Coordinator:
    - V. Voitsekhovskyi (UvA)

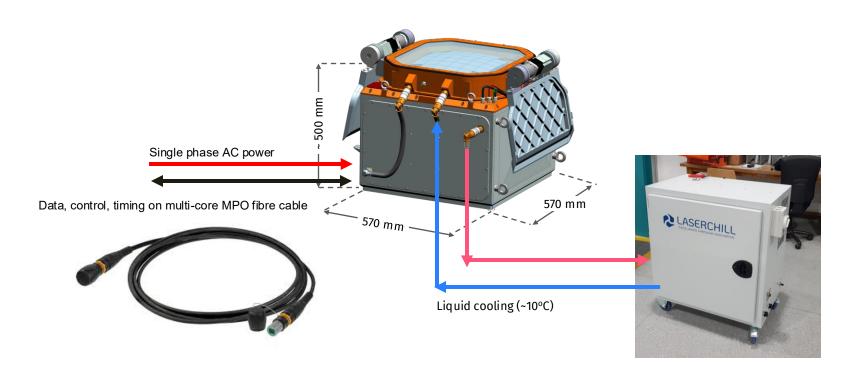




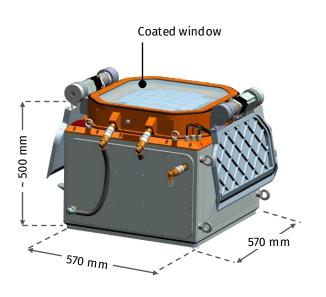






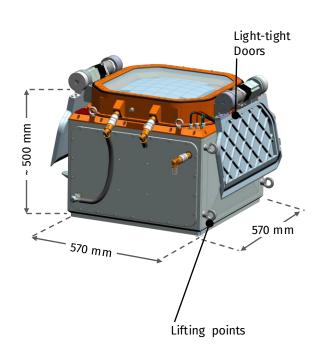


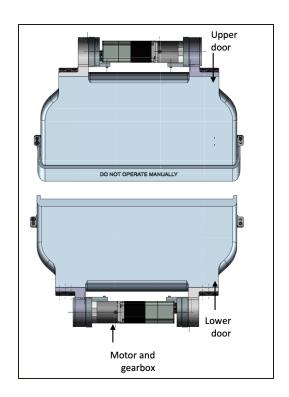




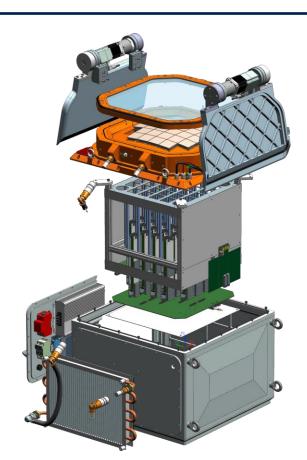




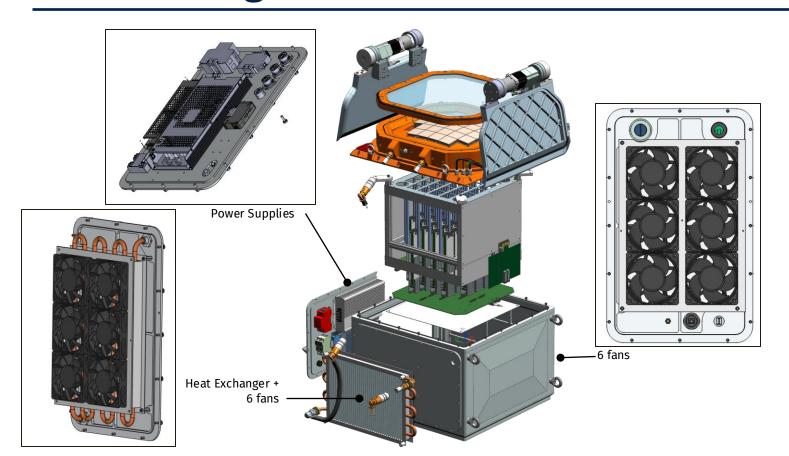




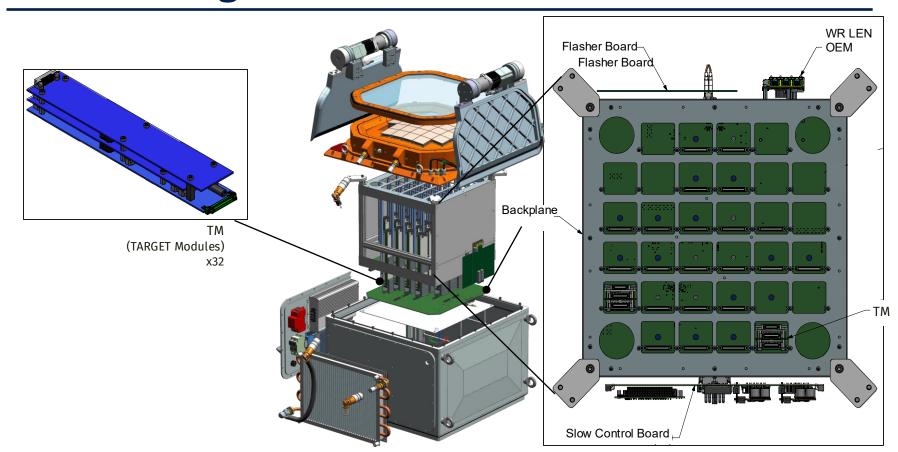




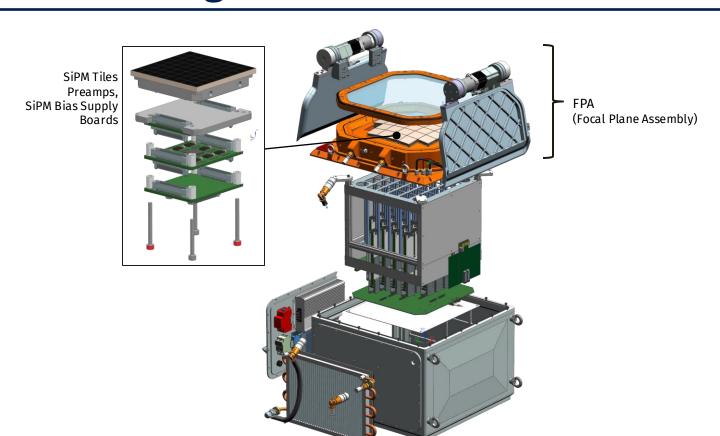




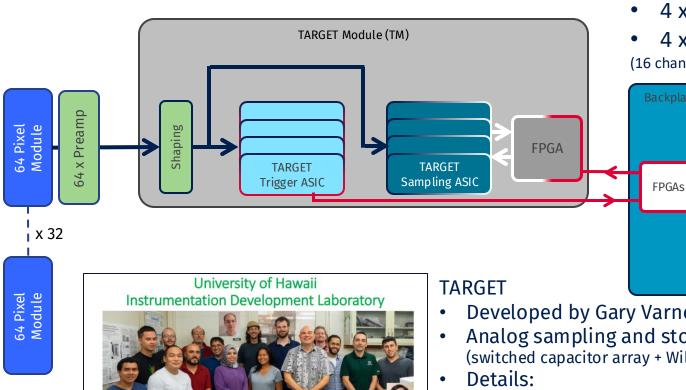








#### **Principle of Operation**



#### Each TM contains:

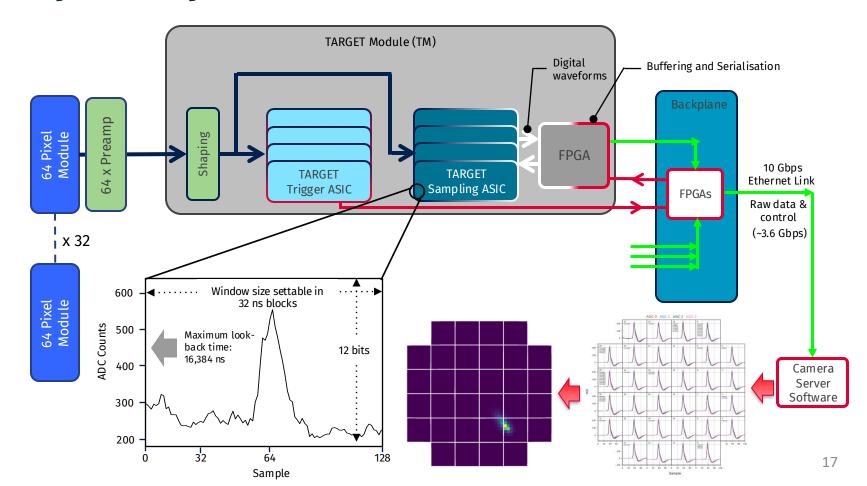
- 4 x Trigger ASIC
- 4 x Sampling ASIC

(16 channels per ASIC)

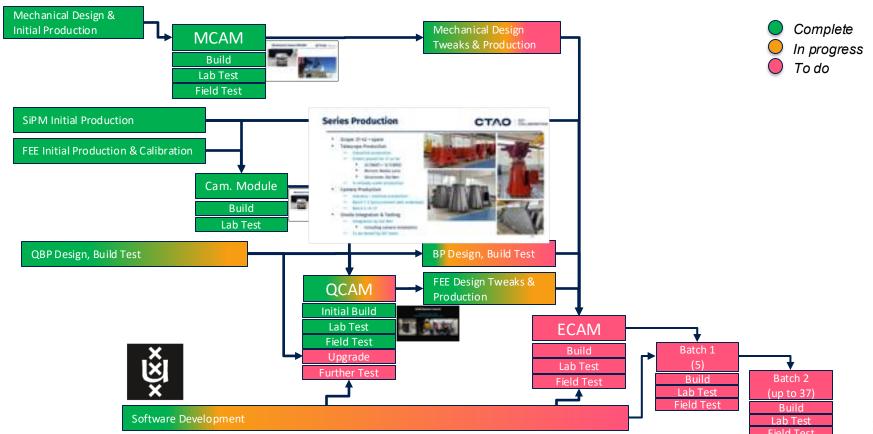
Developed by Gary Varner (U. Hawaii)

- Analog sampling and storage (switched capacitor array + Wilkinson ADC)
  - https://arxiv.org/abs/1607.02443
  - https://arxiv.org/abs/1610.015

#### **Principle of Operation - Readout**



## **Camera Development Path**



## **Mechanical Camera (MCAM)**



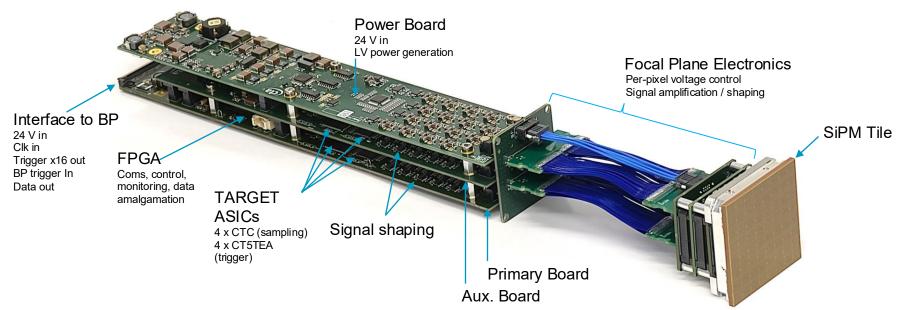




#### **Camera Module**



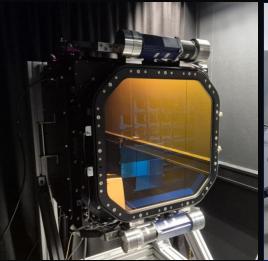
- Camera Module = SiPM tile + Focal Plane Electronics + TARGET Module
- 64 channels of triggering & digitisation

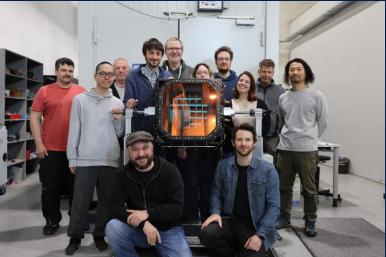


## **QCAM (Quarter Camera)**

Full mechanics, power, cooling 1/4 SiPMs, FEE (i.e. 8 modules, 512 pixels, ~4° FoV)









Tenerife, July 2025, ASTRI Mini Array
 https://www.oact.inaf.it/en/project/astri-mini-array-en/



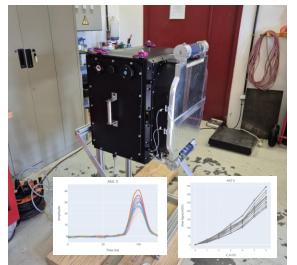






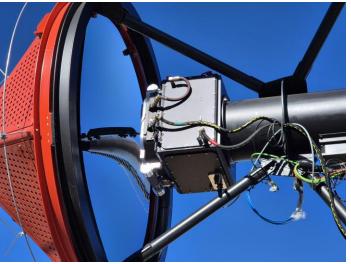


- July 21st
  - Camera arrival, unpack, workshop tests
- July 22<sup>nd</sup>
  - Camera installation, turn on tests



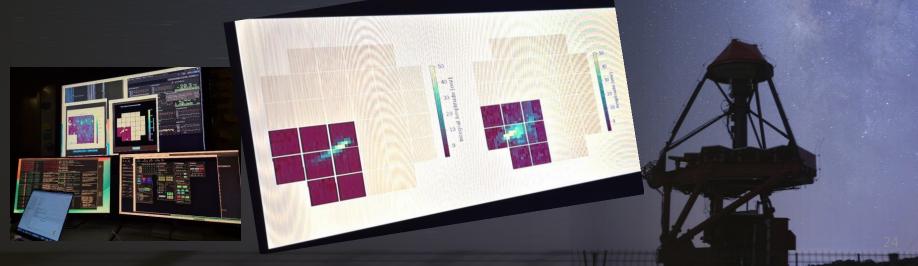




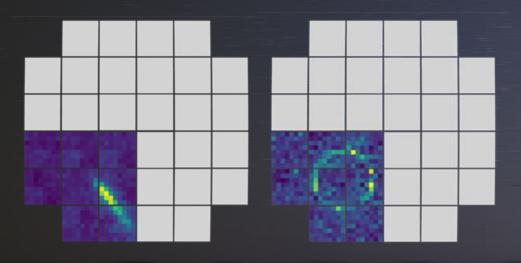


- July 21st
  - Camera arrival, unpack, workshop tests
    July 22<sup>nd</sup>
    - Camera installation, turn on tests
    - First light



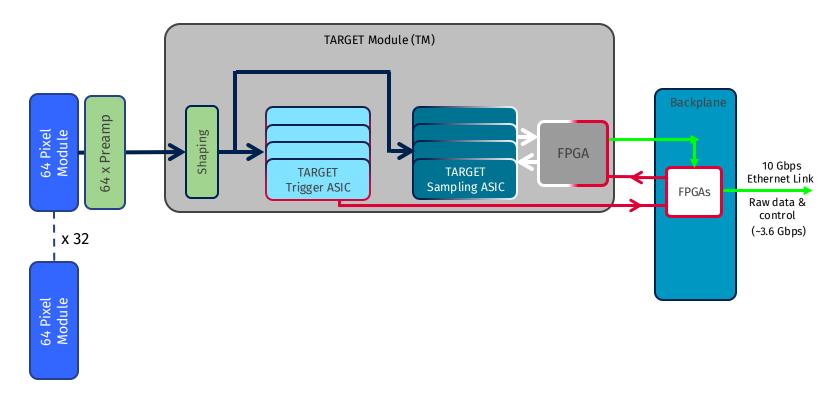


- July 21st
- Camera arrival, unpack, workshop tests
  July 22<sup>nd</sup>
  - Camera installation, turn on tests
  - First light

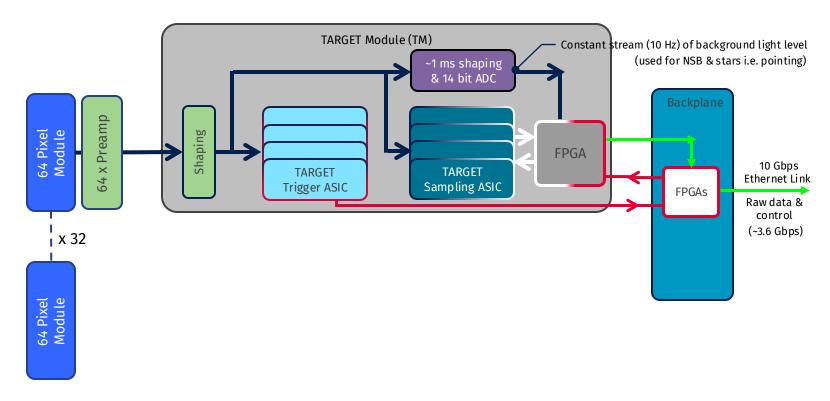




### **Principle of Operation**



### **Principle of Operation - Slow Signal**



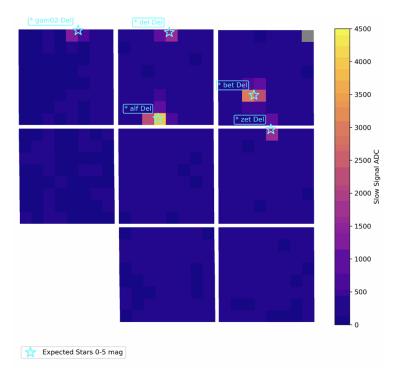


- Pointing reconstruction
  - Use slow signal to estimate star positions
  - Combine with motor encoders & telescope Tpointing model to improve pointing precision
  - Dutch responsibility
    - UvA (Vadym)









20

#### **Series Production**



- Scope: 37-42 + spare
- Telescope Production
  - Industrial production
  - Orders placed for 37 so far
    - 25 (INAF) + 12 (CNRS)
    - Mirrors: Media Lario
    - Structures: Dal Ben
  - 14 already under production
- Camera Production
  - Industry + institute production
  - Batch 1: 5 (procurement well underway)
  - Batch 2: 32-37
- Onsite Integration & Testing
  - Integration by Dal Ben
    - Including camera installation
  - To be tested by SST team

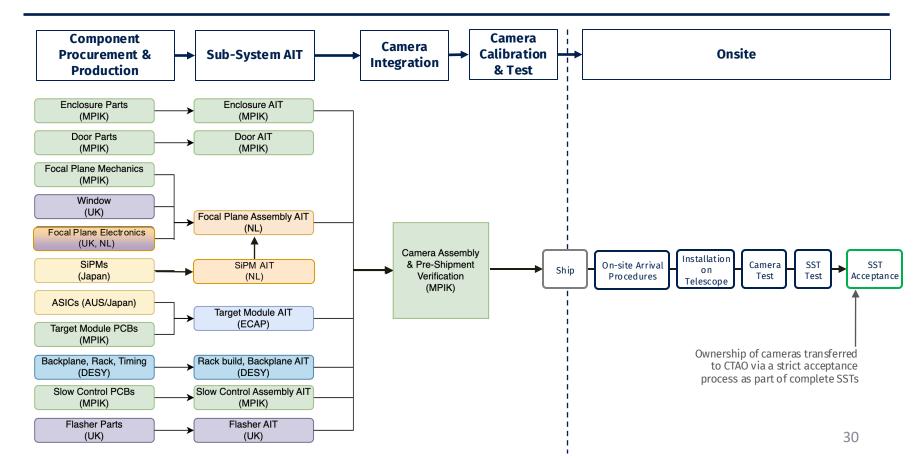








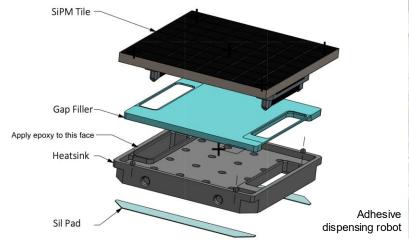
#### **Camera Production Scheme**

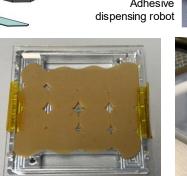


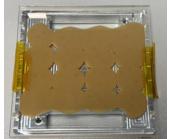


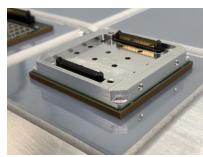


- **Assembly** 
  - SiPMs (Japan)
  - Heatsinks (industry)
- Integration
  - Add heatsinks
  - Glue robot required (SiPMs uncoated)
- Test
  - Uniform illumination

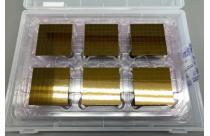












SIPM tiles (w. protective Kapton tape)



Peanut butter practice

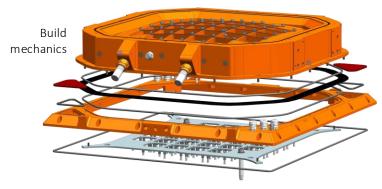
SiPM tile with heatsink mounted

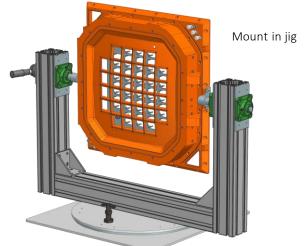
#### Focal Plane AIT 🧱 /





- Assembly
  - SiPMs (in-hand from previous step)
  - Electronics (UK/NL TBD)
  - Mechanics (MPIK)
  - Window (UK)
- Integration
  - Prepare mechanics





#### Focal Plane AIT 🐉



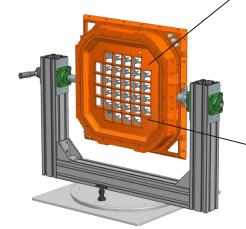


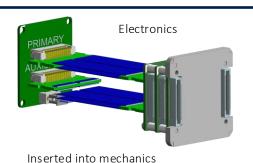


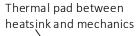
- SiPMs (in-hand from previous step)
- Electronics (UK/NL TBD)
- Mechanics (MPIK)
- Window (UK)

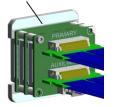


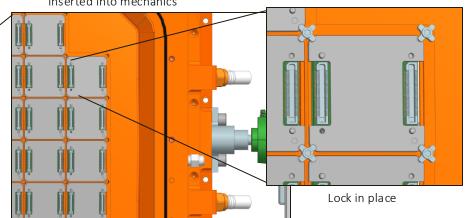
- Prepare mechanics
- Add electronics









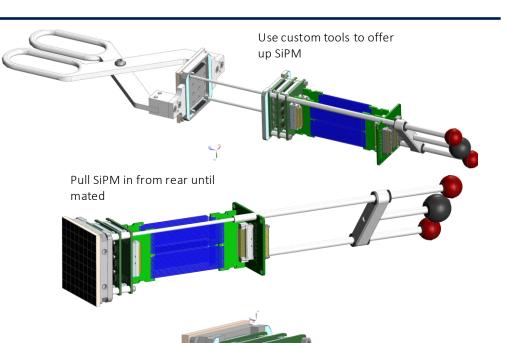


#### Focal Plane AIT 🐉





- Assembly
  - SiPMs (in-hand from previous step)
  - Electronics (UK/NL TBD)
  - Mechanics (MPIK)
  - Window (UK)
- Integration
  - Prepare mechanics
  - Add electronics
  - Add SiPMs
  - Remove Kapton tape





#### Focal Plane AIT 🧱 /

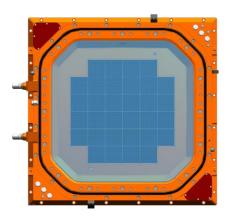


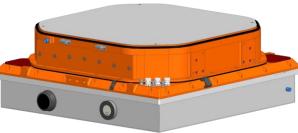


#### Assembly

- SiPMs (in-hand from previous step)
- Electronics (UK/NL TBD)
- Mechanics (MPIK)
- Window (UK)
- Integration
  - Prepare mechanics
  - Add electronics
  - Add SiPMs
  - Remove Kapton tape
- Test
  - I vs V curves
  - Pulsed illumination
  - Seal front & rear surfaces prior to transport to MPIK



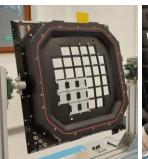




### **QCAM Focal Plane Build**

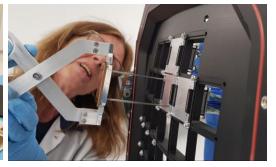


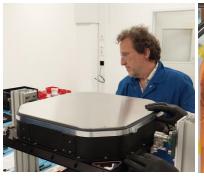




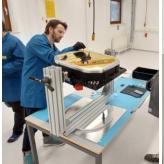


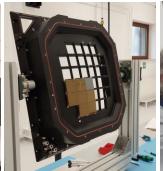














#### **Camera Integration**



- Cameras assembled from sub-systems at MPIK
  - Dedicated camera assembly room, electronics room and control room
  - Large storage area (with inventory control system)







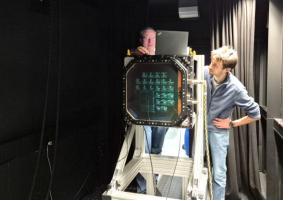
#### **Camera Calibration & Test**



- Setup
  - Darkbox (customised shipping container)
  - Pulsed laser
    - + filter wheel (up to 10<sup>4</sup> attenuation)
    - + diffuser
    - → 1% RMS uniformity at camera position
  - DC LED (NSB)
- Calibration
  - Gain matching university of groningen
  - Timing corrections
  - ++
- Tests
  - Functionality
  - SPE response
  - Charge resolution
  - Time resolution
  - ++++







#### **Summary**



- CTAO is certain now
- SST production is a major challenge, but also a major In Kind Contribution
  - Contributors will secure data rights for their countries
- Deployment in Chile begins in 2026
  - SST structure & optics production is well underway
  - SST camera engineering camera and batch 1 production is on track



#### **Summary**



- CTAO is certain now
- SST production is a major challenge, but also a major In Kind Contribution
  - Contributors will secure data rights for their countries
- Deployment in Chile begins in 2026
  - SST structure & optics production is well underway
  - SST camera engineering camera and batch 1 production is on track
- There is a major Dutch Role in the SST Cameras
  - Leadership
    - Deputy PM
    - Software Coordination
  - Development
    - Software development
    - Pointing reconstruction
  - Series Production
    - SiPM and FPA AIT
    - Calibration of cameras

