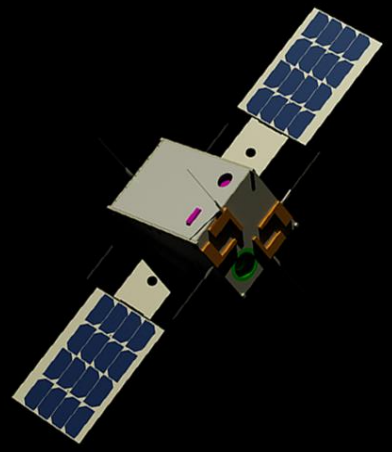


ASI (Rome) & online

13 February 2023

LUMIO SCIENTIFIC WORKSHOP

Call for Membership in the Scientific Working Groups

POLITECNICO MILANO 1863

esa

ASI

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

17:30 Q&A

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

17:30 Q&A

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

17:30 Q&A

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

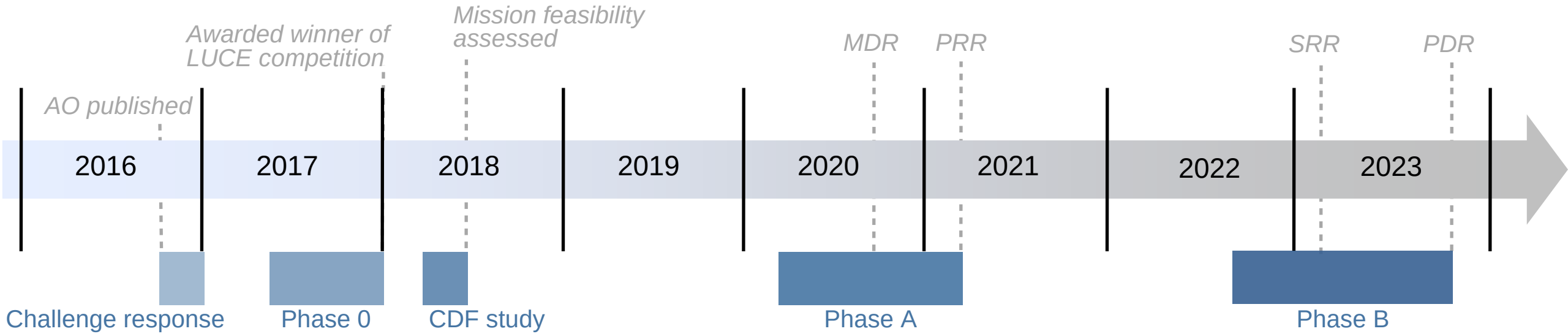
17:30 Q&A

The LUMIO mission

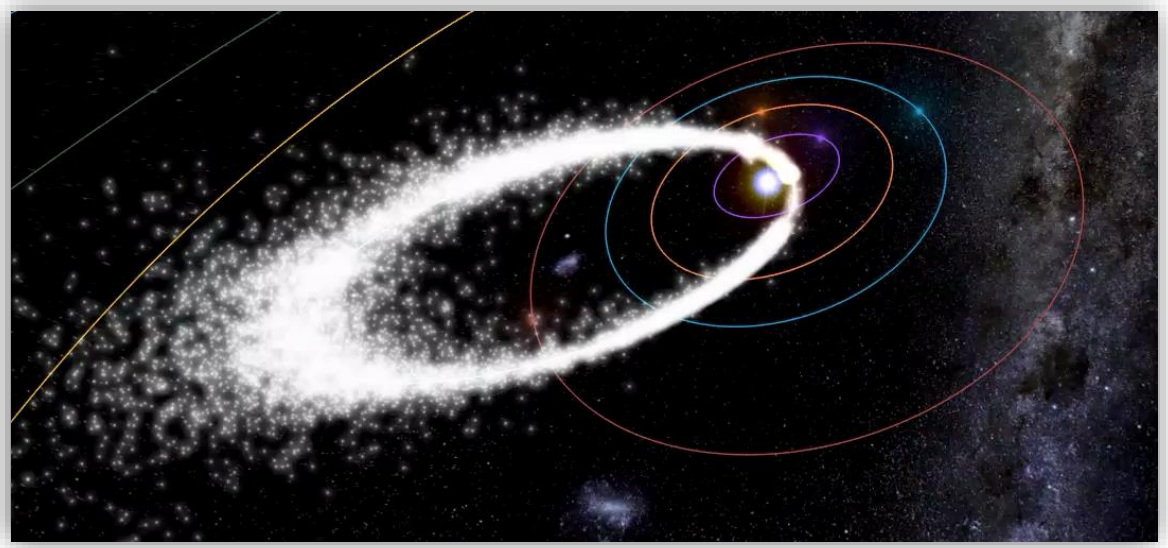
Lunar Meteoroid Impacts Observer

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

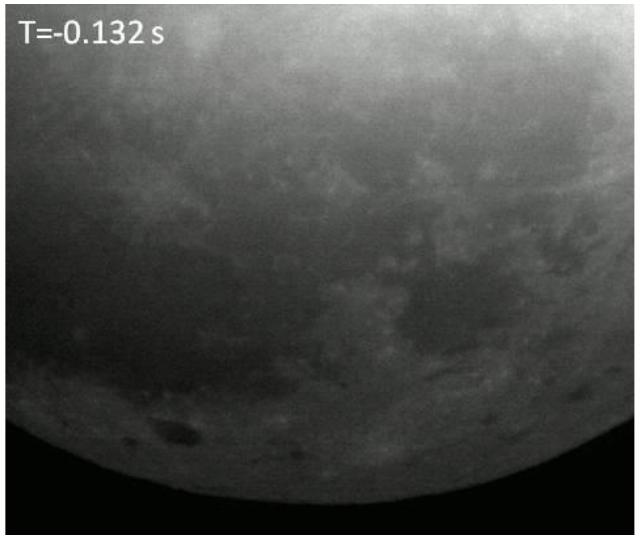
- Phase 0 funded through GSP
- Phase A funded through GSTP
  - IT, NL, NO
- Phase B funded through GSTP
  - IT, NO



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

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

- 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

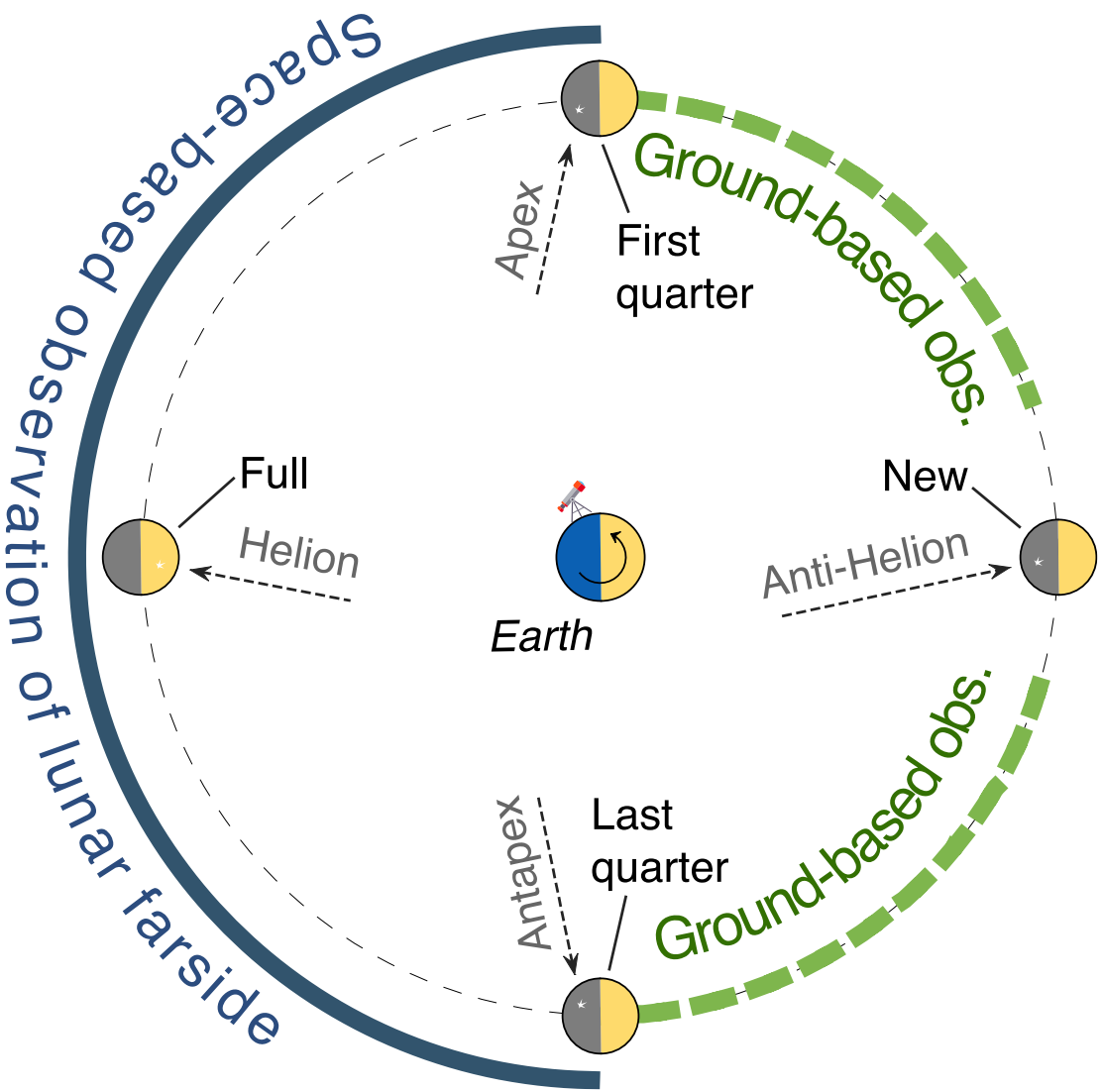
- Possible only during Earth's night
- Only with 10-50% illumination
- Only Apex, Antapex sources detectable
- No full disk possible (straylight)
- Affected by Earthshine
- Constrained by weather
- Signal attenuated by atmosphere

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



Lunar farside space-based observations

Restrictions of Ground-Based Observations

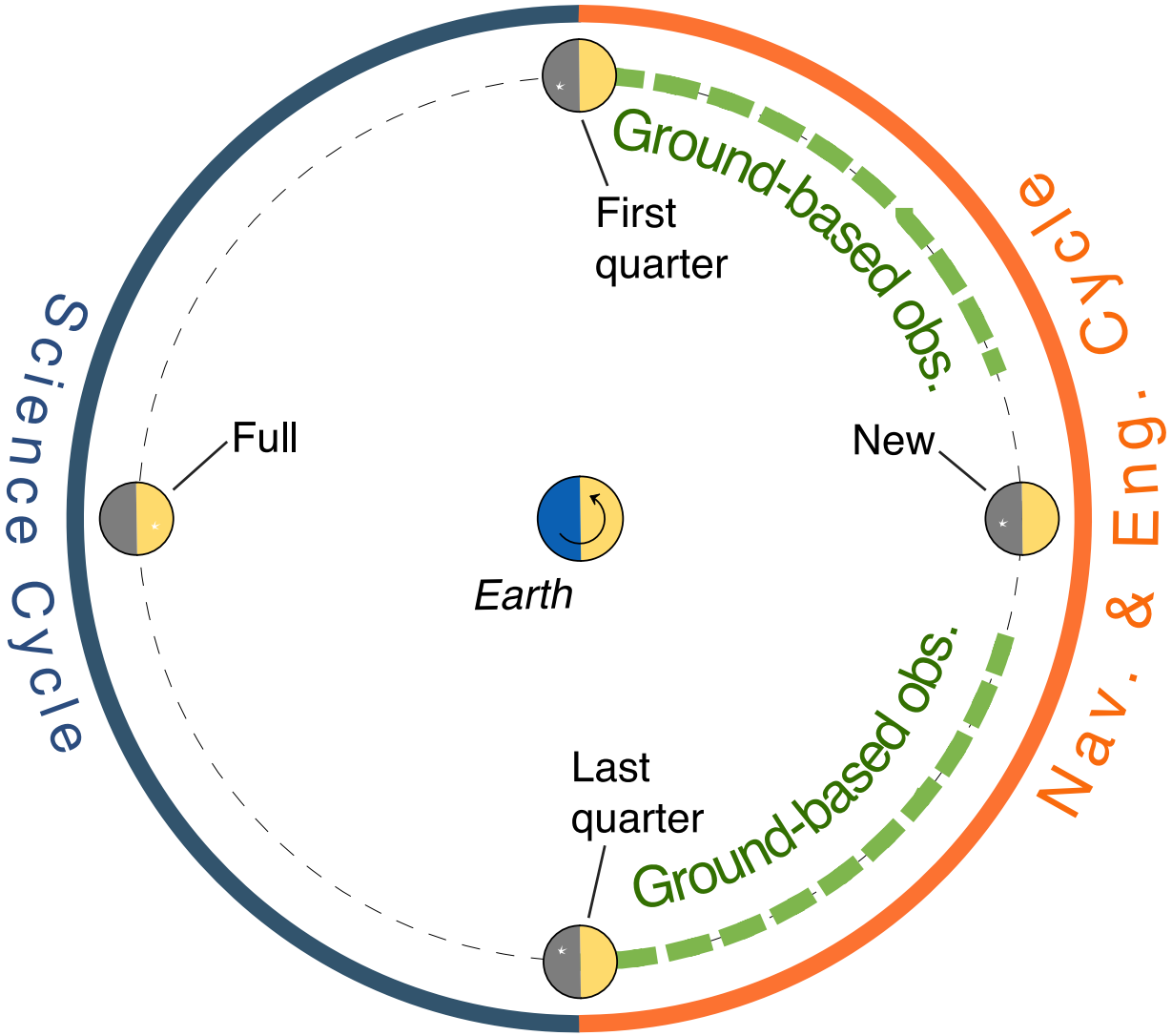
- Possible only during Earth's night
- Only with 10-50% illumination
- Only Apex, Antapex sources detectable
- No full disk possible (straylight)
- Affected by Earthshine
- Constrained by weather
- Signal attenuated by atmosphere

Advantages of Space-Based Observations

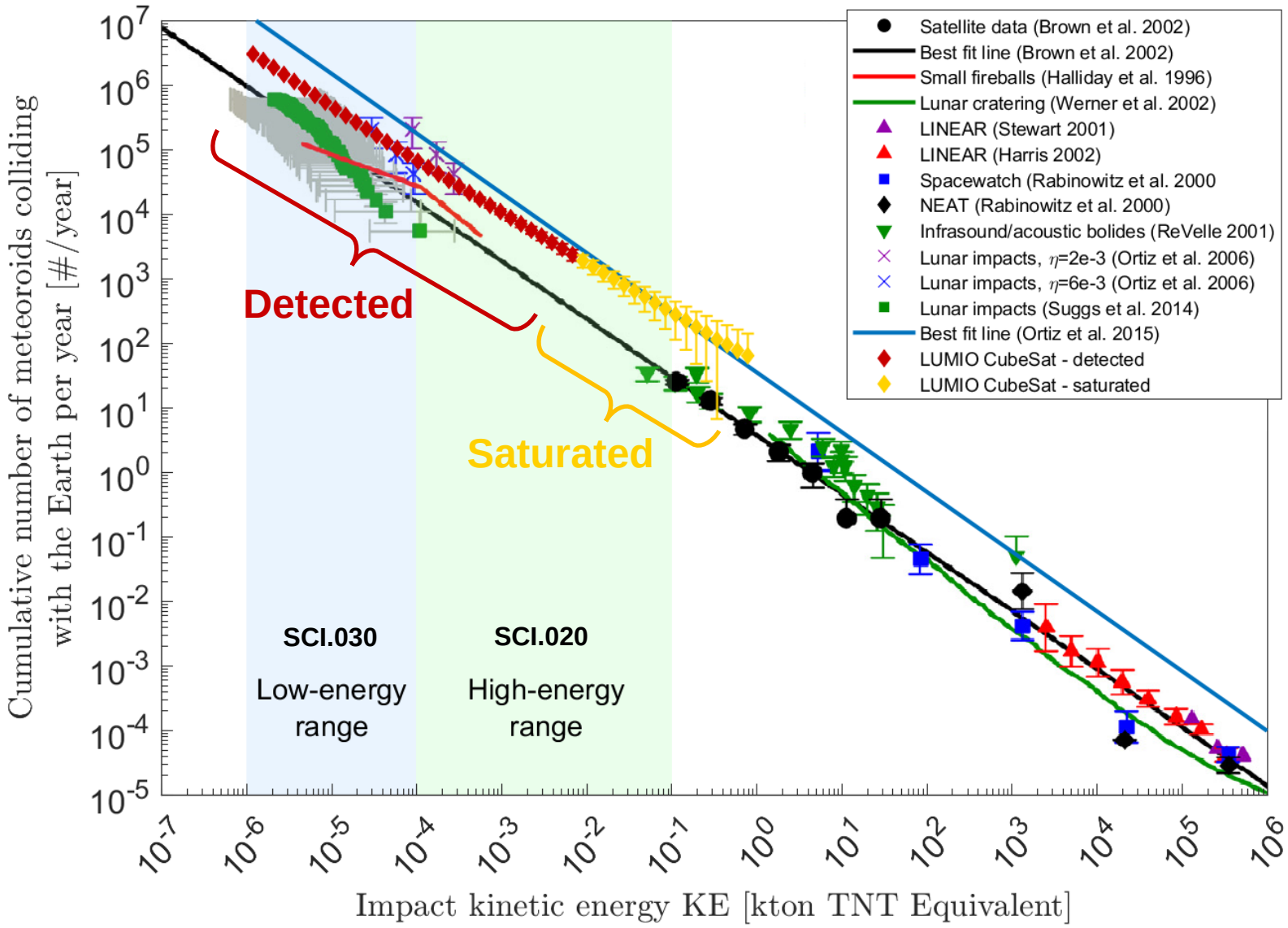
- Uninterrupted observations (~15 days)
- Anti-helion, toroidal sources detectable
- Possible simultaneous obs (space+ground)

Observation of lunar farside

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



Scientific output

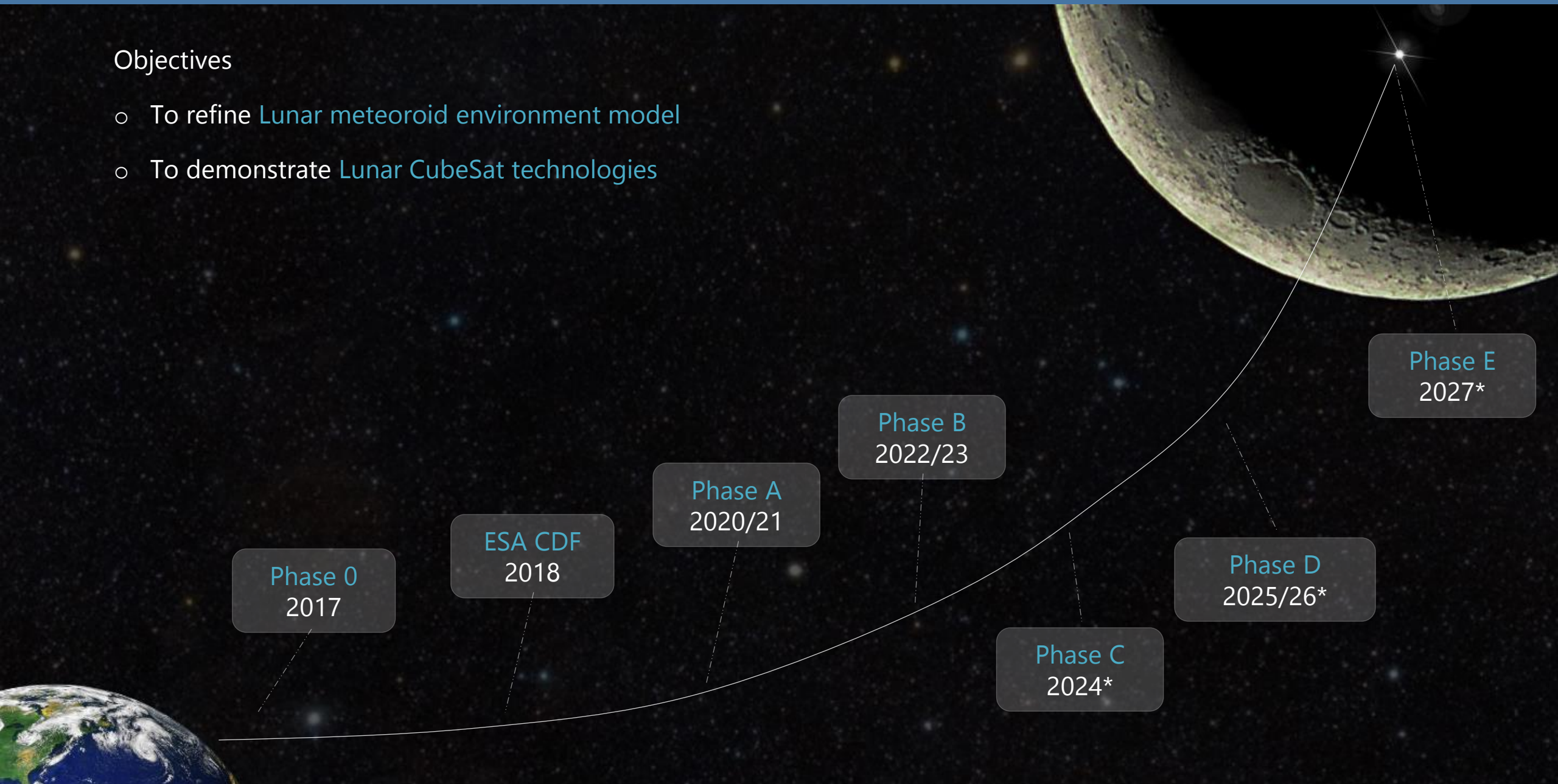


Comparison of the estimated LUMIO lunar CubeSat scientific return with the scientific return of previous programmes. The plot is an elaborated version of Figure 9 in *Suggs et al. (2014)*, courtesy of Dr. R. M. Suggs, Dr. D. E. Moser, Dr. W. J. Cooke, and Dr. R. J. Suggs.

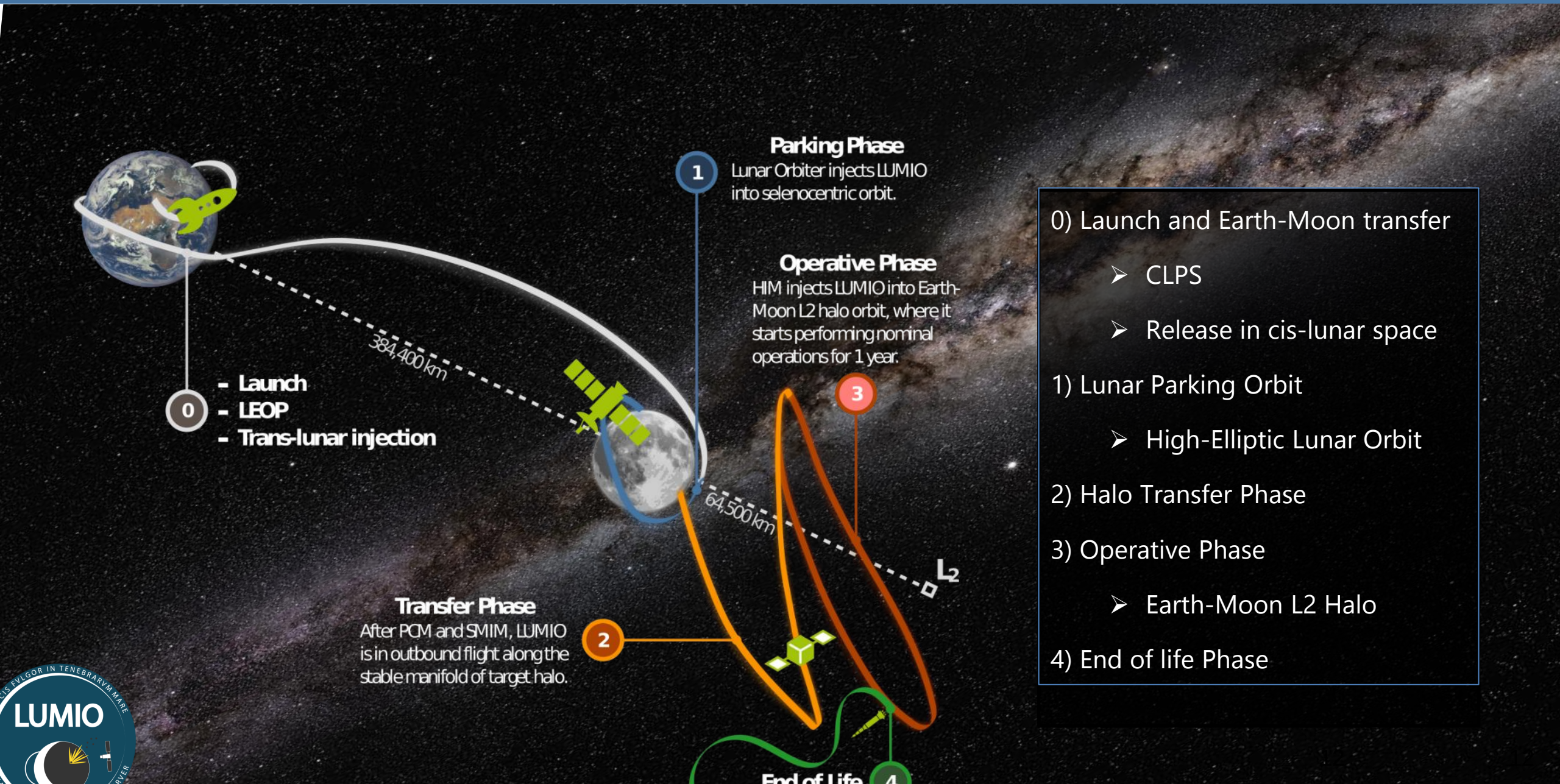
LUMIO mission roadmap

Objectives

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

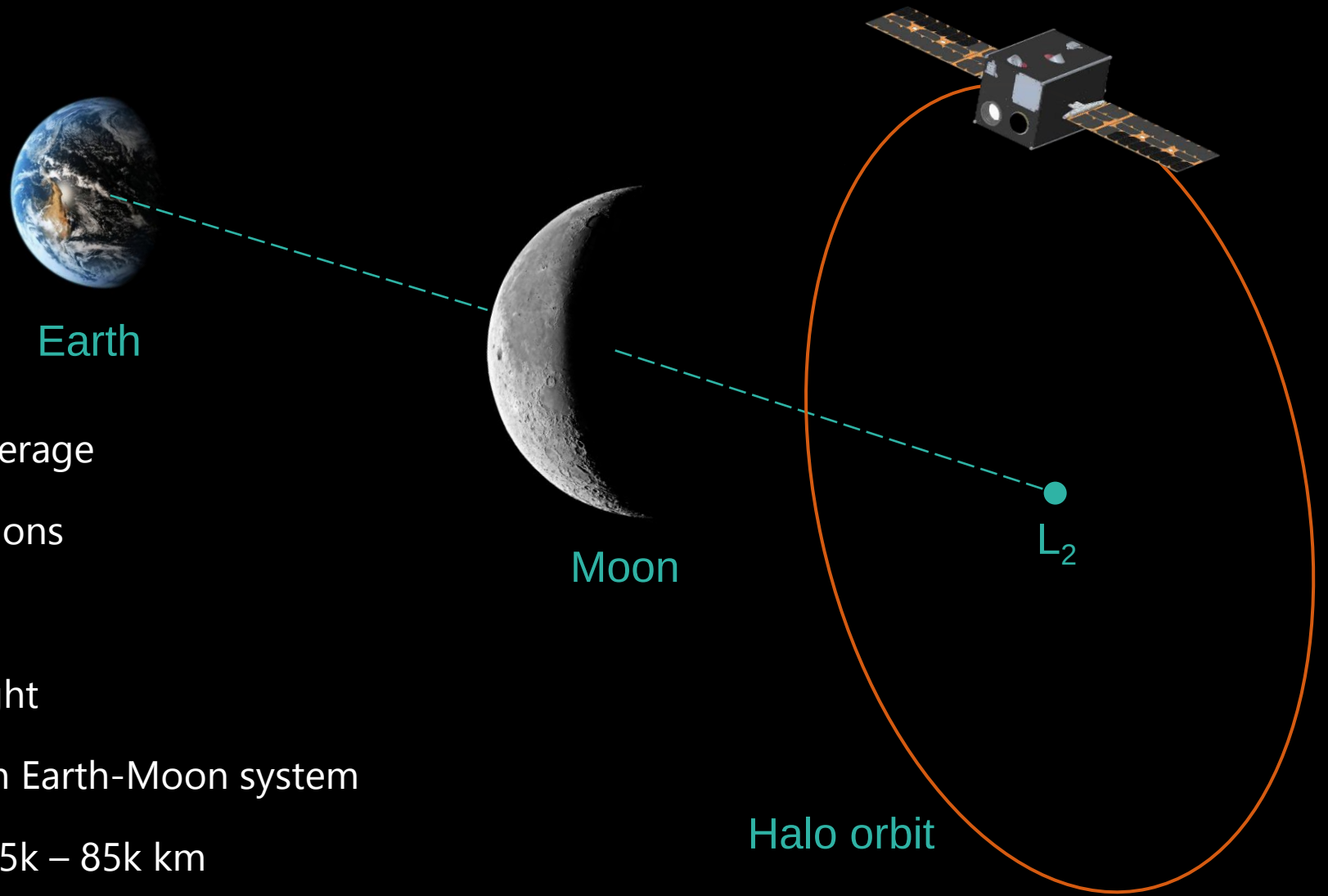


Mission Phases



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

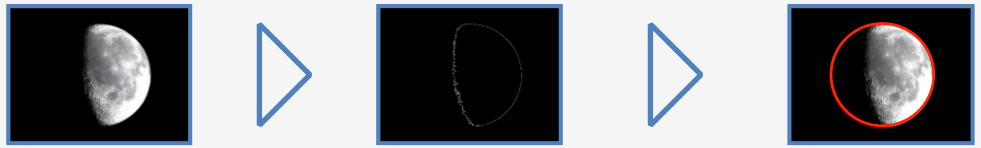
4. Operative Orbit

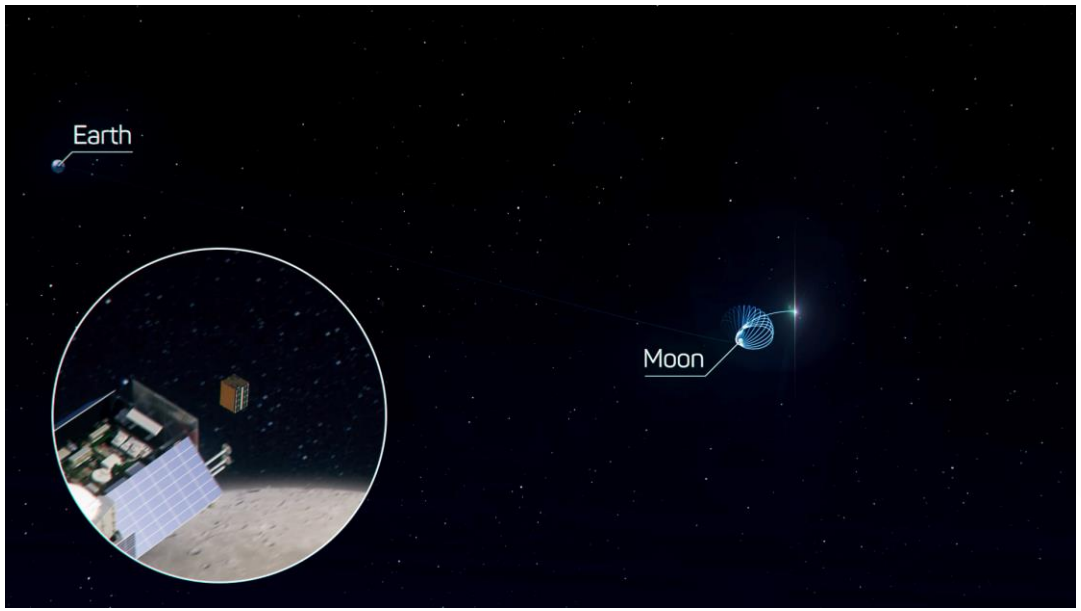


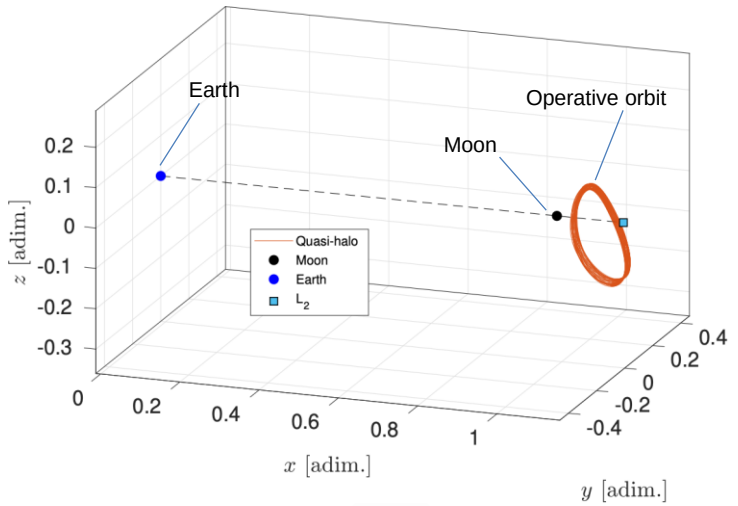
- ✓ Lunar far-side coverage
- ✓ Full-disk observations
- ✓ Eclipse-free orbit
- ✓ Earth always in sight
- ✓ 2:1 resonance with Earth-Moon system
- ✓ Range to Moon: 35k – 85k km

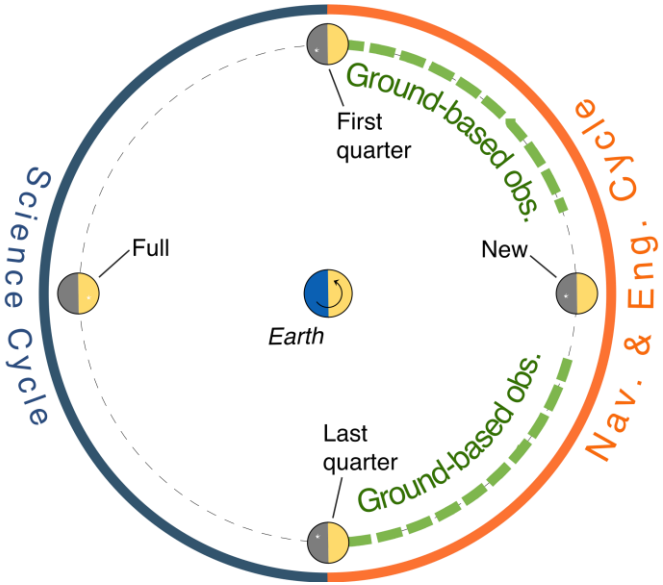
Operative orbit, concept of operations

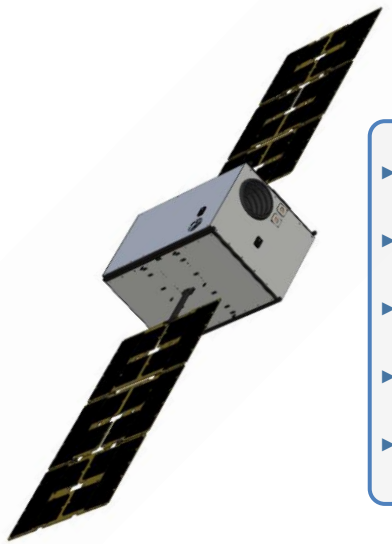
- Operative orbit: L2 halo orbit (farside coverage, Earth & Moon always visible, eclipse free, easily accessible)
- Launch options: CLPS (baseline), Artemis 2 (backup)
- Cost: Δv of 120 m/s (baseline) or 200 m/s (backup)
- Navigation: radiometric (baseline), optical (tech demo)











- 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)

LUMIO mission consortium

Main funding body

European Space Agency

Project Coordination

Norsk Romsenter
Norwegian Space Agency

Funding body

Prime Contractor
Project Management
Science, MA, AOCS/GNC

Platform Provider

Payload Provider

Ingegneria Marketing Tecnologia

X-band & SADA Provider

NAUTILUS
NAVIGATION IN SPACE

Ground Segment Design
& Flight Dynamics Operations

Onboard Payload Data Processing

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

17:30 Q&A

LEONARDO

Electronics

Helicopters

Aircraft

Cyber &
Security

Space

Unmanned
Systems

Aerostructures

LUMIO Lunar CubeSat

Payload Design

Roma

13.02.2023

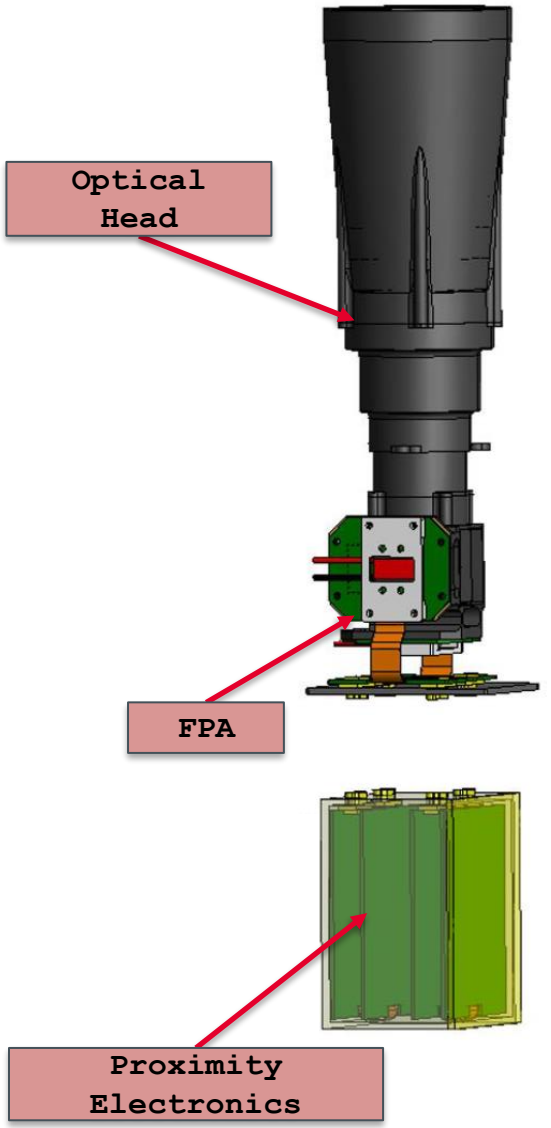
SUMMARY

- 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:

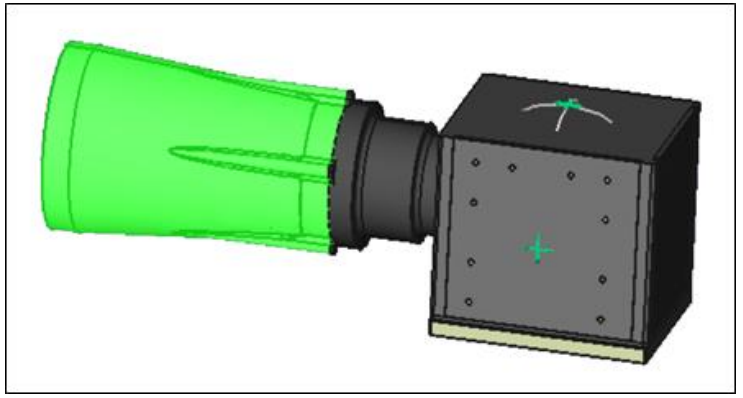
- **Optical Head** ➡ Baffle, Optical Barrel and the Dichroic Cube (beam splitter)
- **Focal Plane Assembly (FPA)** ➡ CCD Detectors and Thermo-Electric Cooler
- **Proximity Electronics** ➡ 1U box containing all electronic elements

LUMIO-Cam: Optical Head

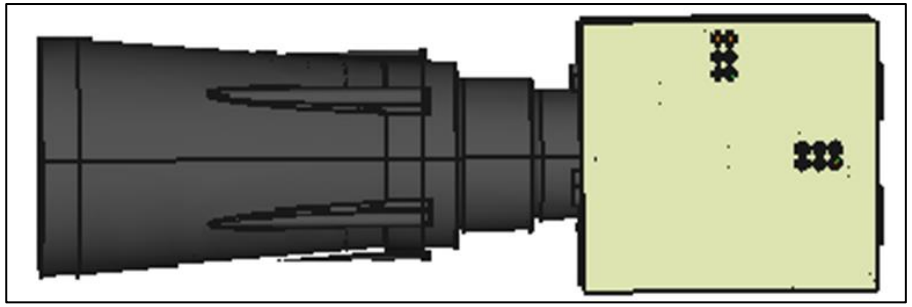
Baffle

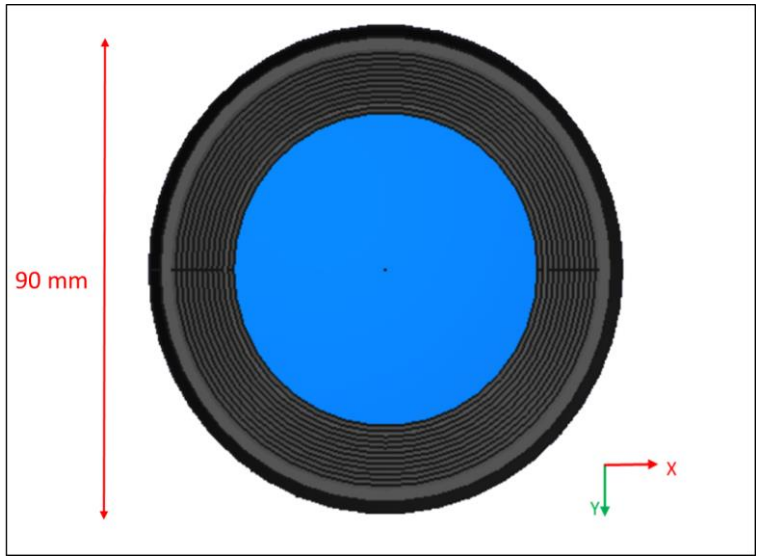
- It has been designed to reduce the Straylight signal coming from the Sun during the payload acquisitions and then to grant the required Signal-to-Noise Ratio (SNR ≥ 5dB).

- 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)



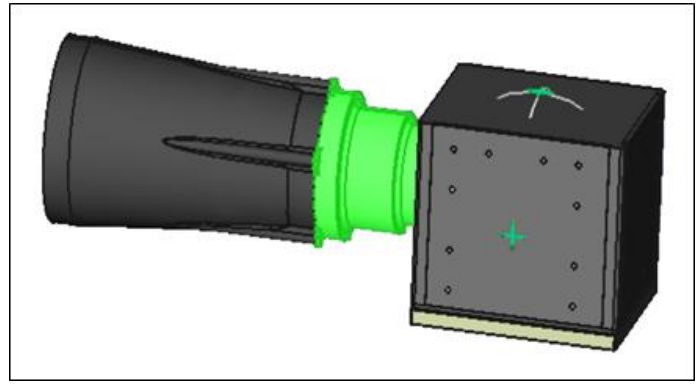


Baffle Entrance Aperture Diameter of 90 mm

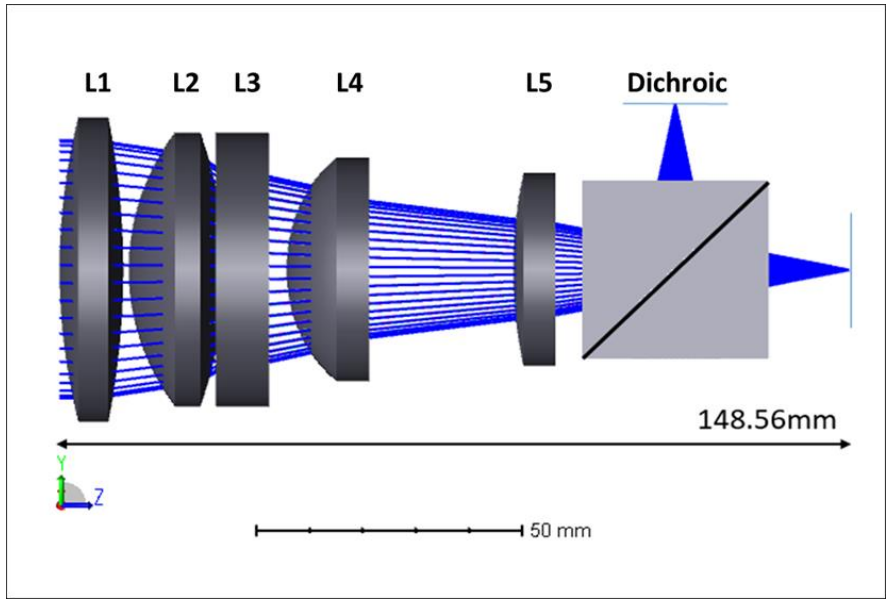
LUMIO-Cam: Optical Head

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)

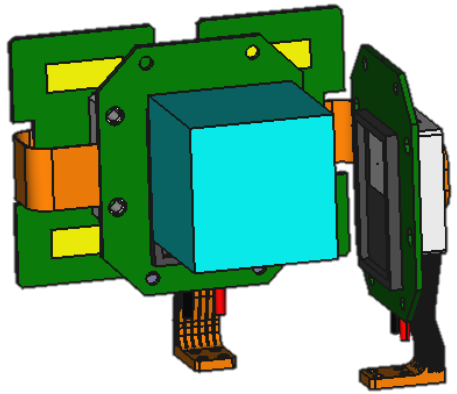


Optical Layout

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

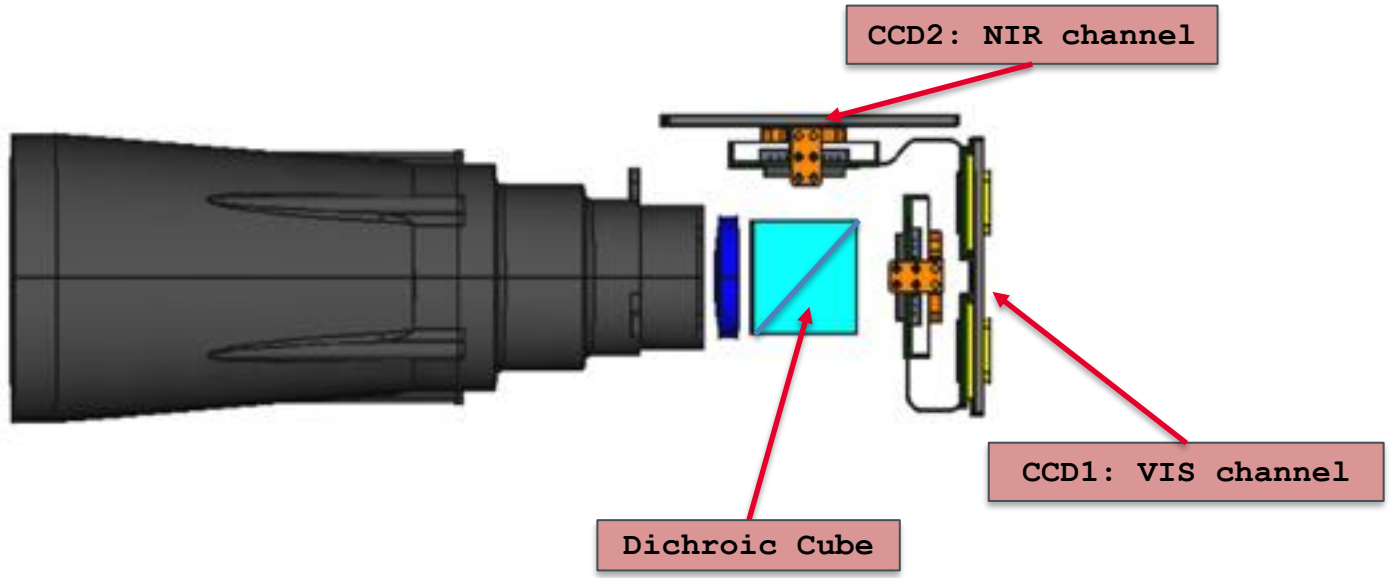
LUMIO-Cam: Optical Head

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.

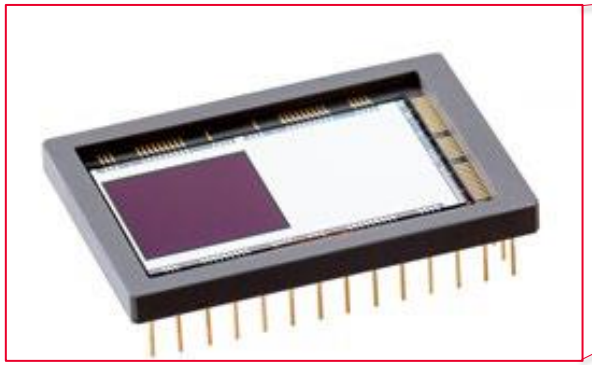
VIS Channel : 450 nm to 800 nm
NIR Channel : 850 nm to 950 nm

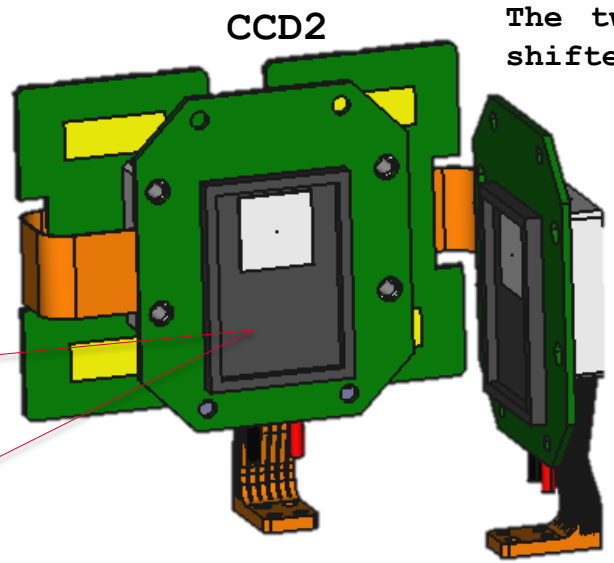


LUMIO-Cam: Focal Plane Assembly

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





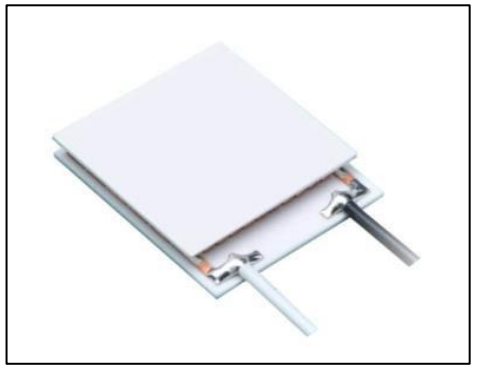
- The CCD201-20 is a frame transfer electron multiplying sensor designed for extreme performance in high frame rate and ultra-low light applications.
- The charge is multiplied in the gain register prior to conversion to a voltage by the Large Signal Output amplifier (OSL).

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

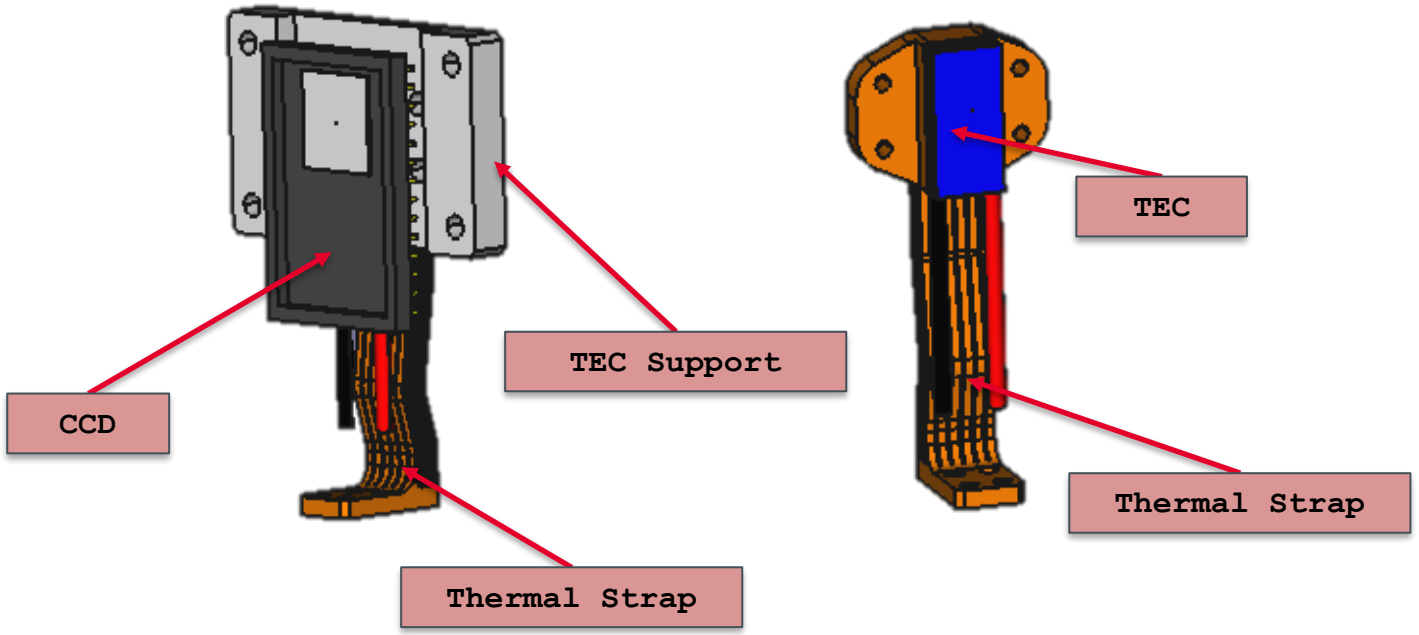
LUMIO-Cam: Focal Plane Assembly

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**



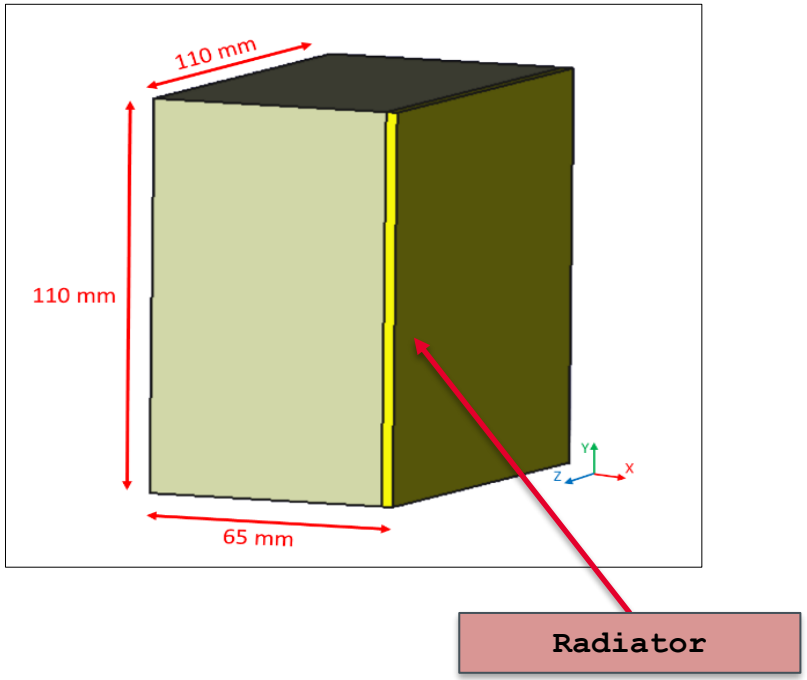
Single Stage TEC



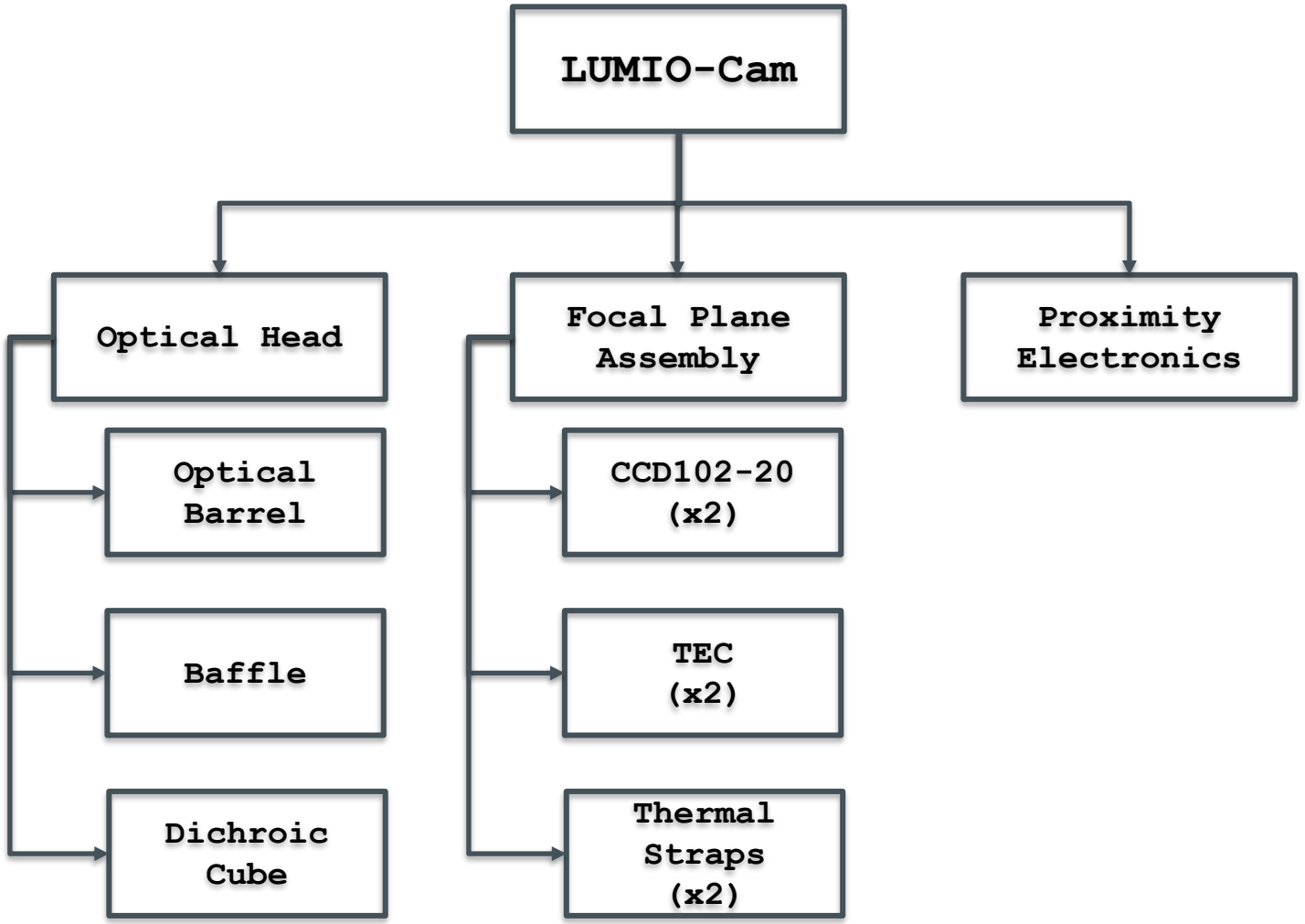
Copper Thermal Strap

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.

LEONARDO

THANK **YOU**
FOR YOUR ATTENTION

leonardo.com

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

17:30 Q&A

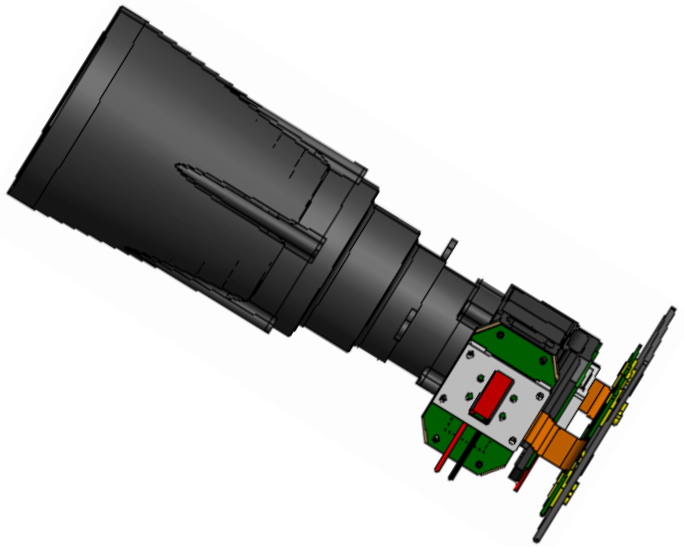
POE simulation

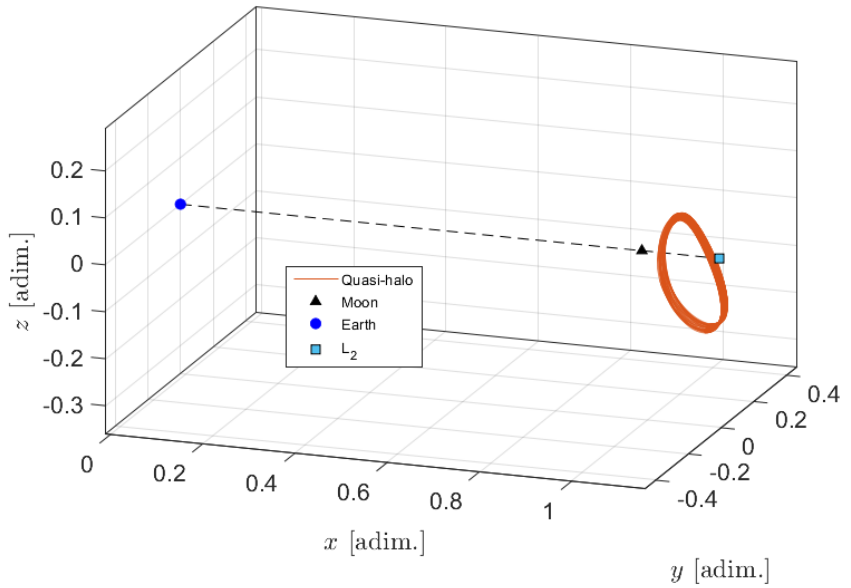
LUMIO-POE

Payload
LUMIO-Cam model

Orbit
Trajectory & attitude

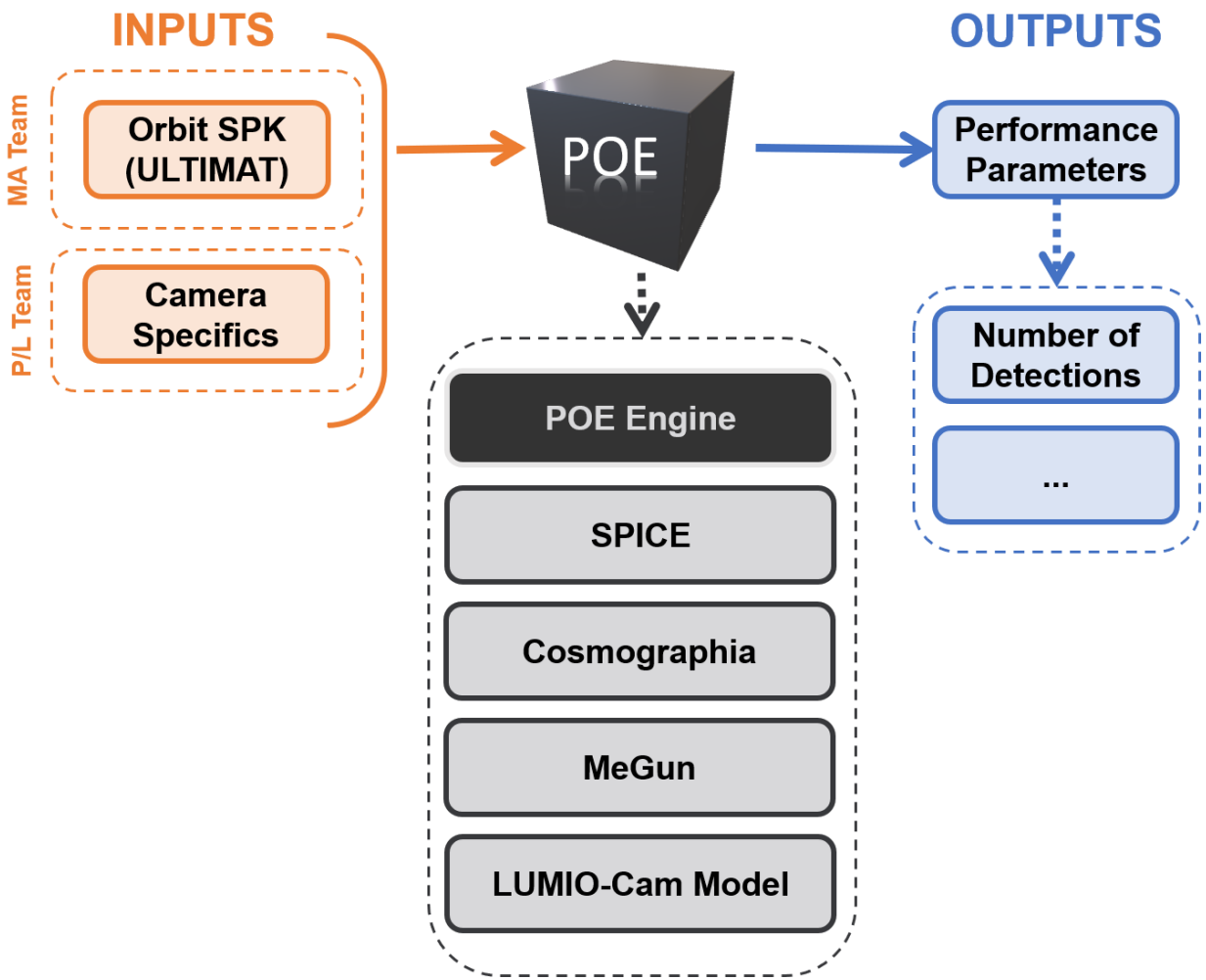
Environment
Meteoroids generation

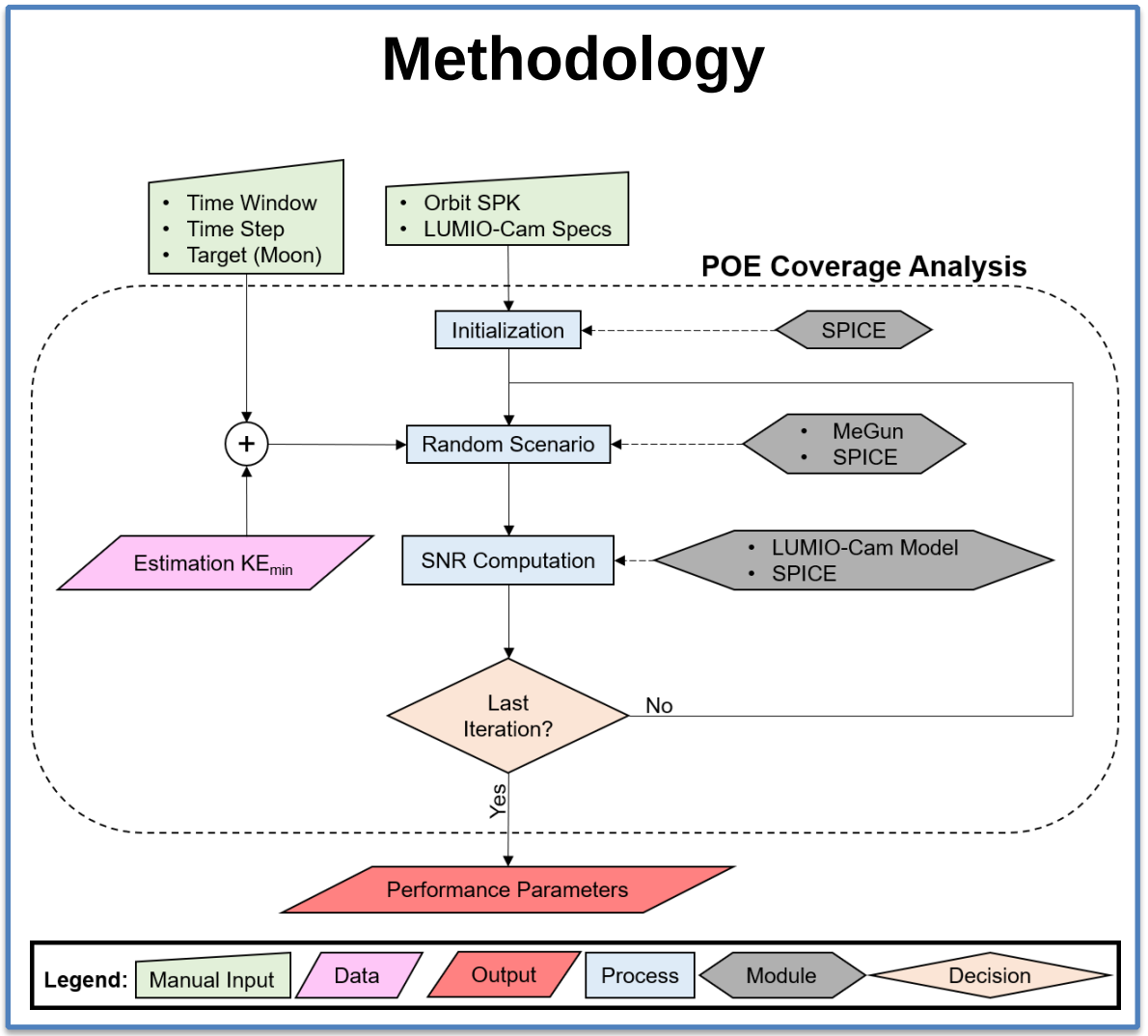




MeGun
(Meteoroid **Gun)**

POE simulation (*cont'd*)



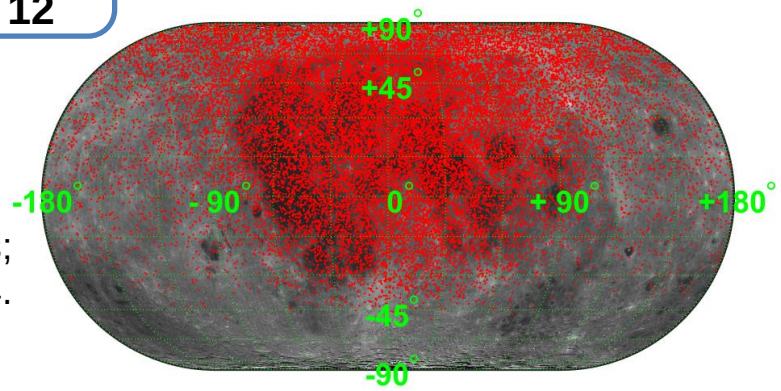


Merisio G., and Topputo F. "Present-day model of lunar meteoroids and their impact flashes for LUMIO mission." *Icarus* 389 (2023): 115180. DOI: 10.1016/j.icarus.2022.115180.

MeGun: Meteoroid environment simulation

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

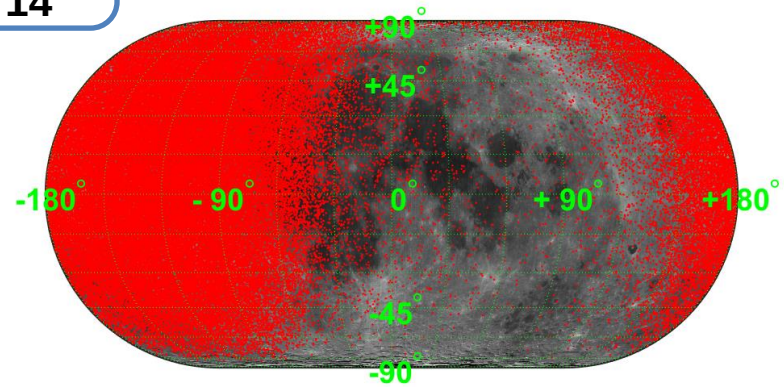
Many impacts in the near side



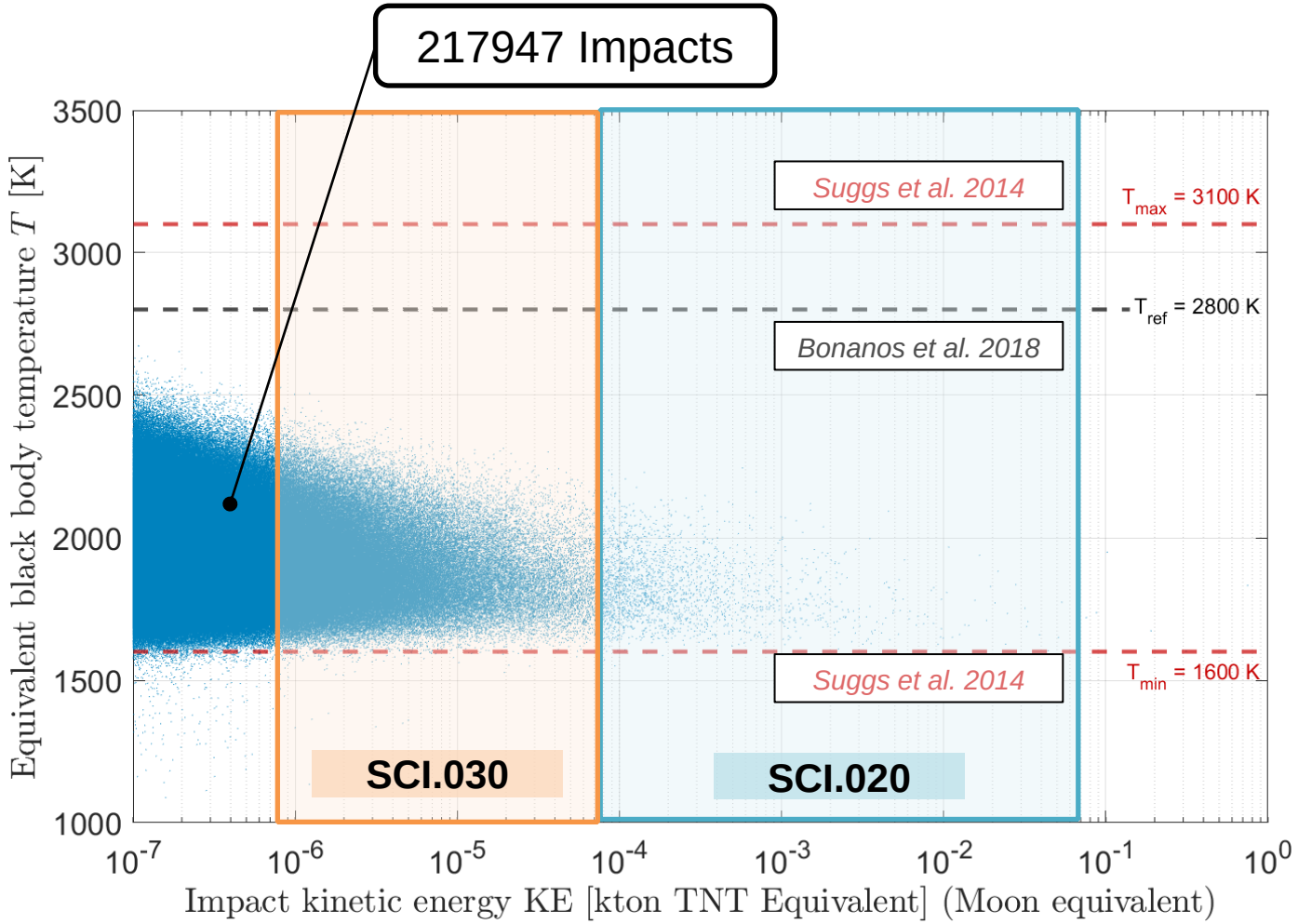
PER impacts;
Moon 2024.

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

Many impacts in the farside

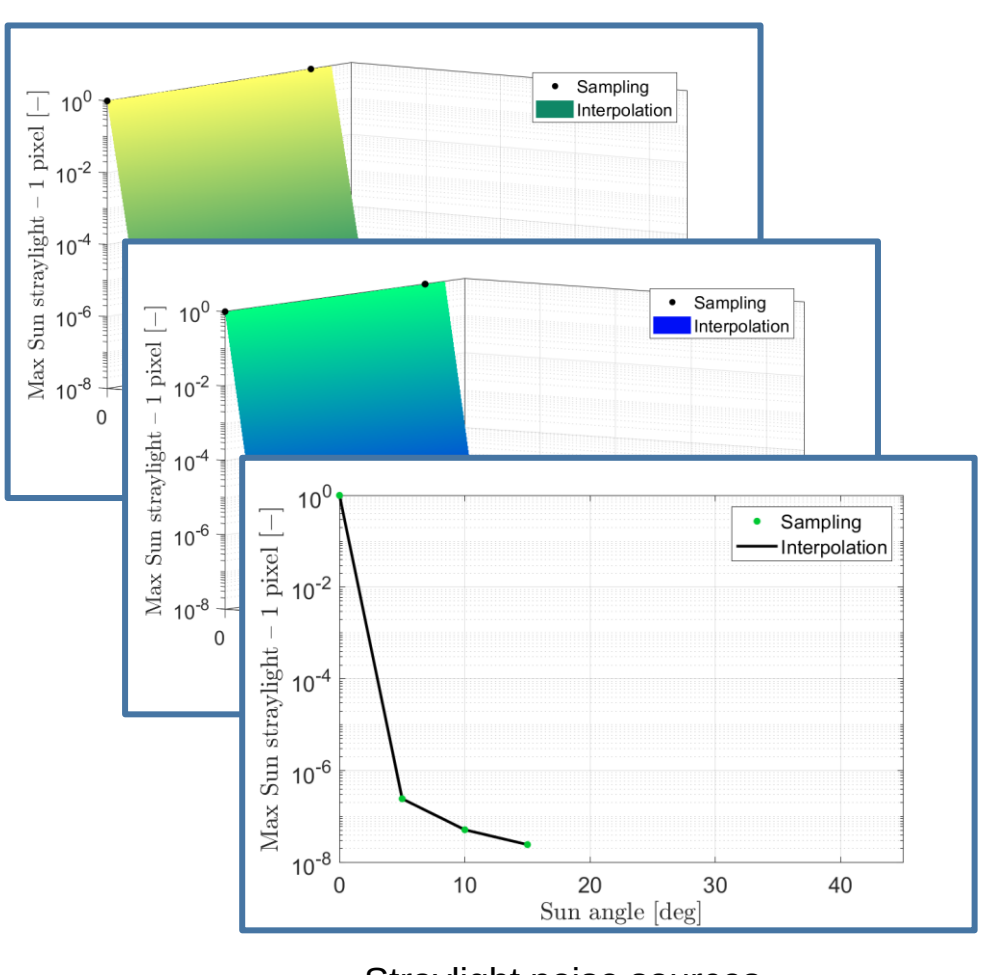


GEM impacts;
Moon 2024.

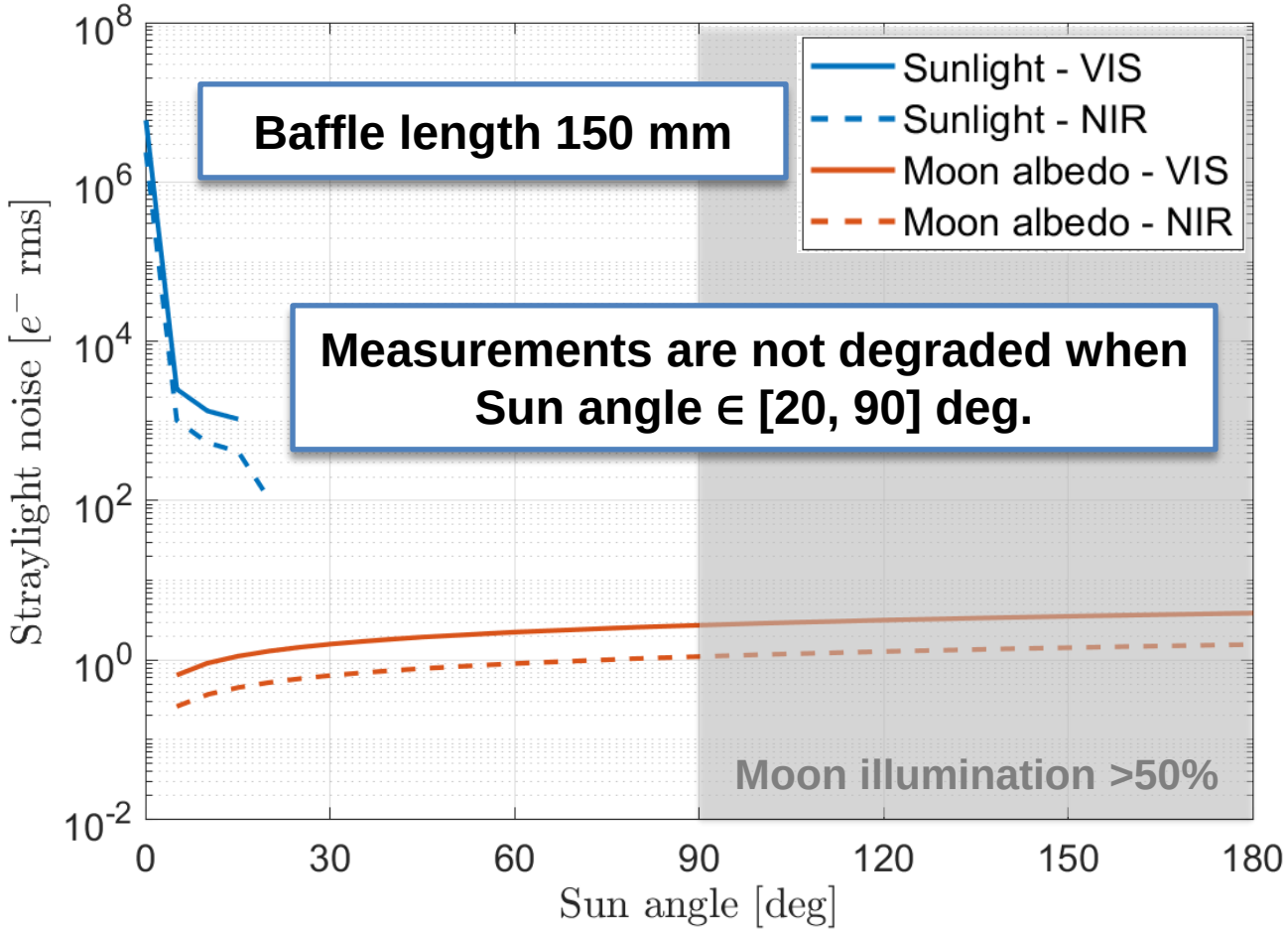


Radiating plume equivalent black body temperatures of lunar impacts in 2024.

Straylight analysis



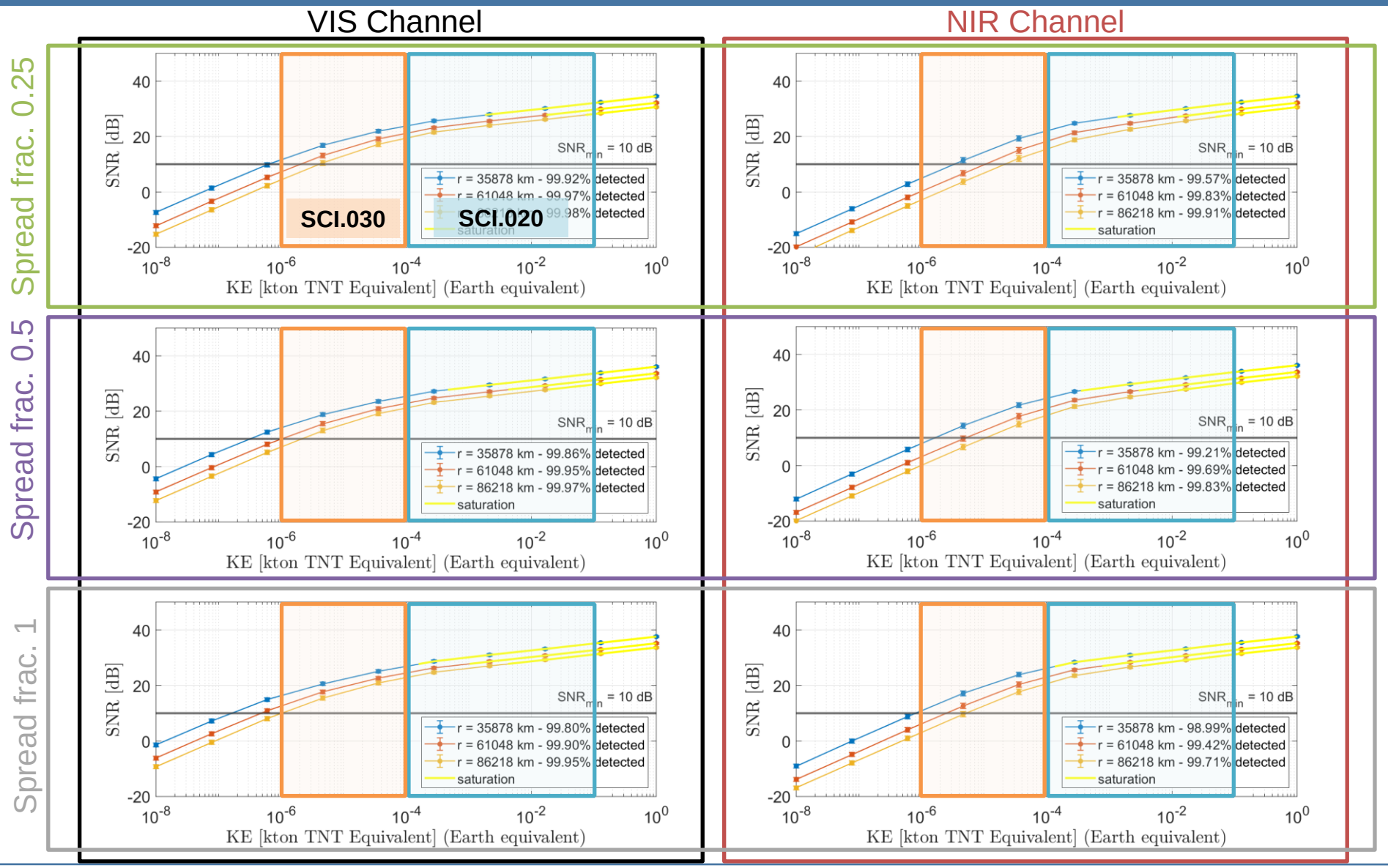
Straylight noise sources.



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

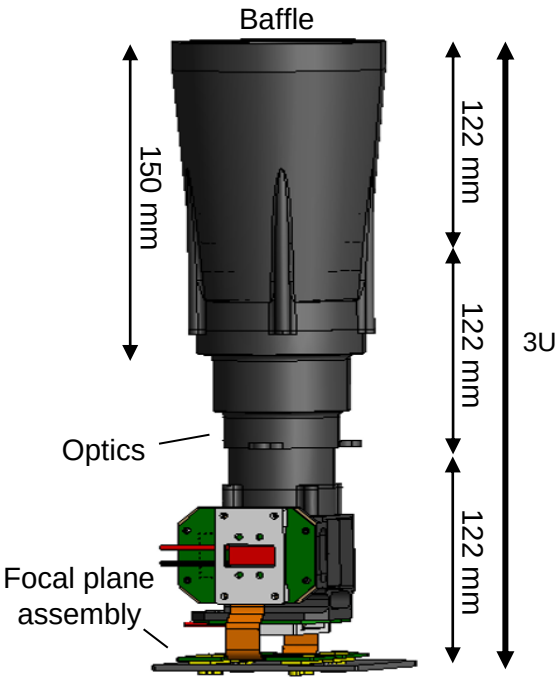
Topputo F., et al. "Meteoroids detection with the LUMIO lunar CubeSat." *Icarus* 389 (2023): 115213. DOI: 10.1016/j.icarus.2022.115213

Radiometric analysis



2 Channels: VIS & NIR

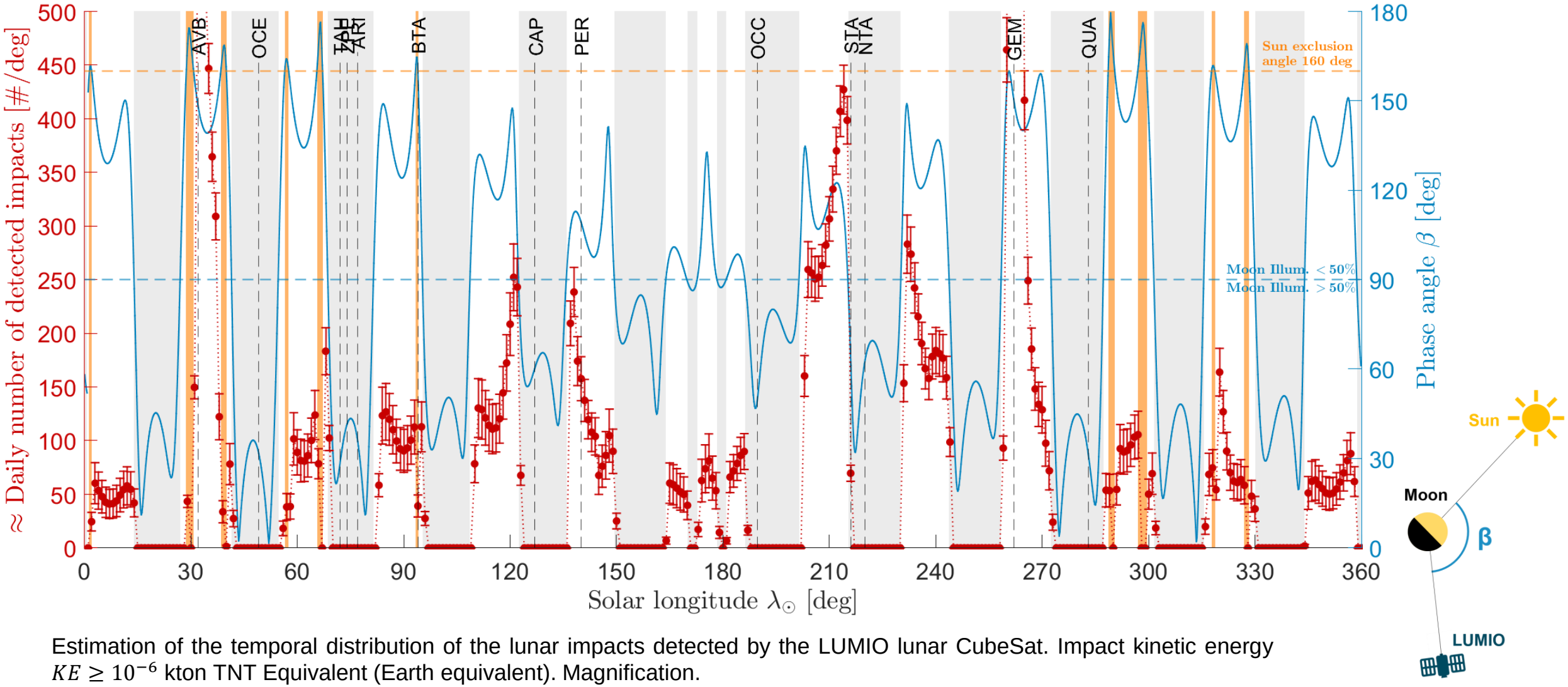
λ_{dic} = 820 nm



LUMIO-Cam.

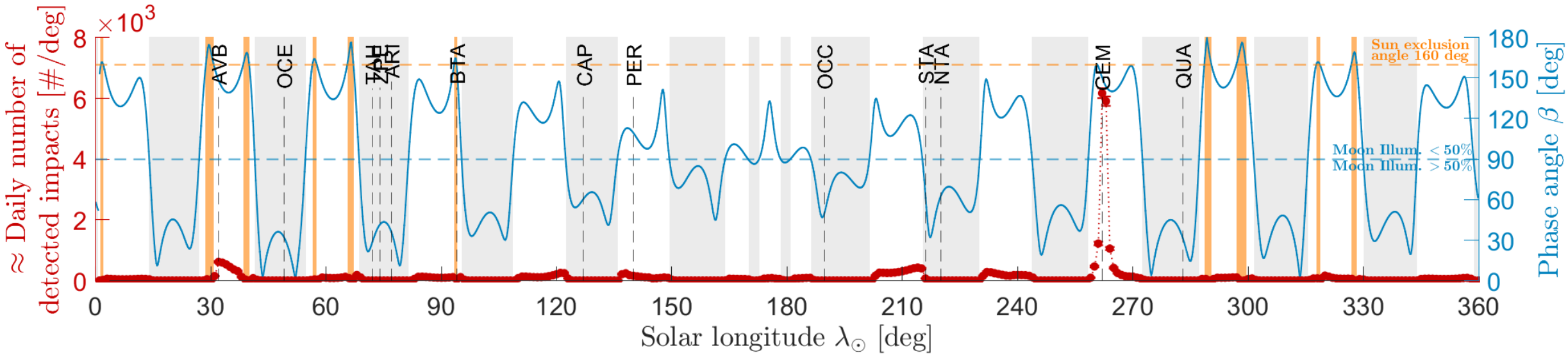
Radiometric analysis about impact flash detections. Gain fixed to 10. 1000 events simulated for impact kinetic energy.

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.

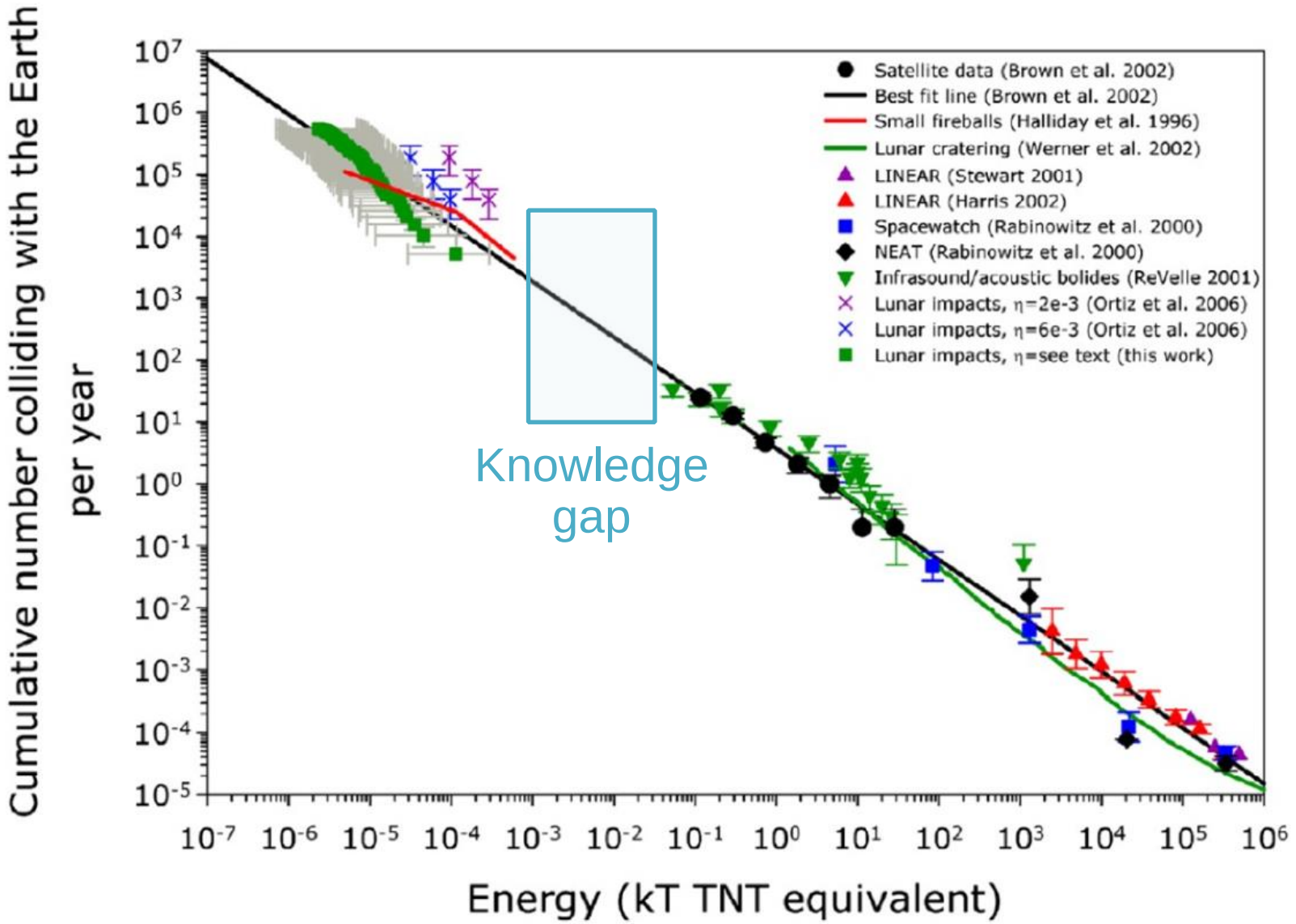
Temporal distribution of detections



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

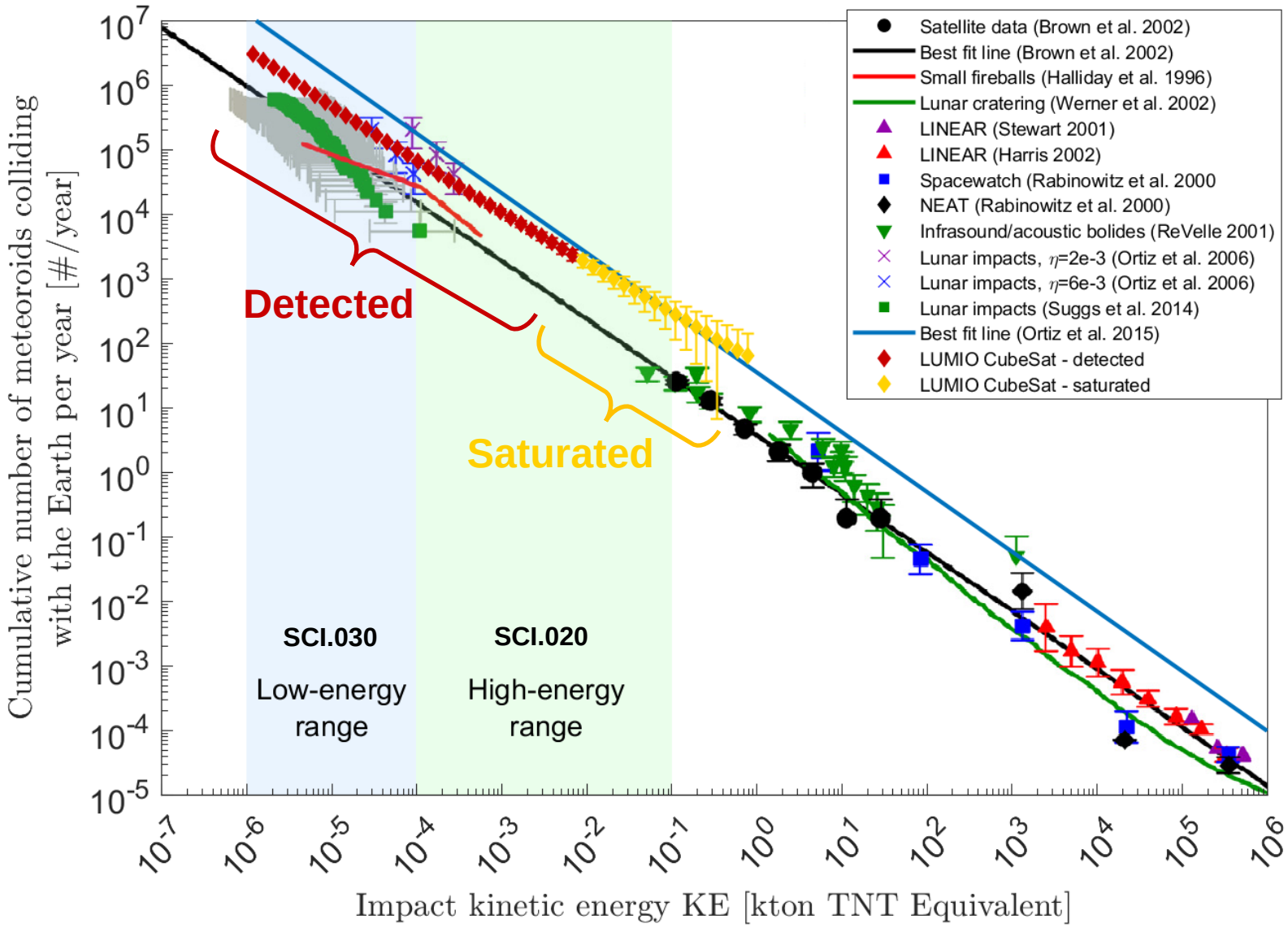
Current knowledge



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.

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

17:30 Q&A

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

- **?** — WG1 chair
- **?** — WG2 chair
- **?** — …
- **?** — WGn chair
- **Alceste Bonanos** — NELIOTA
- **J-P Williams** — LRO/Diviner
- **Demetrio Labate** — Payload Lead
- **Mark Robinson** — LRO/LROC
- **David Paige** — LRO/Diviner

Science Operation Center

- Operations Planning
- Payload Data System

Chairs and members to be selected (Call)

International collaborators

Politecnico di Milano

Leonardo

Purpose of the Call

- The structure of the SWGs will be established as a result of the present Call
  - Both SWG chairs and members will be appointed.

- Topics include but are not limited to:
  - lunar environment & SSA (Space Situational Awareness)
  - meteoroids: physical properties
  - meteoroids: dynamics
  - lunar surface and subsurface: physical properties
  - impacts: modelling and simulation
  - data product: on-board/on-ground image processing
  - data product: synthetic image generation
  - synergies with data from other space missions/observations
  - synergies with experimental laboratory data
  - bonus science (e.g., day-time observation window)
  - citizen science/outreach

Timeline & eligibility

- Timeline
  - **13 Feb 2023**: Call issued
  - **22 Mar 2023 at 18:00 CET**: Proposals due
  - **Apr 2023**: Appointment of SWG chairs & members
  - **May 2023**: KO of activities of the Scientific WGs
  - **Jul/Sep 2023**: Science Team meeting (@PoliMi, open to SWG members)

- Eligibility
  - The call is open to scientists worldwide
  - Scientists already involved in LUMIO are not eligible
  - Early career scientists are specifically encouraged to apply

Appointment conditions

- Appointment conditions
  - The SWG member/chair appointment is *ad personam*
  - Three-year duration (2023-2025), renewable
  - Selected SWG members will be required to participate to scientific activities of the relevant WG
  - Selected SWG chair will be required to coordinate the scientific activities of the relevant WG, in coordination with the LUMIO Scientific Board
  - Phase B activities: preparation of the LUMIO scientific activities for the next phases
  - Commitment of Science Team members is expected to increase as LUMIO advances to Phases C, D and E

Format of the application & evaluation criteria

- Format of the application
  - Curriculum vitae (max 2 pages)
    - Highlight info relevant to the application
  - Scientific application (max 2 pages)
    - Scientific goal of proposed activities
    - Why applicant? Areas of expertise and potential contribution
    - Five notable achievements

Evaluation criteria

- Competence relative to activities proposed
- Novel expertise (relevant to LUMIO context)

- Scientific value of the proposal
- Ideas for the scientific exploitation of LUMIO

- Proposal submission
  - Single document in PDF format (max file size 5 MB)
  - Submit via email to LUMIOScienceTeam@polimi.it

More info

- Call document available at https://dart.polimi.it/lumio-call/

- Requests for further information can be addressed to

Fabio Ferrari

LUMIO Science Lead

fabio1.Ferrari@polimi.it

Call for membership in the scientific working groups of the LUMIO mission

LUMIO (Lunar Meteoroid Impact Observer) is a European Space Agency (ESA) mission aimed at characterizing the lunar and near-Earth meteoroid environment by imaging impact flashes on the farside of the Moon. The mission is supported by the Italian Space Agency (ASI) and the Norwegian Space Agency (NOSA) under ESA's General Support Technology Programme (GSTP) Fly Element.

Through the present Call, the LUMIO Team invites scientists to apply for membership in the LUMIO Scientific Working Groups. Successful applicants will be appointed to be part of the LUMIO Science Team, to support its scientific activities for three years (2023-2025), renewable.

Early career scientists are specifically encouraged to apply.

Full details of this Call can be found in the "Call for Membership in the Scientific Working Groups" document, which can be downloaded here.

Application Submission

Applications, in PDF format, must be submitted via email to LUMIOScienceTeam@polimi.it before the deadline.

Schedule for this call and important dates

Release of this call: 13 February 2023
Deadline for receipt of proposals: 22 March 2023, 18:00 CET
Appointment of the Working Group members: April 2023

LUMIO (Lunar Meteoroid Impacts Observer)

Call for Membership in the Scientific Working Groups

13/02/2023 Issue 1, Rev 0

Written by F. Ferrari, G. Merisio, C. Buonagura, C. Giordano, P. Panicucci, F. Piccolo, A. Rizza, M. G. Pancalli, G. Pilato, D. Labate, V. Franzese, F. Topputo

Verified by D. Koschny, E. Ammannito, R. Moissl

Approved by F. Ferrari, F. Topputo

POLITECNICO MILANO esa asi

Agenda

16:00 Welcome and agenda *(F. Ferrari, F. Topputo, E. Ammannito)*

16:05 LUMIO in the context of ESA Planetary Defence Office *(R. Moissl)*

16:10 LUMIO in the context of ASI Science Directorate *(E. Ammannito)*

16:15 The LUMIO mission *(F. Topputo)*

16:30 LUMIO Payload *(G. Pilato)*

16:40 Overview of the scientific activities *(G. Merisio)*

17:05 The LUMIO Science Team and the Call for Membership in the Scientific Working Groups *(F. Ferrari)*

17:30 Q&A