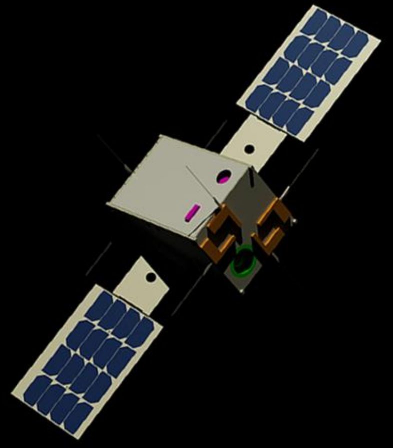

8th IAA Planetary Defense Conference

3-7 April 2023, Vienna, Austria

LUMIO: a CubeSat to detect meteoroid impacts on the lunar farside

F. Ferrari, F. Topputo, G. Merisio, V. Franzese, C. Buonagura, C. Giordano, A. Morselli, P. Panicucci, F. Piccolo, A. Rizza, S. Borgia, A. Cervone, D. Koschny, E. Ammannito, R. Moissl, D. Labate, M.G. Pancalli, G. Pilato, E. Lhome, R. Walker and the LUMIO Team

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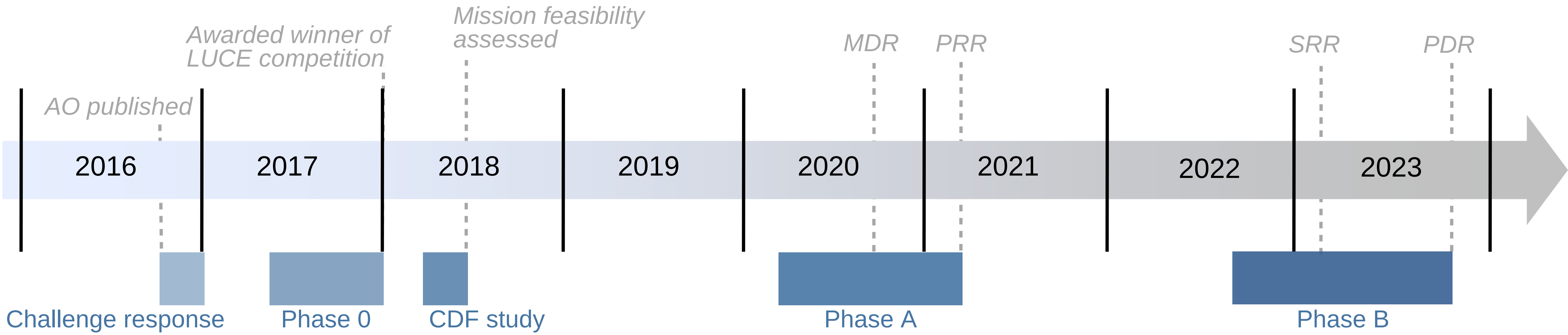
ASI

The LUMIO mission

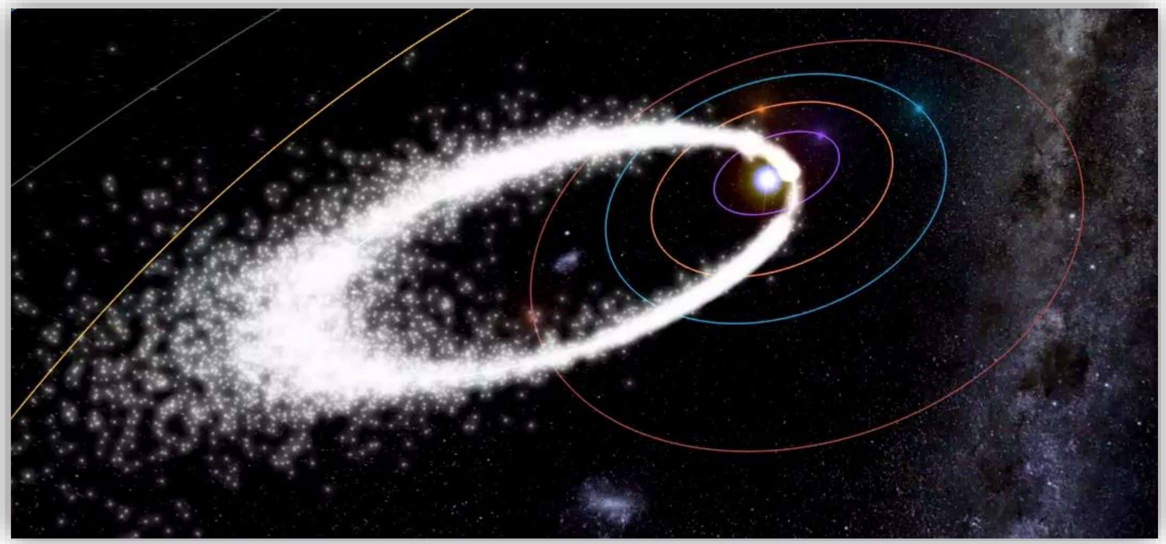
Lunar Meteoroid Impacts Observer

CubeSat mission to a halo orbit at Earth–Moon L_2 that shall observe, quantify, and characterise meteoroid impacts on the Lunar farside by detecting their impact flashes

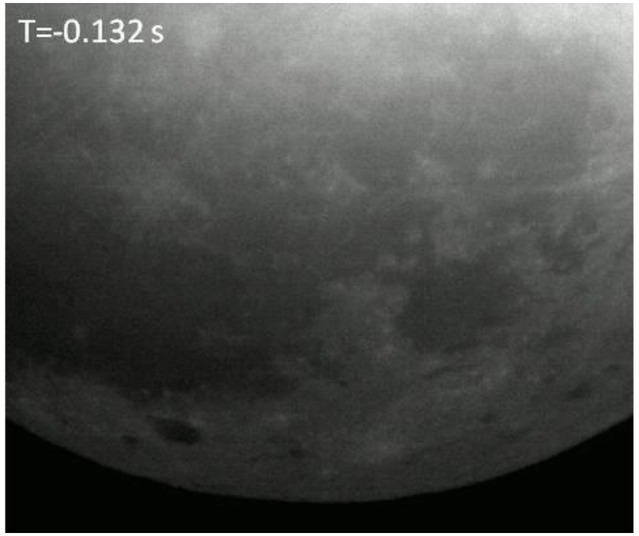
- Phase 0 funded through GSP
- Phase A funded through GSTP
  - IT, NL, NO
- Phase B funded through GSTP
  - IT, NO



Overview of the scientific activities



Rendering of GEM Shower. CREDIT - www.meteorshowers.org



CREDIT – ESA's NELIOTA

Meteoroid Impacts on Lunar surface

Crater excavation

Seismic wave

Particles ejection

Radiation emission

$$KE = \frac{E_V}{\eta}$$

- Observation: lunar nightside
- Detection: short-lived light flashes
- Magnitude: [+10, +5]
- Duration: < 100 ms

Earth-based monitoring programmes:

MIDAS, Spain (1999–Present)

NASA MSFC, AL, USA (2006–Present)

NELIOTA, Greece (2017–Present)

Non-exhaustive list

Lunar farside space-based observations

Restrictions of Ground-Based Observations

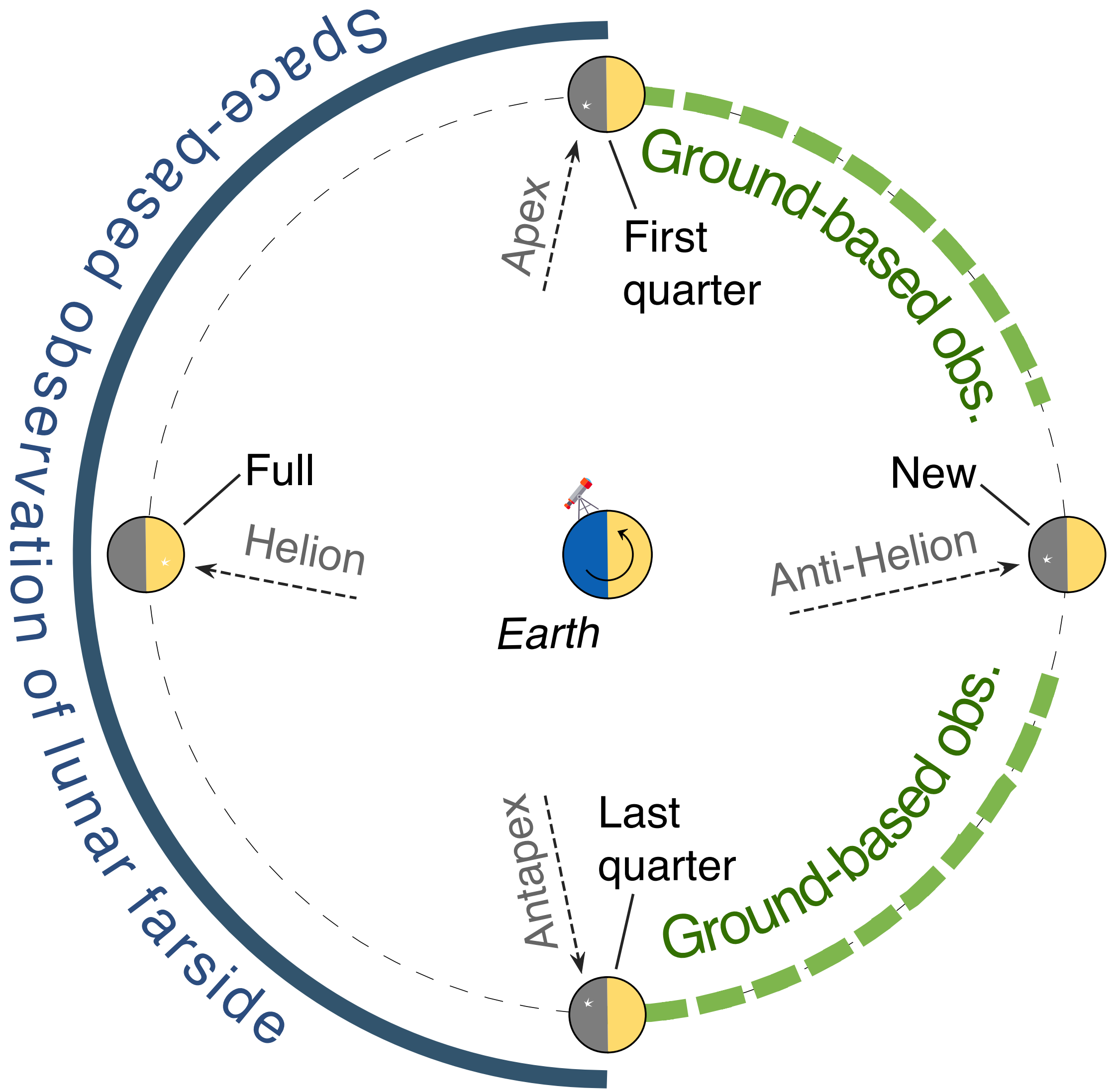
- Possible only during Earth's night
- Only with 10-50% illumination
- Only Apex, Antapex sources detectable
- No full disk possible (straylight)
- Affected by Earthshine
- Constrained by weather
- Signal attenuated by atmosphere

Advantages of Space-Based Observations

- Uninterrupted observations (~15 days)
- Anti-helion, toroidal sources detectable
- Possible simultaneous obs (space+ground)

Observation of lunar farside

√ No Earthshine, high-quality science products
√ Complement ground-based observations



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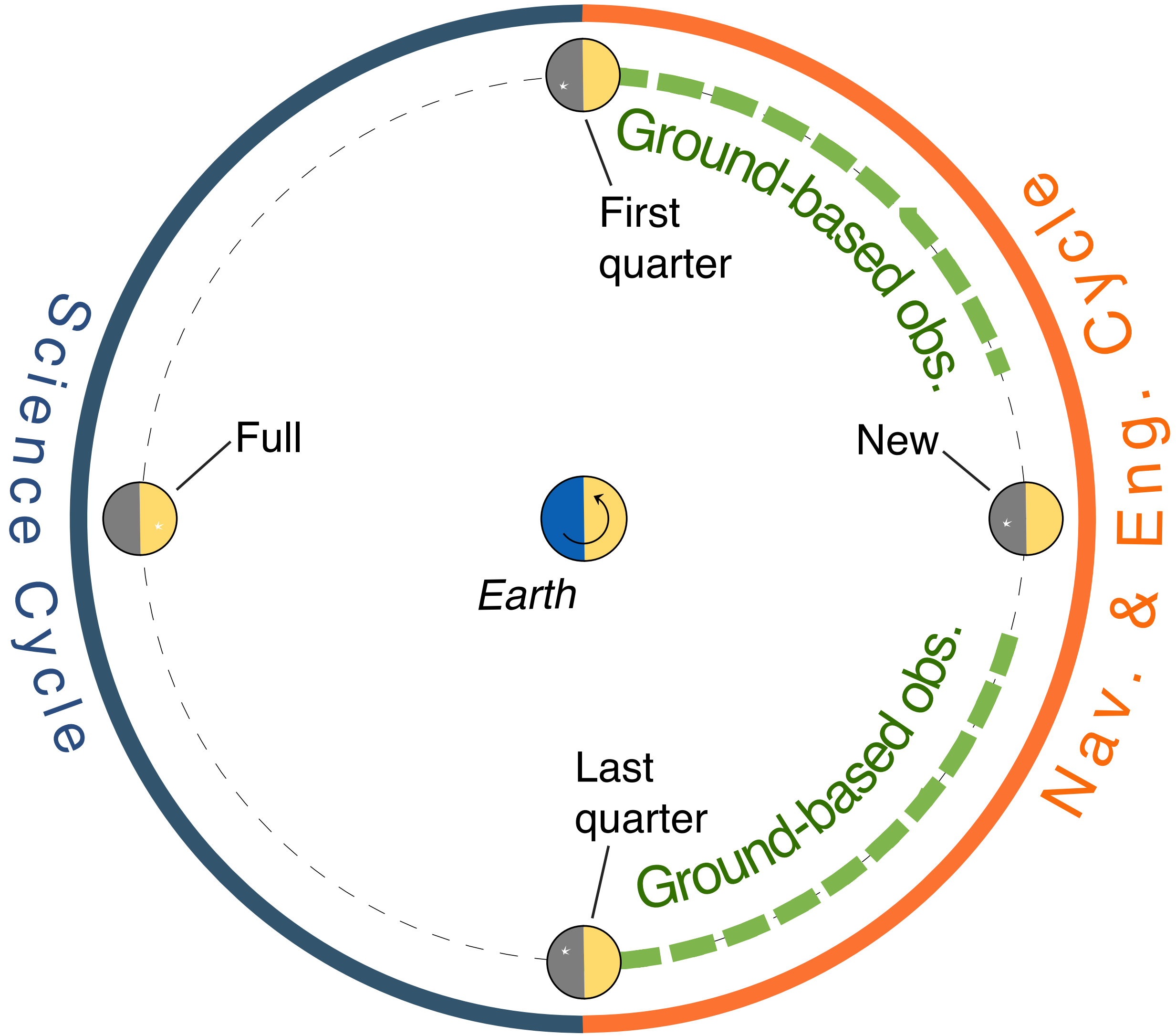
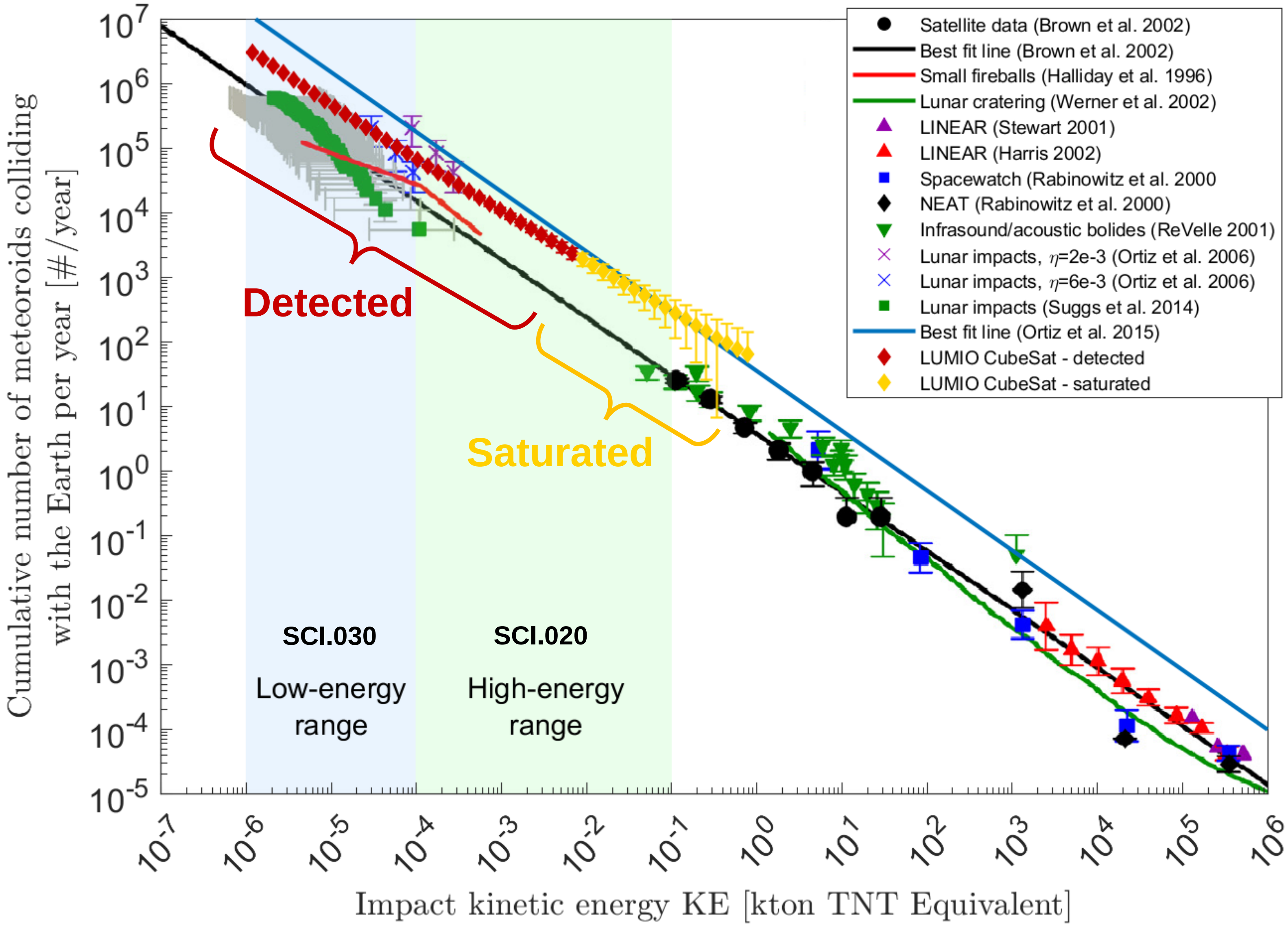


Scientific output

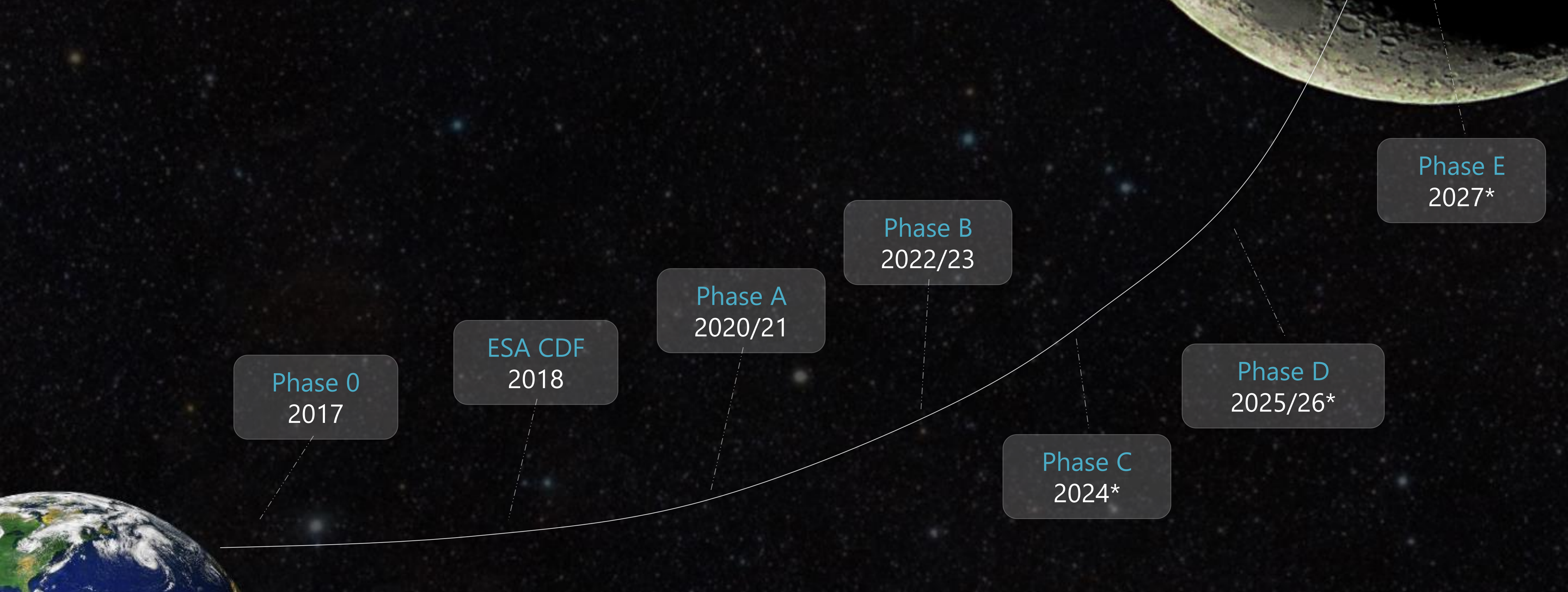


Comparison of the estimated LUMIO lunar CubeSat scientific return with the scientific return of previous programmes. The plot is an elaborated version of Figure 9 in *Suggs et al. (2014)*, courtesy of Dr. R. M. Suggs, Dr. D. E. Moser, Dr. W. J. Cooke, and Dr. R. J. Suggs.

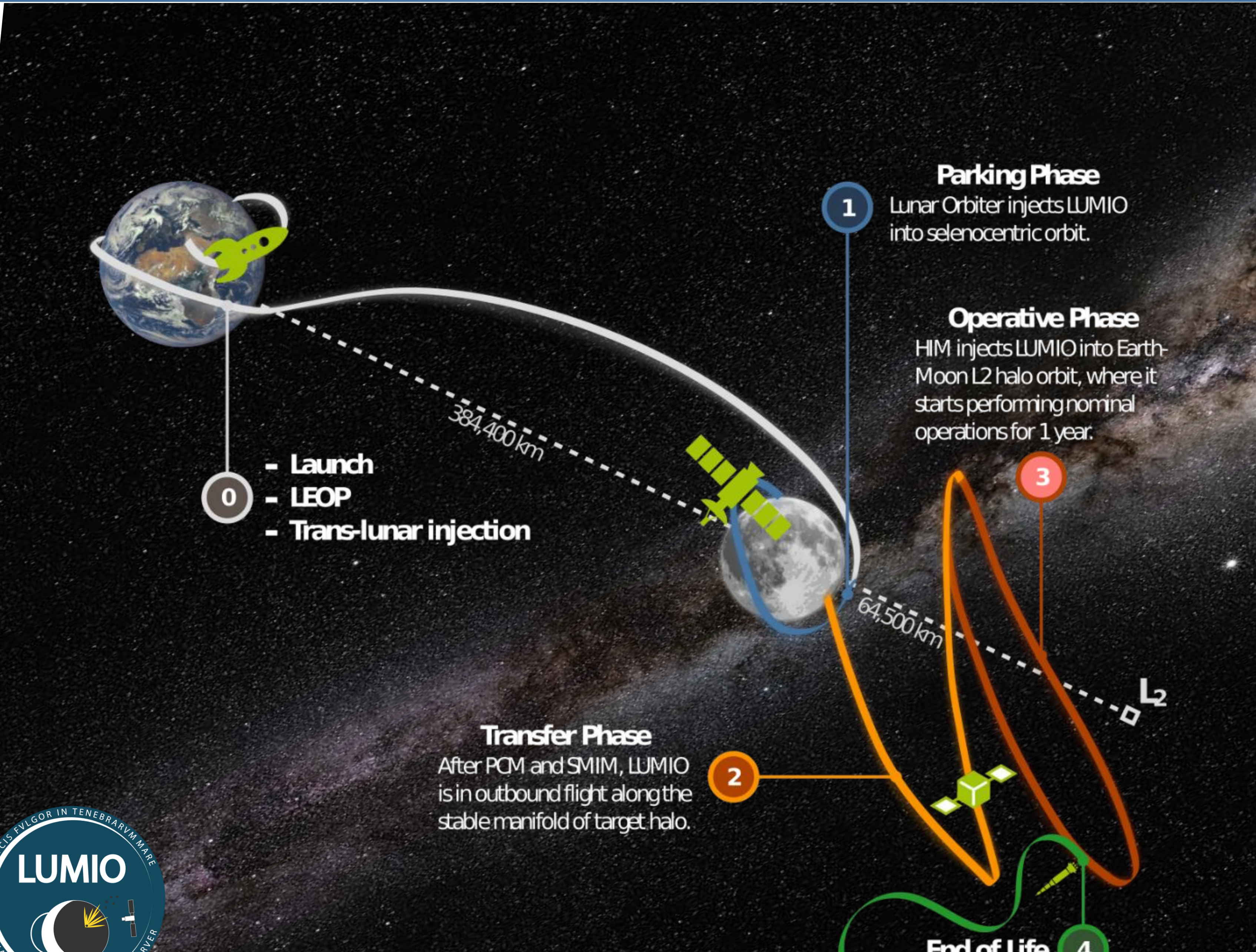
LUMIO mission roadmap

Objectives

- To refine Lunar meteoroid environment model
- To demonstrate Lunar CubeSat technologies



Mission Phases



0) Launch and Earth-Moon transfer
- CLPS
- Release in cis-lunar space

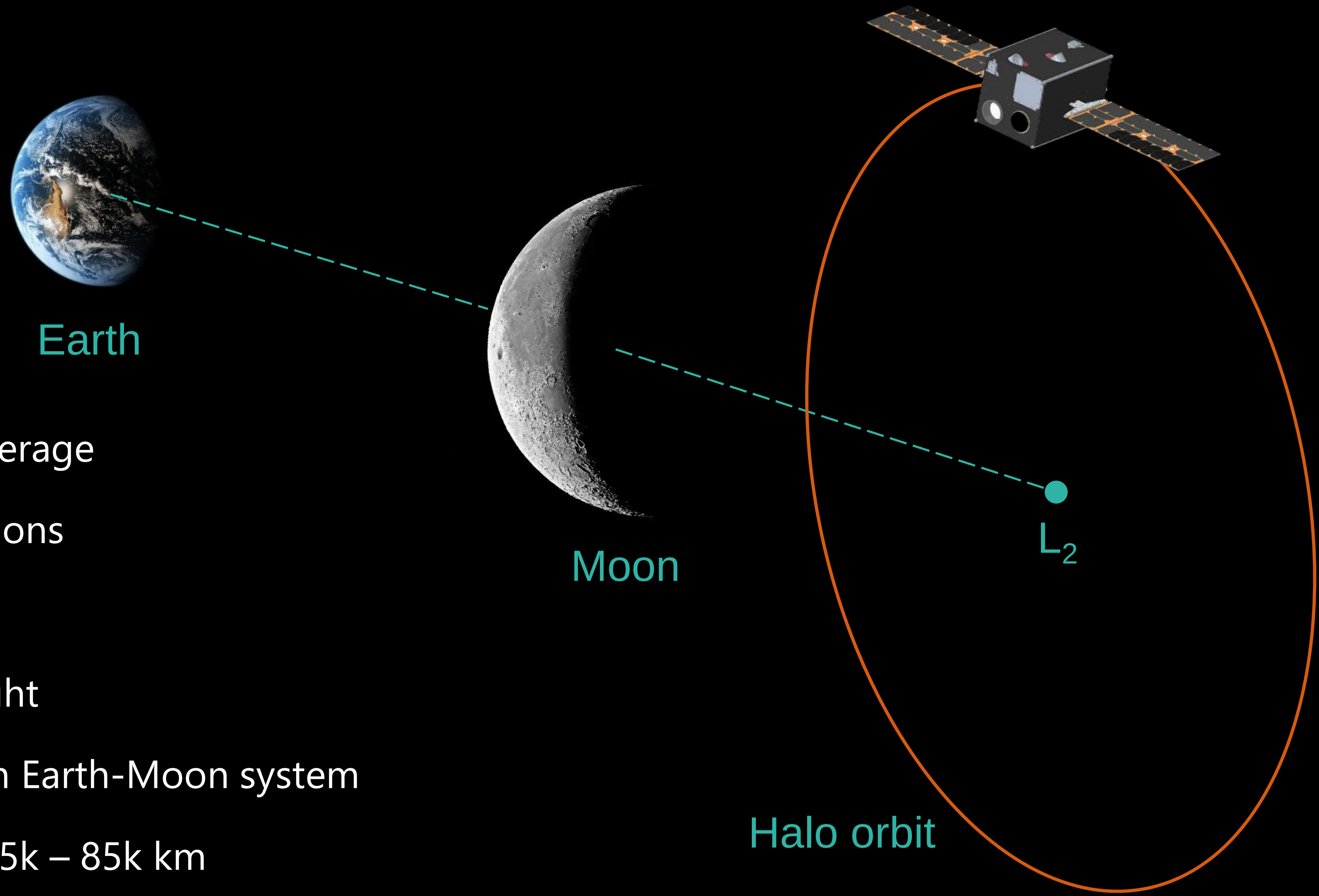
1) Lunar Parking Orbit
- High-Elliptic Lunar Orbit

2) Halo Transfer Phase

3) Operative Phase
- Earth-Moon L2 Halo

4) End of life Phase

Operative Orbit



- ✓ Lunar far-side coverage
- ✓ Full-disk observations
- ✓ Eclipse-free orbit
- ✓ Earth always in sight
- ✓ 2:1 resonance with Earth-Moon system
- ✓ Range to Moon: 35k – 85k km

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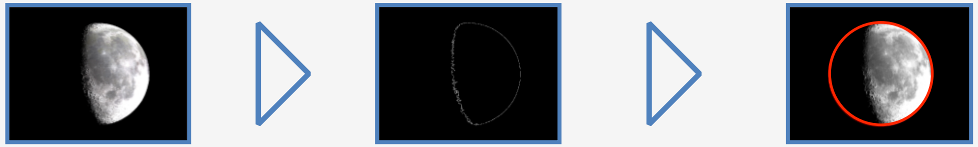
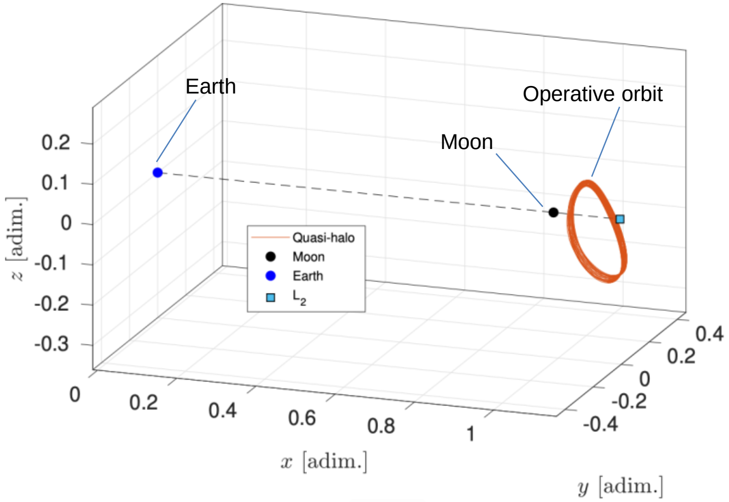
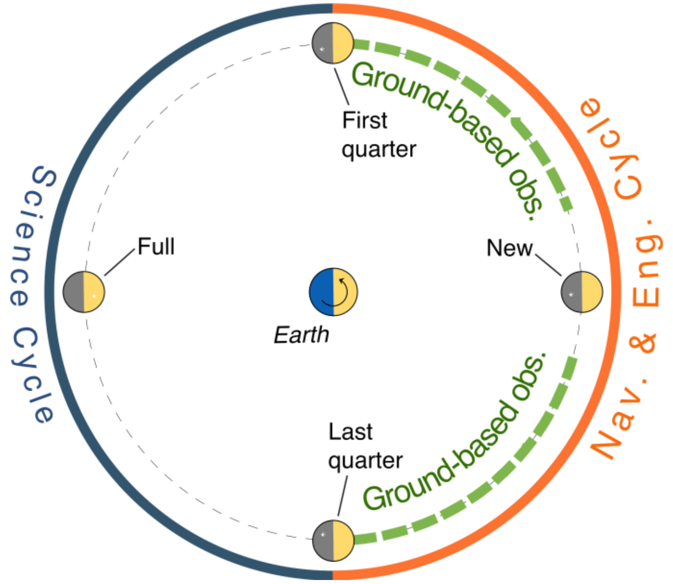
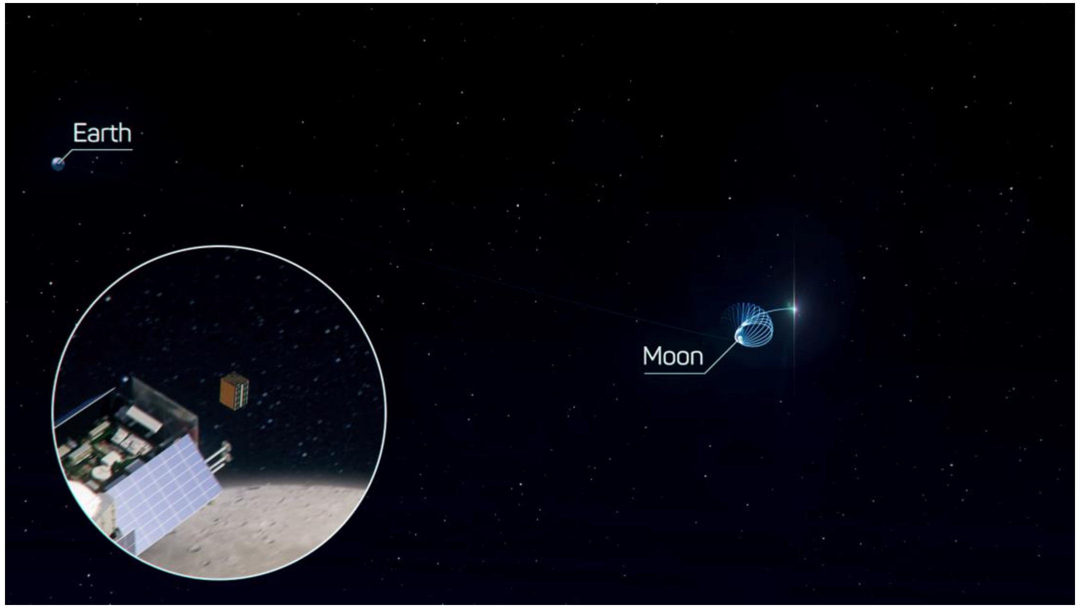
Operative orbit, concept of operations

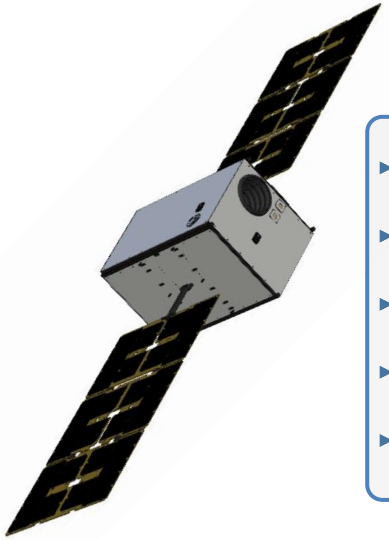
- Operative orbit: L2 halo orbit (farside coverage, Earth & Moon always visible, eclipse free, easily accessible)
- Launch options: CLPS (baseline), Artemis 2 (backup)
- Cost: Δv of 120 m/s (baseline) or 200 m/s (backup)
- Navigation: radiometric (baseline), optical (tech demo)











- 12U (XL) form factor, 2 deployable solar arrays
- Design lifetime: 1.5 years in lunar environment
- Mass: <26 kg; Power: ~110 W generation
- DTE link: X-band (radio nav, P/L data, safe T&C, 1 GS)
- ISL link w/ LPF (TBC): S-band (nominal T&C)

The LUMIO Science Team

Scientific Board

- **Francesco Topputo** – Principal Investigator
- **Fabio Ferrari** – Science Lead
- **Detlef Koschny** – TUM
- **Richard Moissl** – ESA
- **Eleonora Ammannito** – ASI

Science Working Groups

International collaborators:
Alceste Bonanos (NELIOTA)
Mark Robinson (LRO/LROC)
David Paige (LRO/Diviner)
Jean-Pierre Williams (LRO/Diviner)

Topics covered:
Lunar surface characterization
Meteoroid impact modelling
Meteoroid orbital dynamics
Lunar environment & SSA
Radio Science

Science Operation Center

- Operations Planning
- Payload Data System

Selection of SWG chairs and members is now in progress (approx. 25-30 people)

LUMIO mission consortium

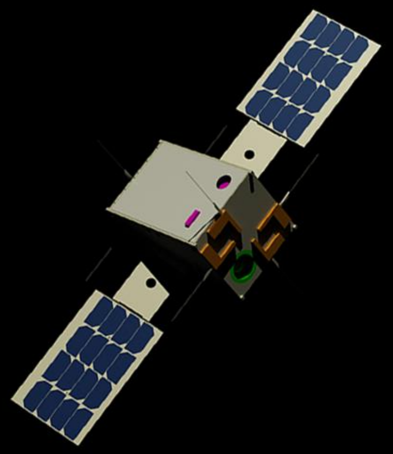
Main funding body

Project Coordination

Funding body

POLITECNICO MILANO 1863	Prime Contractor Project Management Science, MA, AOCS/GNC
argotec	Platform Provider
LEONARDO	Payload Provider
IMT Ingegneria Marketing Tecnologia	X-band & SADA Provider
NAUTILUS Navigation in Space	Ground Segment Design & Flight Dynamics Operations
s[&]t	Onboard Payload Data Processing

Title Text



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LUMIO Lunar CubeSat

Payload Design

Roma

13.02.2023

Electronics

Helicopters

Aircraft

Cyber & Security

Space

Unmanned Systems

Aerostructures

SUMMARY

- LUMIO-Cam Overview
- Optical Head
- Focal Plane Assembly
- Proximity Electronics
- Conclusion

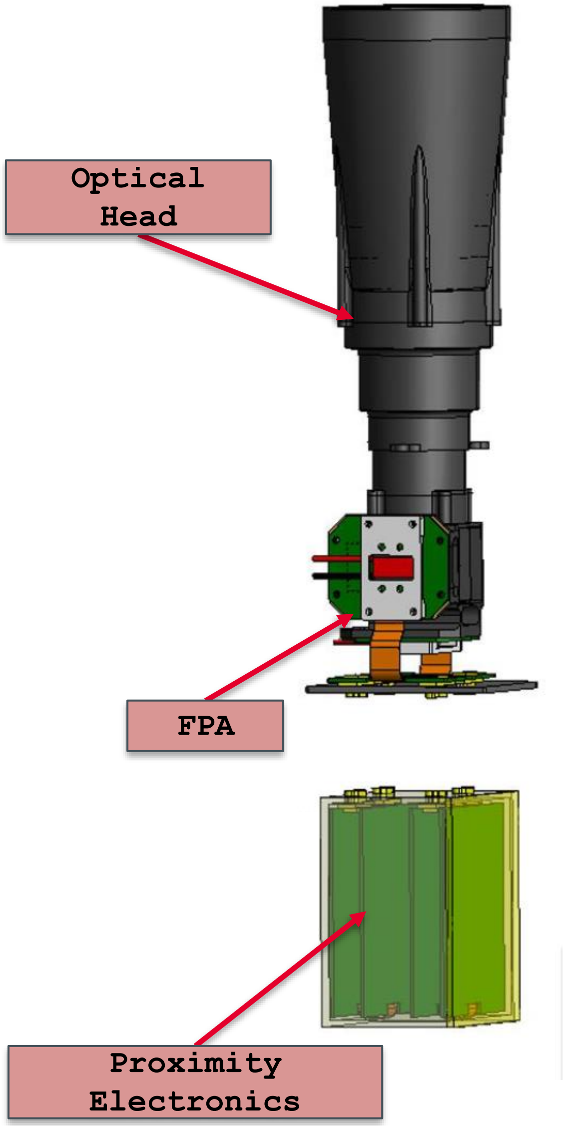
LUMIO-Cam

Overview

- The LUMIO-Cam is an optical payload aiming at acquiring signals coming from the **meteoroids impacts** on the Moon surface.
- It has been designed to fit in a **12U CubeSat** structure, with a total mass of **3 Kg**
- The FoV has been dimensioned to observe the **full Moon disk.**
- Acquisitions are performed within **450 nm and 950 nm spectral region.**
- The LUMIO-Cam is capable of performing two synchronous acquisitions by **splitting the incoming radiation** into two different spectral bands → to avoid false positive

The current design is composed of three main components:

- **Optical Head** → Baffle, Optical Barrel and the Dichroic Cube (beam splitter)
- **Focal Plane Assembly (FPA)** → CCD Detectors and Thermo-Electric Cooler
- **Proximity Electronics** → 1U box containing all electronic elements

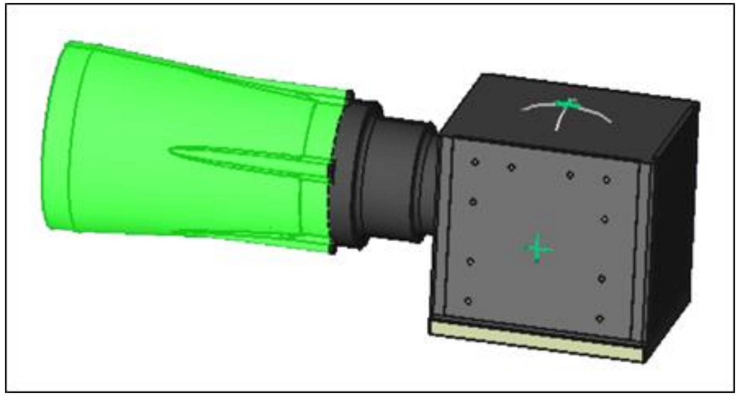


LUMIO-Cam: Optical Head

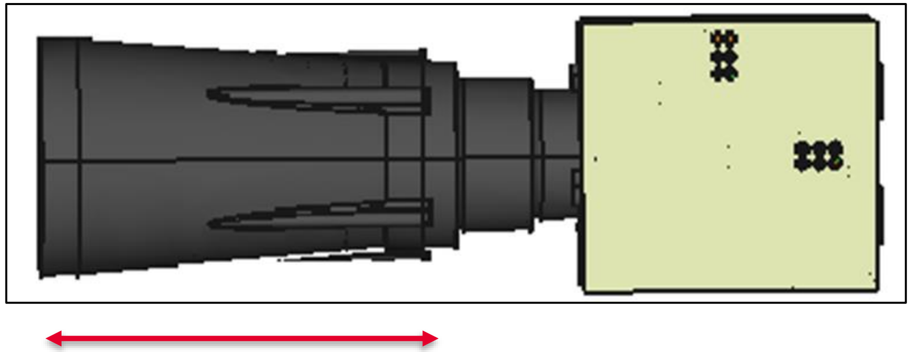
Baffle

- It has been designed to reduce the Straylight signal coming from the Sun during the payload acquisitions and then to grant the required Signal-to-Noise Ratio (SNR ≥ 5dB).

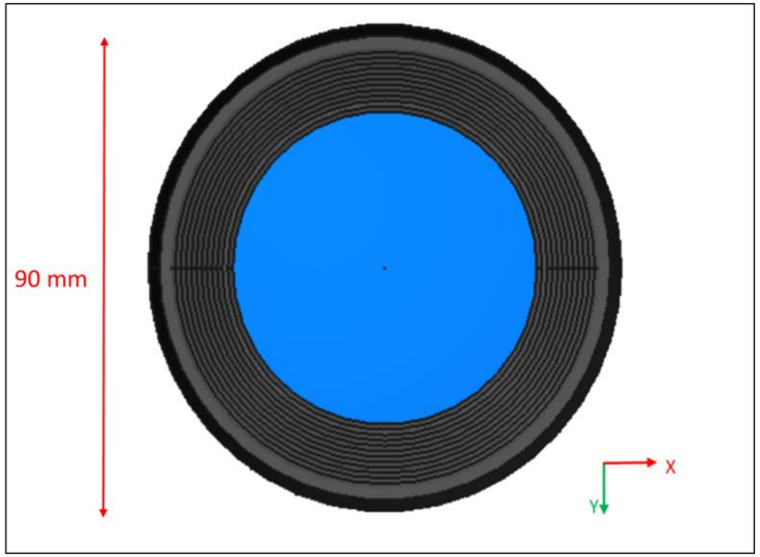
- To meet the scientific requirements and to grant the acquisition period window the **Straylight suppression** has to be performed with a factor of 10^-6 in an incidence angles range between 5 deg and 10 deg → this can be achieved by dimensioning a baffle with a **length of 150 mm**.



Baffle
(highlighted in green)



150 mm



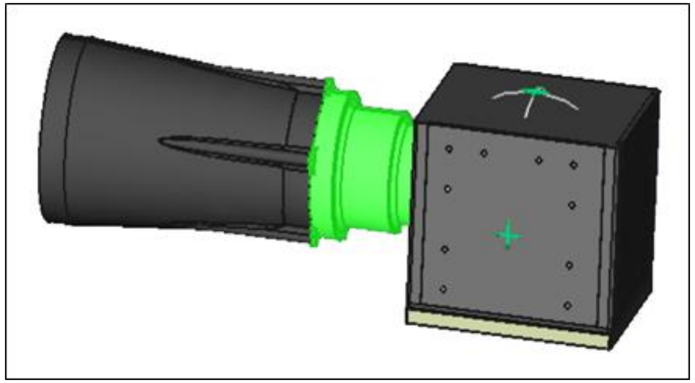
Baffle Entrance Aperture Diameter of 90 mm

LUMIO-Cam: Optical Head

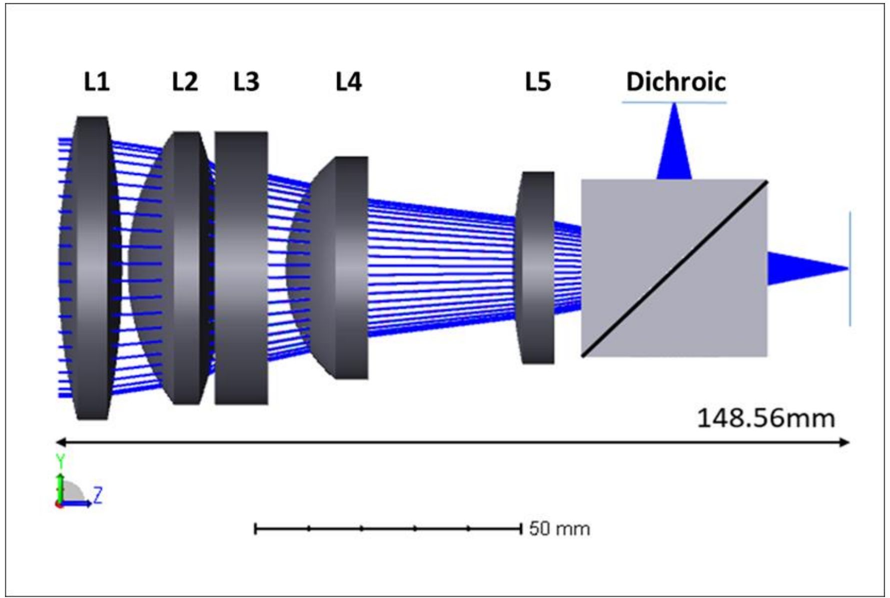
Optical Barrel

- The LUMIO-Cam current design of the Optical Barrel is a dioptric objective composed of **5 lenses**

- FoV of ±3° → dimensioned considering 35000 km of distance between the LUMIO-Cam and the Lunar surface



Optical Barrel
(highlighted in green)

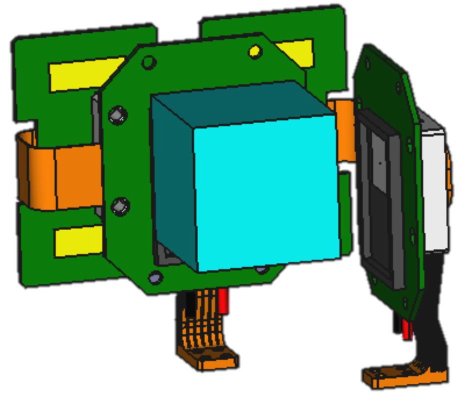


Optical Layout

Optical Main Parameter	
Focal Length	127 mm
Aperture Diameter	50.8 mm
F#	2.5
FoV	±3°

LUMIO-Cam: Optical Head

Dichroic Cube

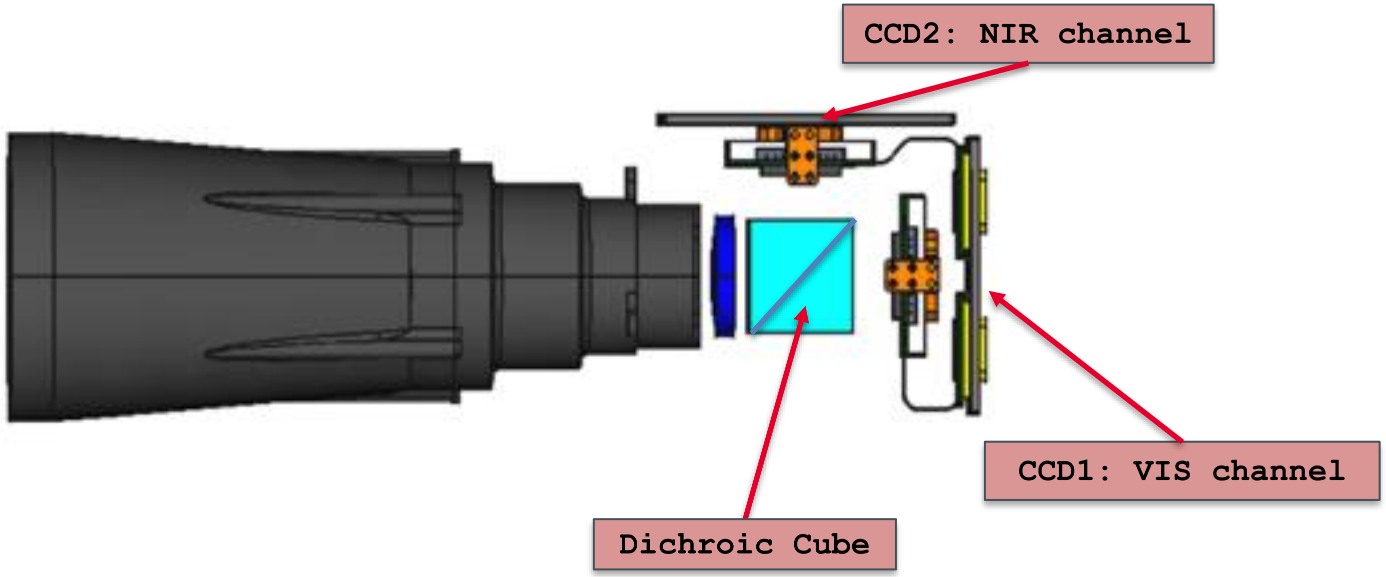


- The Beam Splitter is a **Dichroic Cube** which has been positioned before the two detectors in order to split the incoming radiation → enabling the correlation of the impact flashes signal acquired both in the VIS and NIR spectral bands

- The radiation splitting angle is 90 deg

- The Dichroic splitting wavelength is at 820 nm, incoming radiation is the split into 2 spectral channels.

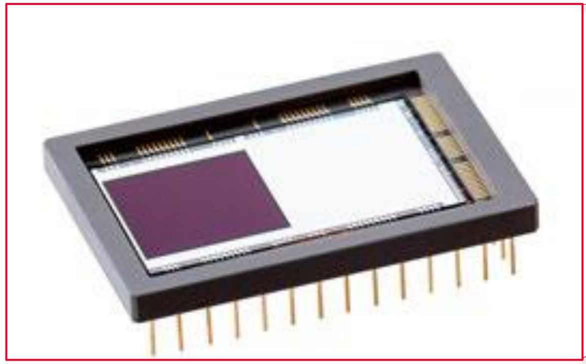
VIS Channel : 450 nm to 800 nm
NIR Channel : 850 nm to 950 nm



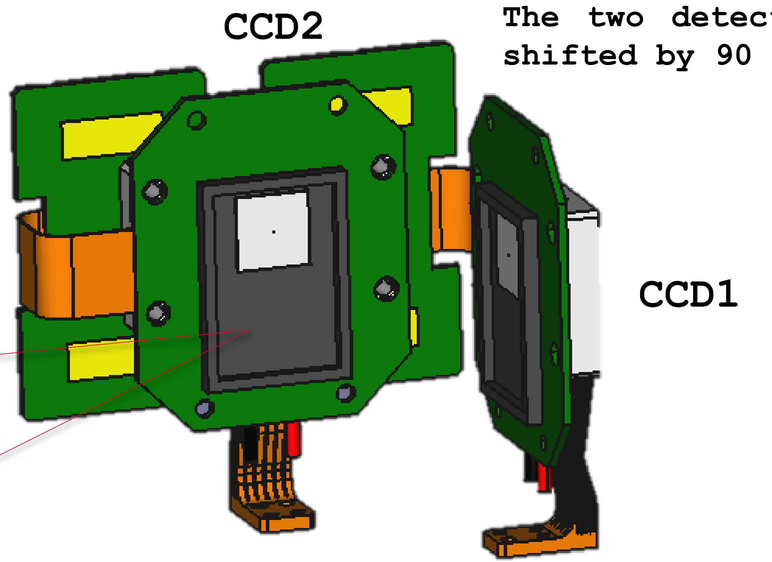
LUMIO-Cam: Focal Plane Assembly

CCD Detectors

- The selected detector for the LUMIO-Cam is the **CCD201-20** (by Teledyne)
- Two identical CCD201-20 will be positioned after the Dichroic Cube



The two detectors are shifted by 90 deg



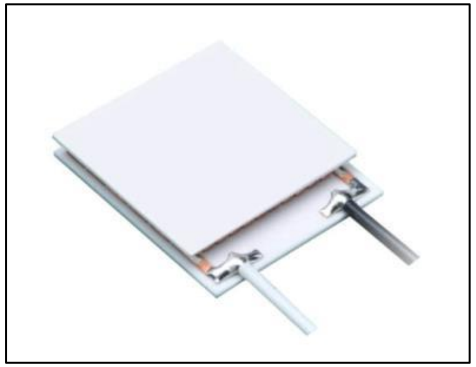
- The CCD201-20 is a frame transfer electron multiplying sensor designed for extreme performance in high frame rate and ultra-low light applications.
- The charge is multiplied in the gain register prior to conversion to a voltage by the Large Signal Output amplifier (OSL).

CCD201-20	
Pixel dimension	13 µm
Number of pixels	1024 x 1024

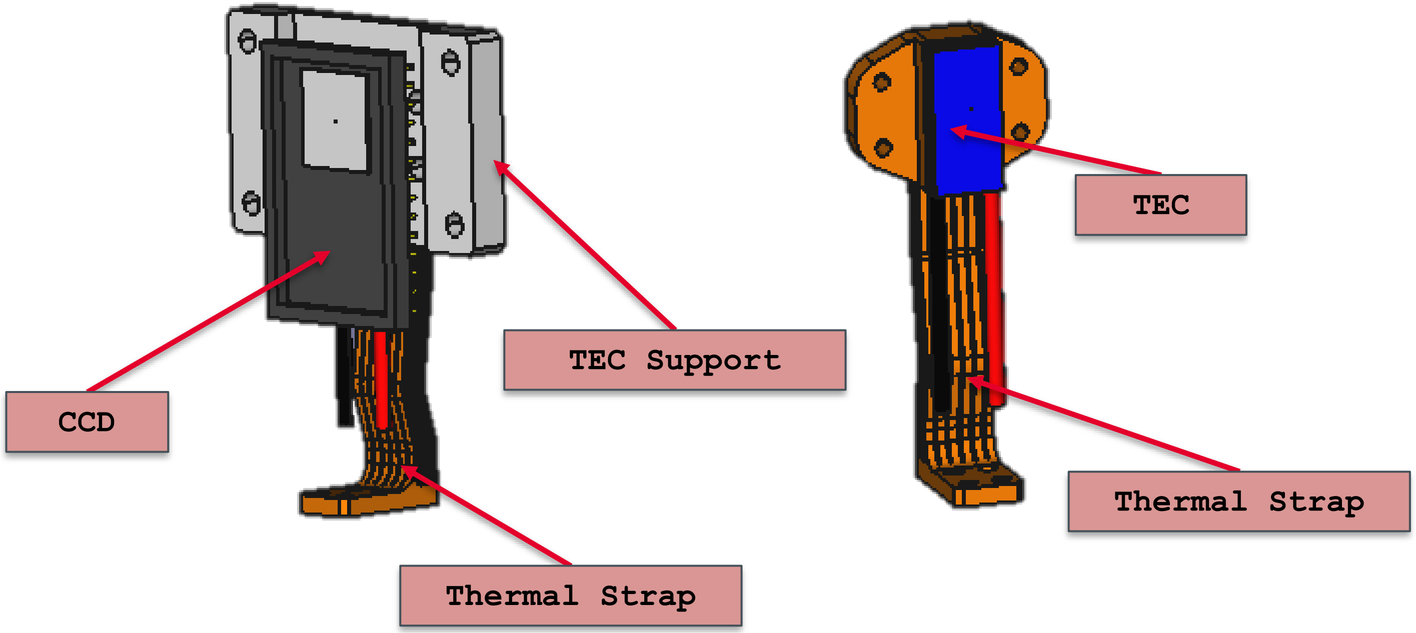
LUMIO-Cam: Focal Plane Assembly

Thermal Design

- Thermal architecture developed to stabilize the Focal Plane Assembly **temperature**
- **Two TEC** have been coupled with each detector
- Dissipated power heat generated by the electronics will be ejected through a **radiator**, thanks to **thermal straps**



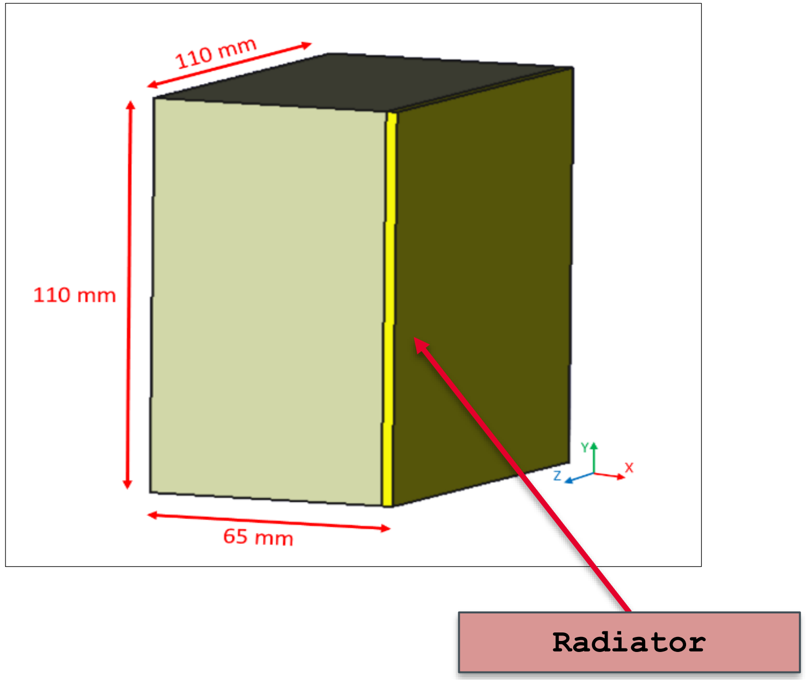
Single Stage TEC



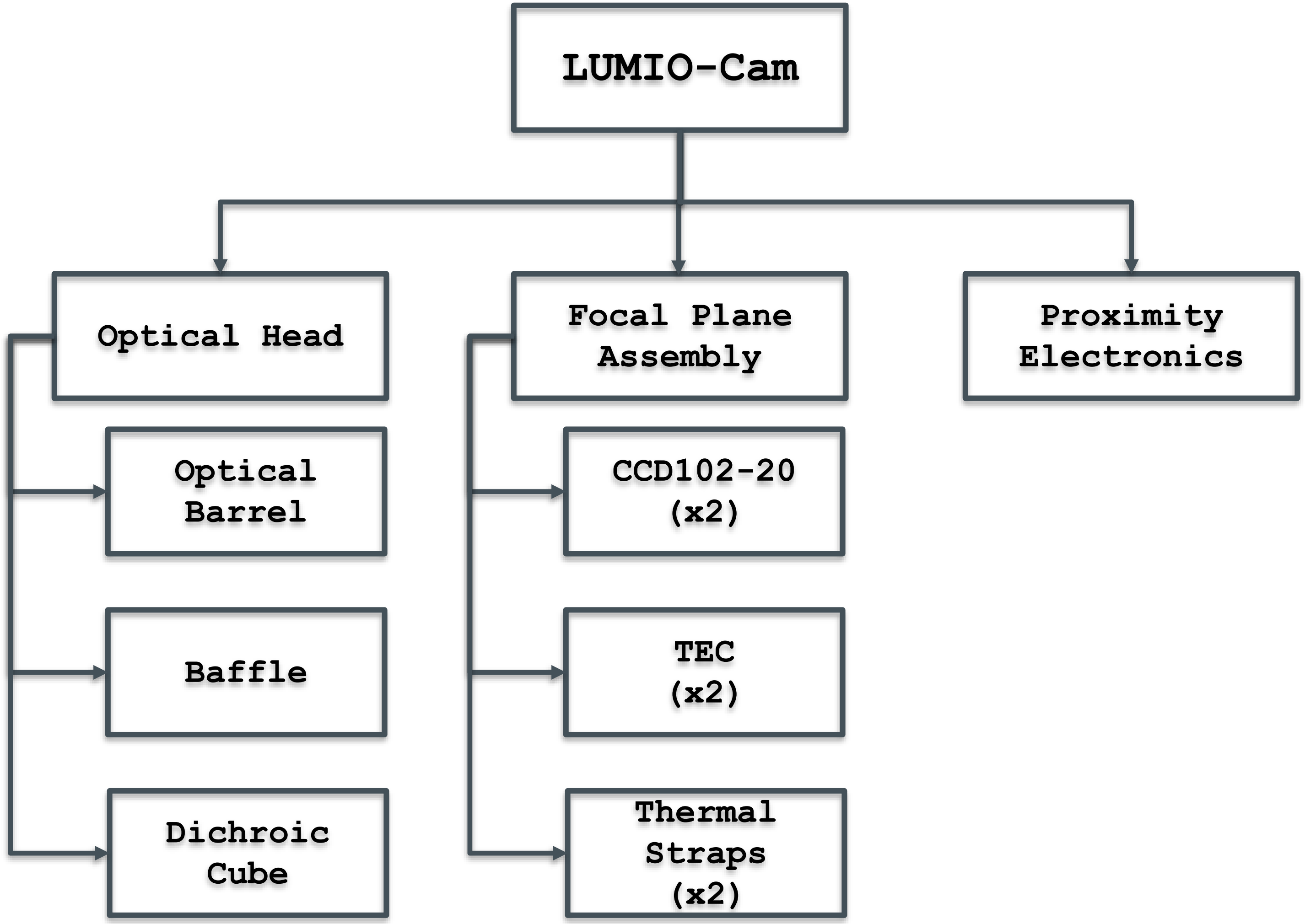
Copper Thermal Strap

LUMIO-Cam: Proximity Electronics

- The Proximity Electronic has the role of **managing and conditioning the two detectors' acquisition** of the digital signals.
- It manages the acquisitions of the **housekeeping parameters.**
- It governs the **Interfaces** with the Main Electronic.
- The Proximity Electronics current design occupies the 60% of 1U of the CubeSat
- The current design includes the PE radiator



LUMIO-Cam: Block Scheme



LUMIO-Cam: Status / Conclusion

- The LUMIO-Cam project is at pre-SRR level (Phase B) and therefore in coming months a refinement of the design will be done accordingly to the SRR outcomes.

- No specific critical points have been identified during Phase A for the design and future development but an iterative work with bus provider is needed to find the best accommodation hypothesis on the bus itself.

- The LLIs have been identified (i.e. detectors and dichroic cube) and an hypothesis of procurement strategy to guarantee the current schedule has been defined and discussed with possible components providers.

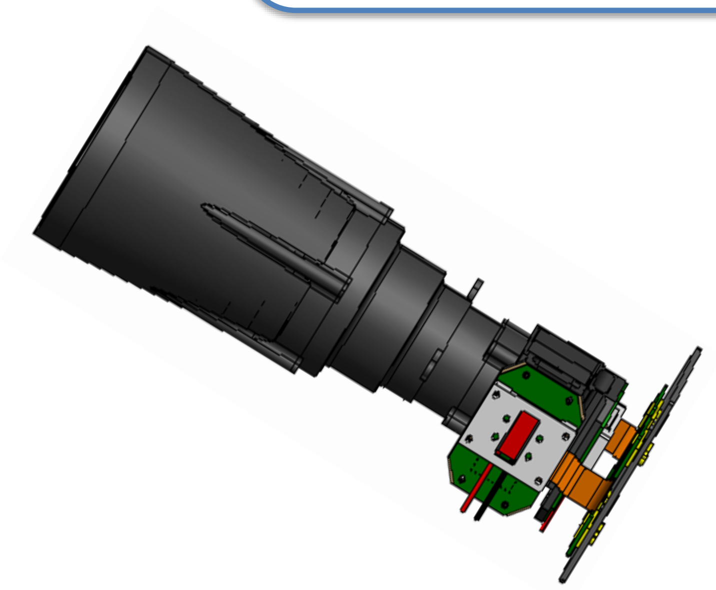
POE simulation

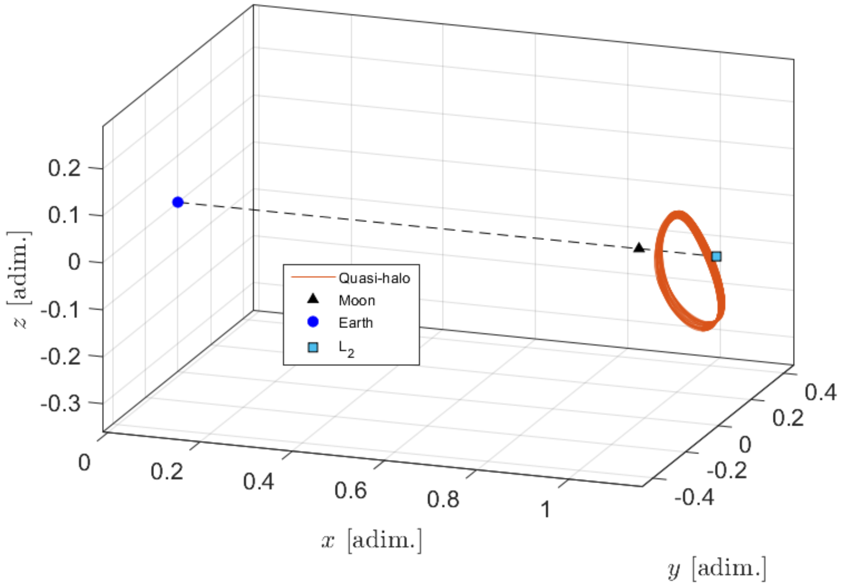
LUMIO-POE

Payload
LUMIO-Cam model

Orbit
Trajectory & attitude

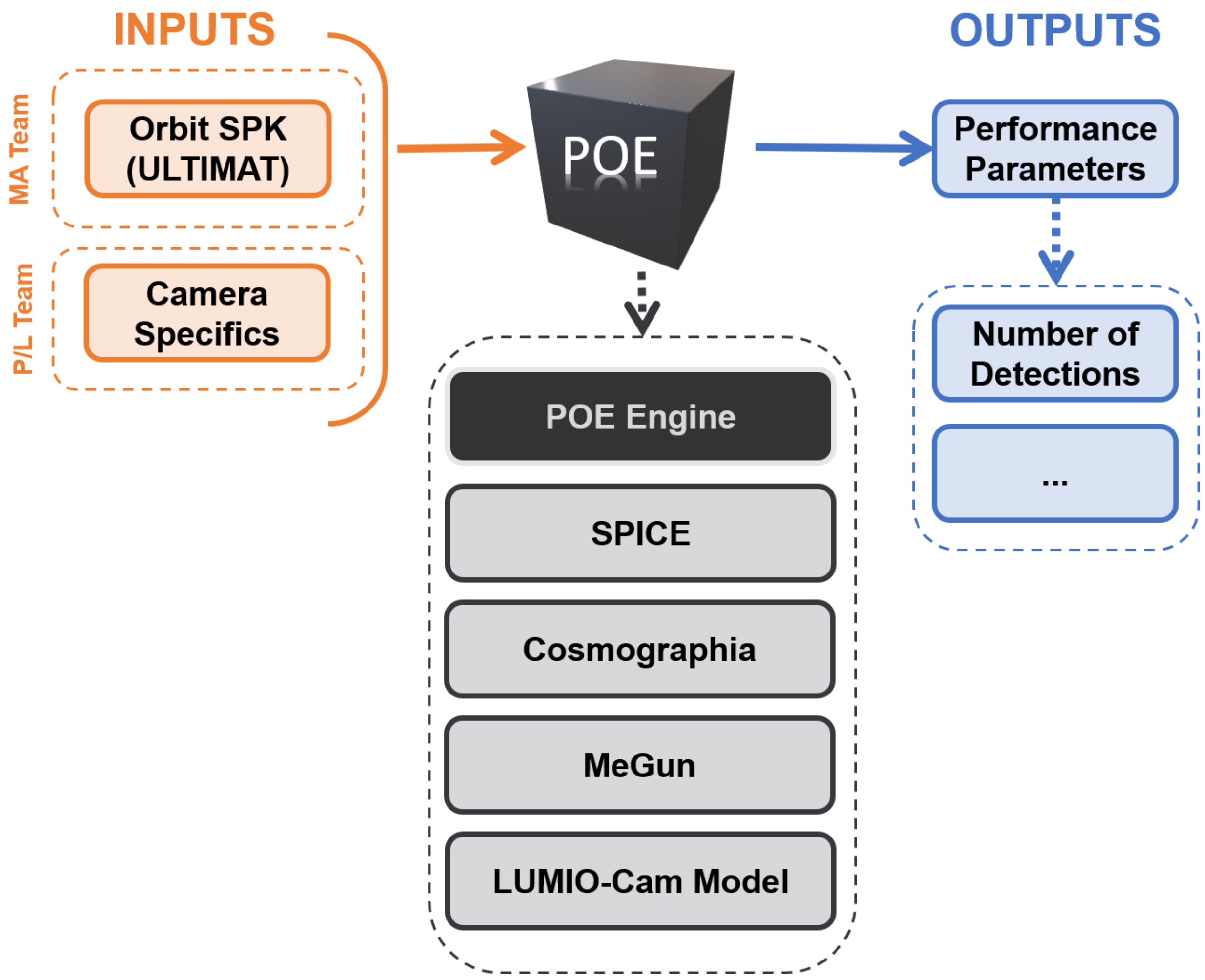
Environment
Meteoroids generation

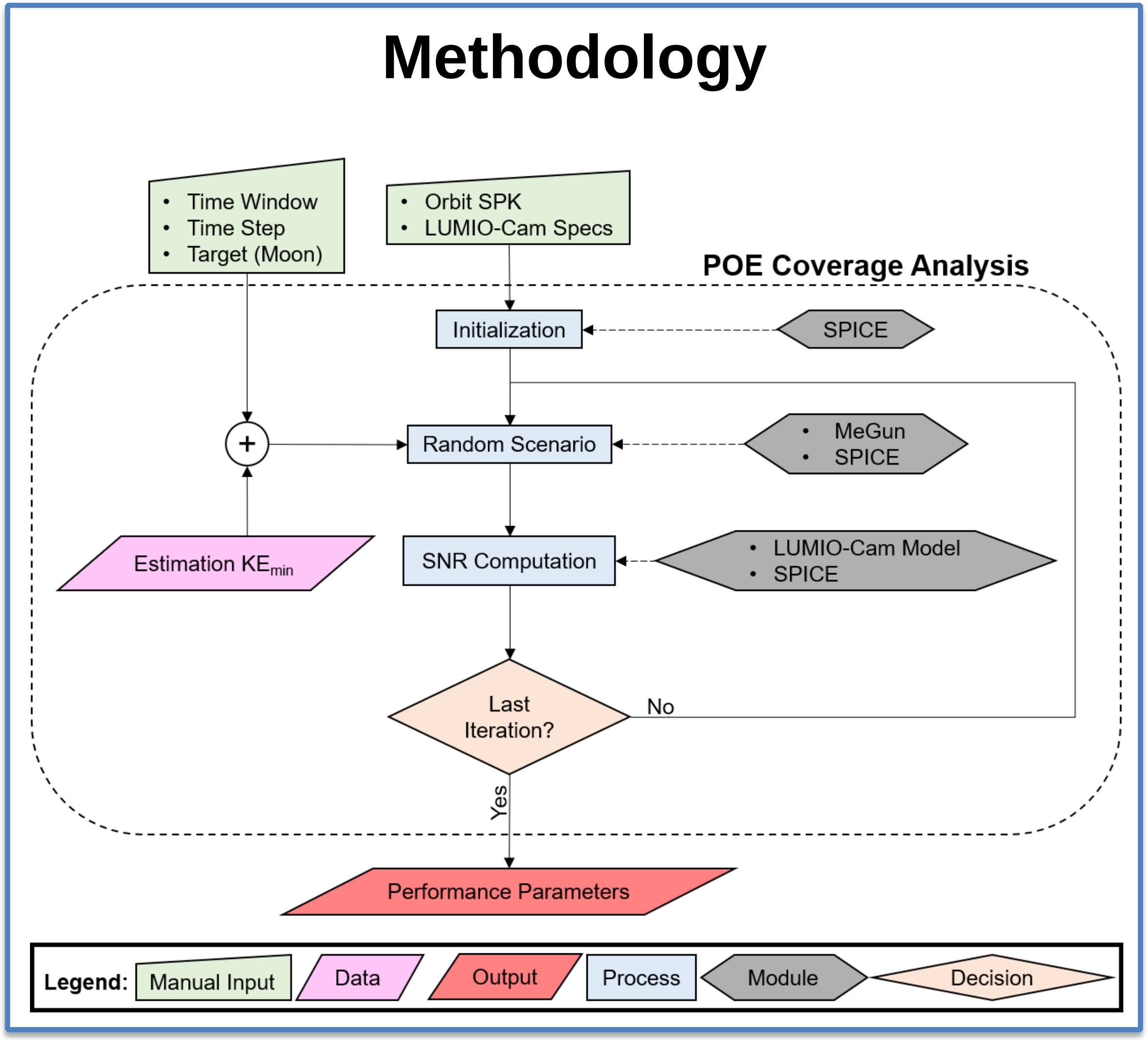




MeGun
(Meteoroid Gun)

POE simulation (*cont'd*)





Merisio G., and Topputo F. "Present-day model of lunar meteoroids and their impact flashes for LUMIO mission." *Icarus* 389 (2023): 115180. DOI: 10.1016/j.icarus.2022.115180.

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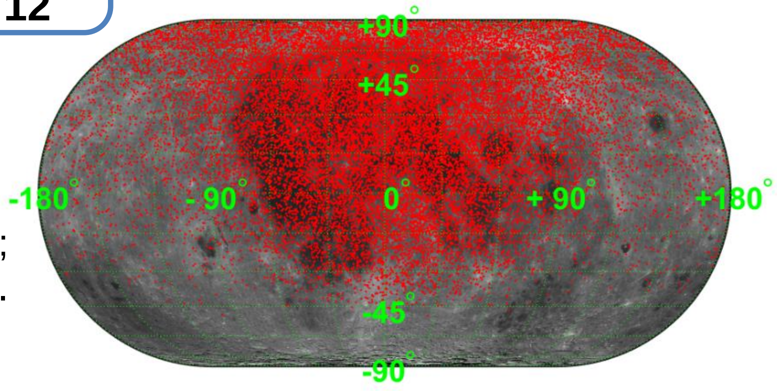
MeGun: Meteoroid environment simulation

Perseids
Code: **PER**
Peak: **Aug 12**

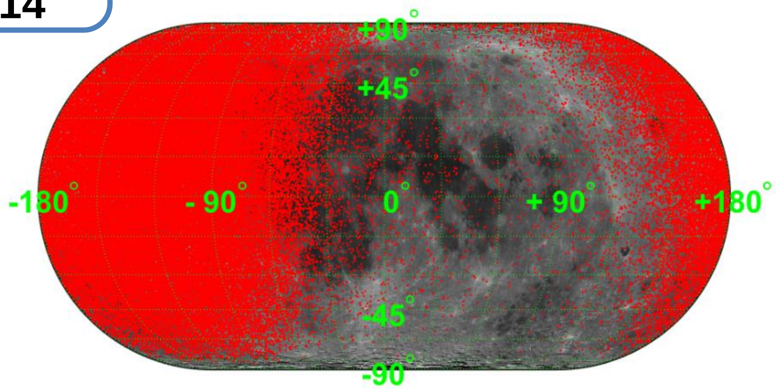
Many impacts in the near side



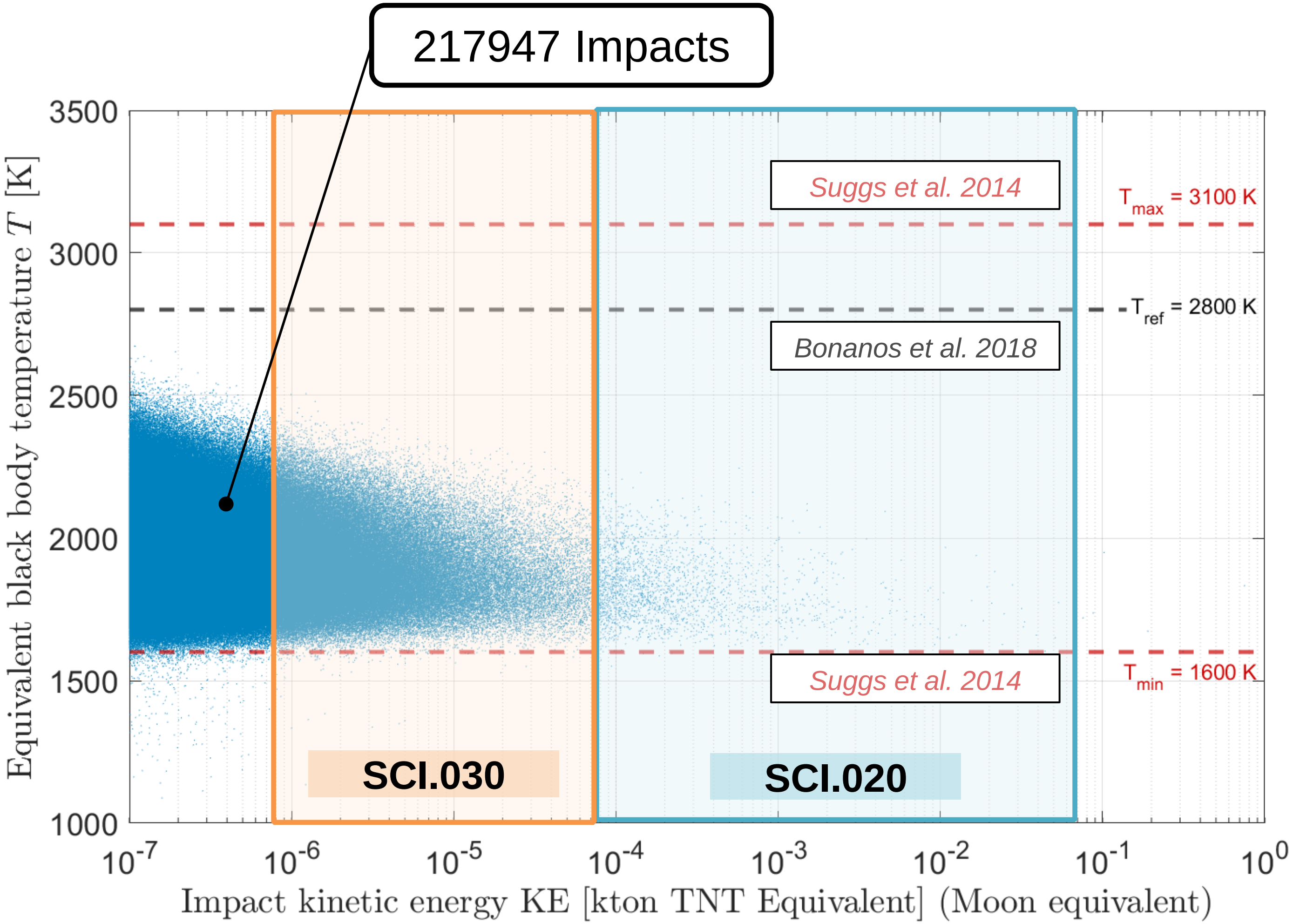
PER impacts; Moon 2024.

Geminids
Code: **GEM**
Peak: **Dec 14**

Many impacts in the farside

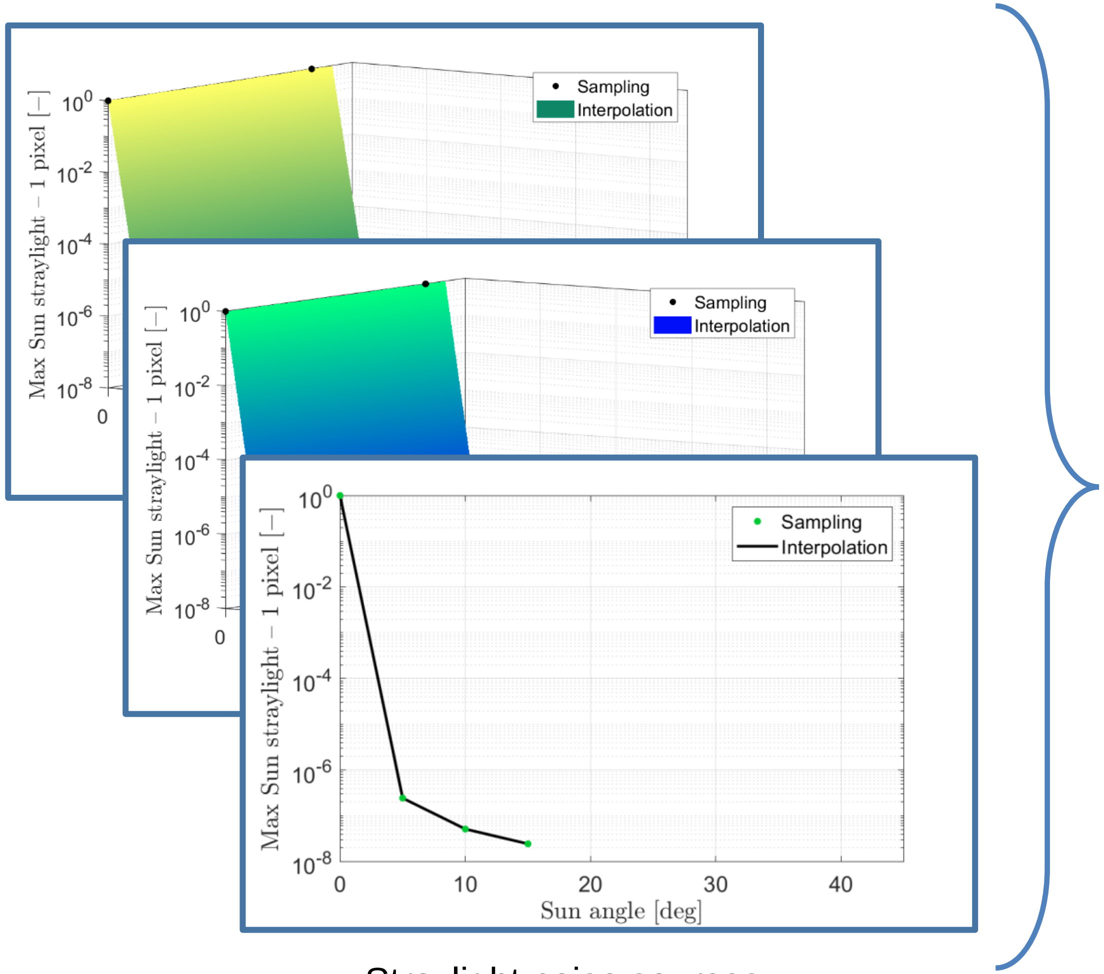


GEM impacts; Moon 2024.

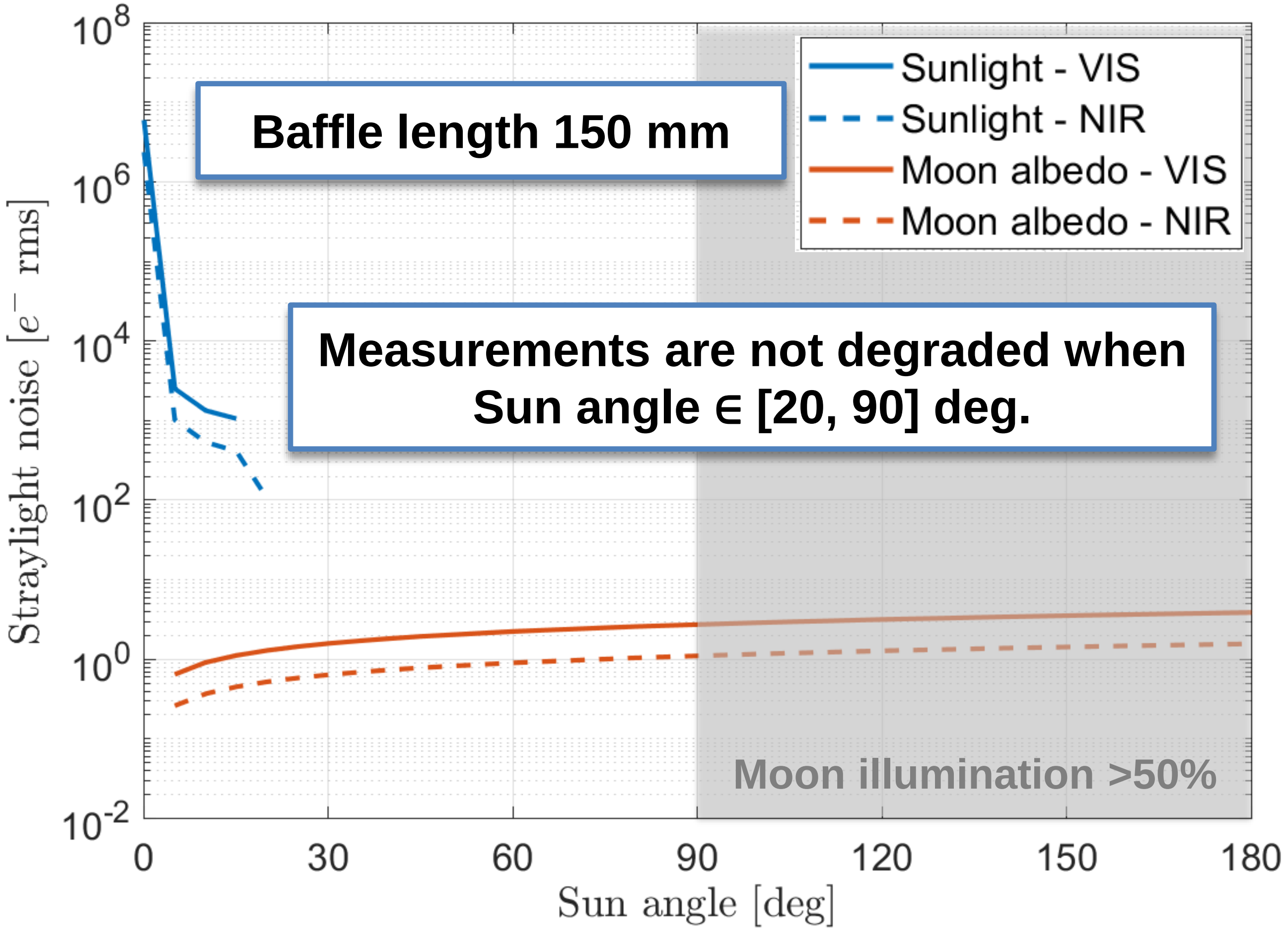


Radiating plume equivalent black body temperatures of lunar impacts in 2024.

Straylight analysis



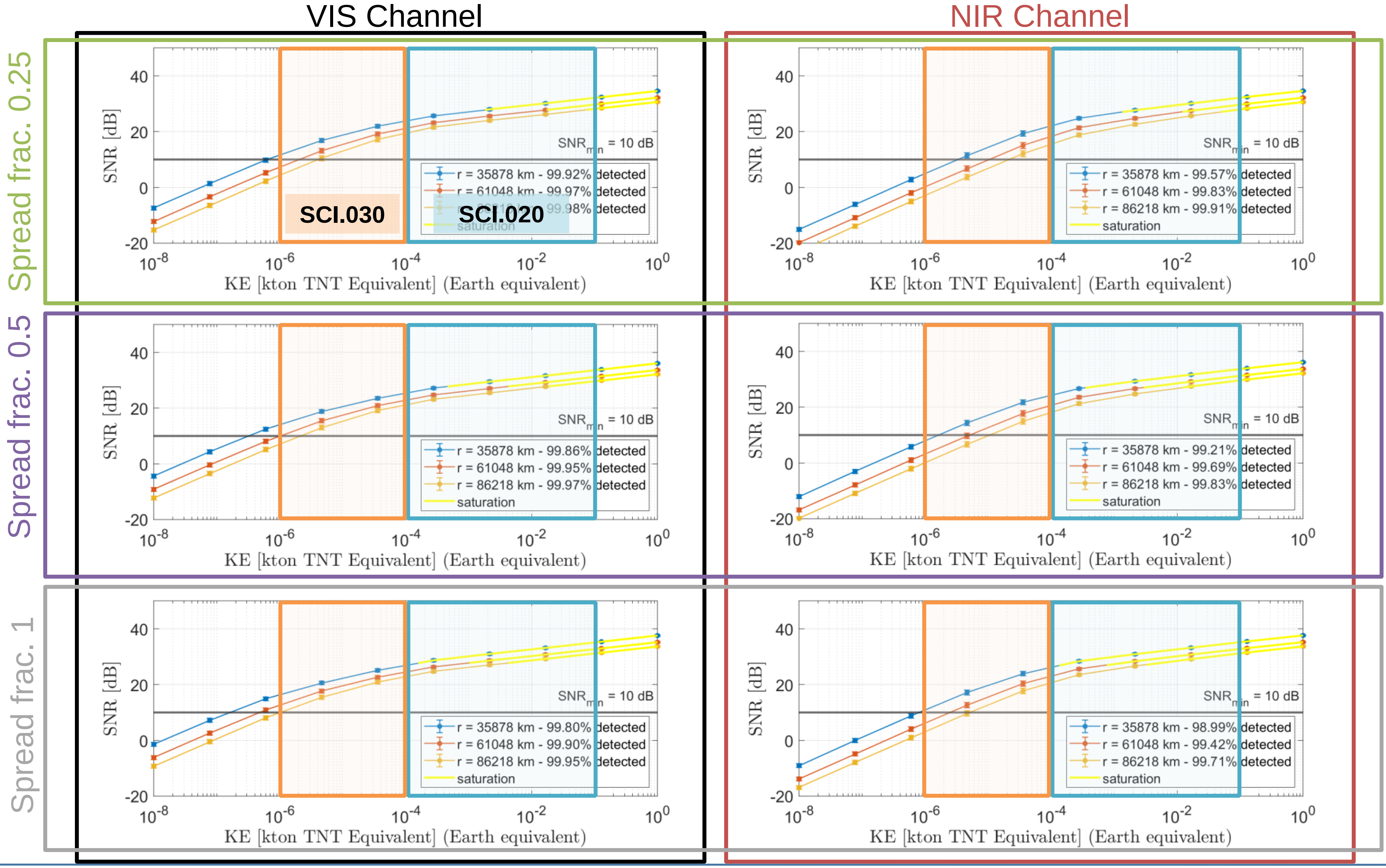
Straylight noise sources.



Straylight noise as a function of the Sun angle in one pixel.

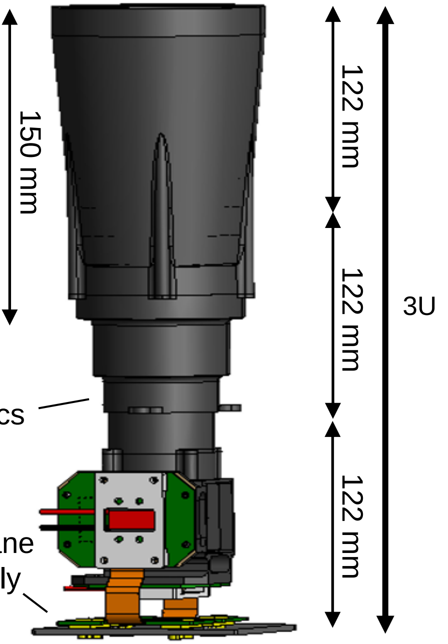
Topputo F., et al. "Meteoroids detection with the LUMIO lunar CubeSat." *Icarus* 389 (2023): 115213. DOI: 10.1016/j.icarus.2022.115213

Radiometric analysis



<u>2 Channels</u>: VIS & NIR

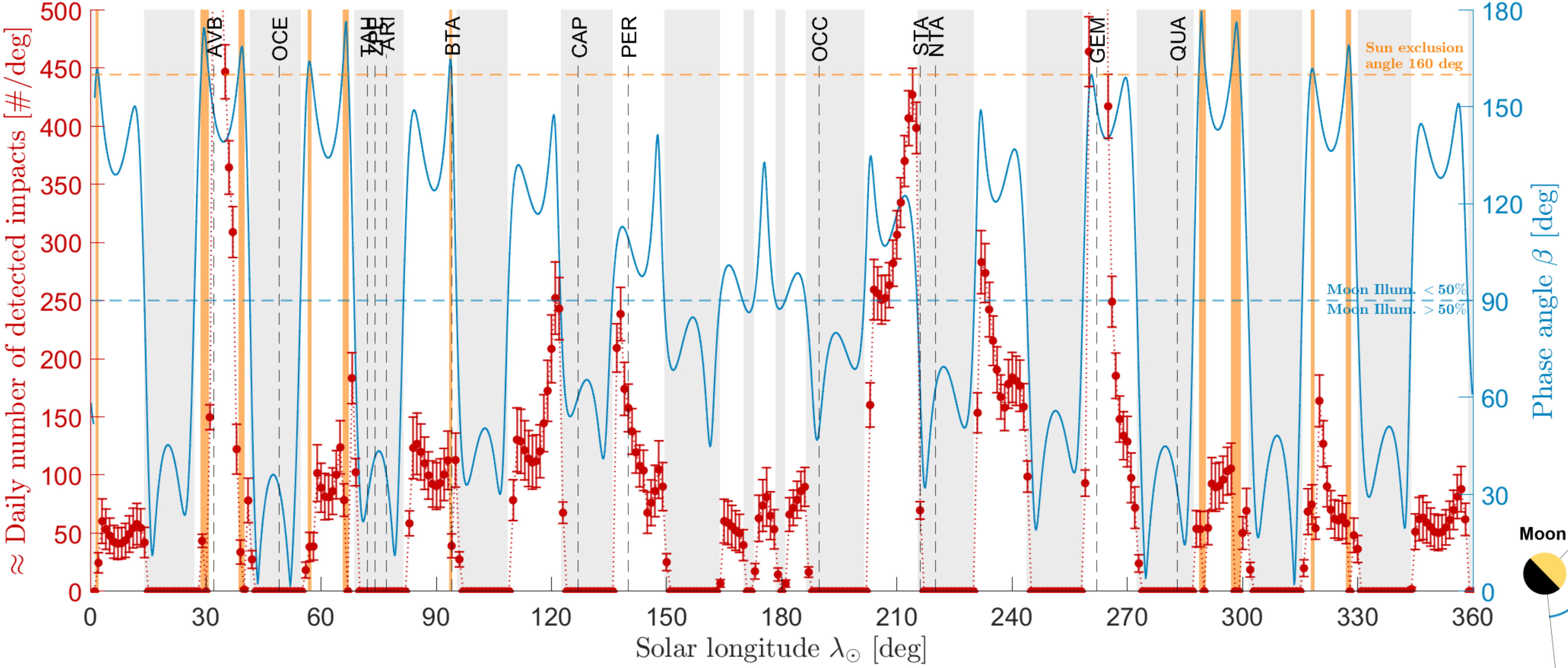
λ_{dic} = 820 nm

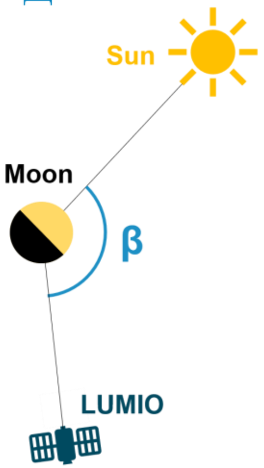


LUMIO-Cam.

Radiometric analysis about impact flash detections. Gain fixed to 10. 1000 events simulated for impact kinetic energy.

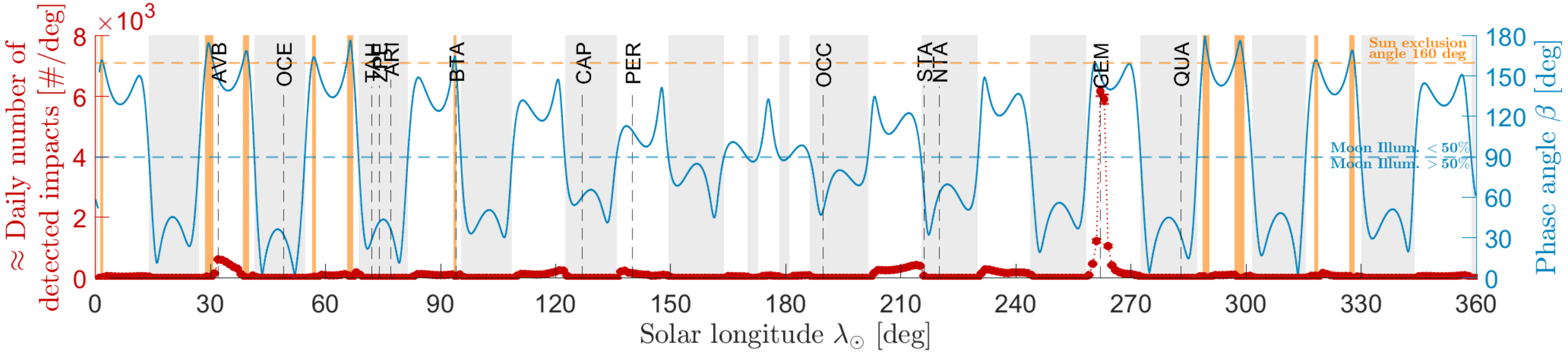
Temporal distribution of detections





Estimation of the temporal distribution of the lunar impacts detected by the LUMIO lunar CubeSat. Impact kinetic energy $KE \geq 10^{-6}$ kton TNT Equivalent (Earth equivalent). Magnification.

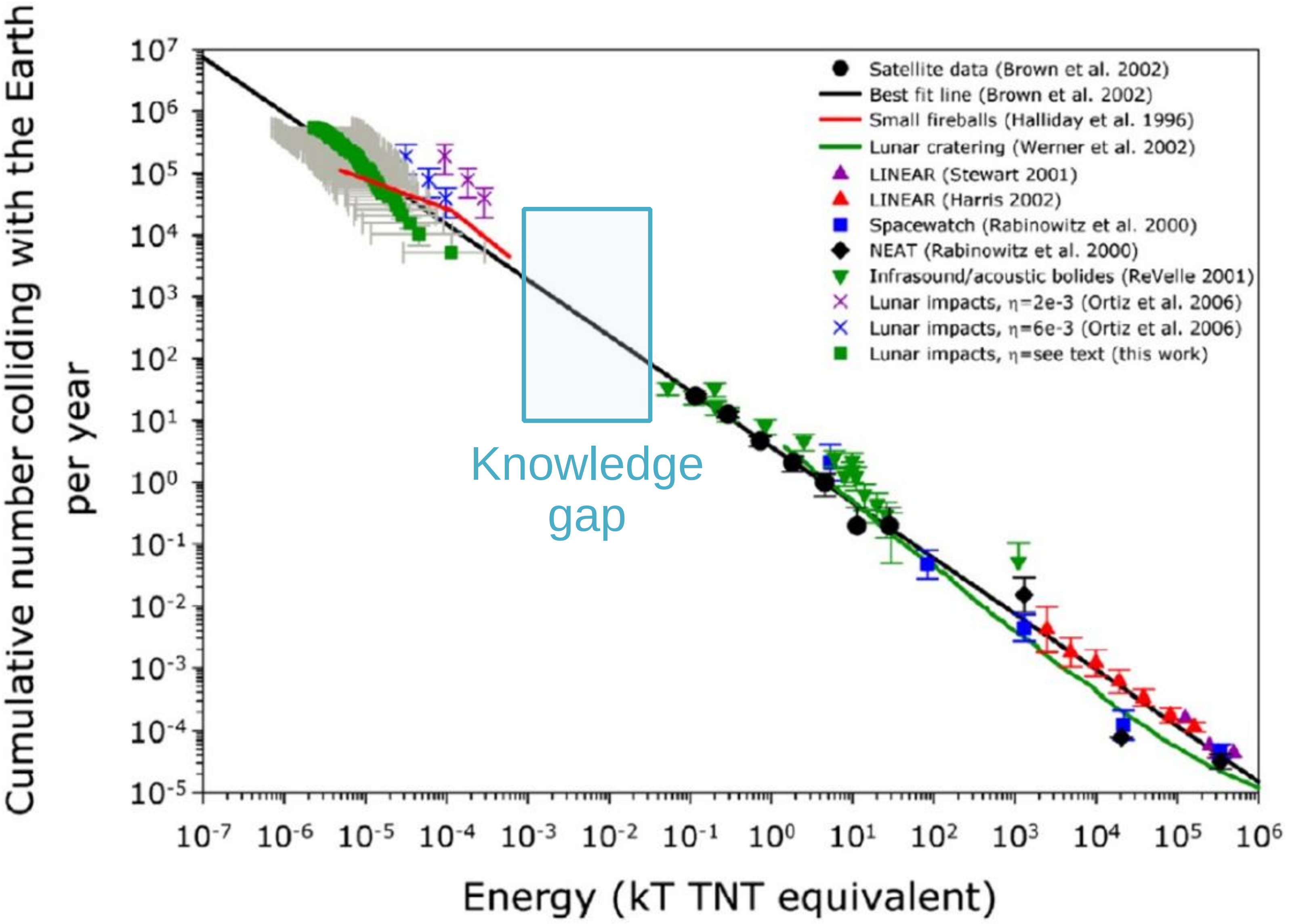
Temporal distribution of detections



Estimation of the temporal distribution of the lunar impacts detected by the LUMIO lunar CubeSat. Impact kinetic energy $KE \geq 10^{-6}$ kton TNT Equivalent (Earth equivalent). Full view.

Topputo F., et al. "Meteoroids detection with the LUMIO lunar CubeSat." *Icarus* 389 (2023): 115213. DOI: 10.1016/j.icarus.2022.115213

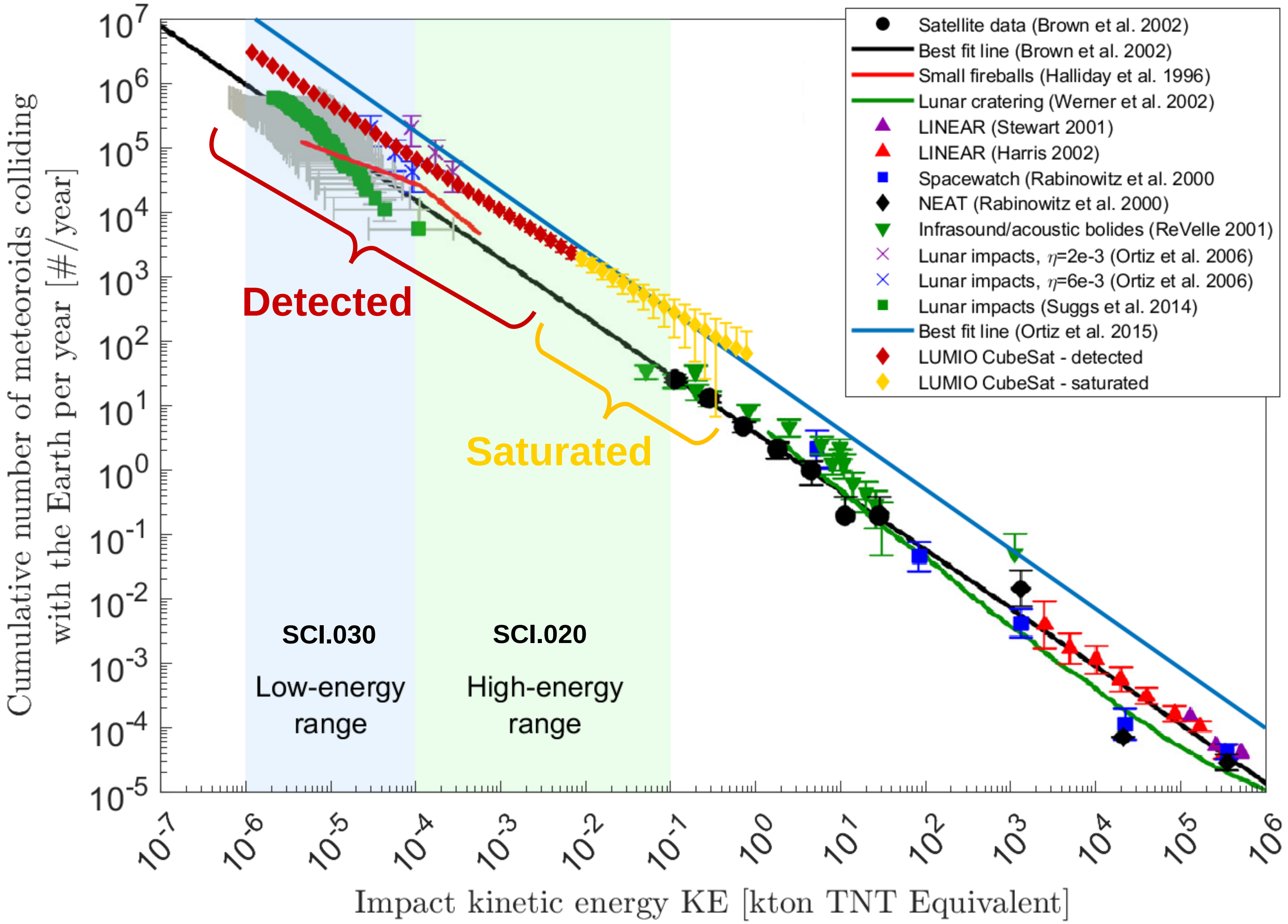
Current knowledge



Ground-based observations.

Number of meteoroids versus energy striking Earth each year, after Brown et al. (2002). Credits: Figure 9 in Suggs et al. (2014), DOI: 10.1016/j.icarus.2014.04.032. Detection by NELIOTA not included.

Scientific output



Comparison of the estimated LUMIO lunar CubeSat scientific return with the scientific return of previous programmes. The plot is an elaborated version of Figure 9 in *Suggs et al. (2014)*, courtesy of Dr. R. M. Suggs, Dr. D. E. Moser, Dr. W. J. Cooke, and Dr. R. J. Suggs.