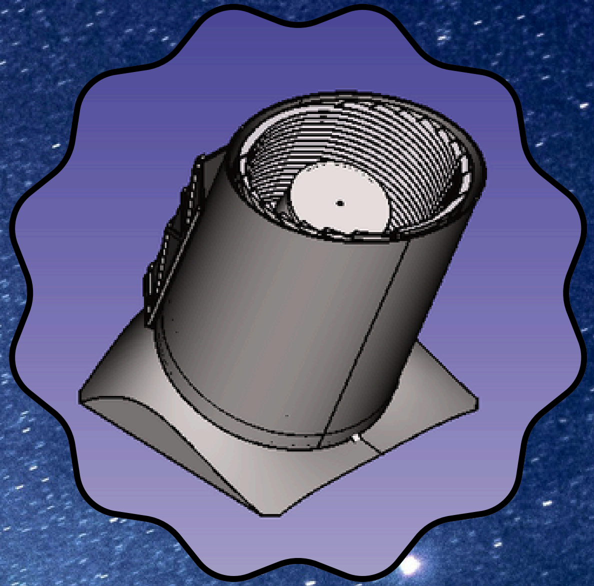
SPS Annual Meeting

Zurich - 13th September2024



The Terzina Telescope

Martina D’Arco

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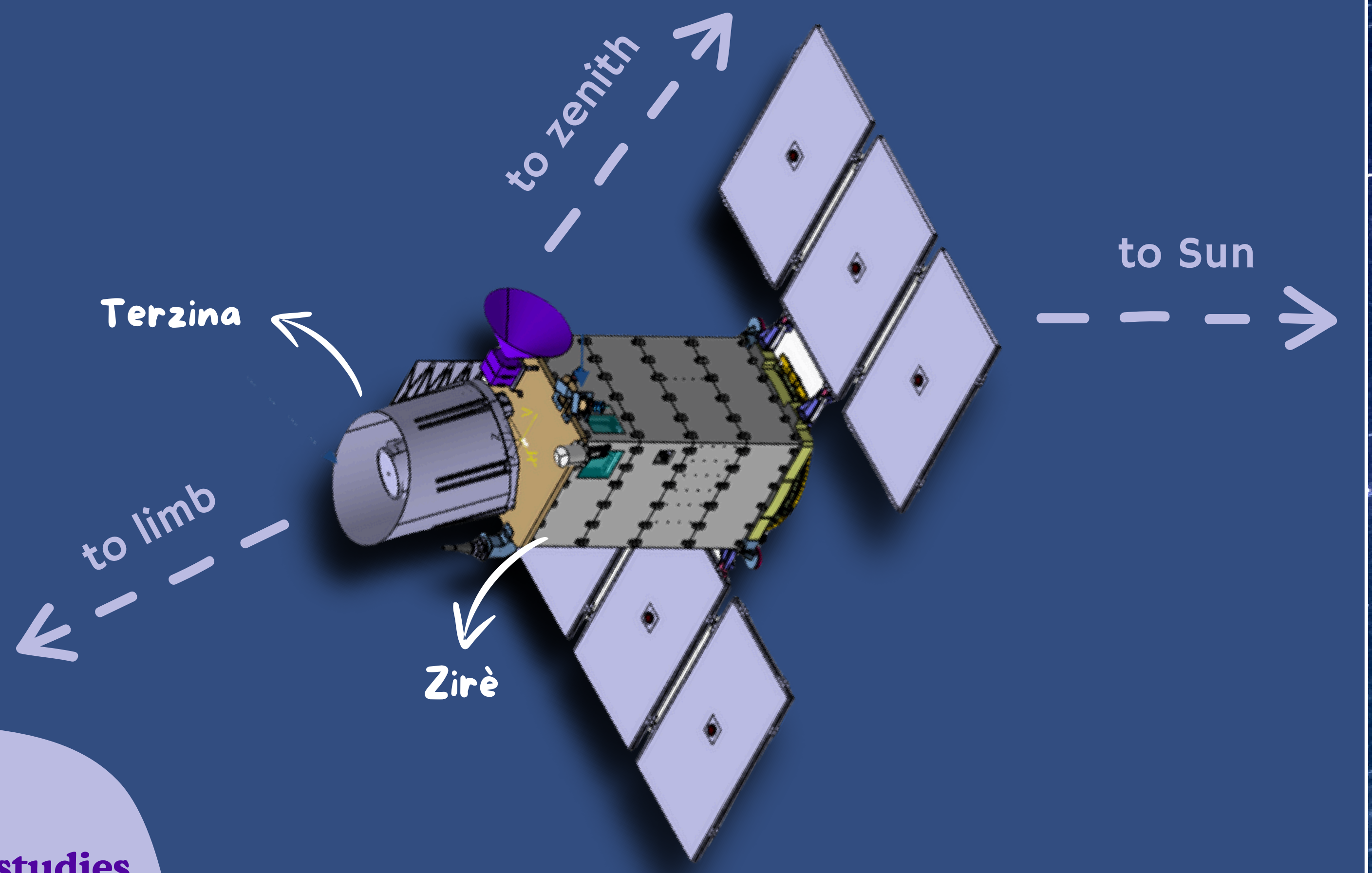
Content

Introduction

- Part of the ***Neutrinos and Seismic Electromagnetic Signal (NUSES)*** space mission project that aims to explore new scientific and technological pathways for future astroparticle physics space-based detectors.
- **Low Earth Orbit (LEO):** altitude of **550 km, 97.8°** inclination, **sun-synchronous orbit** on the day-night border.
- Two instruments: **Zirè** and **Terzina**.



Terzina

- **Pathfinder for future missions devoted to UHE cosmic ray and Earth-skimming UHE neutrino detection demonstrator through space-based atmospheric Cherenkov light detection. [1]**

Zirè

- **Cosmic Ray flux (< 250 MeV) for studies on the Van Allen belts, space weather, and lithosphere-ionosphere-magnetosphere coupling.**
- **Detection of 0.1-10 MeV photons to study transient (Gamma Ray Bursts, Gravitational Waves e.m. follow-up, Supernova emission lines) and steady gamma sources. [2]**

The Physics behind it

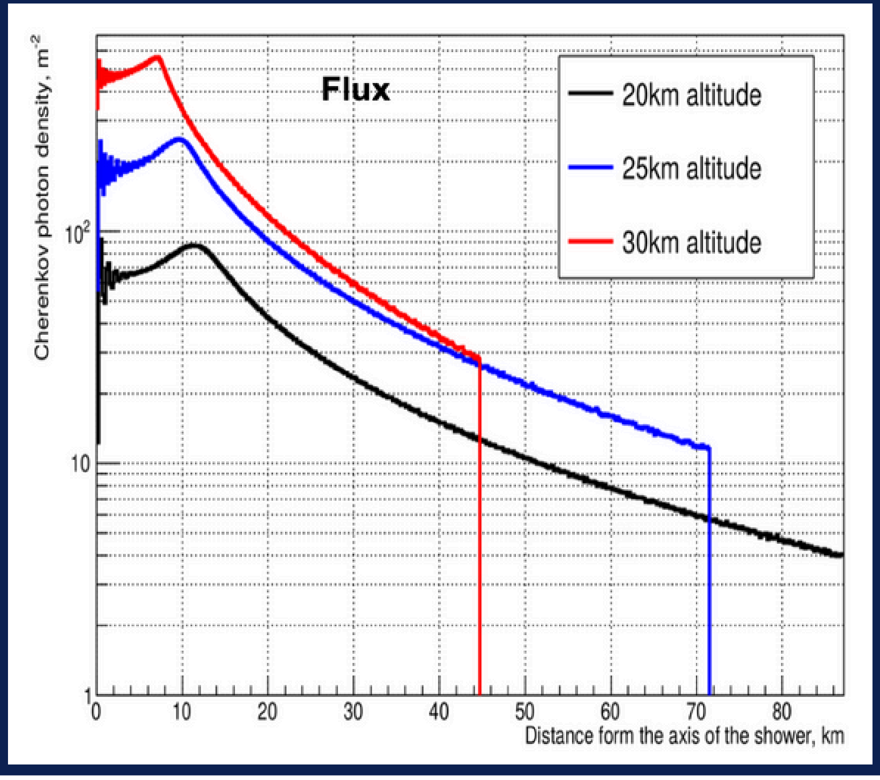
UHECR EAS from space

- **Cosmic Rays (CRs)** with energies beyond 100 PeV can be detected as their interactions with atmospheric nuclei and molecules produce **Extensive Air Showers (EAS)** of ultra-relativistic particles emitting Cherenkov light.

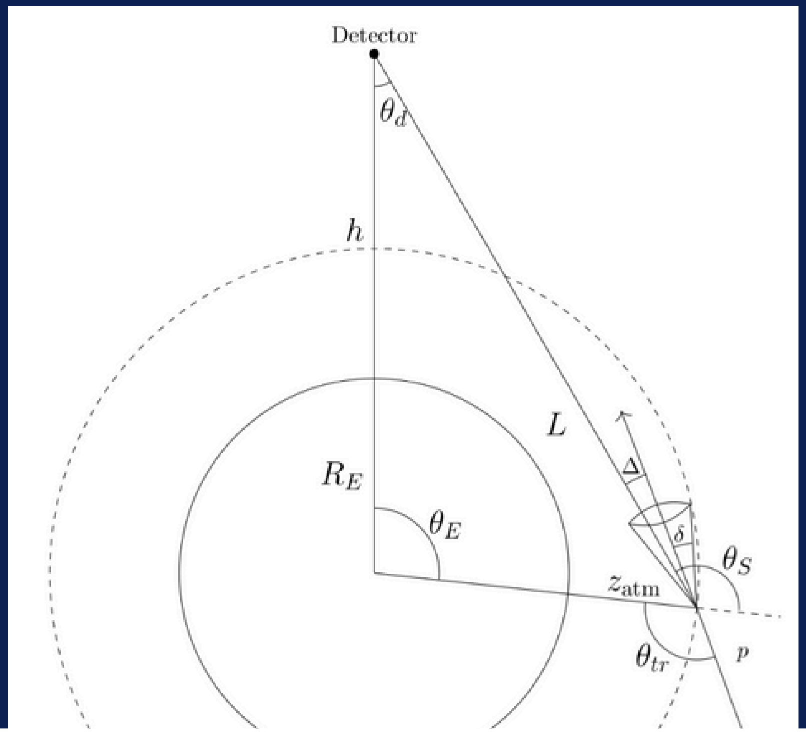
- The region including the direction can be reconstructed as the shower will mostly fall in one pixel of the camera telescope for Terzina of 0.18°.

- The composition of **UHE (ultra-high energy) CRs** cannot be reconstructed by one satellite but by a synchronised constellation as each telescope sees one small part of the Cherenkov cone.

- At Terzina's altitudes, the Cherenkov photon cone has a base radius of a few tens of kilometres, with an integrated flux of about **100 photons/m²** for a proton EAS with 100 PeV energy.



Photon density of the Cherenkov ring as seen from the telescope produced by 100 PeV protons for different heights as a function of distance from the shower axis [6].



Geometry of measuring the Cherenkov signal from cosmic rays arriving from above the Earth horizon [4].

The angle of the detector's optical axis with respect to the local zenith: θ_S

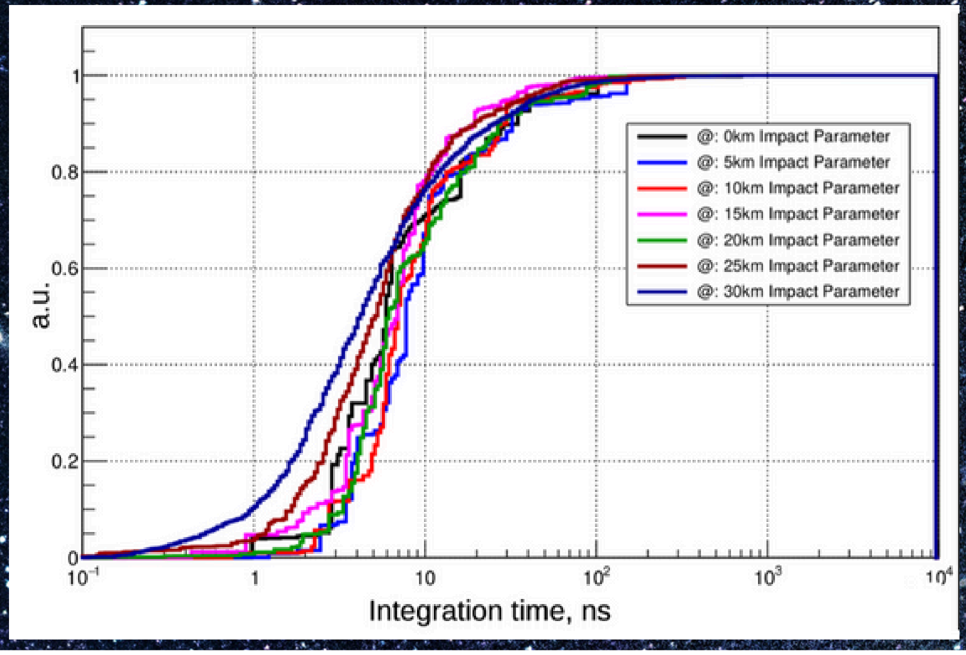
The detector's viewing angle with respect to nadir: $\theta_d = 67.5°$

TheEarth viewing angle with respect to the center of the Earth: θ_E

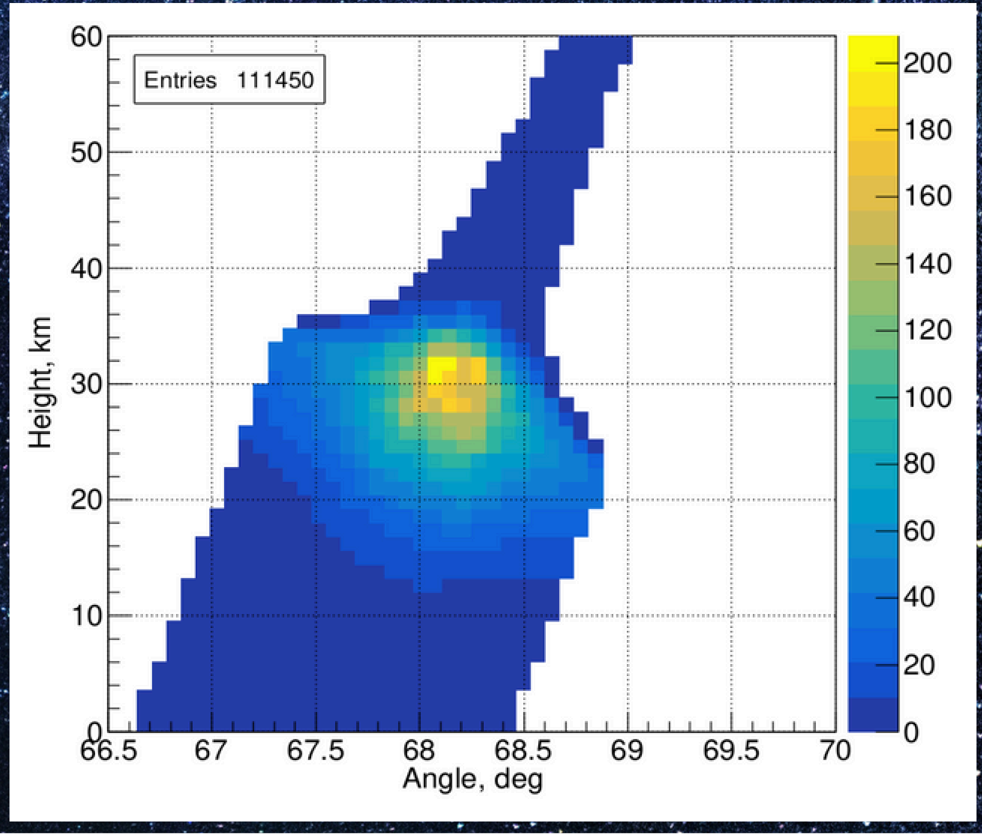
Relevant UHE EAS characteristics for detection

Above the limb:

- High-energy cosmic rays (**> 100 PeV)** striking the atmosphere above Earth's limb produce similar signals.
- The observable trajectories above the Earth's limb are confined within the detector's viewing angle range.
- Typical interaction altitude in the atmosphere between 25-35 km and the relevant angle under which these photons are seen from the telescope is about 1° for showers of 100 PeV energy.
- In 1 year 80.68 events for energy larger than 10 PeV by considering the trigger efficiency



The cumulative time of the Cherenkov photons produce by EAS with different altitude of the impact point of the UHE CR direction [6].



Distribution of the Cherenkov photons produced by a proton EAS of 100 PeV energy as a function of the viewing angle and above the limb altitudes of the first interaction point [1].

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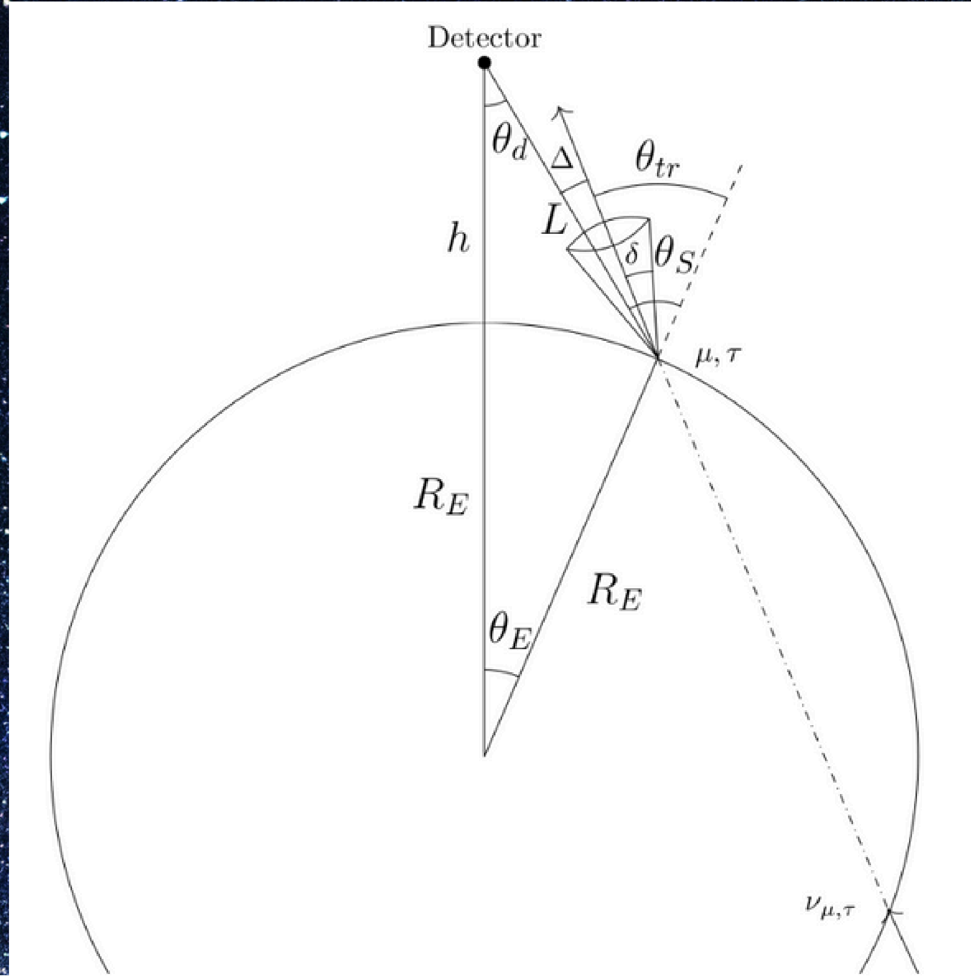
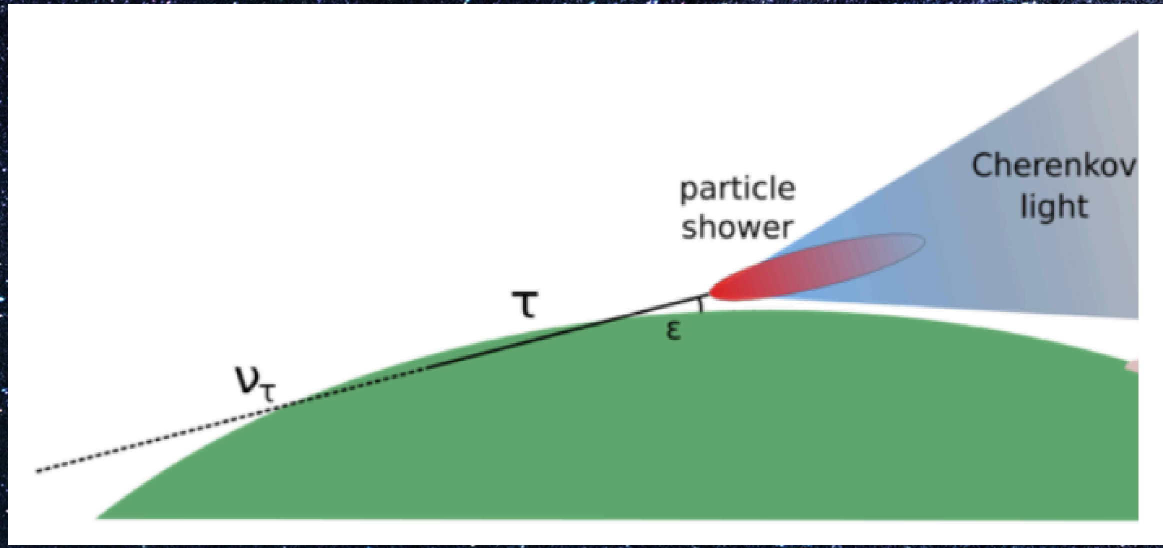
Observing the atmosphere's limb

Below the limb:

- Tau and muon neutrinos above a **few PeV** can be detected as **Earth-skimming events** with up-going EAS.
- These events produce bright, forward-beamed **Cherenkov emission**, detectable by **space-based (LEO)** instruments.
- Cherenkov signals arise when Earth-skimming neutrinos interact near the surface, generating muons or tau-leptons.



Geometry of measuring the Cherenkov signal from cosmic rays arriving from below the Earth horizon [5].



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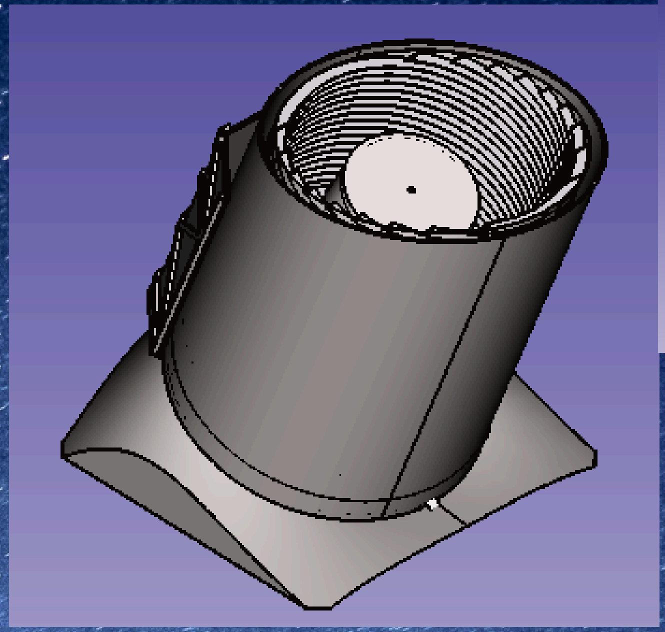
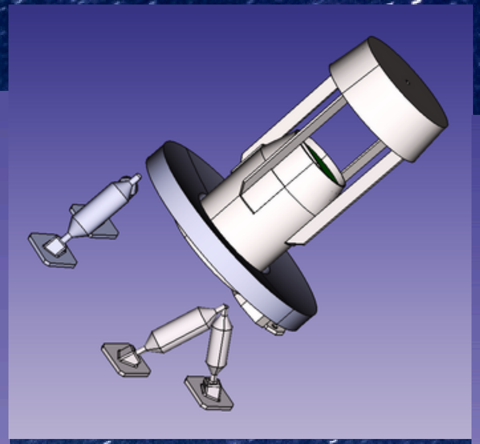
The Terzina Telescope

Design of the Terzina Telescope

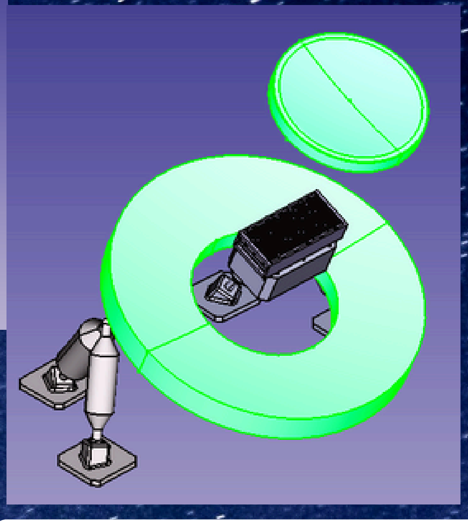
- **Near-UV-optical** telescope with **Schmidt-Cassegrain optics:** primary (diameter 430 mm) and secondary (diameter 194 mm), with a focal length of 925 mm.
- **67.5°** viewing angle of detection from nadir, with a 40% duty cycle.
- **Weight:** approximately **35 kg**.
- **Compact design:** 60 cm x 60 cm x 50 cm.
- **Focal Plane Assembly (FPA)** of **10 Silicon Photon Multipliers (SiPM) arrays** of 8x8 pixels forming 2 rows of 5 arrays each (640 pixels overall).
- **Pixels dimension:** 2.3 mm x 2.7 mm.
- **Field of View per pixel:** 0.18°.
- **Total FoV:** 7.2° x 2.9°.
- **Total area** of the camera plane with projection on the Earth: 360 km x 140 km.



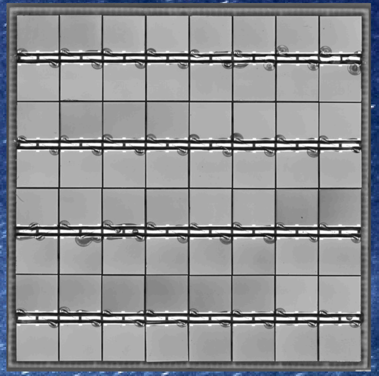
Terzina telescope.



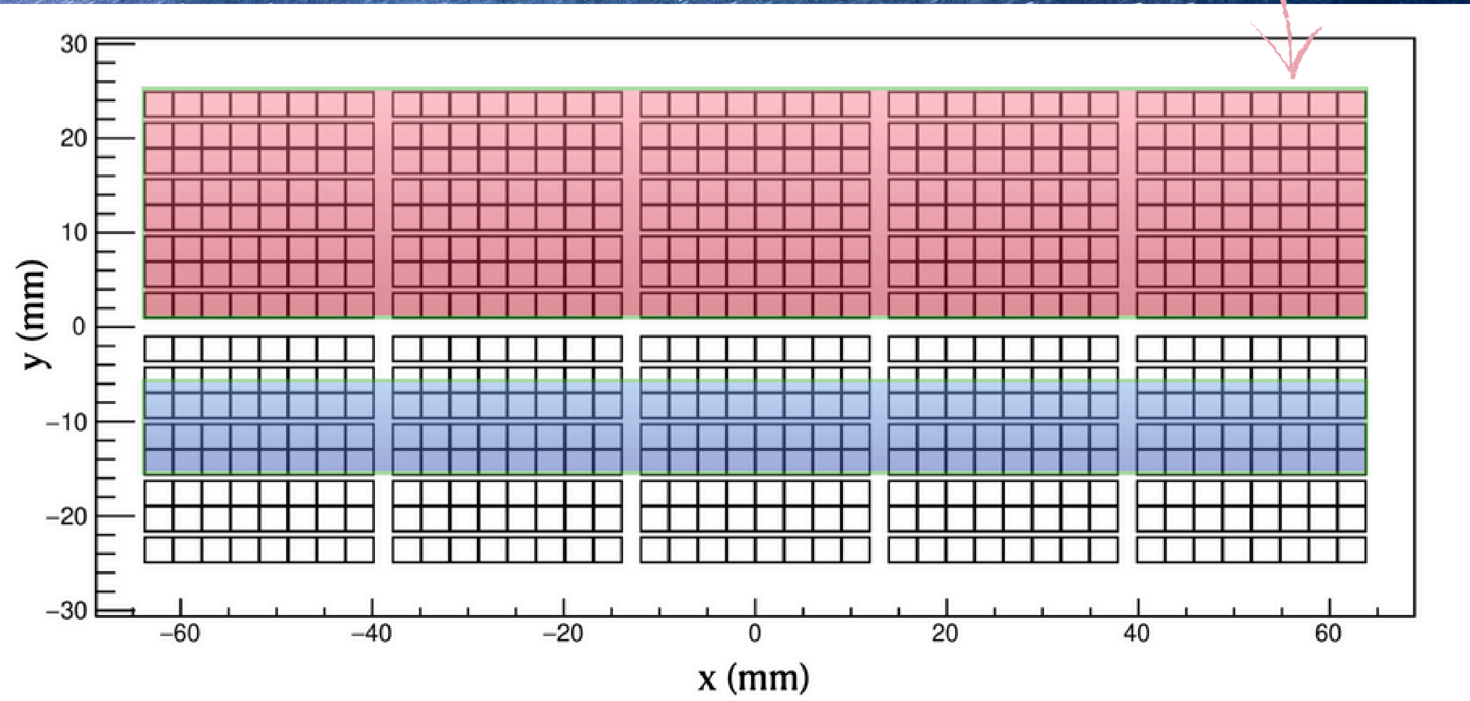
Mirrors of Terzina and holder.



Mirrors of Terzina (in green).



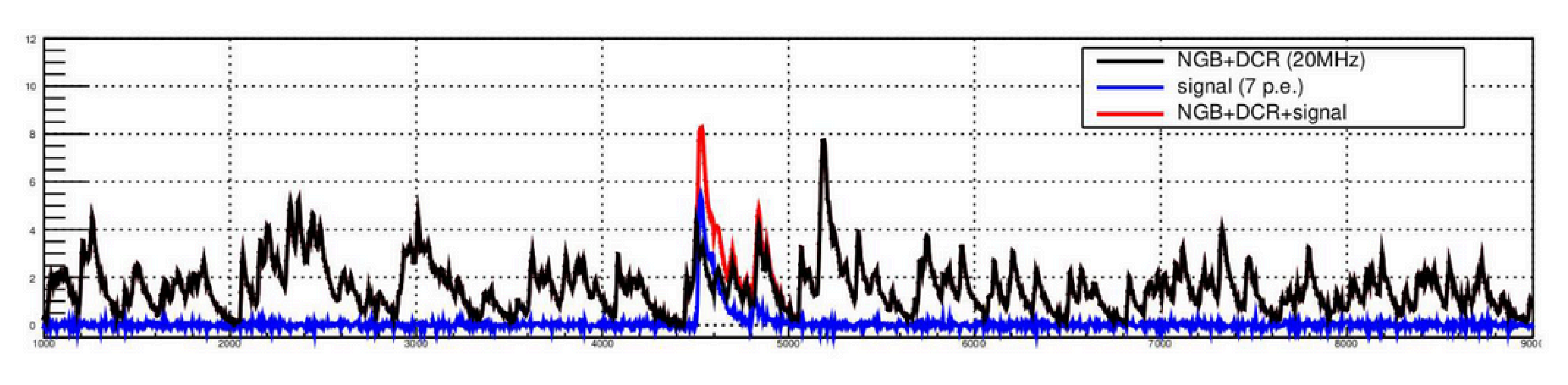
One tile of SiPM.



Scheme of the focal plane showing the pixel structure. ***Red band:*** below the limb. ***Blue band:*** above the limb.

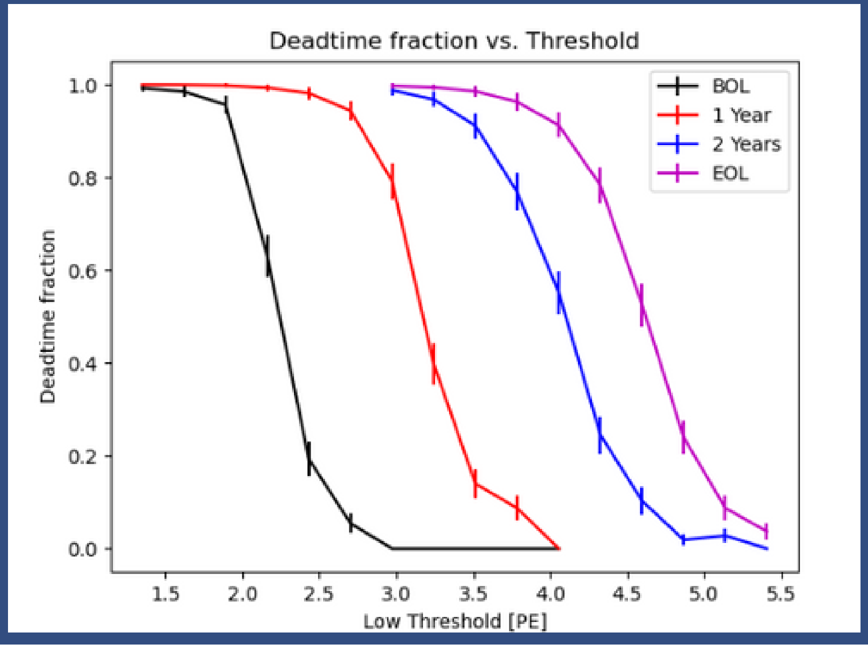
The expected signal and backgrounds

Example of the observed waveform for the signal and the expected background:



It is necessary to analyze also the expected background:

- The **Night Glow Background** (NGB) of visible light [4].
- **City lights.**
- **Moonlight.**
- Background radiation from charged particles (see S. Davarpanah's talk - link)



The dead-time fraction of the readout chain as a function of the trigger threshold.

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City lights

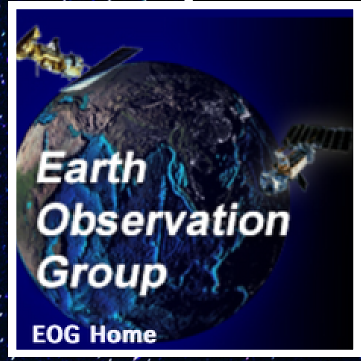
City lights dataset

Nighttime Lights Time Series

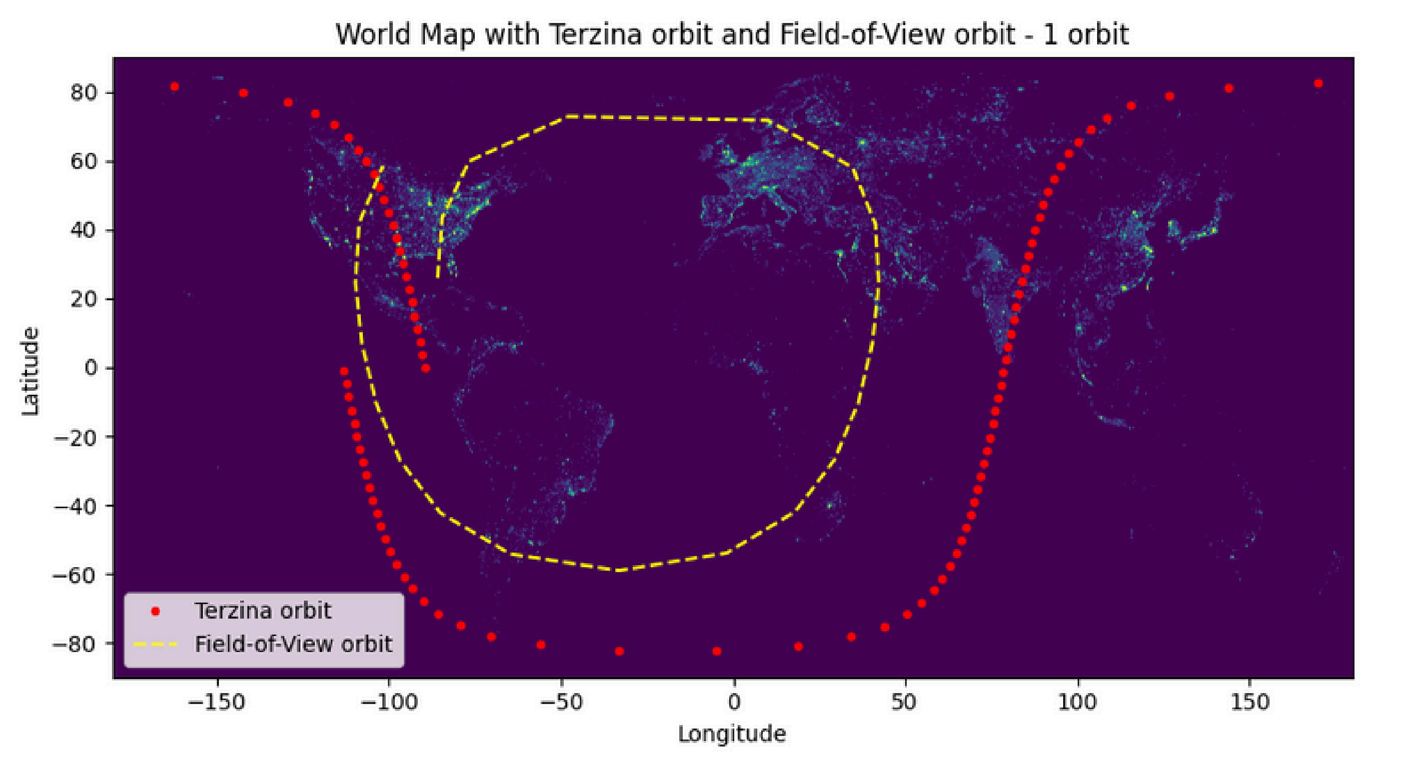
- Defense Meteorological Satellite Program (DMSP), Operational Linescan System (OLS).
- UV telescope operating in the range 400 - 1100 nm.
- Altitude: 830 km - Latitude: [-65°, 75°] - Longitude: [-180°, 180°].
- Raw data containing the average of the visible band digital count (DC) values with no further filtering. Data values in 64 bins in the log scale range from 0-63.

- We need to rescale the dataset to get the number of photons arriving at Terzina from city lights.
- Main points of the procedure are:

1. **From DC counts to the number of photons from the ground.**
2. **From the number of photons from the ground to the number of photons to Terzina.**
3. **Rate during orbit.**



DMSP official website



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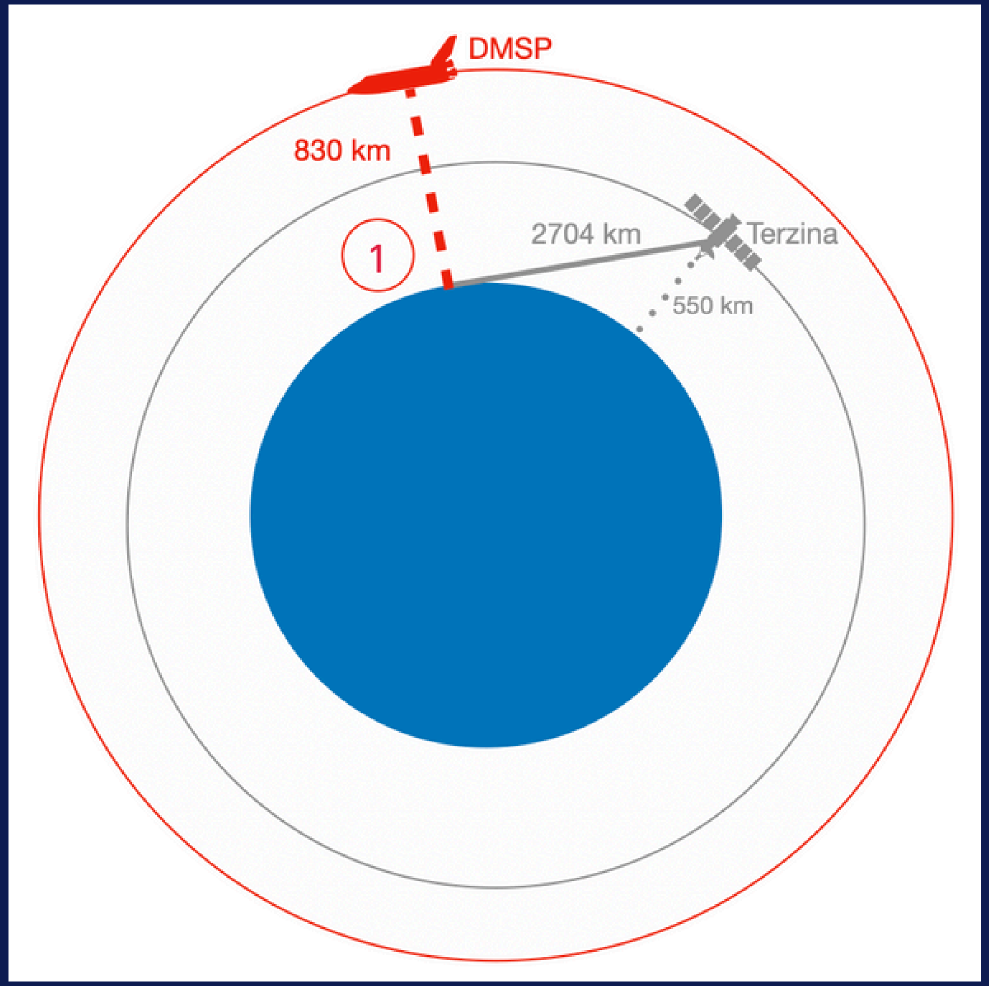
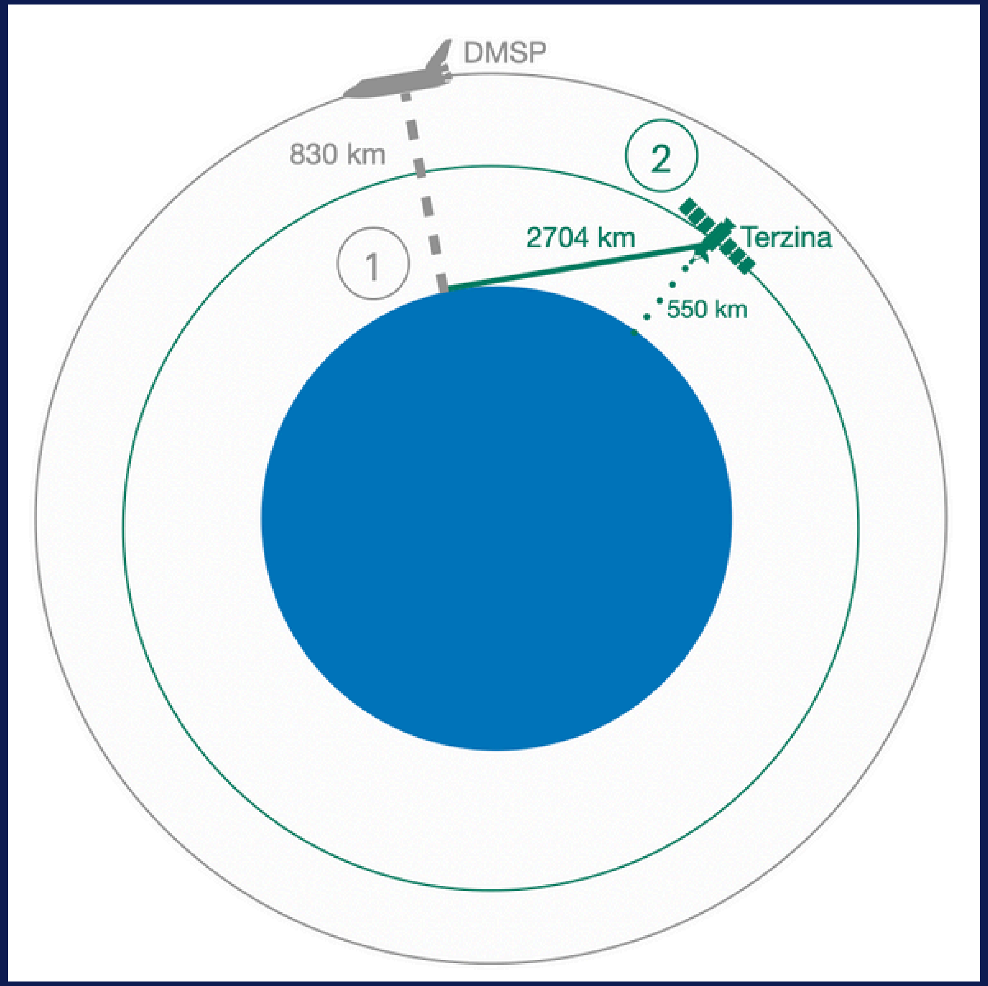
Nighttime lights

1. **From DC counts to number of photons from the ground.**
2. **From number of photons from the ground to number of photons to Terzina.**





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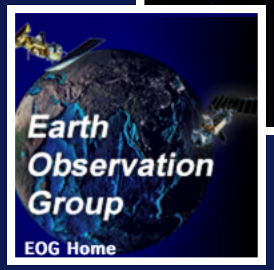
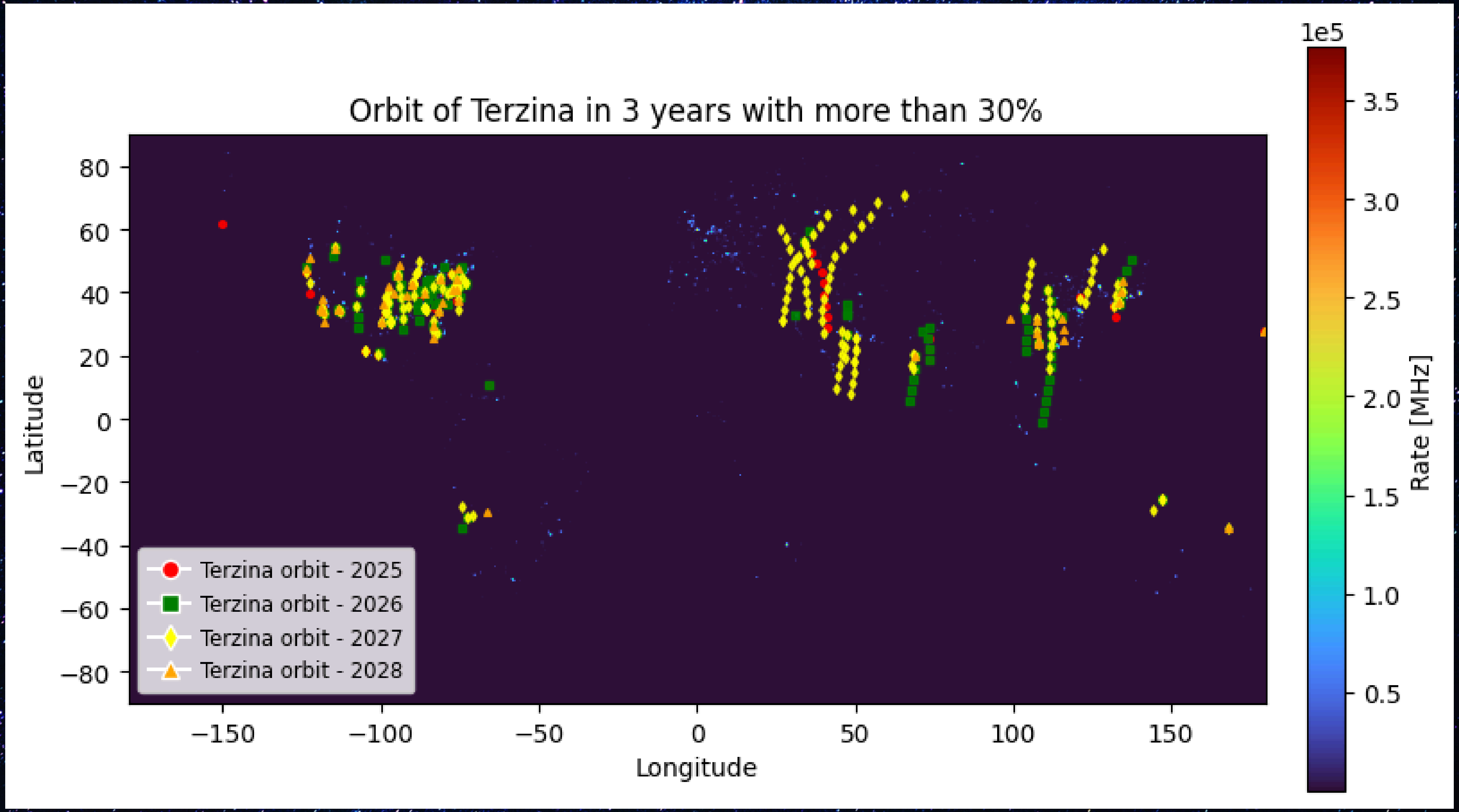
Nighttime lights



3. Rate of photons from (8.5 km x 8.5 km) during orbit.

Points of the graphs represent the moments of the orbits when Terzina detects more than 30% of total city photons.



30% = around 113870 photons per second from a surface of (8.5 km x 8.5 km) to Terzina

NB: this is before the efficiency of the optical system (95%) and of the sensors (63%)

Moonlight

Moonlight

LIME (Lunar Irradiance Model of ESA)

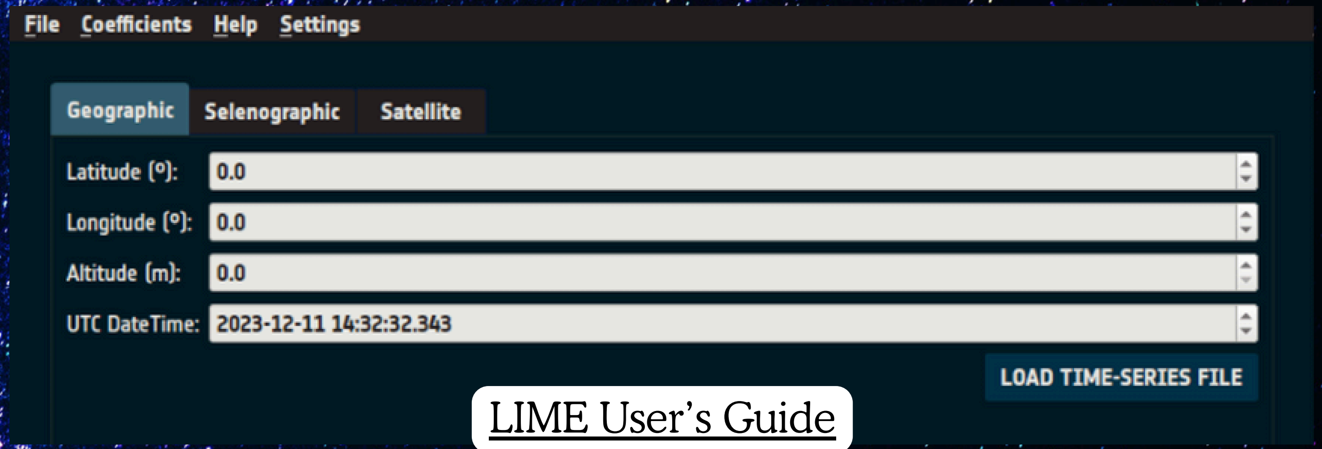
- A new tool for **absolute radiometric calibration** using the Moon, based on the **ROLO** model but with a rigorous uncertainty analysis.
- Top-of-atmosphere **irradiance/reflectance** from the ground in high-altitude stations (2400 m asl and 3570 m asl).
- From measurements, development of a **lunar irradiance model** based on ROLO.

- **LIME ToolBox** to simulate lunar irradiance based on LIME measurements.

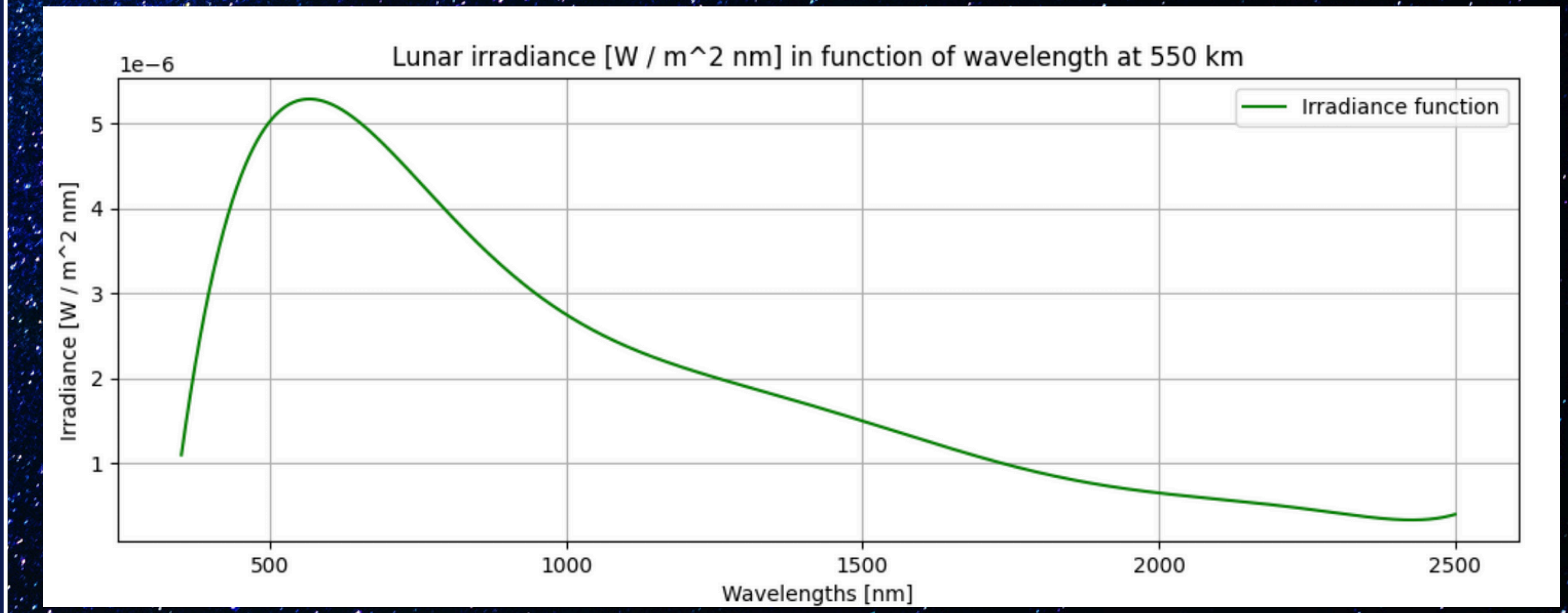
Lunar Irradiance: W per m² per nm, power in function of the wavelength on a surface of m² at an altitude of 550 km from the Earth surface.

LUNAR IRRADIANCE MODEL OF ESA

Paper: https://doi.org/10.5194/acp-24-3649-2024
Website: LIME Material



LIME User's Guide



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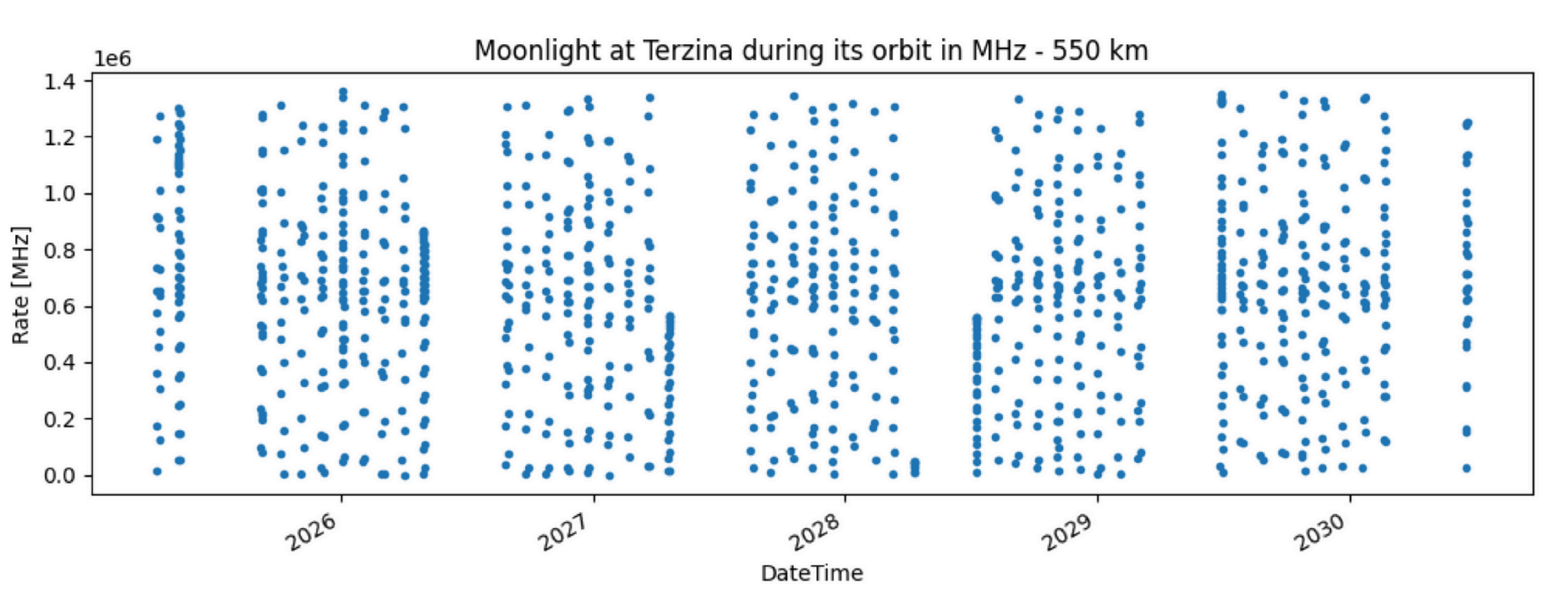
Moonlight

LIME (Lunar Irradiance Model of ESA)

Lunar Irradiance:
W per m² per nm

→ **Number of photons per s** that arrive at Terzina in general from an almost Full Moon.

\+ **Percentage** of orbital time during which the **Moon is in the FoV of Terzina**.

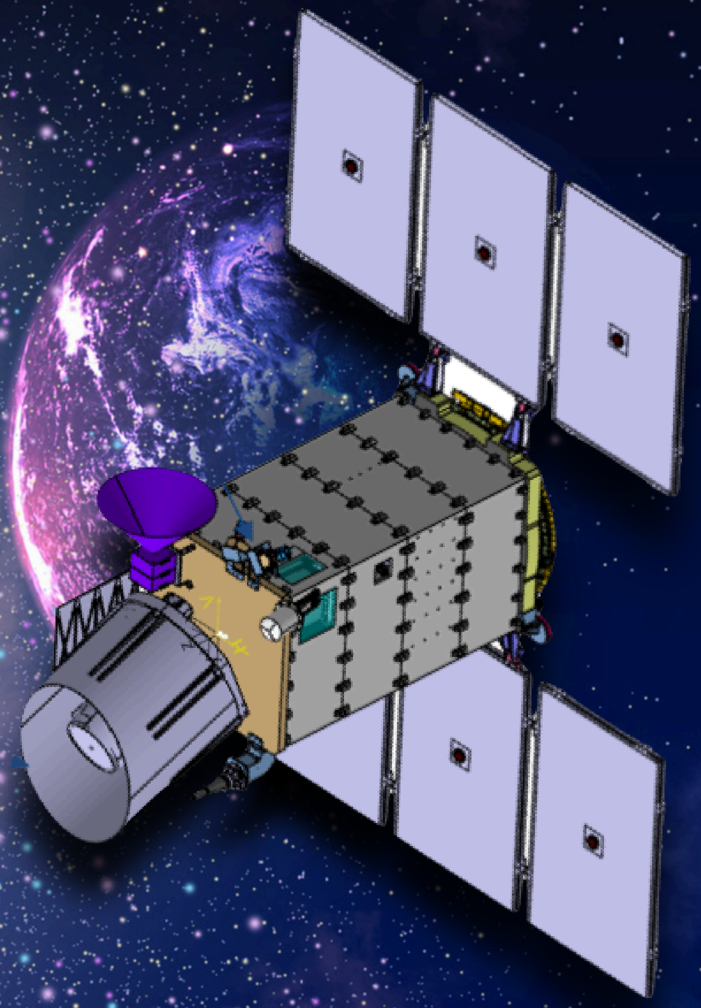


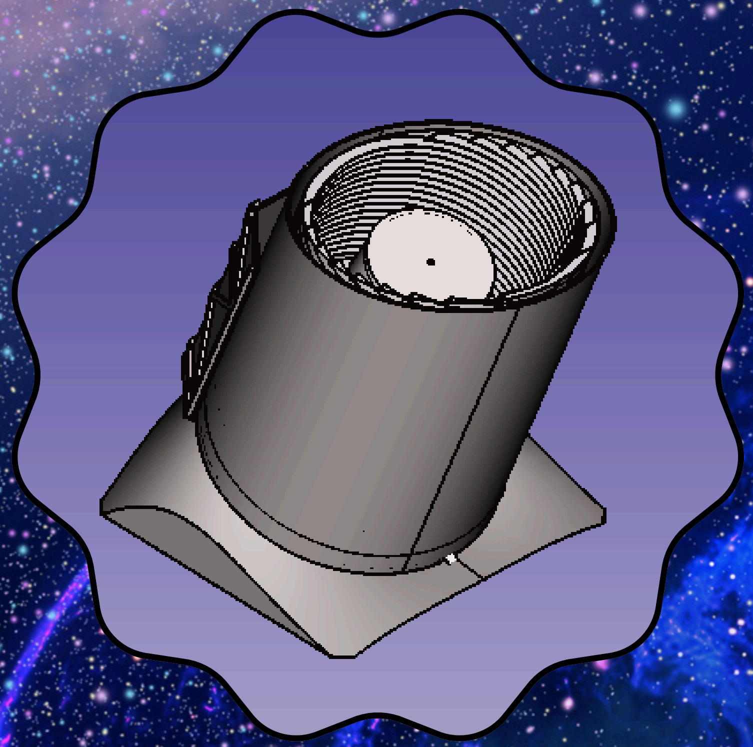
Conclusion

- A lot of background sources are present; it is necessary to know how to shield the experiment from the noise.

- City lights and moonlight can interfere with the camera, potentially causing blindness if not properly managed.

- In general, the Terzina Telescope will be a pathfinder for upcoming space-based detectors.





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swiss physical society

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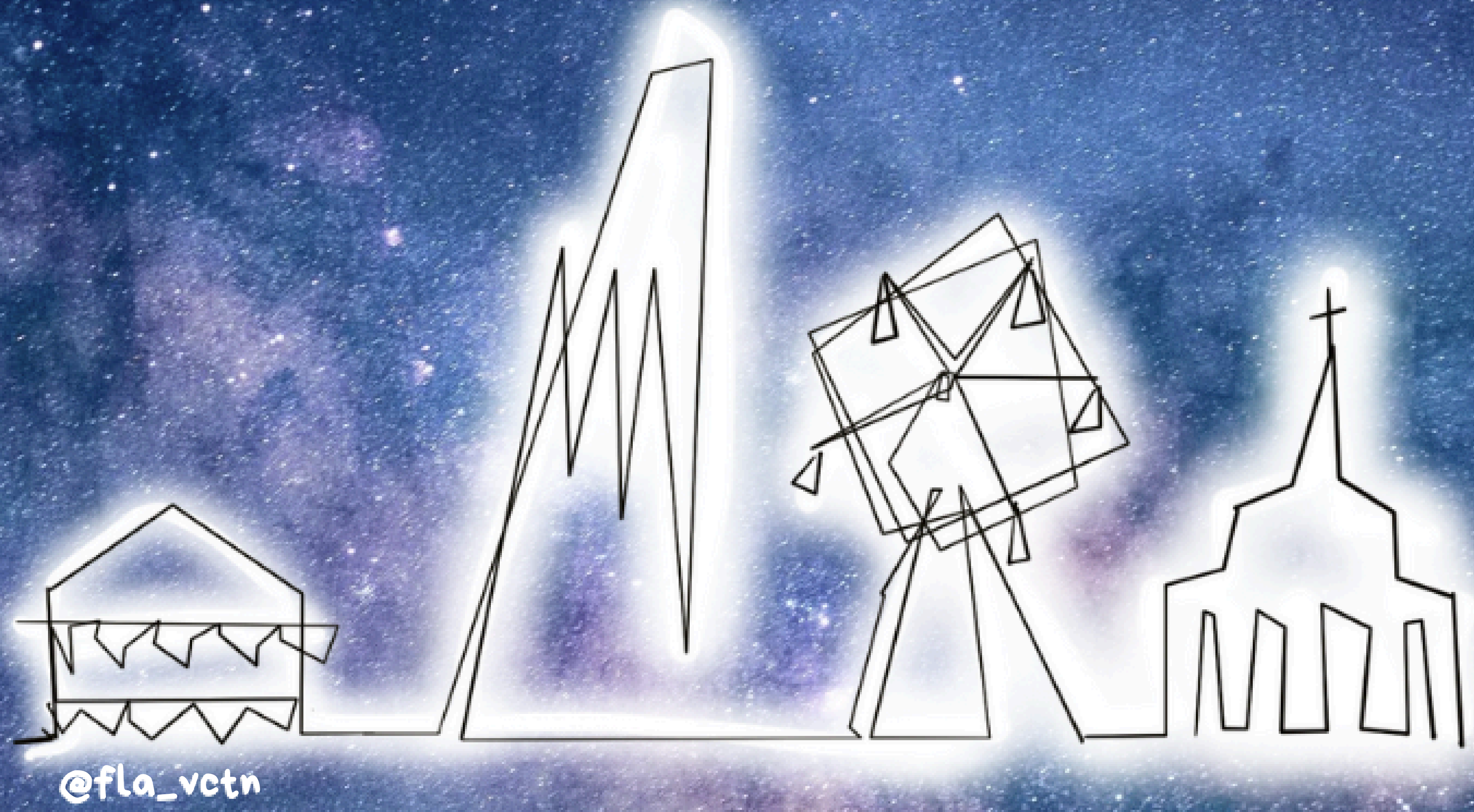
Thank you!



⟨S|P|S⟩ swiss physical society

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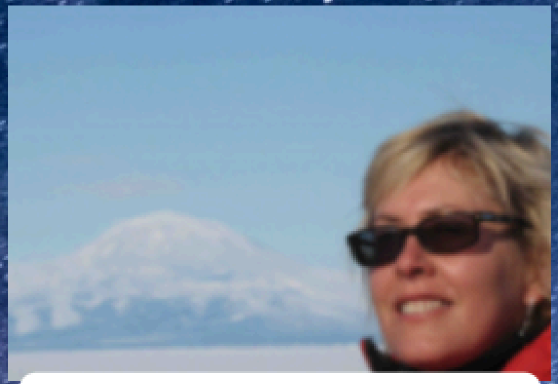
Terzina’s group


Prof. Dr. Teresa Montaruli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Shideh Davarpanah


Martina D’Arco


Dr. Leonid Burmistrov


Dr. Christoph Toennis

References

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- [2] **The Zire experiment on board the NUSES space mission**, *Nuses, R. Aloisio, A. Altomare, B. Barbato, B. Battiston, B. Bertania, et al.*
- [3] **Sub-Orbital and Orbital Detection of High-Energy Astrophysical Radiation via Cherenkov Emission**, *Austin Cummings, PhD Defense.*
- [4] **Modelling the Optical Cherenkov Signals by Cosmic Ray Extensive Air Showers Directly Observed from Sub-Orbital and Orbital Altitudes**, *Austin Cummings, Roberto Aloisio, Johannes Eser, John Krizmanic.*
- [5] **Modelling of the Tau and Muon Neutrino-induced Optical Cherenkov Signals from Upward-moving Extensive Air Showers**, *A. L. Cummings, R. Aloisio, J. F. Krizmanic.*
- [6] **Terzina on board NUSES: a pathfinder for EAS Cherenkov Light Detection from space**, *Leonid Burmistrov.*