LUMIO (Lunar Meteoroid Impacts Observer)

Call for Membership in the Scientific Working Groups

13/02/2023 Issue 1, Rev 0

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Document change log

Version	Date	Reason for change
1.0	13 February 2023	First version issued

Contents

List of Acronyms

ConOps Concept of Operations.

CRTBP Circular Restricted Three-Body Problem.

EoL End of Life.

HIM Halo Injection Maneuver.

LUMIO Lunar Meteoroid Impacts Observer.

Nav&Eng Navigation & Engineering.

RPRnBP Roto-Pulsating Restricted n-Body Problem.

S/C Spacecraft.

SMIM Stable Manifold Injection Maneuver.

TBC To Be Confirmed.

TCM Trajectory Correction Maneuver.

Reference Documents

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

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

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1 The LUMIO Mission

LUMIO (Lunar Meteoroid Impacts Observer) is a European Space Agency (ESA) mission. It aims to characterise the lunar and near-Earth meteoroid environment by imaging impact flashes on the farside of the Moon [1]. 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.
The LUMIO Science Team is in charge of the scientific exploitation of the data acquired by the LUMIO mission, and it is engaged in all aspects of the mission potentially affecting its scientific performance. The LUMIO Science Team includes Scientific Working Groups (SWGs), active on specific scientific areas, relevant for the goals and context of the mission. The present call solicits applications for members of the SWGs.

1.1 Context

The Earth–Moon system is constantly bombarded by meteoroids of different sizes, and their numbers are significant [2]. Fragments of asteroids and comets, dating back to planetary formation times, constantly encounter the Earth and Moon in their orbits, and impact them as meteoroids. Observations of meteor showers on Earth have been studied for at least 50 years [3], in order to construct Solar System meteoroid models. These models can be useful in, e. g., predicting the small-meteoroid flux that deteriorates space equipment or when the next large meteoroid will impact Earth itself. As meteoroids originate from asteroids and comets, meteoroid models can be used to understand the spatial distribution of those objects near the Earth–Moon system.

The flux of meteoroid impacts on the lunar surface is similar to that of the Earth. The observation of impact events provides information regarding the velocities, the temporal and spatial distributions of these objects [4, 5, 6]. This information can be used to increase confidence of meteoroid models, to validate the existing lunar impact models, to contribute to lunar seismology studies and interior modelling, and to initiate a Lunar Situational Awareness programme for future exploration missions.

Earth-based optical observations of the light flashes produced by lunar meteoroid impacts have revealed to be useful in the validation and improvement of meteoroid models [7]. Monitoring the Moon for meteoroid impact flashes allows for the observation of larger areas than those covered by traditional surveys of Earth's upper atmosphere. Thus, theoretically, more meteoroid impacts can be detected in shorter periods of time [8]. Earth-based lunar observations are restricted by weather, geometric, and illumination conditions. As such, LUMIO will improve the detection rate of lunar meteoroid impact flashes, as it would allow for longer monitoring periods. Moreover, being closer to the Moon surface, LUMIO could potentially detect impacts by meteoroids smaller than millimetres in size [9].

1.2 Overview of the mission

Lunar Meteoroid Impacts Observer (LUMIO) is a 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 flashes. This complements Earth-based observations on the lunar nearside, to provide global information on the Lunar Meteoroid Environment and contribute to Lunar Situational Awareness.

LUMIO mission is conceived to address the following:

- **Science Question**. What are the spatial and temporal characteristics of meteoroids impacting the lunar surface?
- **Science Goal**. Advance the understanding of how meteoroids evolve in the cislunar space by observing the flashes produced by their impacts with the lunar surface.
- **Science Objective**. Characterise the flux of meteoroids impacting the lunar surface.

LUMIO is a 12U form-factor CubeSat which carries the LUMIO-Cam, an optical instrument capable of detecting light flashes in the visible spectrum, and to continuously monitor and process the data [10]. Figure 1 summarises LUMIO's mission profile.

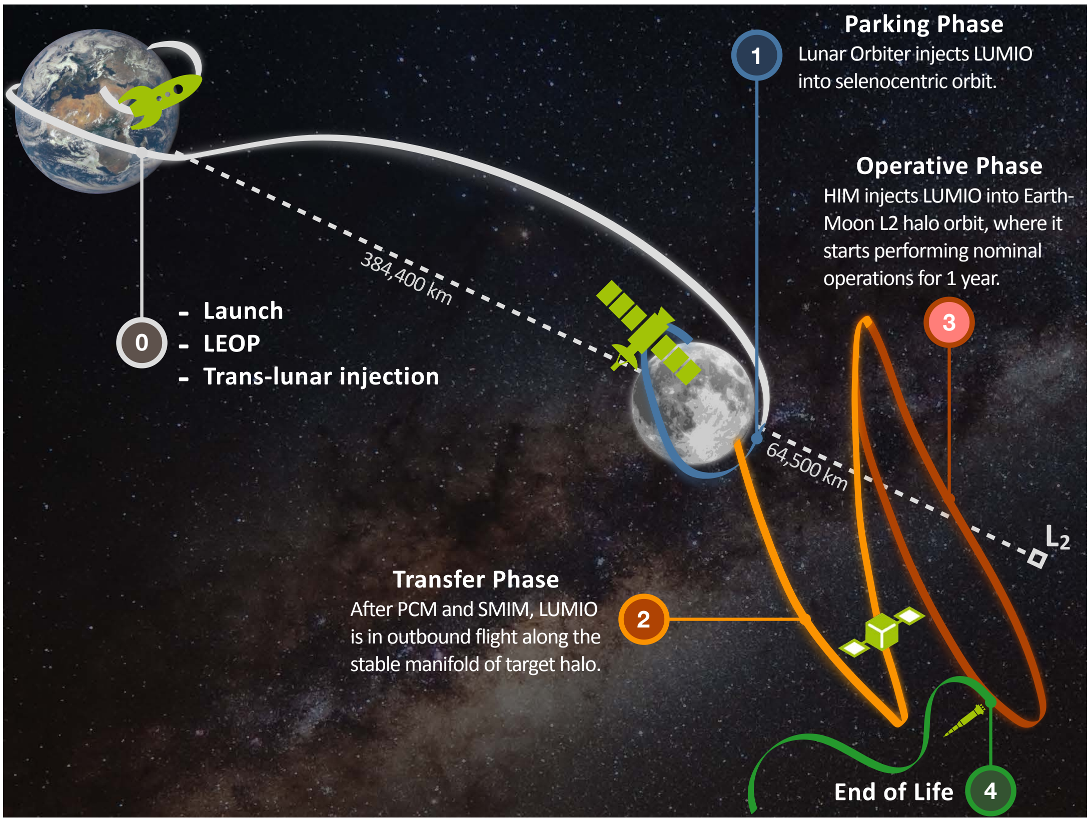


Figure 1: Overview of LUMIO mission.

1.3 Mission objectives

The mission objective of the LUMIO mission are herein presented. The list of top-level objectives is shown in Table 1. Then, the list of the mission objectives follows in Table 2. Finally, the tech-demo objectives are presented in Table 3.

Table 1: Top-level objectives.

Objective ID	Objective
TLO.01	To perform remote sensing of the lunar surface and measurement of astronomical observations not achievable by past, current, or planned lunar missions.
TLO.02	To demonstrate deployment and autonomous operation of CubeSats in lunar environment, including localization and navigation aspects.
TLO.03	To demonstrate miniaturization of optical instrumentation and associate technology in lunar environment.

Table 2: Mission objectives.

Objective ID	Objective
MO.01	To conduct observations of the lunar surface in order to detect meteoroid impacts and characterise their flux, magnitudes, luminous energies, and sizes.
MO.02	To complement observations achievable via ground-based assets in space, time, and quality in order to provide a better understanding of the meteoroid environment.

Table 3: Tech-demo objectives.

Objective ID	Objective
TDO.01	To perform autonomous navigation experiments by using images of the Moon.
TDO.02	To demonstrate CubeSat trajectory control capabilities into lunar environment.
TDO.03	To demonstrate the use of miniaturized optical payload in lunar environment.
TDO.04	To demonstrate the use of miniaturized technologies into lunar environment.

Continue on the next page

Tech-demo objectives (cont.).

Objective ID	Objective
TDO.05	To demonstrate the use of miniaturized propulsion systems in lunar environment.
TDO.06	To perform autonomous, high-performance on-board payload data processing.

1.4 Mission profile

During the 1-year Operative Phase, the Science cycle and the Navigation & Engineering (Nav&Eng) cycle are repeated continuously, every 2 orbit. On average, the Science cycles last 14.3 days, while the Nav&Eng cycle last 13.8 days. Overall, 13 cycles of Science and 13 Nav&Eng cycles are expected to be performed in 1 year. During the Science cycle, the following tasks are accomplished:

- Continuous processing of science images and compression.
- Taking 1 image/day for calibration.
- Housekeeping data downlink for 30 min/day (TBC).

The detailed mission timeline of the LUMIO mission is presented in Table 4.

Table 4: LUMIO timeline (TBC).

Order	Date	Task	Description
1	February 10, 2027	Deployment	Injection into selenocentric parking orbit.
2	February 17, 2027	SMIM	LUMIO maneuvers into the stable manifold of the target halo, starting the transfer phase.
3	February 19, 2027	TCM1	LUMIO performs the fisrt Trajectory Correction Maneuver.
4	February 26, 2027	TCM2	LUMIO performs the second Trajectory Correction Maneuver.
5	March 5, 2027	HIM	The Halo Injection Maneuver places LUMIO in the target operative halo orbit.
6	March 21, 2027	-	Beginning of the Operative phase.
7	March 21, 2028	-	Conclusion of the Operative phase.
8	March 22, 2028	EoL	S/C executes a disposal maneuver and decommissions its systems.

In the Circular Restricted Three-Body Problem, the libration points are at rest with respect to a frame co-rotating with the smaller and larger primaries. Consequently, a halo orbiting the Earth–Moon L_2 always faces the lunar farside, see Fig. 2. On top of this, for a wide range of Jacobi energies, Earth–Moon L_2 halos are almost locked into a 2:1 resonance, that is 2 orbital revolutions in 1 synodic period, $T_{\text{syn}} = 29.4873$ days. The quasi resonance locking, enables LUMIO operations to be steady, repetitive, and regular [11].

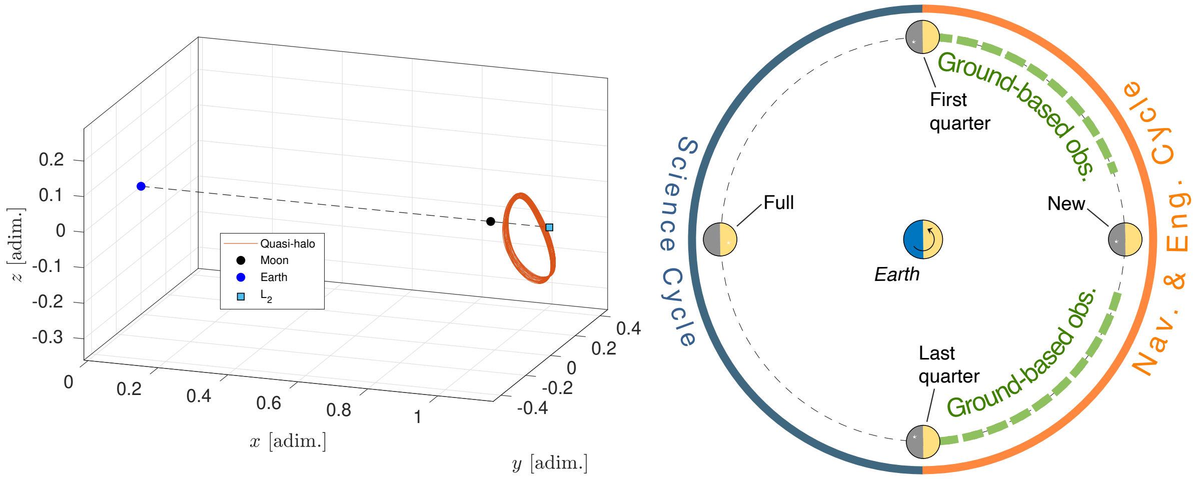


Figure 2: Selected operative Earth–Moon L_2 quasi-halo orbit in the Earth–Moon synodic frame. *Right*: LUMIO Concept of Operations.

Within the Operative Phase, each synodic month LUMIO moves along a) a *Science orbit* (blue solid line in Fig. 2) during the Science cycle and b) a *Navigation and Engineering orbit* (orange solid line in Fig. 2) during the Nav&Eng cycle. During the Science cycle, lasting approximately 14 days, the Moon farside has optimal illumination conditions to perform flash observations (i. e., at least half lunar disk is dark). During the Nav&Eng, the Moon farside illumination conditions are apt to optical navigation experiment routines [12]. In this way, LUMIO Concept of Operations (ConOps) is tight to both resonance mechanisms and illumination conditions.

In Fig. 3 the Moon phase angle (Sun-Moon-S/C angle) as a function of the time epoch during the Operative phase is shown. When the Moon phase angle is under the horizontal dashed blue line at 90°, the Moon illumination is greater than 50% and observation of flashes is harder to be performed. When the Moon phase angle is greater than 160°, the condition on the Sun exclusion angle provided by the baffle (equal to 20°) is violated, decreasing LUMIO-Cam performance. Also in this case observation of flashes is jeopardized. The latter occurs when the Moon phase angle is above the horizontal dashed red line. In Fig. 3 the periods in which the observation of flashes can be carried out successfully are highlighted with a green background.

1.4.1 Operational orbit

The quasi-periodic halo orbit (sometimes referred here as quasi-halo or quasi-halo orbit) about Earth–Moon L_2 characterised by a Jacobi constant $C_j = 3.09$ is the designated LUMIO operative orbit. The selection of LUMIO operative orbit was the result of a thorough trade-off analysis performed during the Phase 0 design [11]. The operative orbit was selected from a set of fourteen quasi-halos orbits about Earth–Moon L_2 computed in the high-fidelity Roto-Pulsating Restricted n-Body Problem (RPRnBP). The operative phase is expected to start on 21 March, 2027 (TBC), and to end on 22 March, 2028 (TBC). The trajectory of the quasi-halo orbit in that time frame is shown in Fig. 4. Finally, the ranges of LUMIO from the Moon and the Earth during the Operative Phase are shown in Fig. 5.

The angular size of the Moon for the LUMIO–Moon distances during the operative orbit is

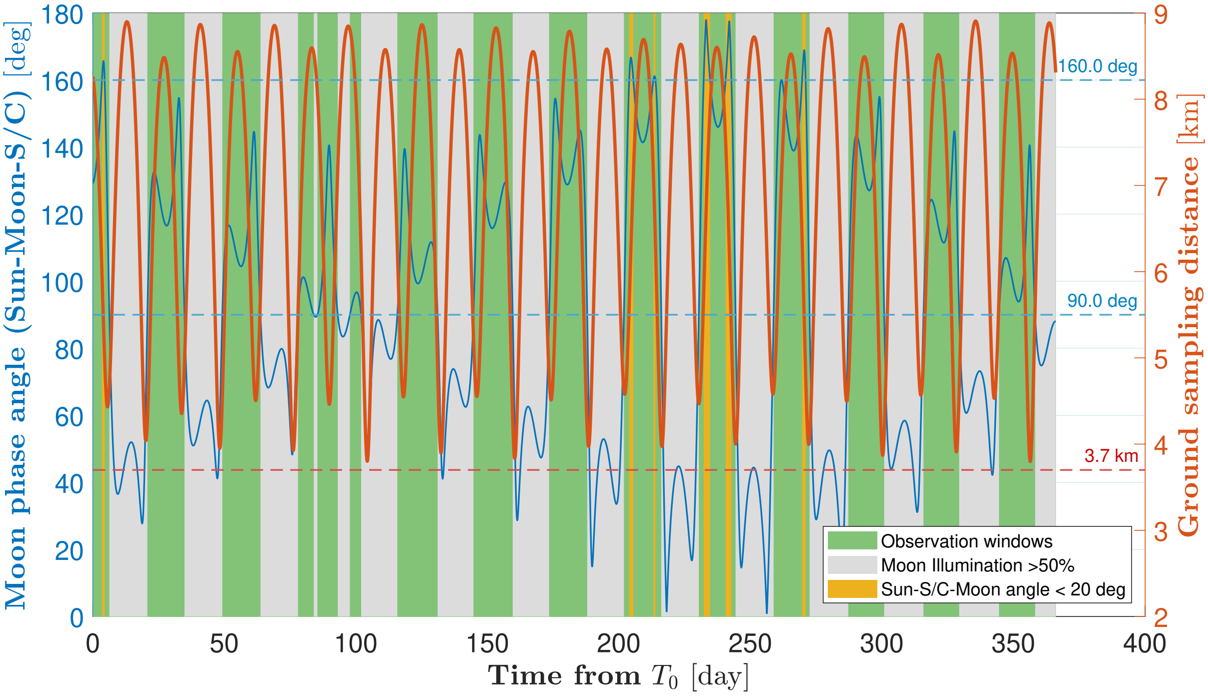


Figure 3: Observation windows. Left y-axis, Moon phase angle (Sun-Moon-S/C angle) as a function of the time epoch during the Operative phase. 50% illumination condition highlighted by the horizontal dashed blue line at 90 deg. Moon phase angle corresponding to Sun exclusion granted by the baffle of the LUMIO-Cam highlighted by the horizontal dashed blue line at 160 deg. Right y-axis, ground sampling distance (GSD). GSD design point for the LUMIO-Cam marked by the horizontal dashed red line at 3.7 km. Observation windows colored in green. Periods when the Moon illumination is greater than 50% colored in grey. Periods in which sunlight hits the first lens of the LUMIO-Cam colored in orange.

shown in Fig. 6. The closest range is 36271.1 km, while the furthest range is 85051.5 km. At these distances, being the Moon diameter equal to 3475 km, the Moon angular dimensions are 5.47 deg and 2.34 deg, respectively (see Fig. 7a and Fig. 7b for the corresponding simulated Moon images). Thus, considering the LUMIO-Cam field of view to be 6 degrees, the Moon is always completely inside the payload field-of-view, provided an accurate pointing at close range. This is also confirmed by Figure 8 which shows the apparent diamter of the Moon in the image for the considered mission timeline.

1.5 LUMIO Payload

LUMIO carries onboard the LUMIO-Cam, an optical payload designed and developed by Leonardo to acquire signals coming from the meteoroids impacts on the Moon surface. The field of view (FOV) is designed to fit the entire disk of the Moon. Acquisitions are performed within 450 nm and 950 nm spectral region. To avoid false positive, the LUMIO-Cam is capable of performing two synchronous acquisitions by splitting the incoming radiation into two different spectral bands. This enables impact flashes signal to be acquired both in the VIS and NIR spectral bands. Additionally, this allows estimating the equivalent black body temperature generated by the plume of impact flashes [4]. Technical properties of the LUMIO-Cam are summarized in Table 5. More information can be found in [1, 10].

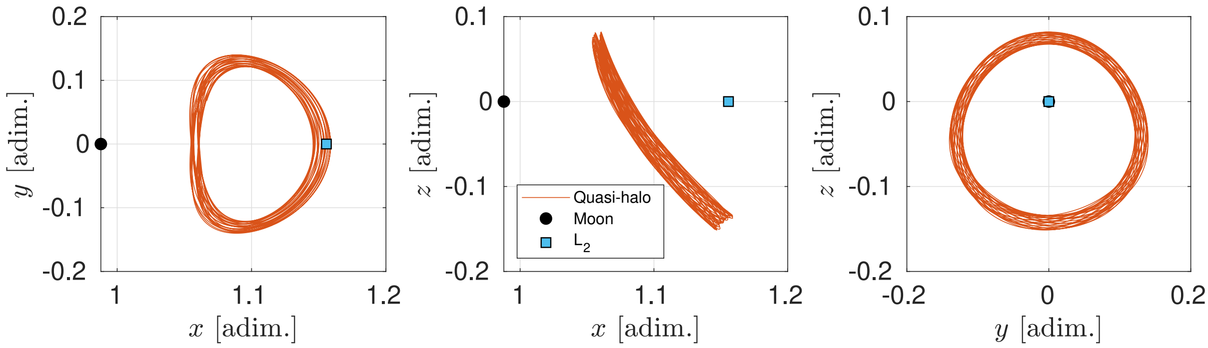


Figure 4: Projection of the selected operative Earth–Moon L_2 quasi-halo in the roto-pulsating frame.

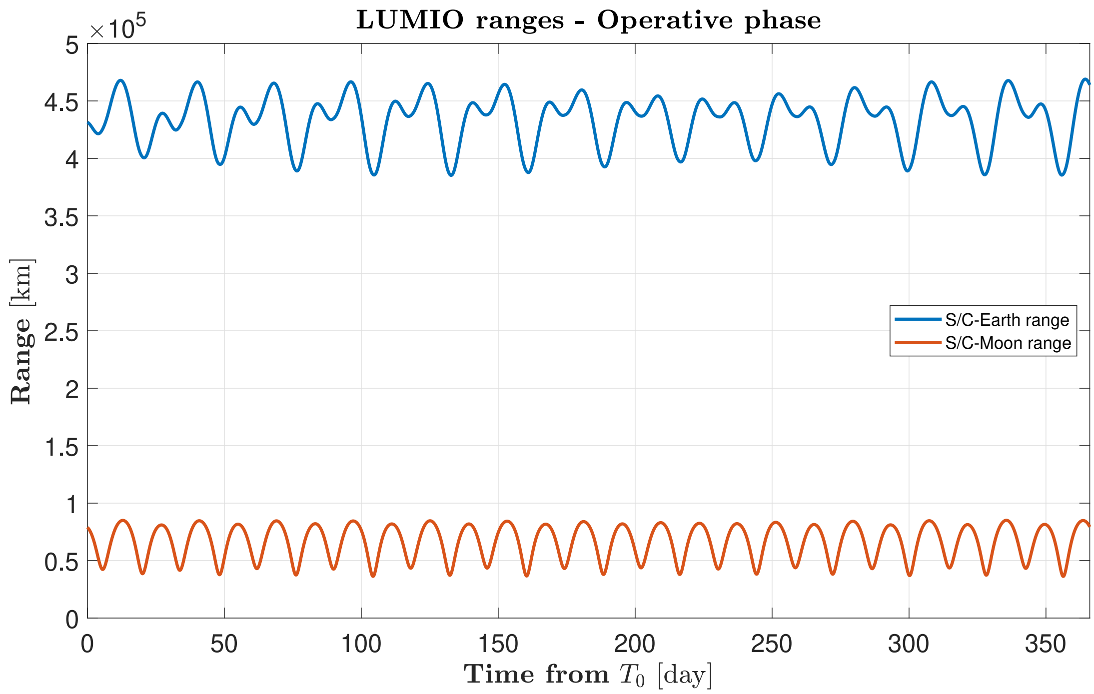


Figure 5: Ranges of LUMIO from the Moon and the Earth during the Operational Phase.

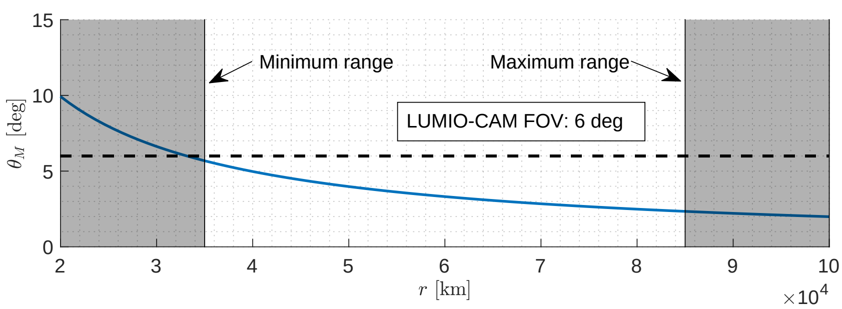
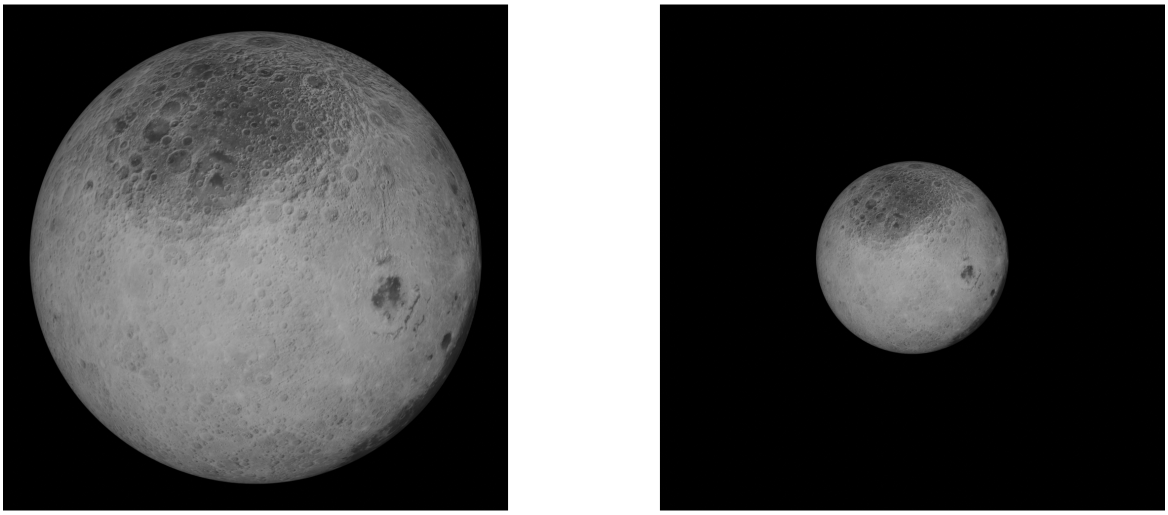


Figure 6: Angular size of the Moon (θ_M) as function of the spacecraft-to-Moon distance r. The LUMIO minimum range, maximum range, and LUMIO-Cam field-of-view are also reported.



(a) Moon image at closest range. (b) Moon image at furthest range.

Figure 7: (a) Moon image at closest range (36271.1 km); (b) Moon image at furthest range (85051.5 km).

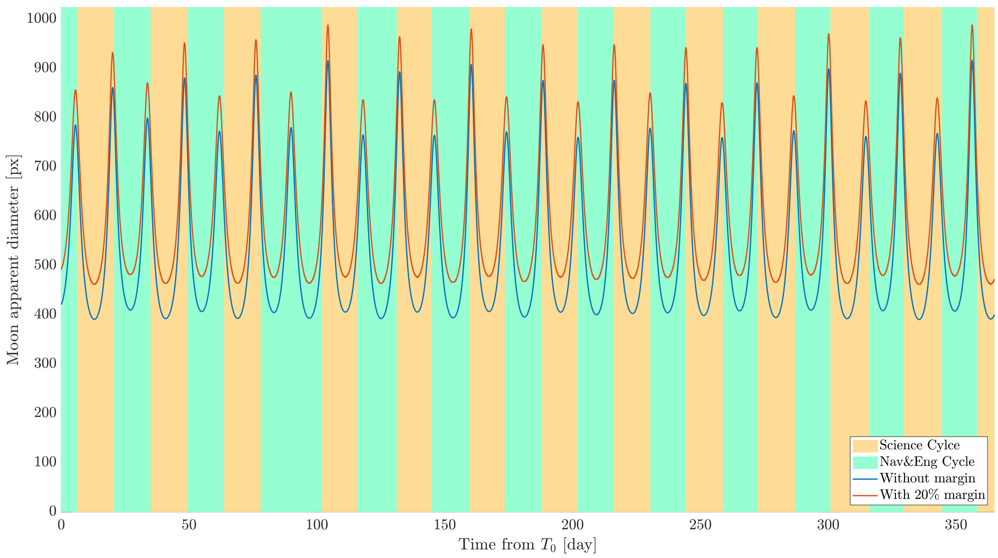


Figure 8: Apparent diameter of the Moon during mission timeline

Table 5: LUMIO-Cam properties.

Resolution	1024x1024 pixels
Field Of View	6.0 deg
Focal Length	127 mm
Aperture Diameter	50.8 mm
Pixel Size	13.3 μm
Optical Center	(512, 512) pixels
VIS channel	450 nm to 800 nm
NIR channel	850 nm to 950 nm

2 Purpose of the present Call

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

2.1 The LUMIO Science Team

Figure 9 shows schematically the structure of the LUMIO science team. The scientific activities are to be supported by the Science Working Groups (SWGs), which will be formed as a result of the present Call. Scientists that are coordinating activities in close synergy with LUMIO are part of the LUMIO Science Team as international collaborators. These include the NELIOTA team[1] and the teams of Lunar Reconnaissance Orbiter's Diviner[2] and LROC[3] payloads.

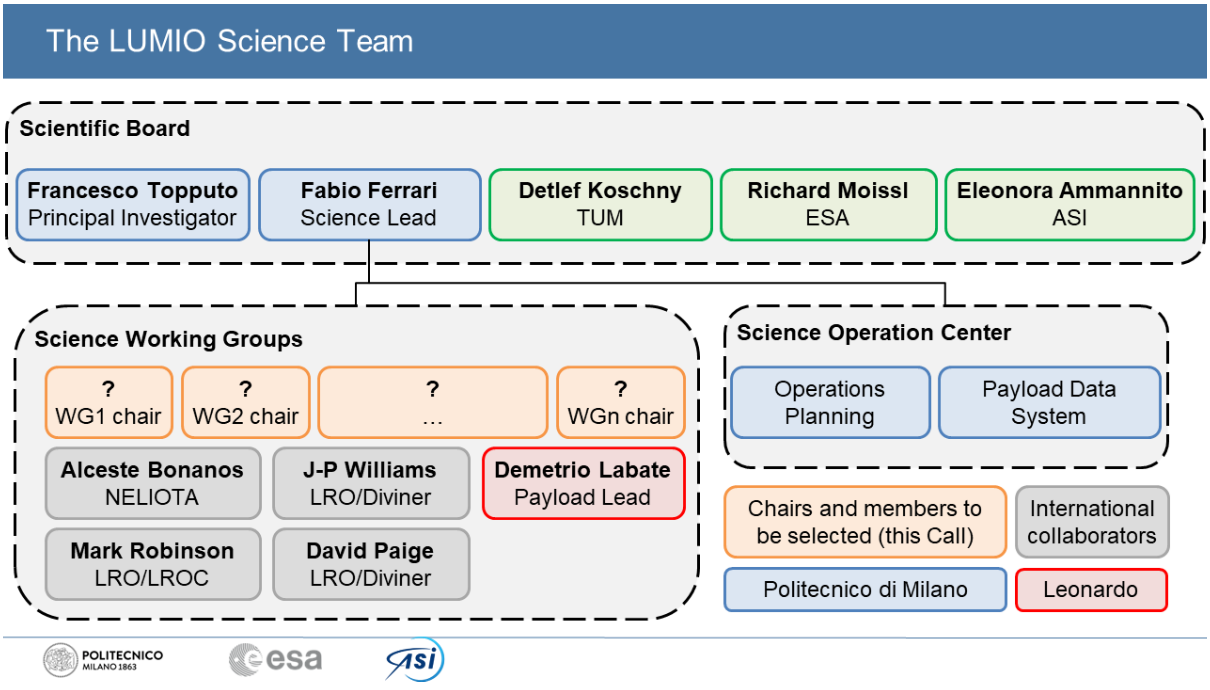


Figure 9: The LUMIO Science Team

2.2 Scientific Working Groups

The structure of the SWGs will be established as a result of the present Call, when the SWGs chairs and team members will be appointed.

Scientists are invited to propose scientific activities in the context of the LUMIO mission. We encourage ideas for the exploitation of LUMIO's data products and payload capabilities to conduct scientific studies related, but not limited, to the main objectives of LUMIO. A list of possible topics include but is not limited to:

- lunar environment & SSA (Space Situational Awareness)

[1] https://neliota.astro.noa.gr/
[2] https://www.diviner.ucla.edu/
[3] https://www.lroc.asu.edu/

- 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
- citizen science/outreach

2.3 Timeline

- **13 February 2023**: Release of this Call
- **22 March 2023 at 18:00 CET**: Proposals due
- **April 2023**: Appointment of SWGs' chairs and members

2.4 Eligibility

This call is open worldwide to scientists interested in the LUMIO mission topics.
Scientists involved in LUMIO's (programmatic, scientific, or technical) management, or being responsible for hardware or software development and procurement activities, as well as other LUMIO Science Team members are not eligible.
Early career scientists are specifically encouraged to apply.

2.5 Appointment conditions

The SWG member/chair appointment is *ad personam*, and has a three-year duration (2023-2025), renewable.
Each selected SWG member will be required to participate to the scientific activities of the relevant working group.
Each selected SWG chair will be required to coordinate the scientific activities of the relevant working group, in coordination with the LUMIO Scientific Board.
Science Team members are expected to support the preparation of the scientific activities during LUMIO Phase B. Commitment of Science Team members is expected to increase as LUMIO advances to Phases C, D and E.

2.6 Evaluation criteria

The assessment and evaluation of individual proposals will be based on the following criteria:

- The scientific value of the proposal and the level to which the proposal identifies specific competences in the broad context of the LUMIO mission;
- Candidate's competence and experience relative to the scientific activities proposed.

It is here remarked that the topics of this Call are not restricted to the LUMIO Scientific Objectives only, but are open to scientific investigations in the broad context of LUMIO. In particular, synergies with other data/missions are especially encouraged, as well as measures/investigations complementary to LUMIO data products.

3 How to apply

3.1 Format of the application

Applications should consist of two parts, merged into a single document.

1. **Curriculum vitae** (max 2 pages). Including the applicant's contact information and all information about the applicant's career that the applicant considers relevant to the present Call.
2. **Scientific application** (max 2 pages). The application should clearly indicate the scientific goals of the proposed activities for which the candidate intends to apply. The application should explain why the applicant considers herself/himself suited for membership of the LUMIO SWGs, the applicant's areas of expertise relevant to the LUMIO scientific goals, her/his potential contributions, etc. The application should not contain a list of publications, but rather it should explicitly list the applicant's five "notable achievements" that in the applicant's opinion make her/him particularly suited for consideration. These might be specific publications the applicant has authored, responsibility in scientific missions and/or instruments and/or research projects, etc.

3.2 Proposal submission

Applications will be accepted exclusively in PDF format, with a maximum file size of 5 MB, to be sent via email to LUMIOScienceTeam@polimi.it. Applications must be received not later than the date indicated in Section 2.3. Proposers will receive confirmation upon successful receipt of their proposals by email. Applications received after the deadline will not be considered. Applications that exceed the page limit or that do not respect the structure described in Section 3.1 will not be considered.

Requests for further information can be addressed to:

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