The Terzina Instrument onboard the NUSES satellite – An update

Roberto Aloisio

Gran Sasso Science Institute

INFN – Laboratori Nazionali del Gran Sasso

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

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The NUSES Collaboration

Italian led mission conceived as a **pathfinder** for **new observation methods and technologies** in the study of high and low energy radiations from space enabling new sensors and tools.

The NUSES mission is funded by the Italian government, the Italian space agency and INFN

60+ persons from different research institutions and industrial partners

Italian Institutes:

- Gran Sasso Science Institute
- Laboratori Nazionali del Gran Sasso
- University dell'Aquila
- Università di Torino and INFN Torino
- Università di Trento and INFN-TIFPA
- Università di Bari, INFN Bari
- Università di Padova and INFN Padova
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN Lecce

Other Institutes:

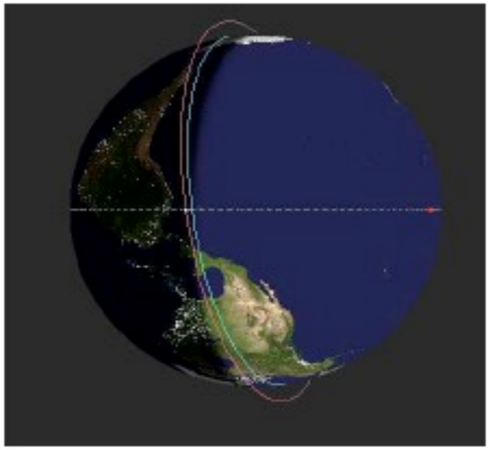
- University of Geneva
- Columbia University
- NASA Goddard Space Flight Center
- Pennsylvania State University

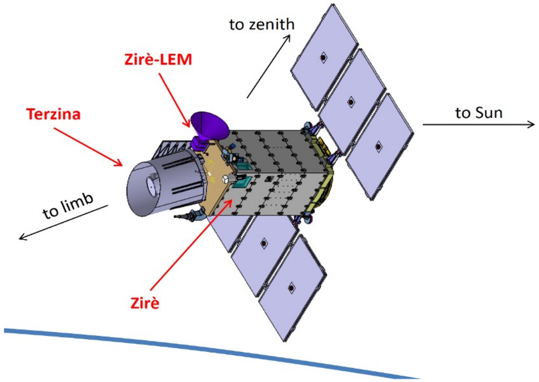
Industrial partners:

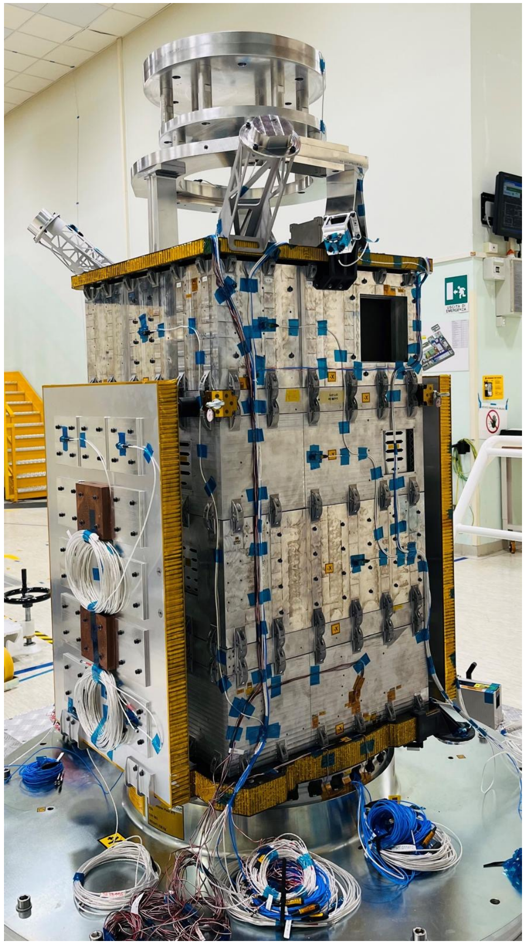
- Thales Alenia Space
- Fondazione Bruno Kessler
- Fondazione Gran Sasso Tech

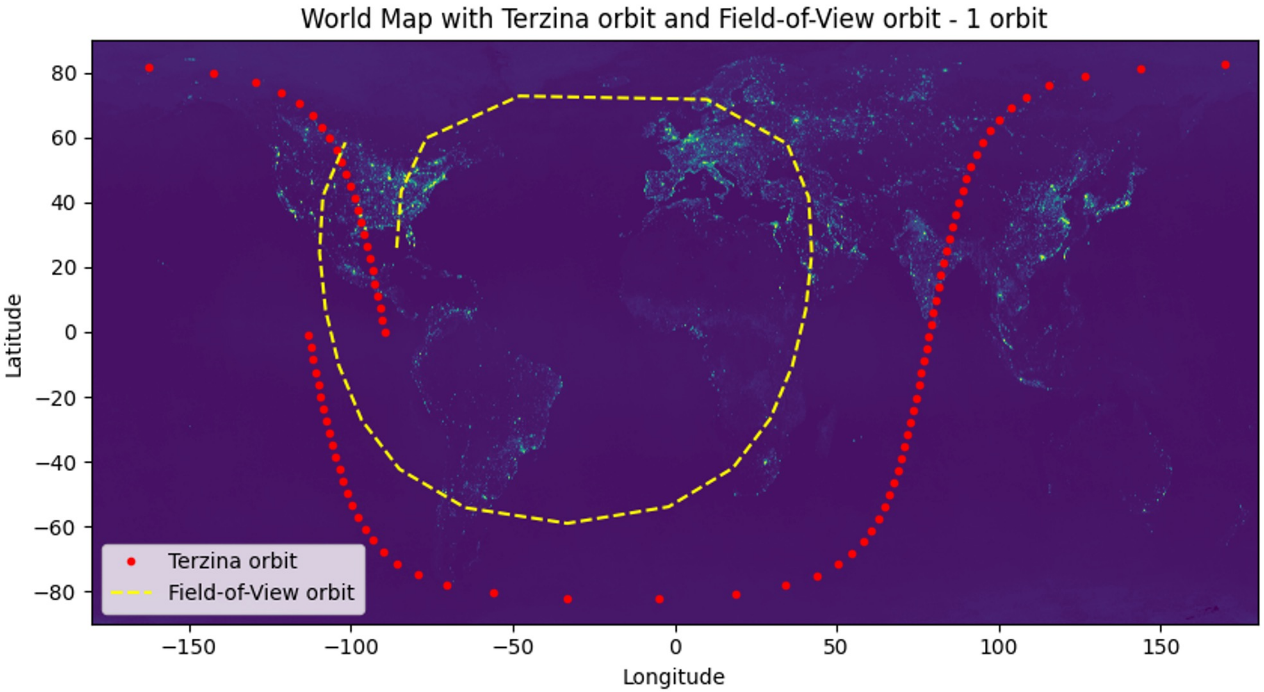
NUSES Satellite

- The NUSES satellite hosts two payloads: Terzina and Zirè.
- Low Earth Orbit (LEO) with high inclination, sun-synchronous orbit on the day-night border (BoL altitude 550 Km, LTAN = 18:00, inclination = 97.8°).
- Orbit optimized for Cherenkov photons detection.
- Ballistic mission (no orbital control).



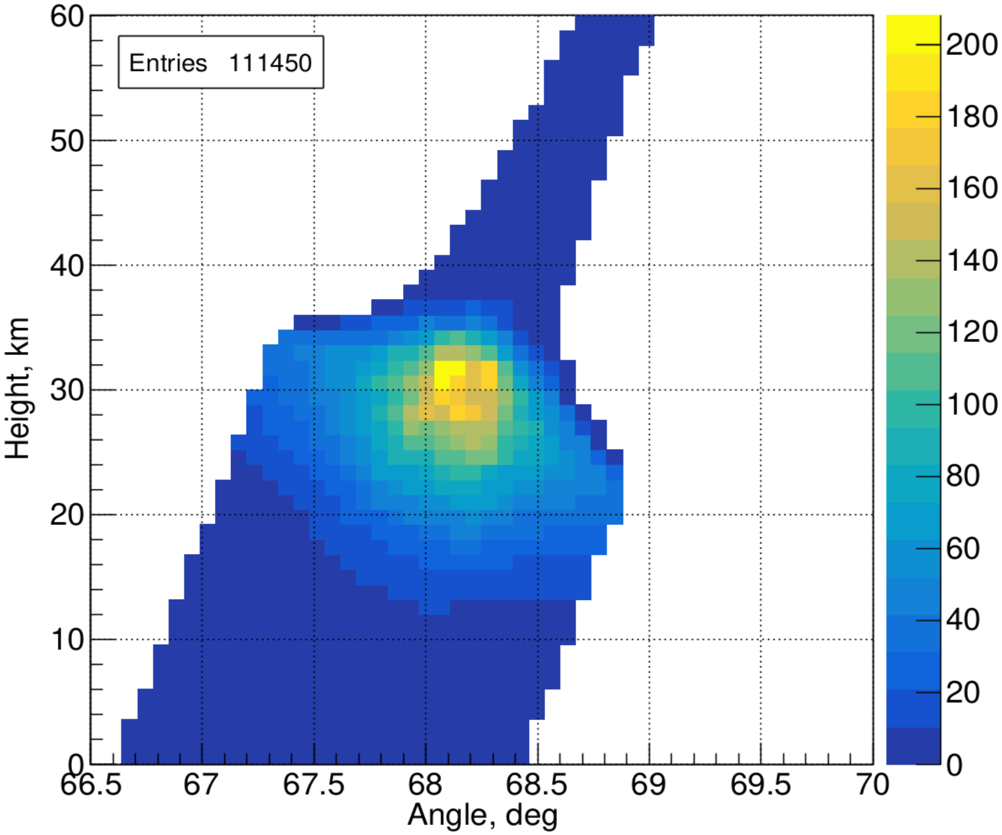




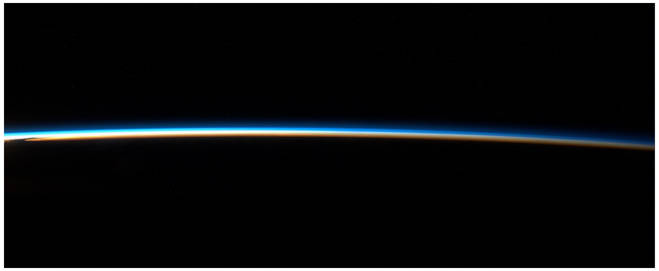


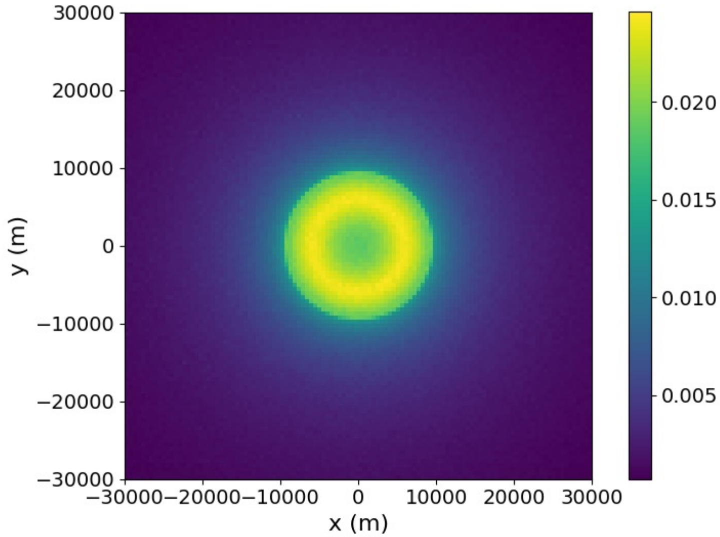
The EAS Cherenkov signal

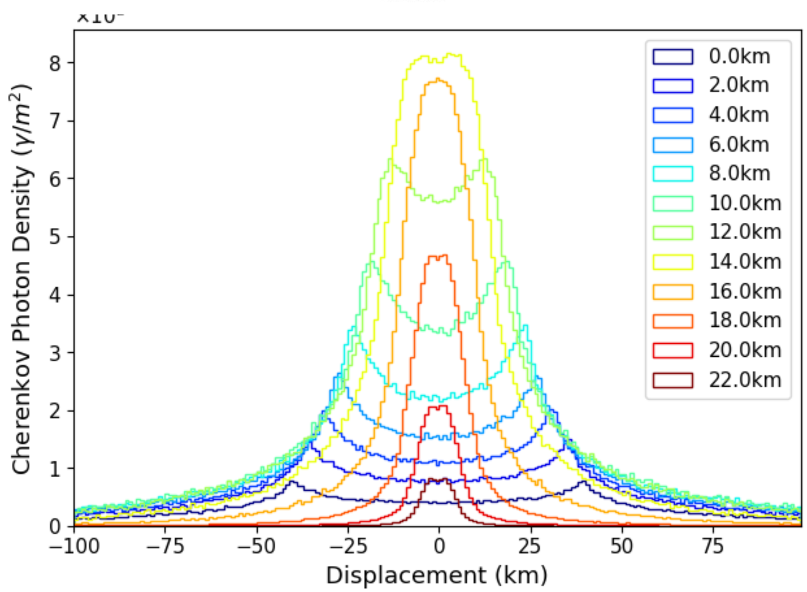
- ✓ Looking at the atmosphere limb (just below) for neutrinos detection and (just above) for CR, γ detection a tiny layer of the atmosphere shines in Cherenkov.
- ✓ Both orbital and high altitudes are suitable to detect the EAS Cherenkov emission.
- ✓ At orbits of ~ 500 km most contributing layers of the atmosphere around altitudes 20 – 40 km.



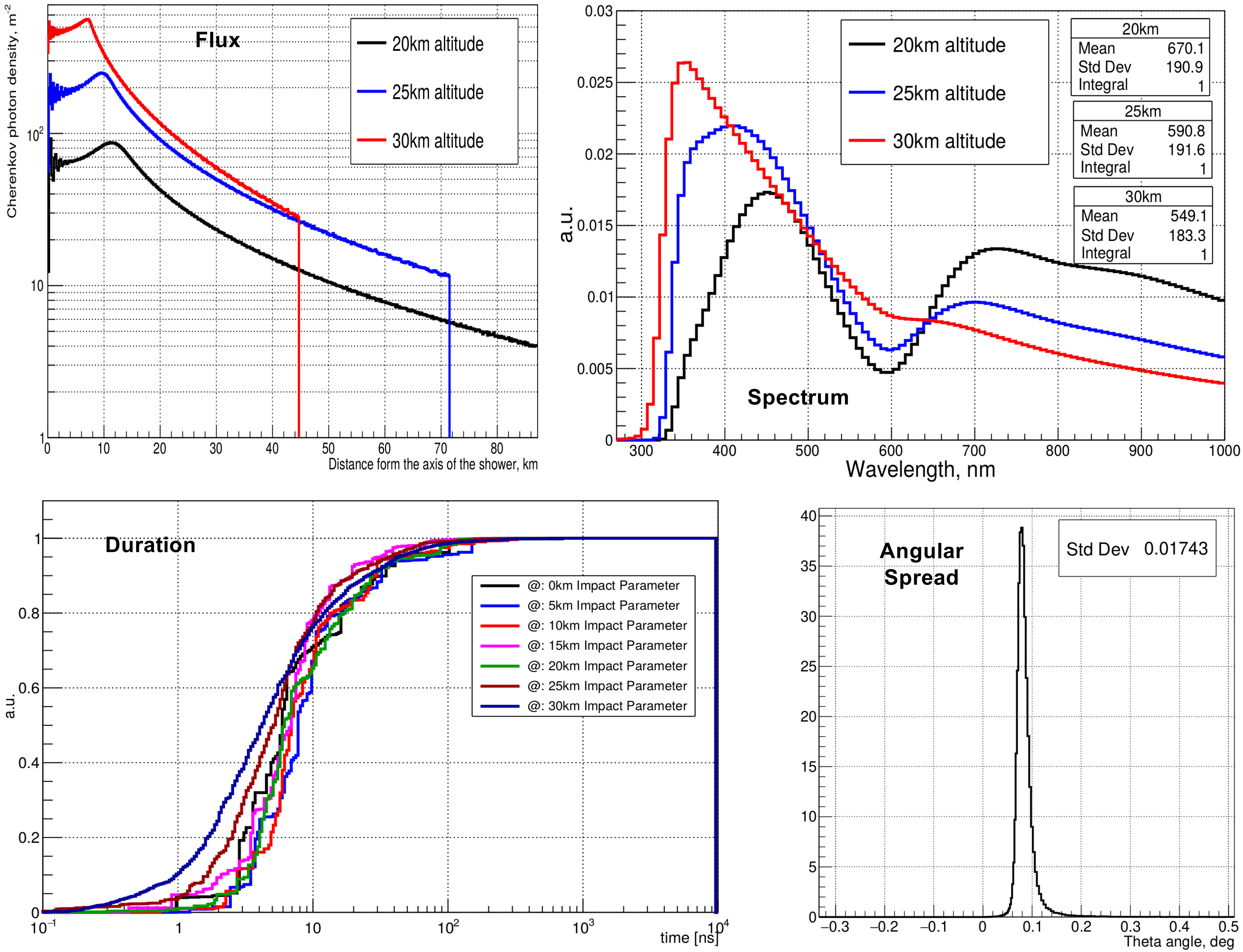
EAS-Cher-sim https://pypi.org/project/easchersim/1.1/







Cummings, RA, Krizmanik (2020)



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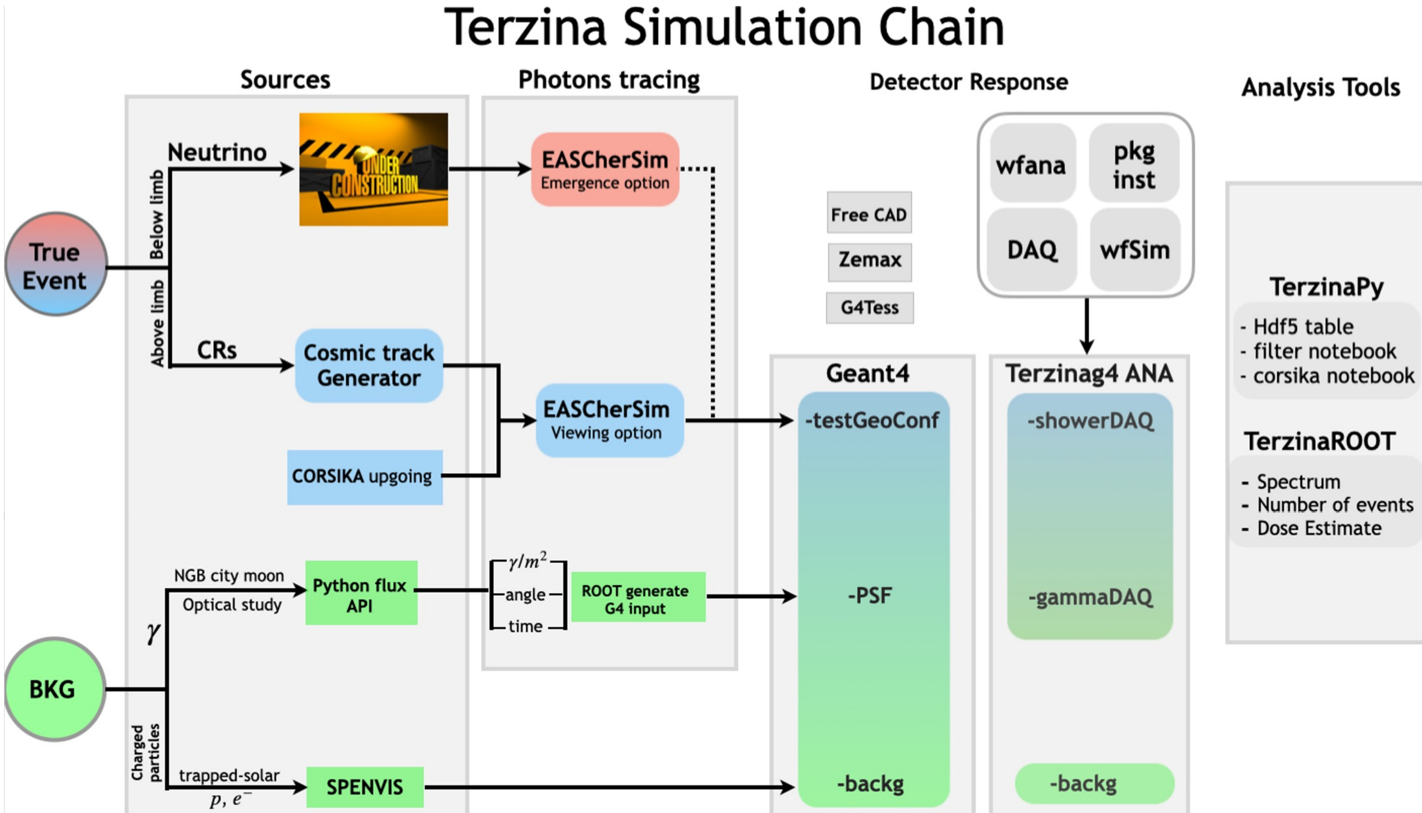
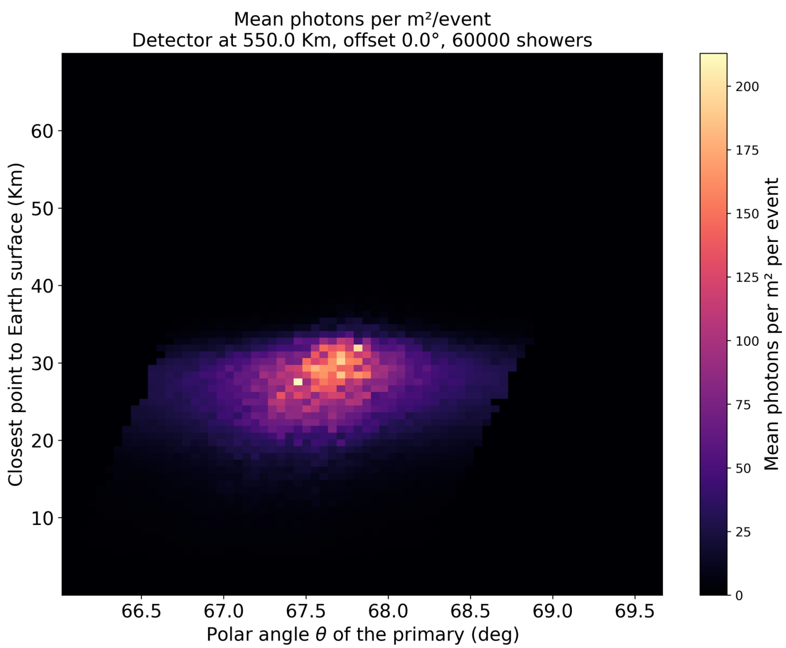
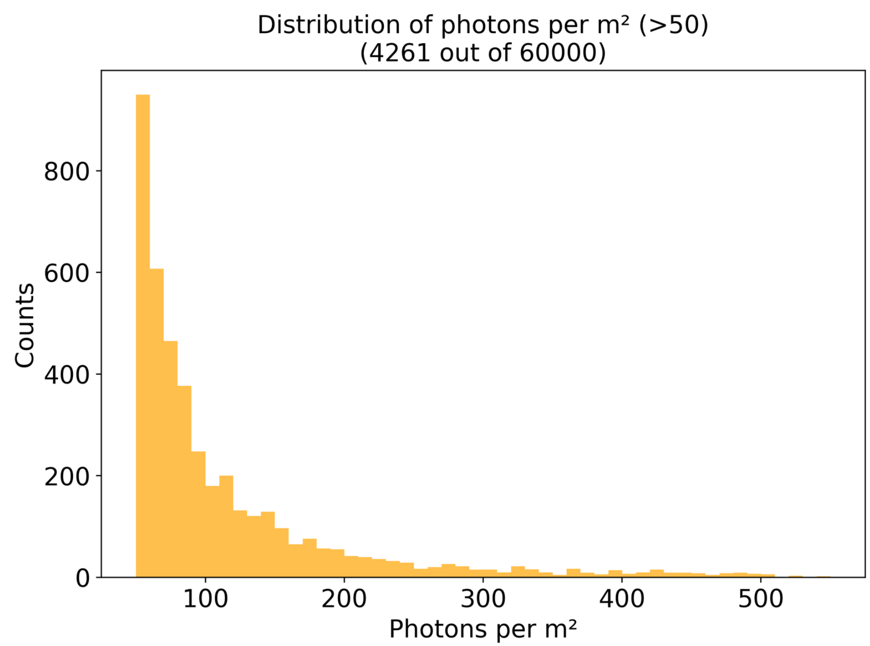


Terzina Simulation Chain
Sources
Photons tracing
Detector Response
Analysis Tools
True Event
Below limb
Above limb
Neutrino
UNDER CONSTRUCTION
EASCherSim
Emergence option
CRs
Cosmic track Generator
EASCherSim
Viewing option
CORSIKA upgoing
Free CAD
Zemax
G4Tess
wfana
pkg inst
DAQ
wfSim
Geant4
-testGeoConf
-PSF
-backg
Terzinag4 ANA
-showerDAQ
-gammaDAQ
-backg
TerzinaPy
- Hdf5 table
- filter notebook
- corsika notebook
TerzinaROOT
- Spectrum
- Number of events
- Dose Estimate
BKG
γ
NGB city moon
Optical study
Python flux API
γ/m^2
angle
time
ROOT generate G4 input
Charged particles
trapped-solar
p, e^-
SPENVIS



Mean photons per m^2/event
Detector at 550.0 Km, offset 0.0°, 60000 showers
Closest point to Earth surface (Km)
Polar angle θ of the primary (deg)
Mean photons per m^2 per event

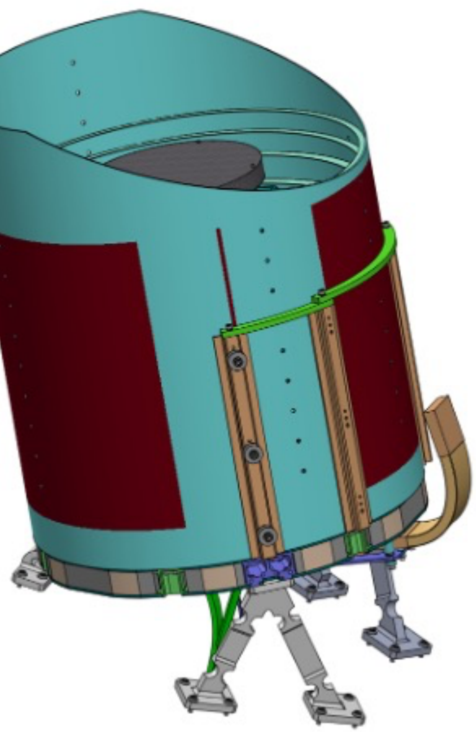


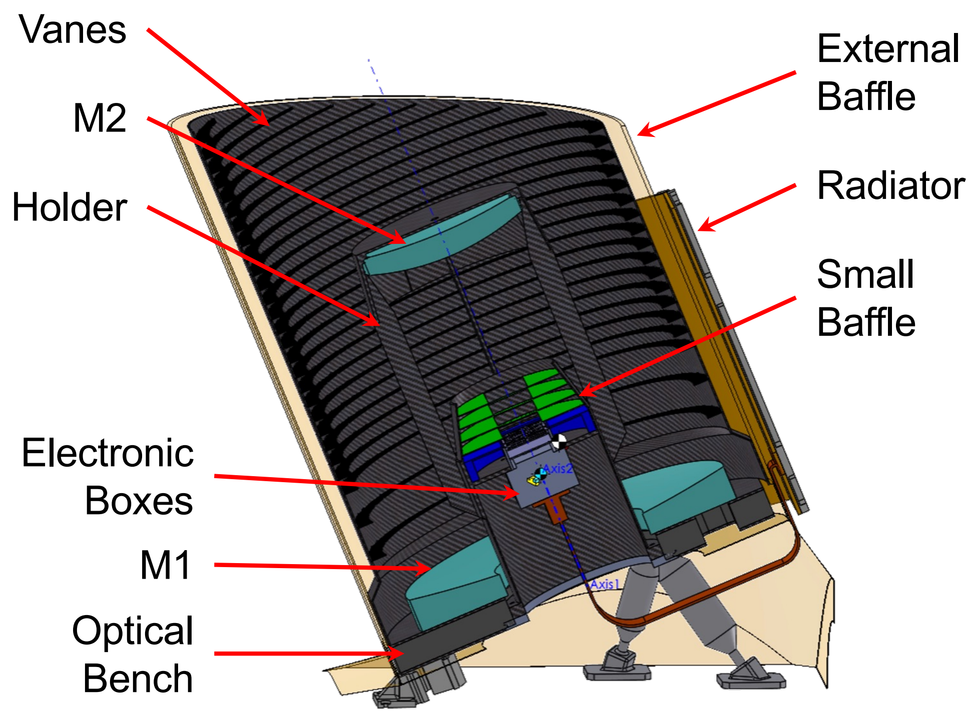
Distribution of photons per m^2 (>50)
(4261 out of 60000)
Counts
Photons per m^2

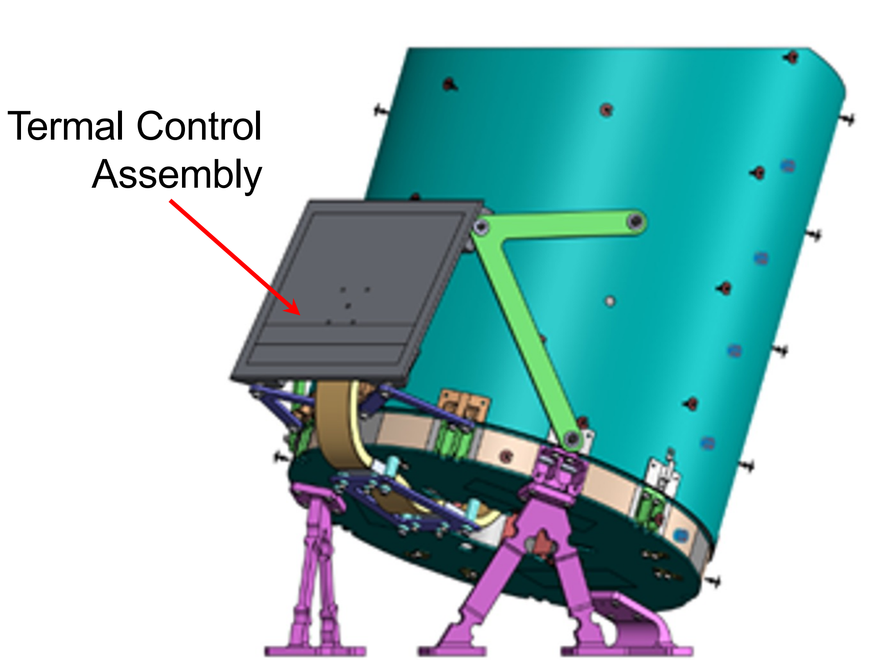
Terzina payload

A near-UV-optical telescope composed of:

1. the structural (mechanics) and thermal control (TC) assembly,
2. the optical head unit,
3. the focal plane assembly (FPA),
4. the front-end electronics (FEE) and data acquisition (DAQ) boards.

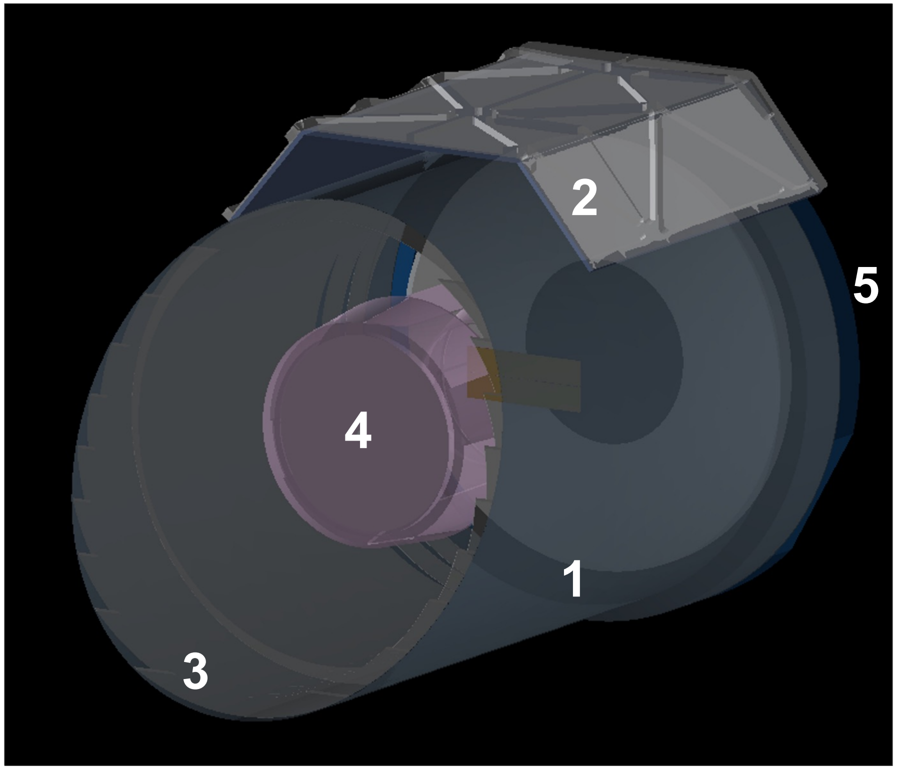


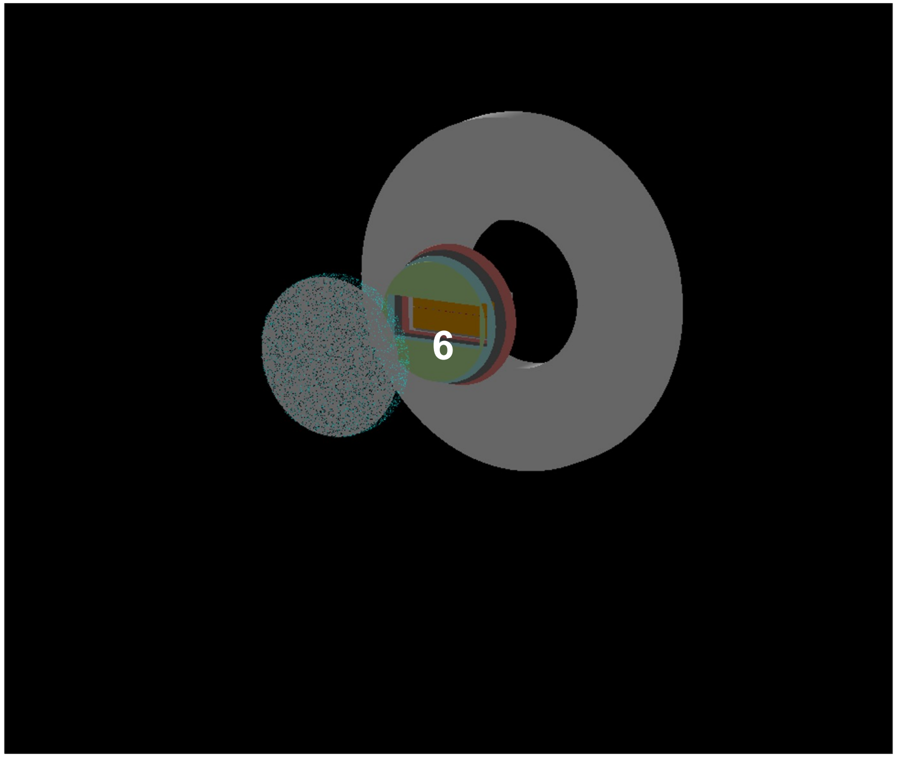


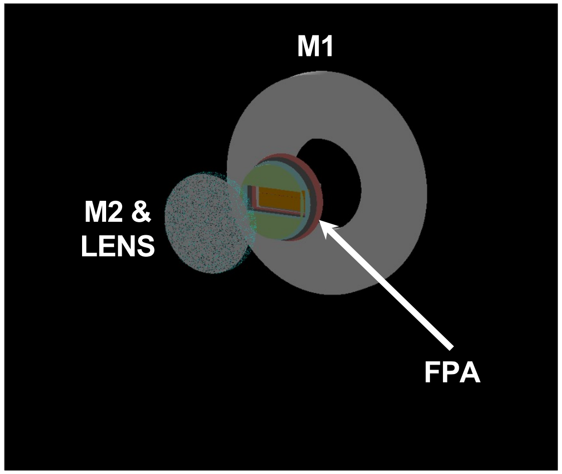


Baffles and radiators. For radiation shielding and thermal dispersion. Specifically:

1. enveloping baffle in carbon fiber.
2. radiators in aluminum.
3. vanes in carbon fiber.
4. holder in carbon fiber composed of:
   1. a small baffle (4 mm thick)
   2. a tower protecting second mirror
5. optical bench in aluminium
6. FPA vanes and covers in carbon fiber







Terzina total weight ~45 kg

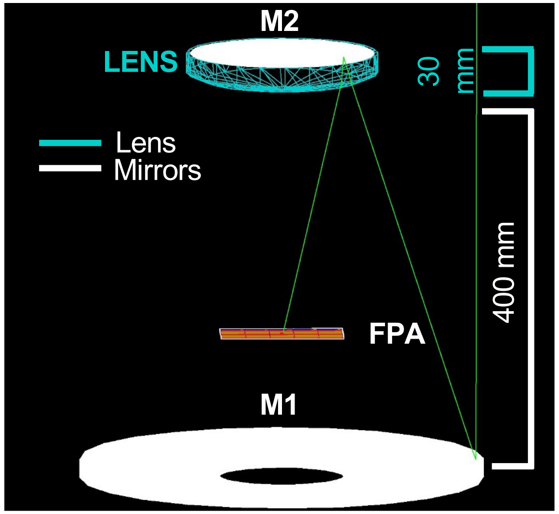
Terzina optical head unit

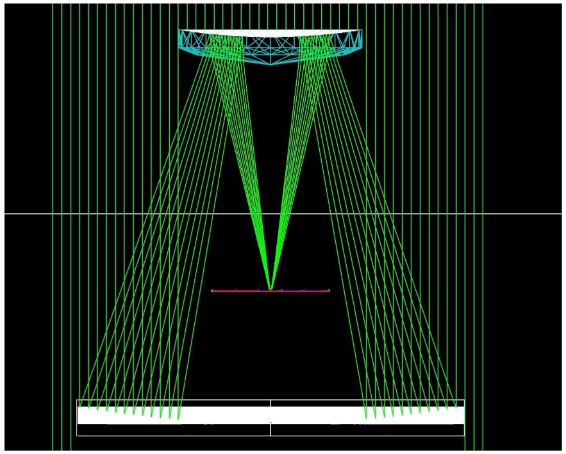
A near-UV-optical catadioptric telescope:

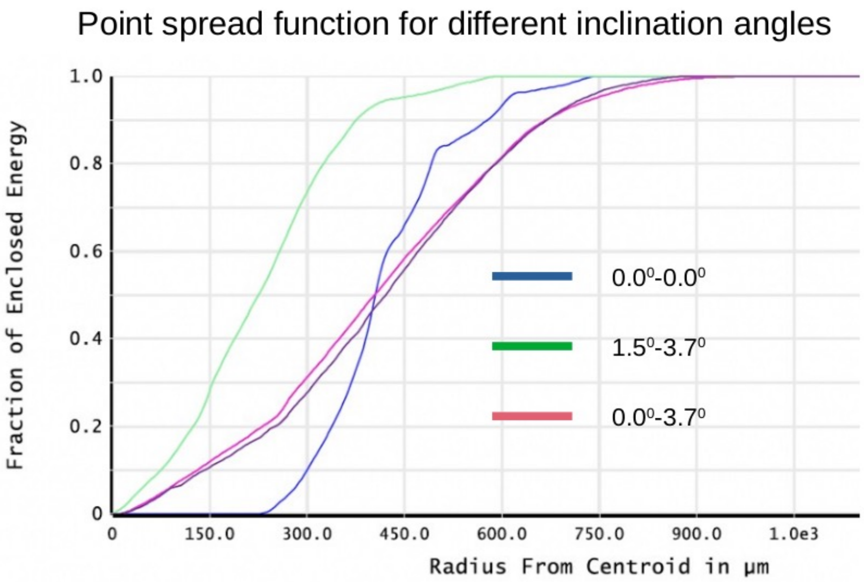
- ✓ combines both refractive (lens) and reflective (mirrors) elements to form an image.

The optics is Schmidt–Cassegrain:

- ✓ a primary parabolic mirror (**M1**)
- ✓ a secondary aspherical mirror (**M2**)
- ✓ a corrector plate (**lens**) attached to the secondary mirror
- ✓ focusing photons on the focal plane assembly (**FPA**).





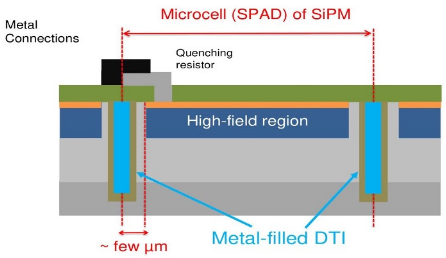


Equivalent focal length F_L	925 mm
Field of View (FoV)	7.2° x 2.9°
Point spread function (PSF)	< 1 mm
Effective area	0.1 m^2
Shadowing	8 %
Threshold energy	100 PeV

SiPM characterization

NUV-HD-MT SiPM arrays provided by FBK:

- ✓ metall-filled trenches provide optical isolation
- ✓ optical cross-talk is strongly suppressed (by a factor of 10)



A selection of SiPM arrays has been recently characterized, measuring radiation and temperature effects on: V_{BD}, DCR, PDE.

Proton irradiation: 50 MeV beam at IFJ Pan in Krakow

- ✓ DCR increased linearly with dose
- ✓ Variation of V_{BD} was not observed.

Electron irradiation: β-source (90Sr).

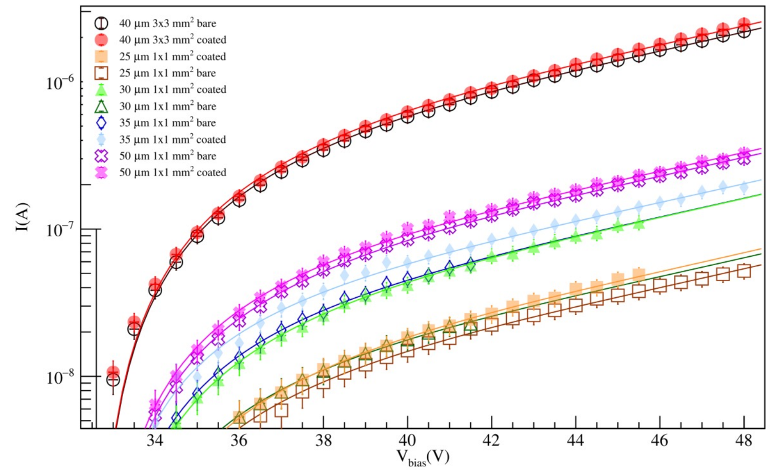
- ✓ Less damage w.r.t to proton source.
- ✓ Coated SiPMs receive less dose, but resin layers introduce Cherenkov noise.

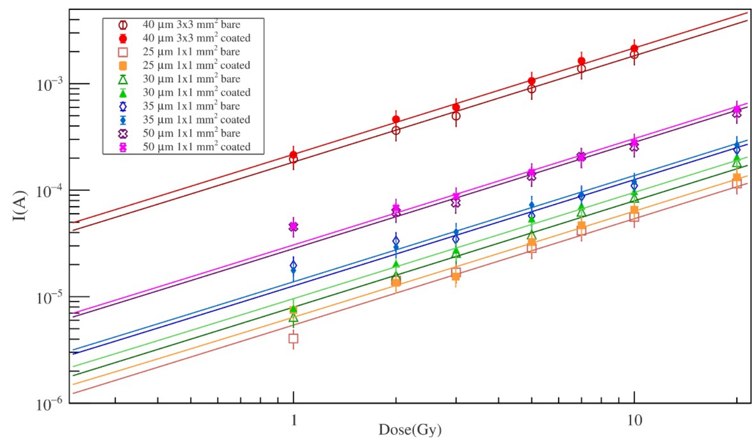
Radiation damage to the SiPM increases: DCR, power consumption and energy threshold.
Annealing as a mitigation strategy:

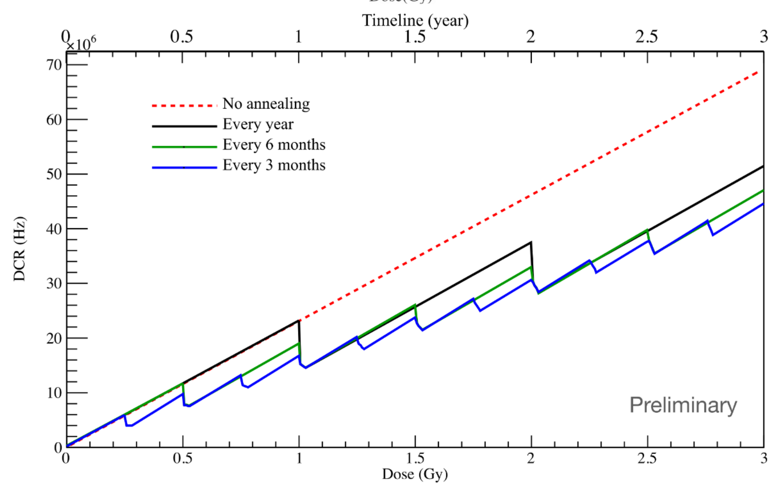
- ✓ heating above 50° C for several hours (TBD), followed by gradual cooling, every 3 to 6 months.

Measurements in a climate chamber show that up to 40% of the response is recovered.

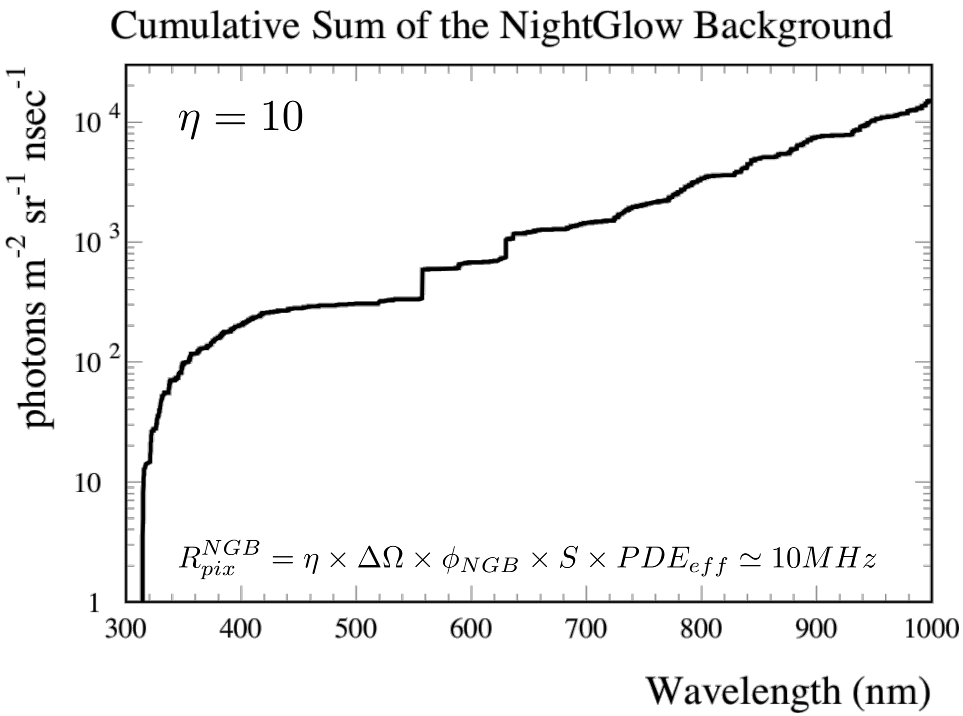
JCAP 2025, arXiv:2503.00532

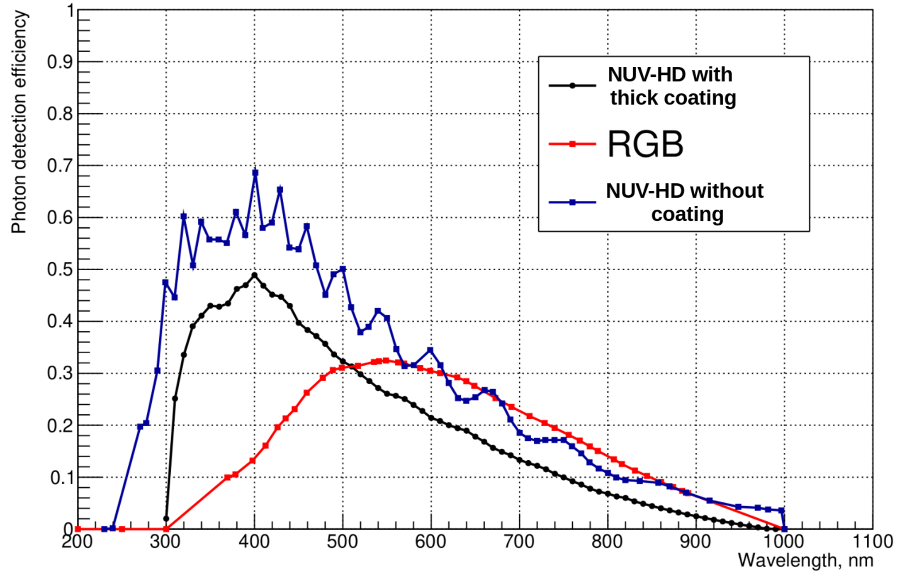


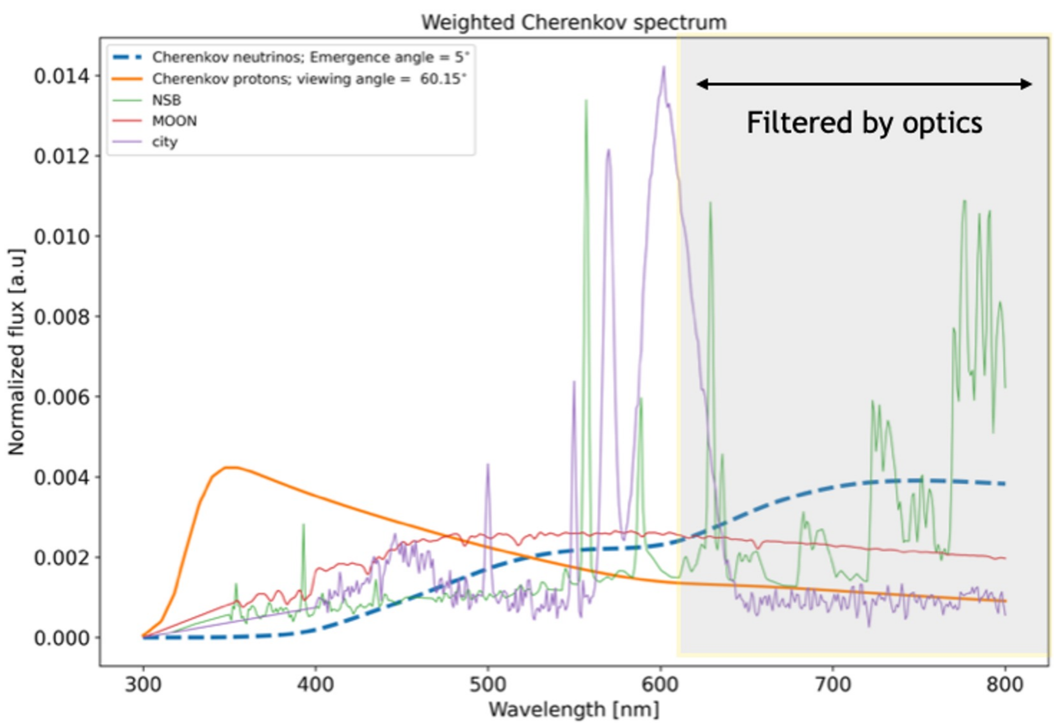


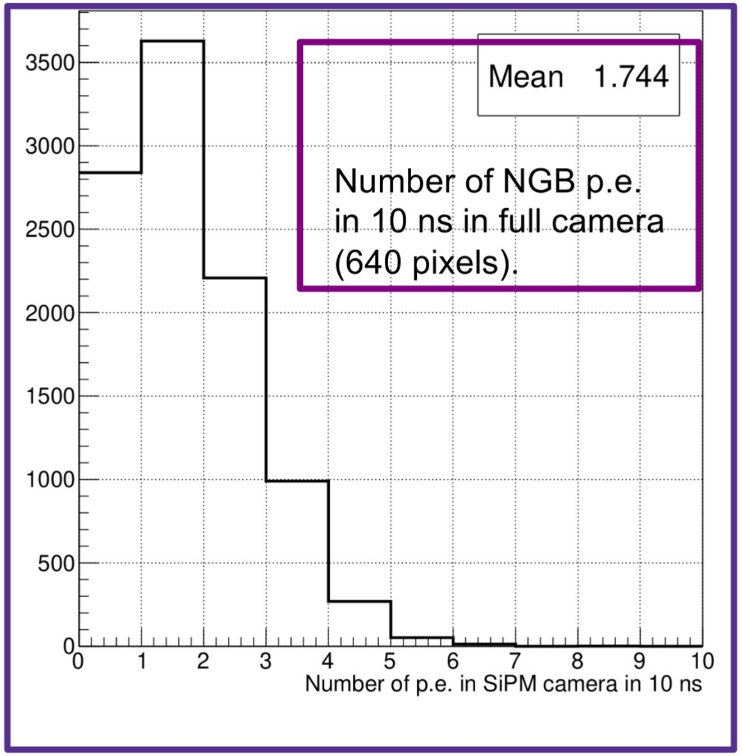


Night Glow Background









Telescope FP & DAQ

SiPM arrays: **8 x 8 channels**

Pixel: **3 x 3 mm² (eff. 2.3 x 2.7 mm²)**

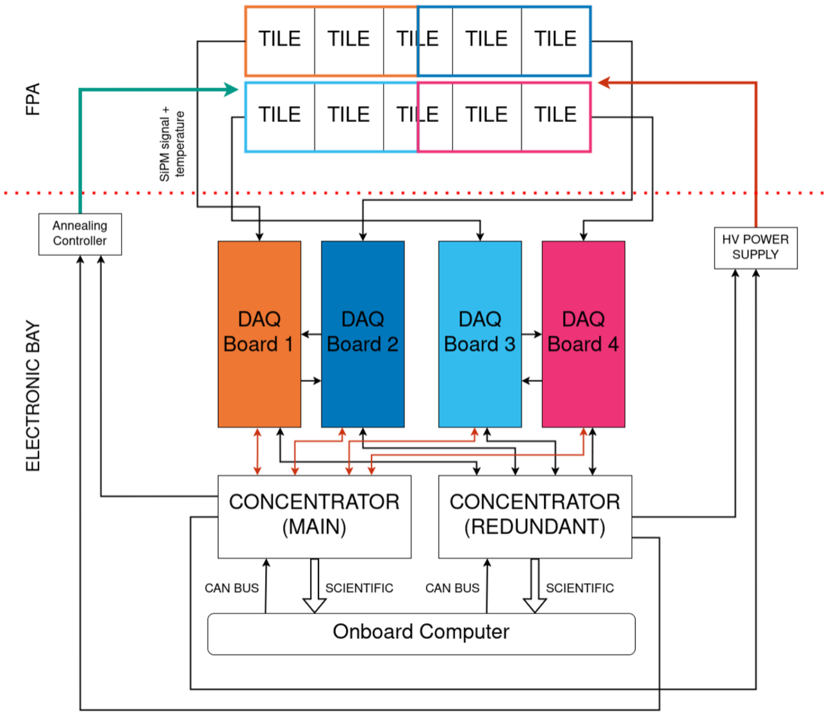
Pixel FoV: atan(r_{pix}/F_L) ~ **0.18°**

DCR: ~ **100 kHz/mm²**

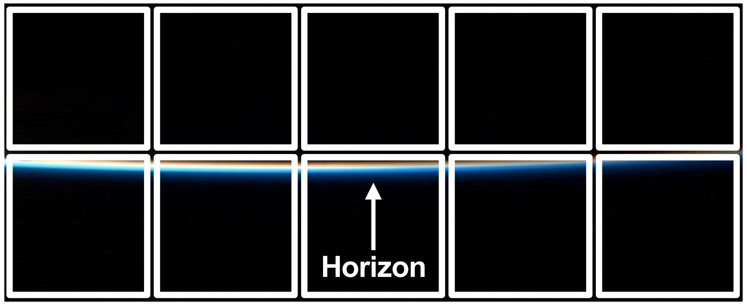
CT: ~ **7%**

PDE @ 450 nm: ~ **50%**

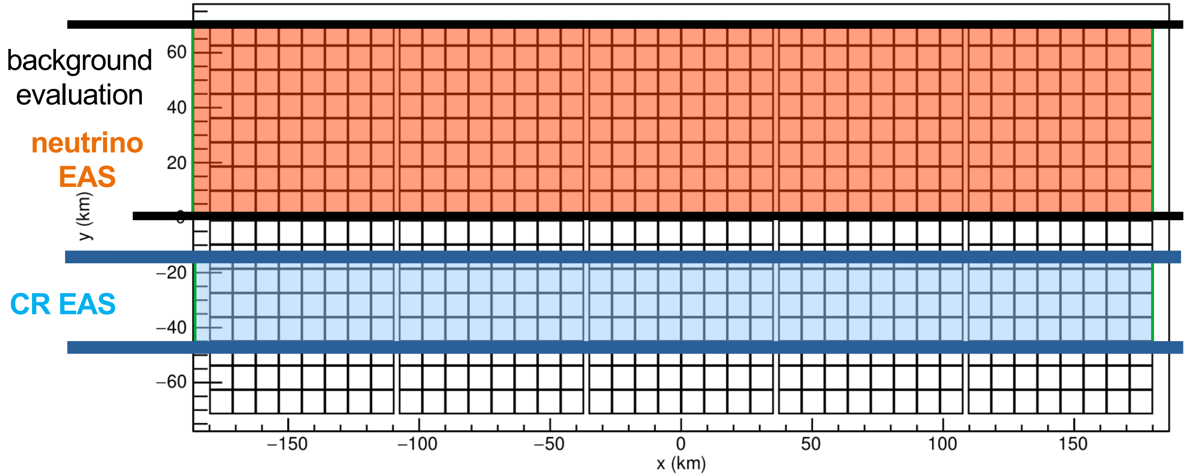
V_{BD}: **32.6 V**

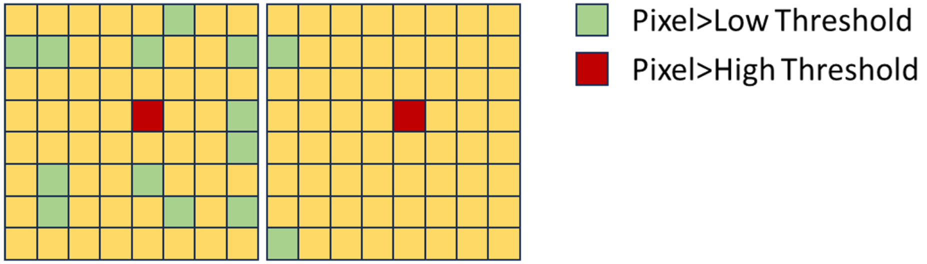


✓ Each DAQ board has 5 CITIROC ASICS, each reading 32-channels.



Camera plane with Earth projection of total area 360x140 km²





✓ High Threshold Trigger (HTT) and Low Threshold Trigger (LTT) for tile readout
  HTT: 1 pixel above HT
  LTT: 2 adjacent pixels above LT within Δt=10 ns.

✓ Negligible delay between second pixel above LT and readout.

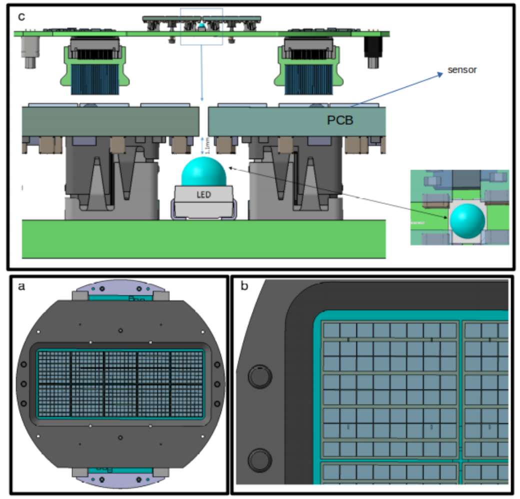
✓ Onboard analysis of the hit-map topologies for event recording.

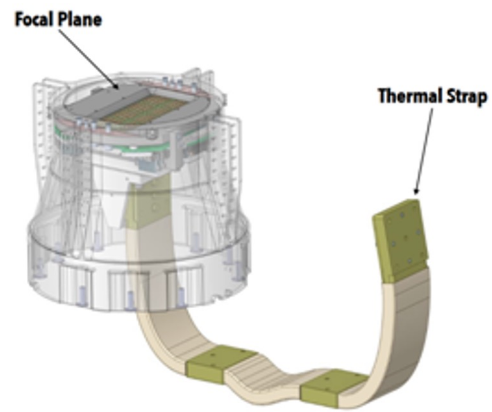
✓ For each trigger: dead time between events of 15 μs.

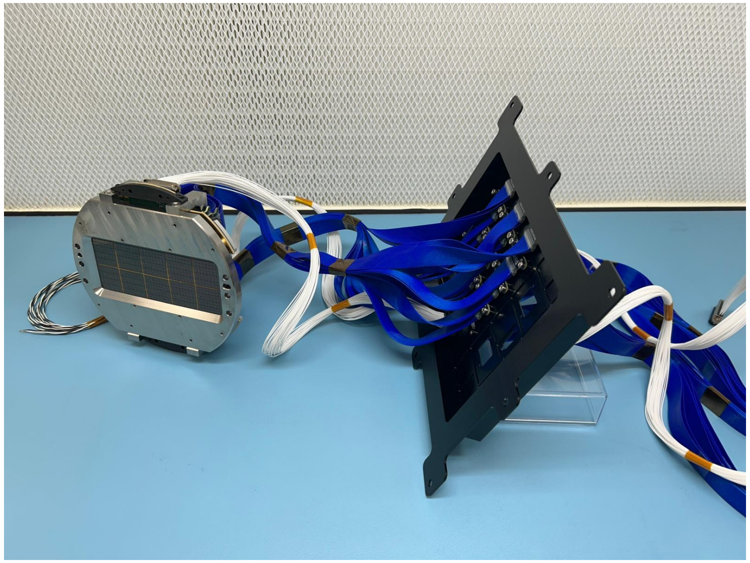
Terzina focal plane assembly

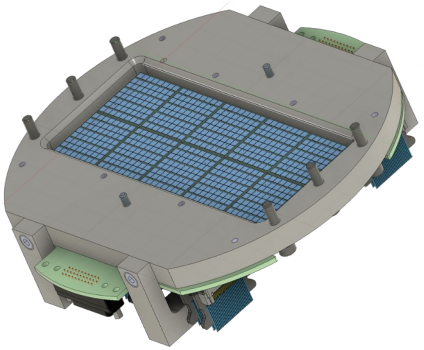
SiPM based camera, consisting of, total 640 pixels (channels). SiPMs connected to a PCB providing:

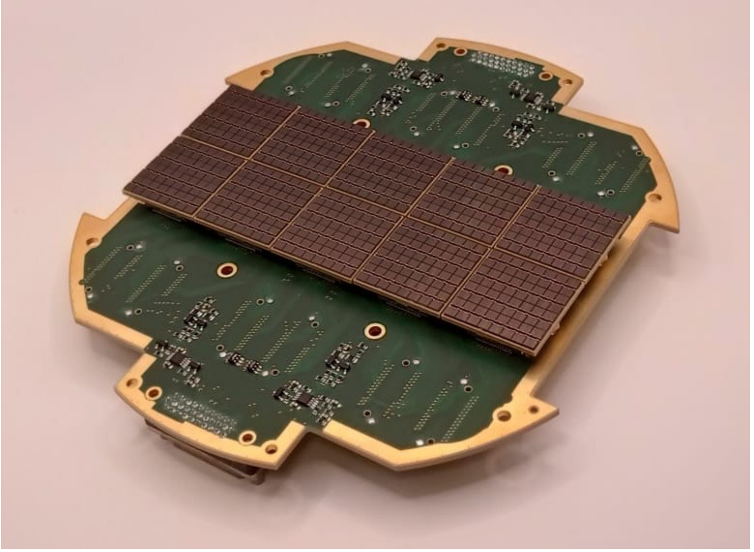
- ✓ bias HV
- ✓ signal routing to a DAQ board
- ✓ temperature & radiation sensors
- ✓ LED pulser

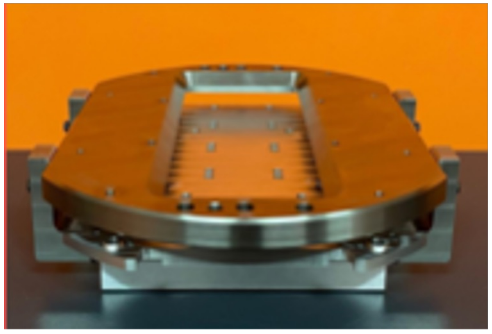












Next steps

- STM integration and tests successfully completed
- EQM integration and tests ongoing to be completed by the end of June 2025
- FM integration and tests July 25 – February 26 (procurement completed)
- Payloads FM assembly, integration and tests February 2026 – April 2026
- Delivery to TASI for payload integration with the platform 30/4/2026
- Delivery of the satellite to ASI July 2026

Launch fixed by ASI in October 2026 – Most probably through a Falcon9 flight

Thank you