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Designing the Radio Link for a Lunar CubeSat: the LUMIO Case

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Abstract

The Lunar Meteoroid Impact Observer (LUMIO) is a mission designed to observe, quantify, and characterize the meteoroid impacts by detecting their flashes on the lunar far side. Earth-based lunar observations are restricted by weather, geometric and illumination conditions, while a lunar orbiter can improve the detection rate of lunar meteoroid impact flashes, as it would allow for longer monitoring periods. This paper will focus on the communications and radio navigation system of the mission, designed for the ESA roadmap for lunar exploration. LUMIO has been designed to operate autonomously after deployment from a lunar mother spacecraft in a low inclination lunar orbit and to reach without human intervention his final destination orbit close to the Earth-Moon L2 point, where science can be carried out. Being the destination orbit always in view from Earth (despite a distance of 460000 - 480000 km), Direct-to-Earth communication was added to the mission as a mean to reduce risk and allow independent verification of several of the innovative technologies that would be demonstrated, first of all autonomous navigation. A detailed link budget analysis will be presented for all mission phases for both the link with the mother spacecraft in low lunar orbit and the link with Earth. Beside defining the achievable data transfer, we will focus also on evaluating the available ground stations to better evaluate mission cost with respect to science return. Radio-navigation performances will also be evaluated to estimate the position and relative velocity accuracy, given also the limited performances available for the on-board navigation transponder. This will help also better defining the on-board autonomous navigation system, constraining the total error budget. Further strategies, such as beacon tones, will be evaluated to lower the overall operational cost by employing continuous monitoring with a low performances ground station and, only when needed, perform high speed downlink using a deep-space class ground station. This strategy is considered of extreme importance, especially for small missions, to allow opportunistic operations on high gain antennas, given their very busy schedule.

Keywords: LUMIO, CubeSat, Lunar, Radio, link

1. Introduction

The Lunar Meteoroid Impact Observer (LUMIO) is a CubeSat mission to a halo orbit at Earth–Moon L2 that shall observe, quantify, and characterise meteoroid impacts on the Lunar farside by detecting their flashes, complementing Earth-based observations on the Lunar nearside, to provide global information on the Lunar Meteoroid Environment and contribute to Lunar Situational Awareness.

LUMIO was one of the proposals submitted to the ESA SysNova LUnar CubeSats for Exploration (LUCE) call by ESA. SysNova is intended to generate new and innovative concepts and to verify quickly their usefulness and feasibility via short concurrent studies [1]. LUMIO was selected as one of the four concurrent studies run by ESA, and it won ex aequo the challenge. An independent assessment conducted at ESA's Concurrent Design Facility (CDF) has shown the feasibility and the scientific value of the mission [2], proposing a number of design iterations that, together with the initial design proposed by the LUMIO team in response to the SysNova challenge, contributed to form the Phase 0 study of the mission. Details on this Phase 0 study have been provided by the LUMIO team in numerous publications and presentations [3, 4, 5].

The LUMIO Phase A study, funded by ESA under the General Support Technology Programme (GSTP), through the support of the national delegations of Italy (ASI), the Netherlands (NSO) and Norway (NOSA), has been kicked off in March 2020 and has been completed

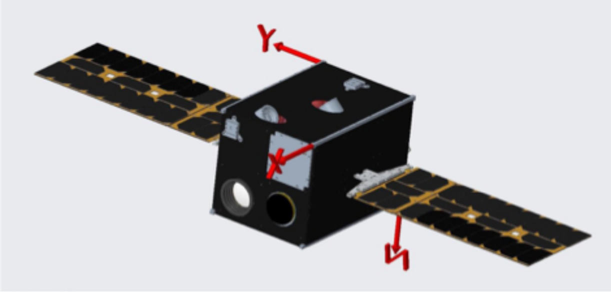


Fig. 1: Rendering of the LUMIO spacecraft configuration resulting from the Phase A study

in March 2021. The initial results of the Phase A have been presented by the LUMIO team in a previous paper [6], while the final Phase A design is illustrated in detail in a companion paper presented at the IAC 2021 [7].

This paper will discuss in detail the Phase A design of the communication system, considering Direct-to-Earth (DTE) and Inter-Satellite Link (ISL). In section 2, mission description is given including mission phases, payload description, and communication system requirements. In section 3, commercial radios considered for the mission are studied for both DTE and ISL. Section 4 and 5 show the link budgets, and radionavigation considerations for both DTE and ISL links respectively. In section 6, communication system trade-off is discusses in detail. Lastly, conclusion is given in the end.

2. Lunar Meteoroid Impact Observer

The LUMIO mission is conceived to answer the question: "What are the spatial and temporal characteristics of meteoroids impacting the lunar surface?" answering such question can contribute to advancing the understanding of how meteoroids evolve in the cislunar space by observing the flashes produced by their impacts with the lunar surface.

The mission utilises a 12U form-factor CubeSat (Figure 1) which carries the LUMIO-Cam, an optical instrument capable of detecting light flashes in the visible spectrum to continuously monitor and process the data. The mission implements a novel orbit design and COTS CubeSat technologies, to serve as a pioneer in demonstrating how CubeSats can become a viable tool for interplanetary science and exploration. Figure 2 shows a simplified representation of the mission profile, divided in the following phases:

Earth-Moon transfer: After launch, LUMIO is carried inside its mothership to a Lunar parking orbit. During the transfer the spacecraft is switched off inside its deployer and the batteries are kept charged by a power connection with the mothership.

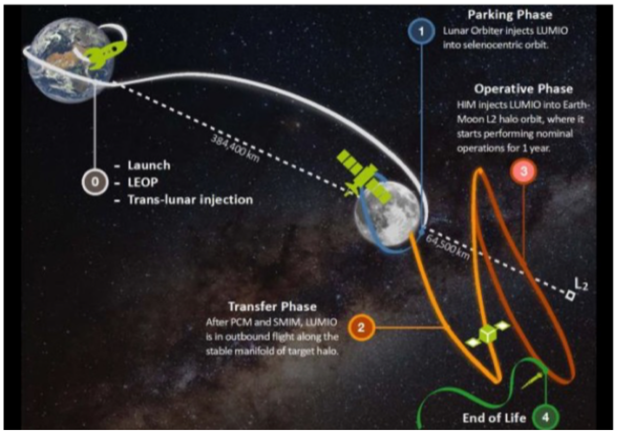


Fig. 2: LUMIO mission concept and phases

Parking: LUMIO is released in its Lunar parking orbit by the mothership. After detumbling and deployment of the solar arrays, the payload and all subsystems are commissioned. The spacecraft stays in the parking orbit and, when necessary, performs station keeping and wheel desaturation maneuvers.

Transfer: LUMIO autonomously transfers from the Lunar parking orbit to the final operative orbit. The transfer is performed by means of a Stable Manifold Injection Manoeuvre (SMIM), two Trajectory Correction Manoeuvre (TCM) maneuvers, and a Halo Injection Manoeuvre (HIM).

Operational phase: In this phase, expected to last at least 1 year, LUMIO accomplishes its scientific objectives. The phase is divided in two sub-phases: the science cycle, during which scientific data (images) are continuously acquired, processed and compressed; the navigation and engineering cycle, during which orbital navigation maneuvers are performed and, eventually, station keeping and wheel desaturation maneuvers are conducted. The science cycle takes place when Moon illumination allows for scientific observations (solid blue line), while the navigation and engineering cycle takes place when scientific observations of the Lunar farside are not possible.

End-of-Life: Finally, all spacecraft systems are decommissioned, and the end-of-life maneuvers are performed.

The satellite payload, called LUMIO-Cam, is a compact imager that will observe, quantify, and characterize meteroid impacts on the lunar farside by detecting their flashes. The instrument, developed by Leonardo, has been designed to operate in a bandwith 450 and 950 nm, implementing a double Focal Plance Assembly configuration. The LUMIO-Cam employs two CCD detectors (one per focal plane) with 1024x1024 active pixels, associated to an optics with a Field of View of 6 deg and 127 mm focal length [5].

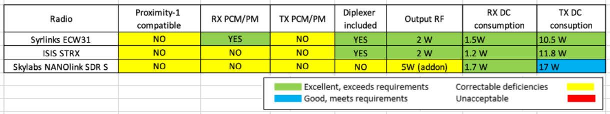
The communication system Phase A design is based on a combination of Inter-Satellite and DTE link. The ISL has been studied considering the Lunar Pathfinder spacecraft, developed by SSTL, as a commercial data relay spacecraft to serve Lunar assets. The DTE link has also been studied to transmit the payload data considering feasible ground-stations.

A selection of the most important requirements for the communication subsystem is presented in Table 1 considering various subjects such as frequency allocations and sharing in the Lunar region, spacecraft mass/volume/power budget, telemetry/tracking windows.

3. Radio Selection

The original mission design employed a mother spacecraft, the SSTL Lunar Pathfinder spacecraft [8], to ensure connectivity to Earth and basic navigation. Since this approach had never been demonstrated before in Lunar orbit, a baseline communications and navigation solution was also added to the mission, relaying on well-proved radiometric navigation using a DTE link. This latter solution will be considered the selected baseline while the ISL will be considered as a technology demonstrator.

Based on the Lunar Pathfinder communication system, the main requirements for the crosslink communication system would be: S-band communication, Proximity-1 compatible, full-duplex operations and no navigation support. In order to meet the mission cost and schedule goals of flying in 2024, only Commercial Off-The-Shelf (COTS) radios have been considered with only minor modifications with a preference for the European market. This led the following commercial devices to be included in the trade-off: Syrlinks EWC31, ISIS STRX and Skylabs NANOlink SDR S. Based on the performances of these three radios, the trade-off in Figure 3 has been prepared.



Radio	Proximity-1 compatible	RX PCM/PM	TX PCM/PM	Diplexer included	Output RF	RX DC consumption	TX DC consuption
Syrlinks ECW31	NO	YES	NO	YES	2 W	1.5W	10.5 W
ISIS STRX	NO	NO	NO	YES	2 W	1.2 W	11.8 W
Skylabs NANOlink SDR S	NO	NO	NO	NO	5W (addon)	1.7 W	17 W

🟩 Excellent, exceeds requirements
🟦 Good, meets requirements
Correctable deficiencies 🟨
Unacceptable 🟥

Fig. 3: ISL radio preliminary trade-off

Table 1: The most important LUMIO communication subsystem requirements

Req.ID	Requirement	Rationale
COMMS.010	The spacecraft shall have a telecommand receiver operating according to Recommendation SFCG 32-2R1	Frequency Allocations and Sharing in the Lunar Region
COMMS.020	The spacecraft shall have a telemetry transmitter operating according to Recommendation SFCG 32-2R1	Frequency Allocations and Sharing in the Lunar Region
COMMS.030	The spacecraft shall have a payload data transmitter operating according to Recommendation SFCG 32-2R1	Frequency Allocations and Sharing in the Lunar Region
COMMS.040	Data links should implement a 20% margin on throughput	
COMMS.070	The communication system shall provide radio navigation support with a position accuracy of 1km 3sigma	Required to locate the spacecraft and validate the optical navigation experiment
COMMS.080	The satellite receiver shall be operational in all mission phases	Required to always be capable to command the spacecraft
COMMS.090	The payload transmitter shall operate continuously for a continuous ranging session	Maximum expected communication window with Earth (worst case) considering lunar visibility and realistic ranging session length
COMMS.100	The telecommand receiver shall support a minimum data rate to request at least 10% of the total satellite telemetry	Support basic operations and allow satellite health check verification
COMMS110	The telemetry transmitter shall support transmitting 3 MB of telemetry in one day	Support basic operations and allow satellite health check verification, based on the 10% of the spacecraft housekeeping budget
COMMS.120	The payload data transmitter shall be able to transmit 73.6 MB during one Nav&Eng cycle	Allow to transfer the full science data package per operations cycle within 1lunar month, based on the average science data budget
COMMS.130	The spacecraft shall be commandable for more than 95% of all spacecraftorientations in all operational scenarios	Upper limits to the spacecraft orientations where commanding is notpossible to constrain the required antenna pattern/configuration
COMMS.140	The spacecraft telemetry shall be receivable for more than 95% of all spacecraft orientations in all operational scenarios	Upper limits to the spacecraft orientations where commanding is notpossible to constrain the required antenna pattern/configuration
COMMS.150	The communication system shall have a maximum volume of 2U (CubeSat form factor).	From spacecraft volume budget
COMMS.160	The communication system shall have a wet mass of no more than 2 kg.	From spacecraft mass budget
COMMS.170	The communication system shall require a power of no more than 25 W during transmission, and no more than 2 W during reception	From spacecraft power budget

From the main requirements, it can be seen that none of the radios supports the Proximity-1 standard: this is a correctable deficiency in all cases as the radios are all software-defined and would allow to be customized to support a receiver. Among the three, only the Syrlinks ECW31 supports PCM/PM in its receiving chain (this is due to the radio being also configurable as coherent transponder). Furthermore, the radio already includes a diplexer (as the ISIS STRX) to be used directly on a single antenna. All radios support at least 2W of RF out-

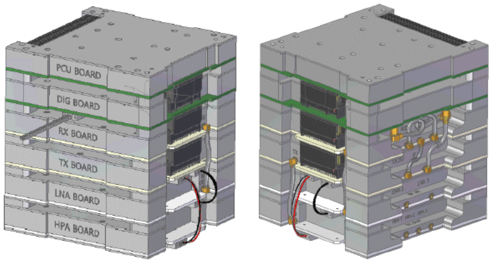
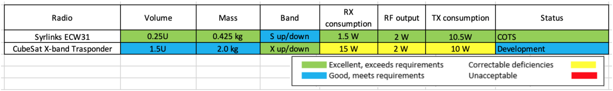


Fig. 4: CubeSat Deep Space X-band transponder in development [9]

put power with the NANOlink potentially going up to 5W with the use of an external power amplifier: despite this feature is considered useful, improving the ISL downlink speed, this has not been considered critically important. Due to these reasons, the preferred radio for the ISL link would be the Syrlinks EWC31.

The DTE link is used, besides for data downlink, also to perform radiometric navigation. This leads to the need for a radio that would be capable of operating as a coherent transponder, making this the main driver for the selection. Two devices on the European market have been considered: Syrlinks EWC31 (S-band uplink/downlink) and a European Deep Space X-band transponder [9], currently in development. The Syrlinks EWC31 is a flight-proven radio, capable of operating as an S-band coherent transponder and providing the required output power with minimal receiver power consumption. The European X-band transponder is instead a new development, taking the heritage of a space proven deep-space transponders in a CubeSat form factor. An output power of 2W Radio Frequency (RF) output power would be required for the project to meet the power consumption requirements and this modification has been deemed acceptable in the overall mission development plan. This radio also features three cold redundant RF Power Amplifier (PA)s and Now Noise Amplifier (LNA)s, greatly simplifying system integration with respect to guaranteeing omnidirectional commandability of the system while the Syrlinks EWC31 would require a coupler/splitter, increasing losses. Keeping the previous points in mind, a trade-off between the two radios is shown in the Figure 5. A final selection for the DTE radio will be performed also based on the available ground station options.



Radio	Volume	Mass	Band	RX consumption	RF output	TX consumption	Status
Syrlinks ECW31	🟩 0.25U	🟩 0.425 kg	🟦 S up/down	🟩 1.5 W	🟩 2 W	🟩 10.5W	🟩 COTS
CubeSat X-band Trasponder	🟦 1.5U	🟦 2.0 kg	🟩 X up/down	🟨 15 W	🟨 2 W	🟨 10 W	🟦 Development

🟩 Excellent, exceeds requirements
🟦 Good, meets requirements
Correctable deficiencies 🟨
Unacceptable 🟥

Fig. 5: DTE radio preliminary trade-off

4. Direct-to-Earth Link

The DTE link is used for payload data downlink, ranging and tracking in nominal conditions. Due to the better link budget and the increased simplicity in running eventual recovery operations from the ground (instead of via the ISL), it was selected to also run emergency operations via the DTE link.

The DTE link is using a traditional configuration with one ground station (in principle, to limit mission cost, but multiple stations are considered as well) communicating directly with LUMIO. This study considered the RF spectrum allocated for the space operations service and the space research service considering also that LUMIO will never exceed the 2M kilometers distance from Earth. This means the “near Earth” bands have been considered for this study. Several ground stations have been evaluated, both from institutional providers (as ESA/NASA) and from commercial suppliers (Kongsberg Satellite Services, and Leaf Space) also from the point of view of the available services, performances and frequencies and only X-band or S-band uplink/downlink options have been considered. UHF communication have not been considered due to radio protection concerns [10] and higher bands have not been considered due to the lack of maturity of the technology for CubeSats.

The ground station antenna selection took into account both S- and X-band “near-Earth” antennas, in particular the Sardinia Deep Space Antenna (SDSA) (Figure 6) was selected as a baseline X-band uplink and downlink after comparing it against several other institutional antennas and commercial solutions. Cebreros DSA2, with a diameter of 35m and part of the ESTRAK network, has been considered as a backup antenna. Regarding commercial suppliers, the Santa Maria ground station (Leaf Space) located in the Azores islands features an S-/X-band 10m antenna. In the KSAT network, antennas ranging from 7.3m to 32m feature S-band up / downlink and X-band downlink for Telemetry Tracking and Command (TT&C) and payload downlink. Considering available CubeSat radios, achievable Doppler accuracy, cost and frequency coordination effort, the preferred solution was to use an X-band downlink and uplink, which would require using the SDSA, the Cebreros or the Santa Maria antenna.

From the LUMIO point of view, the Earth is always between 30deg to 50deg with respect to the center of the Moon (this is considered the nominal mission attitude) as can be seen in Figure 7. The graph also represents the distance in logarithmic scale to already provide a hint on the antenna gain variation as a function of the angle. With respect to access time, it can be said that LUMIO is always in direct line-of-sight view from Earth and, considering a single ground station, this leads to a visibility of approx-

Fig. 6: Sardinia Deep Space Antenna [11]

imately 8h (continuously) per day (varying depending on the ground station latitude and elevation map, further details in the next sections) and a gap of approximately 16h per day.

The link budgets for the different DTE communication links have been calculated considering the final mission configuration. Based on the parameters given in Table 2 and 3 for downlink and uplink respectively, worst- and best-case link margins have been calculated. The margin in the tables include a 3 dB safety margin. DTE downlink link margin for 450 kbps with SDSA and DTE uplink link margin can be seen in Figures 8 and 9 respectively.

Radiometric ranging and tracking are considered the baseline method for navigation and have been assessed to verify that the radio and ground station performances are enough to meet the mission requirements. Radiometric tracking performances have also been assessed to estimate the required ranging/tracking time as part of the total mission cost estimation. Considering both communication architectures (ISL and DTE), precedence has been given to DTE ranging/tracking as this is an established technique and is considered the baseline method for the mission. Nevertheless, potential ranging/navigation possibilities have been researched also via the ISL.

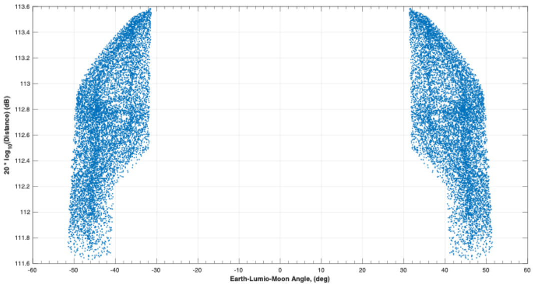


Fig. 7: Earth viewing angles (with respect to the Moon Center) during the operational phase

Table 2: DTE downlink budget assumptions

Parameter	Value	
	Min	**Max**
Distance (Operational orbit)	376765 km	475822 km
Distance (Transfer phase)	376765 km	475822 km
Frequency	8450 MHz	8450 MHz
Atmospheric losses	0.5 dB	0.5 dB
TX power	3 dBW	3 dBW
TX path losses	1 dB	1 dB
TX antenna gain	1.9 dBi	4.5 dBi
Data rate	450 kbps	900 kbps
Required Eb/No	2.5 dB	2.5 dB
RX G/T	56 dBK	56 dBK
Link Margin	3 dB	3 dB

Table 3: DTE uplink budget assumptions

Parameter	Value	
	Min	**Max**
Distance (Operational orbit)	376765 km	475822 km
Distance (Transfer phase)	376765 km	475822 km
Frequency	7200 MHz	7200 MHz
Atmospheric losses	0.5 dB	0.5 dB
TX EIRP	87 dBW	87 dBW
RX antenna gain	1.9 dBi	4.5 dBi
Data rate	10 kbps	10 kbps
Required Eb/No	2.5 dB	2.5 dB
RX temperature	25 dBK	25 dBK
Required Eb/No	9.6 dB	9.6 dB
Modulation losses	5 dB	5 dB
Link Margin	3 dB	3 dB

An orbit determination analysis has been carried out using Cebreros, ESTRACK ground station and the Sardinia Deep Space Antenna. In the simulations, ranging sessions have been scheduled according to the mission phases and have followed the 7 + 7 + 14 days scheme. Two-way transparent range measurements have been used at the beginning and end of every ranging session while coherent Doppler measurements have been considered every 20 minutes. It was found that 3 hours of tracking for each session would fit well within the navigation requirements for both antenna options. Based on the results of the previous sections, the ground contact times for the nominal operational mission and transfer phase have been estimated for DTE as total of 192 hours (over the course of 1 year) including payload downlink, nominal tracking, and emergency operations. It should be noted that this time allocation only considers payload data downlink and navigation. TT&C has not been included in this overview as the expected short duration would lead to a considerable extra amount of hours for the selected ground stations.

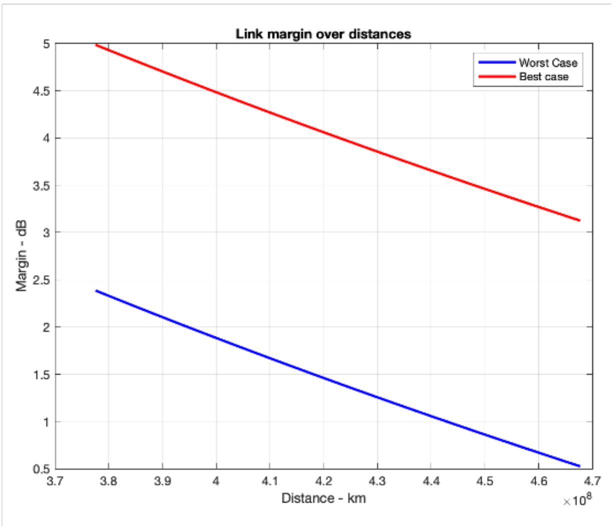


Fig. 8: DTE downlink link margin for 450kbps link with SDSA

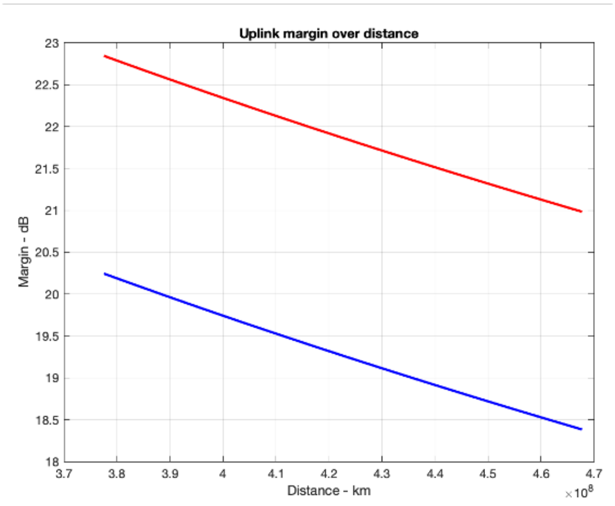


Fig. 9: DTE uplink margin

5. Inter-Satellite Link

In addition to the DTE link, an ISL has also been selected for the configuration. This is due to several reasons, in particular due to the need for an on-board always available for commanding. The ISL provides optimal performances for this aspect, despite data rates are very limited as a consequences of the available volume (to fit a higher gain antenna) and power. The ISL will this be used for commanding the satellite under nominal conditions due to the constrained power budget. It is considered too complex to add a redundant antenna for the ISL (to ensure full coverage in all mission scenarios) due to the added losses introduced in couplers/splitters. This would further reduce the achievable data rate and make the Proximity-1 link unfeasible [12].

The ISL is expected to involve, as relay satellite, the SSTL Lunar Pathfinder spacecraft, is a commercial data relay spacecraft developed by SSTL under ESA contract to service lunar assets [13]. An overview of the mission architecture can be seen below in Figure 10.

The satellite features a UHF and an S-band full-duplex link used to communicate to assets located on the Moon surface and closely orbiting it. Depending on the position of the asset, this can fall in the radio-astronomy protection area (see [10] for further details), it was selected not to proceed with the UHF band mainly because LUMIO would be always located inside such radio protection zone during its operational phase (at least 1 year). This emission might come close to the Hydrogen line with extreme red-shift, causing potential problems to future radio-astronomy missions [10] and, for this reason, only S-band is thus considered in the study.

Based on their orbital parameters, the Lunar Pathfinder will always be located in the direction of the Moon (approximately) and of the Earth from the LUMIO point of view with varying distances, during the operational phase: the relative viewing angles are shown in the Figure 11 (all simulations refer to the operational phase). This plot shows that an optimal antenna would be directly pointed towards the center of the Moon with a beam-width wider than 30 degrees. In the plot, distance was already plotted in logarithmic scale, and to the second power, providing a direct indication for the antenna gain difference at the maximum/minimum distance.

Based on the Lunar Pathfinder antenna specification, the Lunar Pathfinder will need to have position knowledge to proper point the antennas. Considering approximately a 1dB pointing loss on the Lunar Pathfinder side, the Lunar Pathfinder would require knowing the LUMIO position with an error of 1000 – 3000 m (depending on

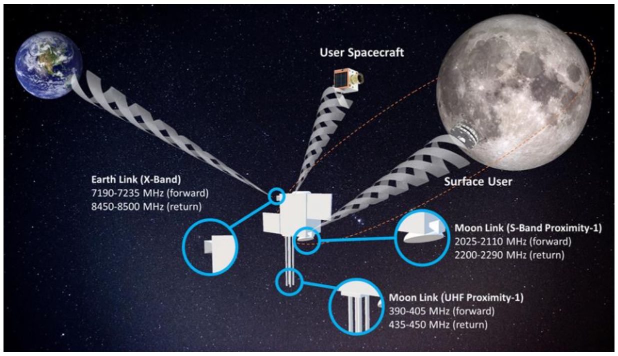


Fig. 10: Lunar Pathfinder mission architecture [13]

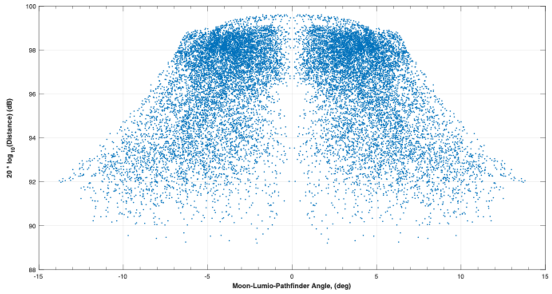


Fig. 11: Lunar Pathfinder viewing angles (with respect to the Moon Center) during the operational phase

the relative distance), which is considered easy to achieve based on the navigation requirements [14].

Considering an approximate EIRP for LUMIO in S-band of 9dBW, the achievable data rates with the Lunar Pathfinder are in the order of 0.5–4 kbps (depending on the relative distance): The link budgets for the different communication links have been calculated considering the final mission configuration and using the real antenna radiation patterns for the satellite side, also accounting for nominal and off-nominal attitude. Based on the parameters given in Table 4 and 5 for downlink and uplink respectively, worst- and best-case link margins have been calculated. The margin in the tables include a 3 dB safety margin. ISL uplink and downlink link margins for 500bps can be seen in Figures 12 and 13.

Considering the low achievable rates and the lack of coherent operations in the Lunar Pathfinder transponder, the ISL cannot be used for navigation purposes. Potentially, though, techniques similar to the NASA CAPSTONE mission [15] could be used in conjunction with Linked Autonomous Interplanetary Orbit Navigation (LiAISON) navigation techniques [16], autonomous navigation can be achieved (despite the low accuracy, not sufficient for the mission purposes). This could be a potential experiment to run during the mission but cannot be considered a baseline solution. Based on the results of the previous parts, the ISL contact time for the nominal T&C operation has been estimated as 8 hours per day for the downloading the complete satellite telemetry, out of an average contact time of approximately 23 hours per day.

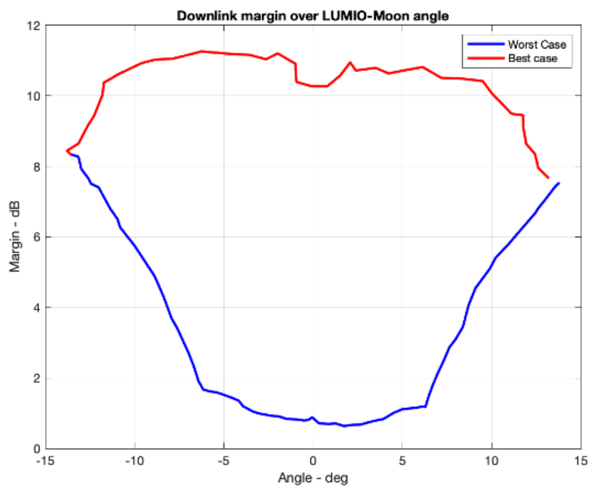


Fig. 12: ISL downlink link margin for 500bps link

6. Communication system trade-off

The previous sections presented all the components building up the communication system, namely the ground station, satellite radios (ISL and DTE). The full communication system trade-off is presented here as it is the sum of all the possible combinations of components. Several open choices are still possible at this stage, also depending on the satellite available power, mass and volume budgets. The ISL link presence is also depending on this trade-off as its presence is not mandatory while the DTE link is considered the baseline for radiometric navigation as it offers a well-proven solution.

The radio selection is also connected to the operational frequency band selection and ground station availability. Moreover, frequency coordination aspects should also be considered to secure the available spectrum together with future plans for frequency bands usage. S-band, over this aspect, has seen a declining usage for long-distance communication and several ground stations are not installing or upgrading their S-band equipment due to this shift in bandwidth allocation. As a last consideration, LUMIO requires radiometric navigation as a baseline: X-band in this aspect provides better performances with respect to S-band in terms of Doppler accuracy and this is the predominant component in the navigation error budget. Despite a formal trade-off analyzing the total cost of owner-

Table 4: ISL downlink budget assumptions

Parameter	Value	
	Min	**Max**
Distance (Operational orbit)	31772 km	89870 km
Distance (Transfer phase)	1 km	89870 km
Frequency	2200 MHz	2200 MHz
TX power	3 dBW	3 dBW
TX path losses	1 dB	1 dB
TX antenna gain	4.5 dBi	6.5 dBi
Polarisation losses	0.5 dB	0.5 dB
Data rate	500 bps	4000 bps
Required Eb/No	2.5 dB	2.5 dB
Link Margin	3 dB	3 dB

Table 5: ISL uplink budget assumptions

Parameter	Value	
	Min	**Max**
Distance (Operational orbit)	31772 km	89870 km
Distance (Transfer phase)	1 km	89870 km
TX power	3 dBW	3 dBW
TX path losses	1 dB	1 dB
TX antenna gain	23.6 dBi	23.6 dBi
Polarisation loss	0.5 dB	0.5 dB
Data rate	500 bps	500 bps
Required Eb/No	2.5 dB	2.5 dB
Link Margin	3 dB	3 dB

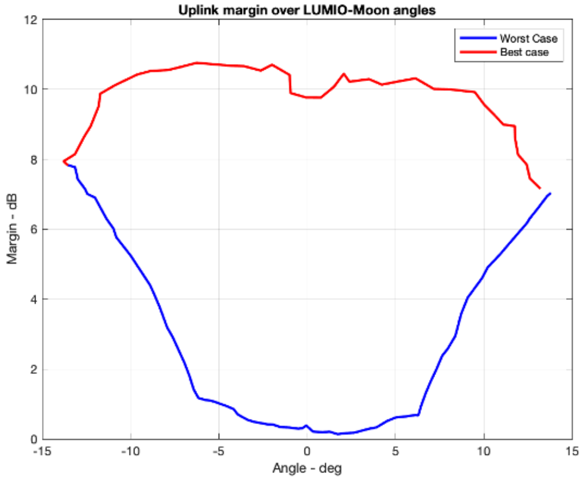


Fig. 13: ISL uplink link margin for 500bps link

ship and end-to-end performances of the two systems has been performed, it was selected to use X-band as the baseline solution. This choice drives the selection of the European Deep Space X-band transponder [9] for LUMIO. Unfortunately, due to the limited power budget, this radio cannot be used for the full mission duration for the TT&C link and, moreover, this would lead to a drastic increase in ground station time, inflating the overall mission cost. To address this issue, the ISL link has been selected for TT&C, providing an extended satellite commanding window (23 hours a day) also thanks to the existing ground infrastructure of the SSTL Lunar Pathfinder mission.

7. Conclusions

The LUMIO mission, with the primary science goal of observing and characterizing meteoroid impacts on the Lunar farside, will allow to significantly improve the current meteoroid distribution models and possibly reduce their uncertainty. LUMIO will be fully complementary, in both space and time, to Earth-based observations, and will therefore represent a fundamental contributor to Lunar Situational Awareness.

LUMIO is a 12U CubeSat equipped with the LUMIO-Cam, an optical instrument capable of detecting impact flashes while continuously monitoring and processing the images. This paper focused on its communications and radio-navigation system. The Phase A design is based on a sophisticated architecture, involving a combination of ISL and DTE link. In this study, the most important requirements for the communication subsystem have been presented and discussed, followed by available commercial radios, ground-stations, detailed link budget analysis for both the links and radio-navigation performances. The presented design (developed as part of the mission Phase A study) shows the mission is feasible and it can reach the required performances. The mission phase B is expected to start at the end of 2021 or at the beginning of 2022.

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