



SILENCE

A deployment and operation study of the LGWA

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In cooperation with

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Who we are

- Group of students from the MSc in Space Systems at ETH Zurich, Switzerland
- Chose the LGWA for a mission design study, named it SILENCE
- Worked on the concept for two months, with support of Jan Harms



SILENCE

Seismic Investigation in the Lunar
Environment for Cosmic Events



Mission Design

Mission Objectives

Primary Objectives

- Measure Gravitational Waves
- Demonstrate mission operation in a PSR

Secondary Objectives

- Characterize seismic activity on the Moon
- Strengthen European scientific presence in space

Constraints and Scope

Constraints

- Use the LGWA array as payload
 - Layout: 4 stations over 1km diameter circle with a central station
- Cryogenic low-temperature variation environment, specifically a PSR
- Low noise environment
- Low ground tilt at the seismic stations

Scope

- Rover based deployment independent of a human mission
- Assumed unavailability of a nuclear power source (RTG)
- Single landing



Requirements

L0-1: Measure GWs on the Lunar surface

L1-1: Enable measurements in the 1 mHz - 1 Hz range with a sensitivity of $1 \text{ pm}/\sqrt{\text{Hz}}$ at 0.1 Hz and $1 \text{ fm}/\sqrt{\text{Hz}}$ at 1 Hz

L1-2: Transfer collected data continuously to earth

L2-1: Keep $T_{\text{IMU}} < 4.5 \text{ K}$

L2-2: Measure with $f_s > 20 \text{ Hz}$

L2-3: Collect seismic and telemetry data

L2-4: Process and store data

L2-5: Enable communication with Earth

L0-2: Deploy and operate the payload in a PSR for 10 years

L1-3: Feature a circular four station array with diameter 1 km and a central station as payload

L1-4: Deploy the payload in a PSR with $\Delta T < 50 \text{ K}$

L1-5: Operate the payload in the PSR for at least 10 years

L2-6: Keep components at operating temperatures

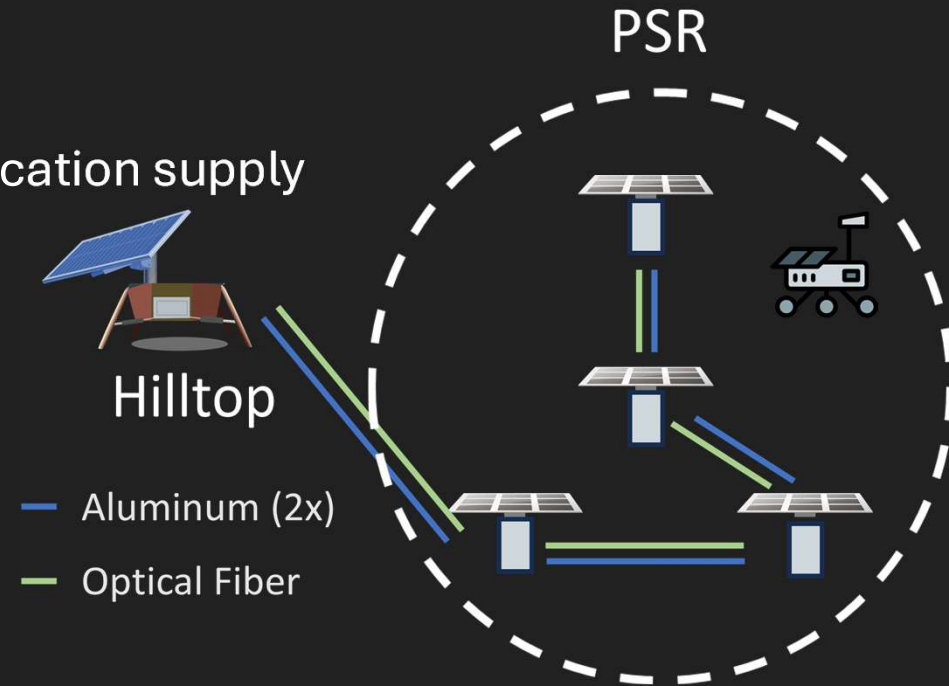
L2-7: Supply the system with power

L2-8: Be robust against Radiation

Architecture and Deployment

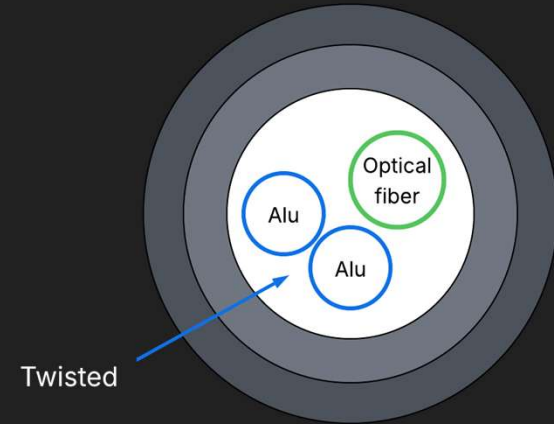
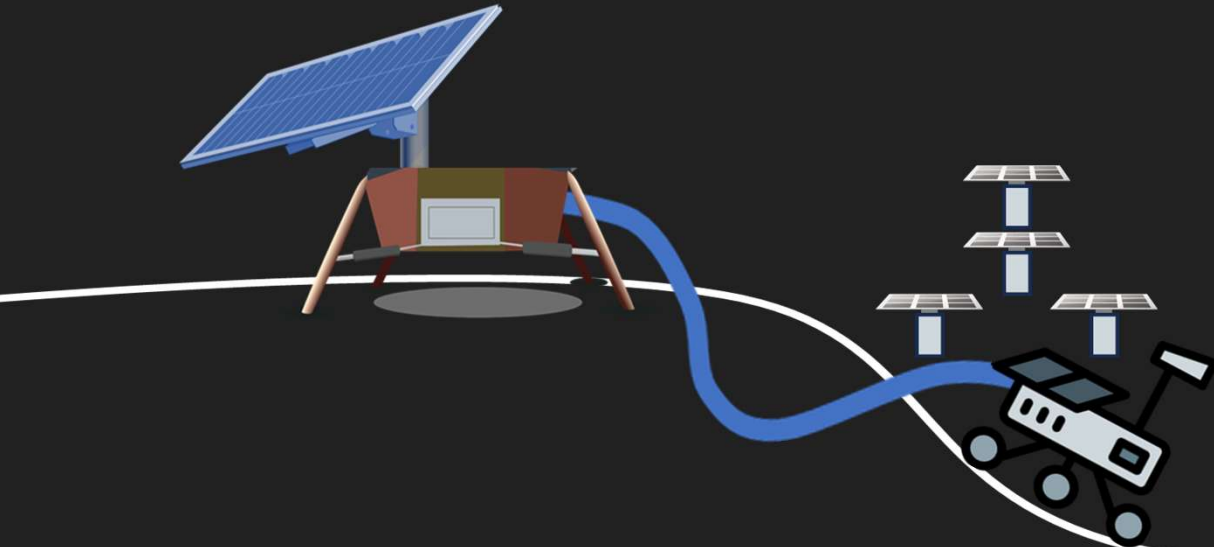
Architecture

- High-solar illumination landing site
- Lander based power, laser and communication supply
- Rover-based deployment into a PSR
- Cable connected array



Deployment Concept

- Hilltop landing
- Single drive into PSR with preconnected array
- Combined power & laser cable



Deployment Platforms

Ariane 64

- Transfer to LTO



ESA Argonaut Lander

- Precision landing
- Sustained operation
- 1'500 kg payload



Astrolab FLEX Rover

- Autonomous payload delivery
- 1'500 kg payload
- 500 kg weight



Trade-offs



Landing Site

Outside PSR

Low risk illuminated landing

Low risk power generation

Inside PSR

Low complexity LGWA array distribution

Low complexity lander integrated solar panels



Deployment Method

4 Mobility Platforms	1 Rover, Multiple Drives	1 Rover, Single Drive
(Redundancy)	Lowest total mass	Low risk single crater rim crossing
Lowest complexity of unit: minimal carrying capacity and no pickup		Low mass
Mass vs. complexity	Mass vs. risk	

- Adapting the means of deployment to available partnerships has high potential for cost savings



Power Delivery

Power Cables

Low heat dissipation in each station

Higher TRL

Low temperature transmission components

Low complexity link

Power beaming

Low loss free-space beaming

Low risk wireless transmission

Low mass infrastructure



Placement of the Communications module

On the lander

Low risk integrated communications module

Low thermal complexity for communication electronics

Low complexity of adding communication to power cable

Inside the PSR

Low risk data collection due to shorter cable

Low noise environment



Placement of the Laser

On the lander

Low thermal complexity at the seismic stations

Low complexity of a single laser system

On each seismic station

Low mass due to lack of optical fiber cable

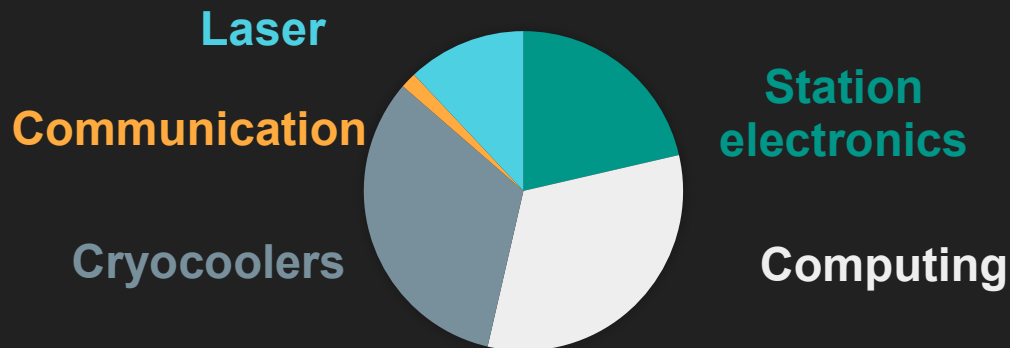
Low risk due to multiple laser systems

Subsystem Sizing

Power

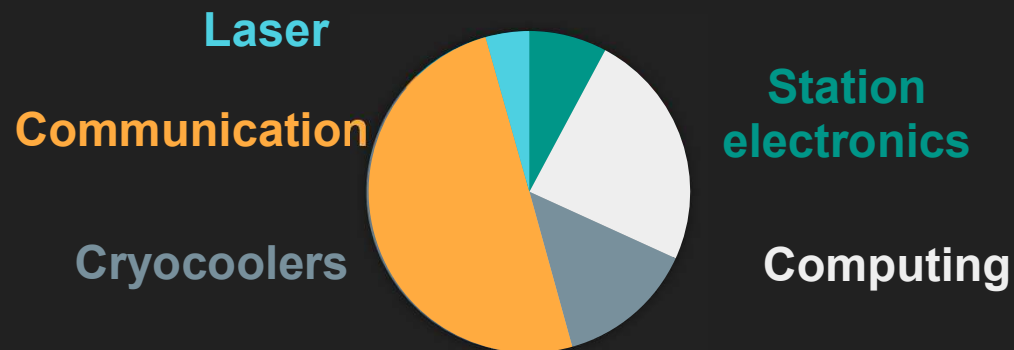
- 2 m² two-sided GaAs solar panel
- 40.2 kWh Lithium-ion battery, driven by duration of lunar night

Continuous consumption ~ 75 W¹



Peak consumption ~ 200 W¹

Active data processing and communication



¹ Estimates based on van Heijningen et al. 2023, The New SMAD (Wertz et al., 2011)

Communications

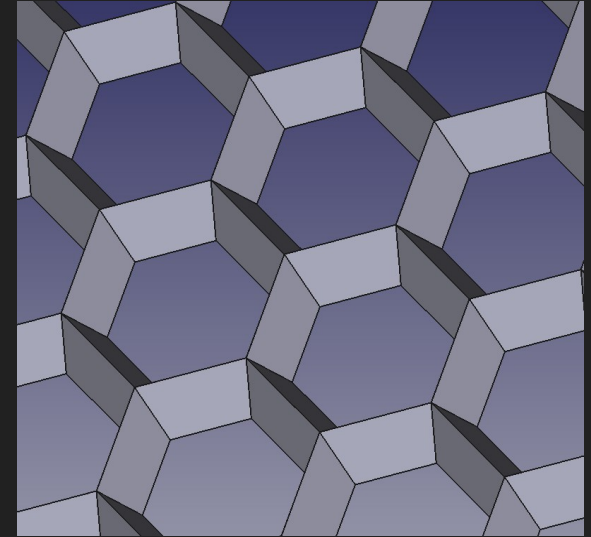


- Lander collects data from all seismometers
- Lander stores and downlinks to lunar relay over Ka band when visible
- Relay forwards to Earth
- Established ground stations
- LunaNet standards



Thermal

- Must be nearly vibration-free
- 4.5 K using sorption-based JT cooler with H₂ and He stages¹
- Radiator for H₂ cooler 1.3 m² at ~87 K, radiator for He cooler 5.1 m² at ~51 K
- Incoming thermal radiation from crater walls should be rejected
- Advanced Radiator Geometry



Tapered open honeycomb radiator

¹ Cooler specifications from van Heijningen et al. 2023

Design Drivers

Criterion	Drives...
Maximum time in the shade	Battery size
Distance from high-illumination landing site to PSR	Cable mass
IMU temperature requirement	Radiator size, feasible sites
Availability of Orbital Relay	Communications design, power
Availability of deployment partner for a rover	Cost

PSR Selection

Requirements



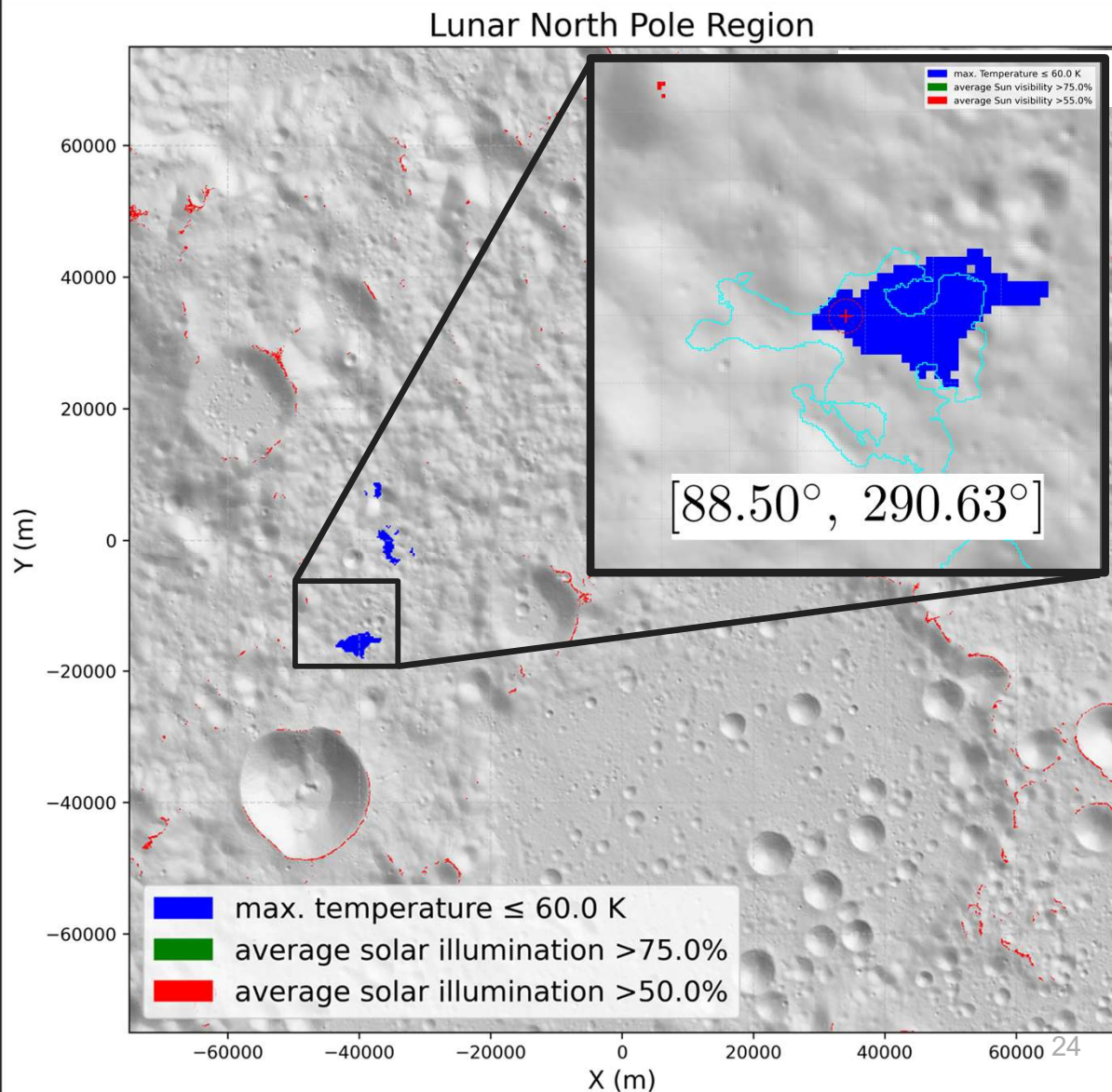
	Landing site	Experiment deployment site
Most important requirements	High average solar visibility (>50%)	T max <60 K
Other relevant requirements	Terrain slope <5° is favorable	Terrain slope <10° is favorable Low temperature amplitude over a lunar day

Selection

- Landing site - deployment site distance drives cable mass
- Longest time in the shade drives battery capacity

Based on

- LRO topography data
- Diviner temperature data
- Solar illumination from Mazarico et al. 2011
- PSR map from Brown et al. 2022



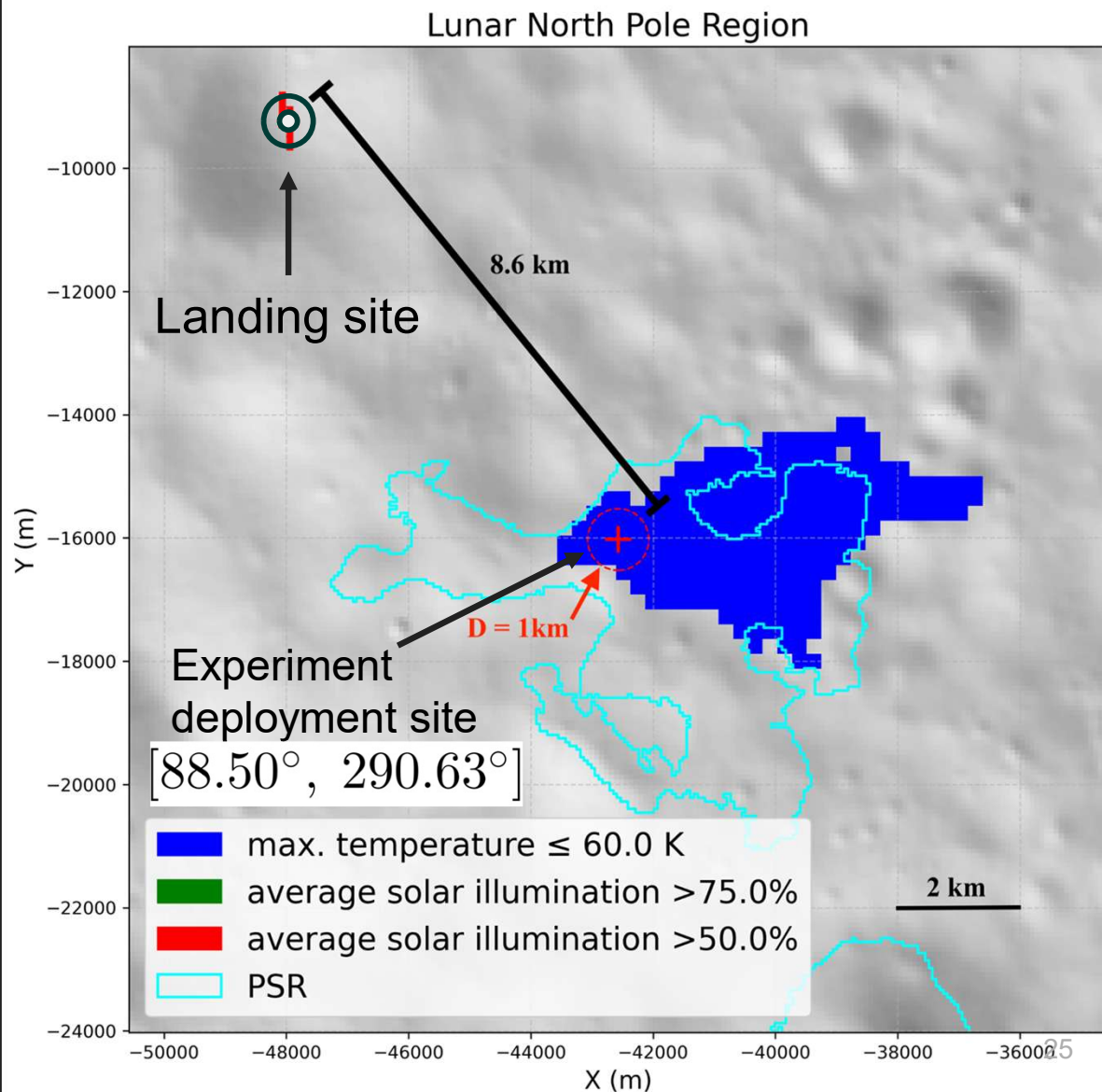
Baseline

Landing site (100m radius)

- Min avg solar illumination: **54%**
- Max slope: **4.0°**

Experiment deployment site

- Max Temperature: **59.7 K**
- Max slope: **7.7°**



Baseline

Landing site (100m radius)

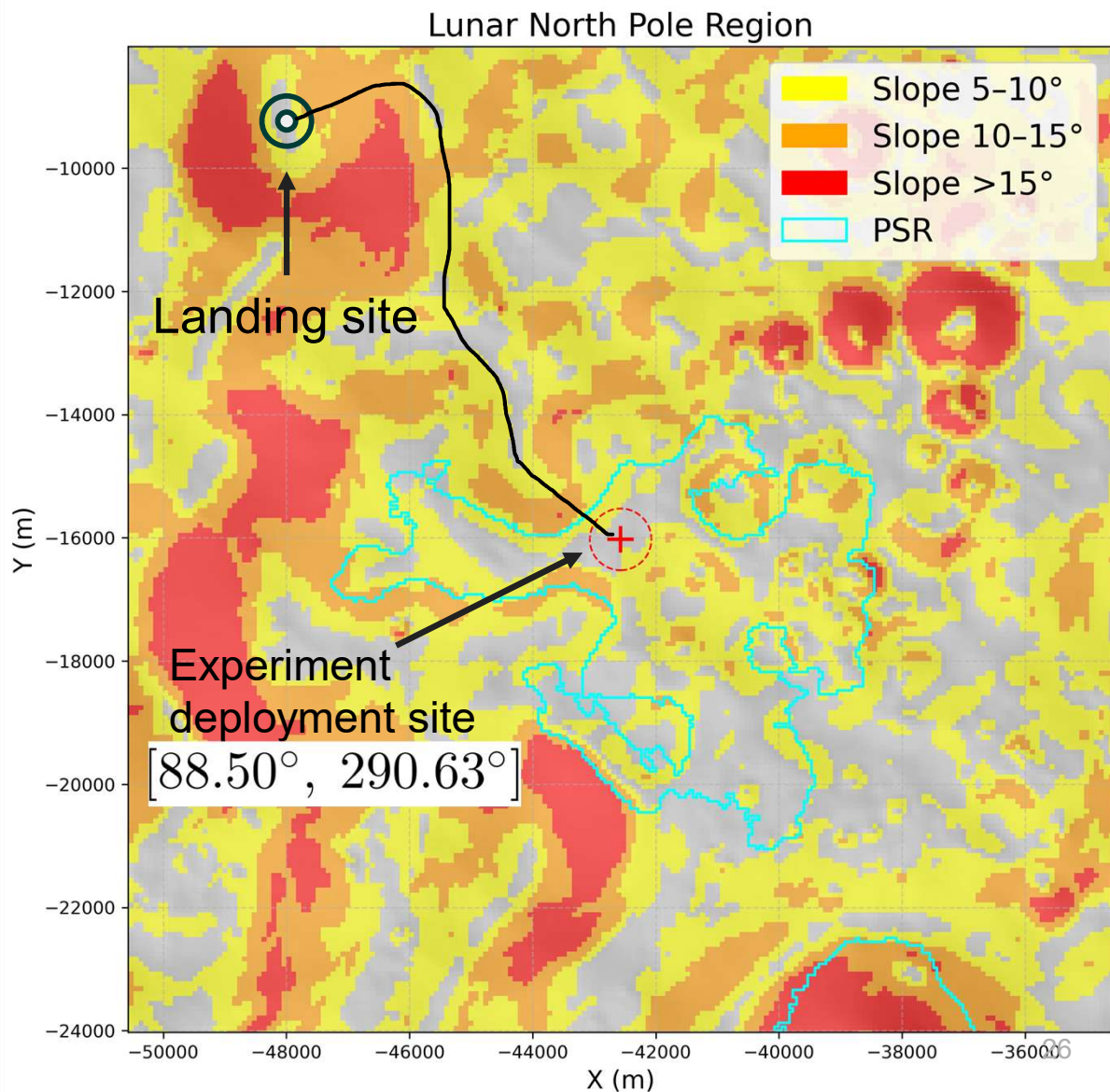
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Experiment deployment site

- Max Temperature: **59.7 K**
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Deployment path

- Distance: **8.6 km** (as the crow flies)
- Slope: **<15°**



Landing Site Illumination Conditions

Illumination conditions

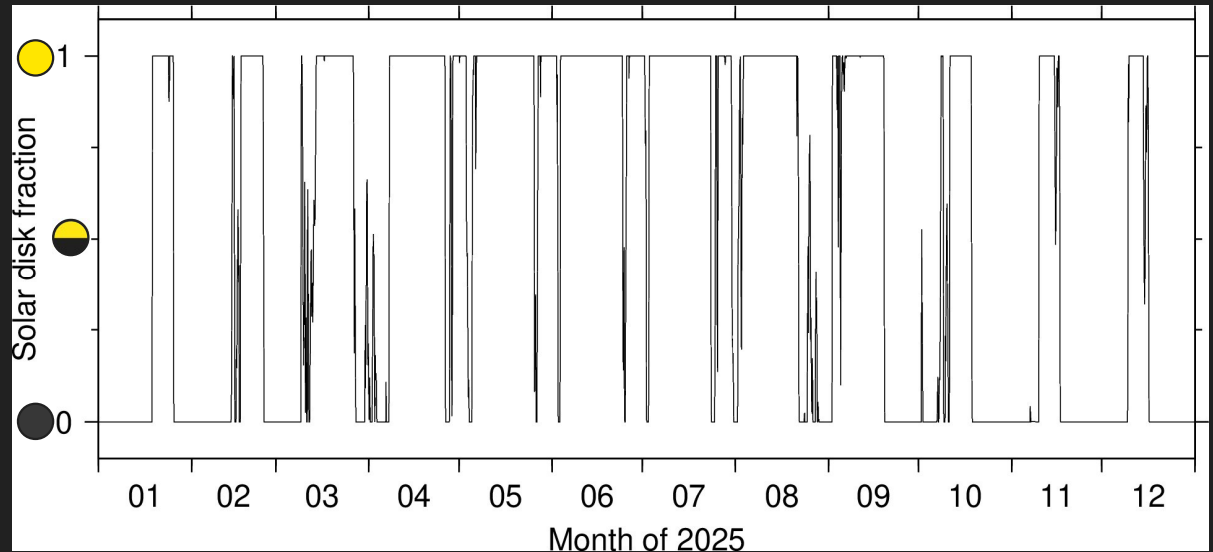
Min average solar illumination: **54%**

Max time in shade:

538 hours¹ (22.4 days)

→ Drives battery mass

1: Sun fully visible, 0: fully shaded



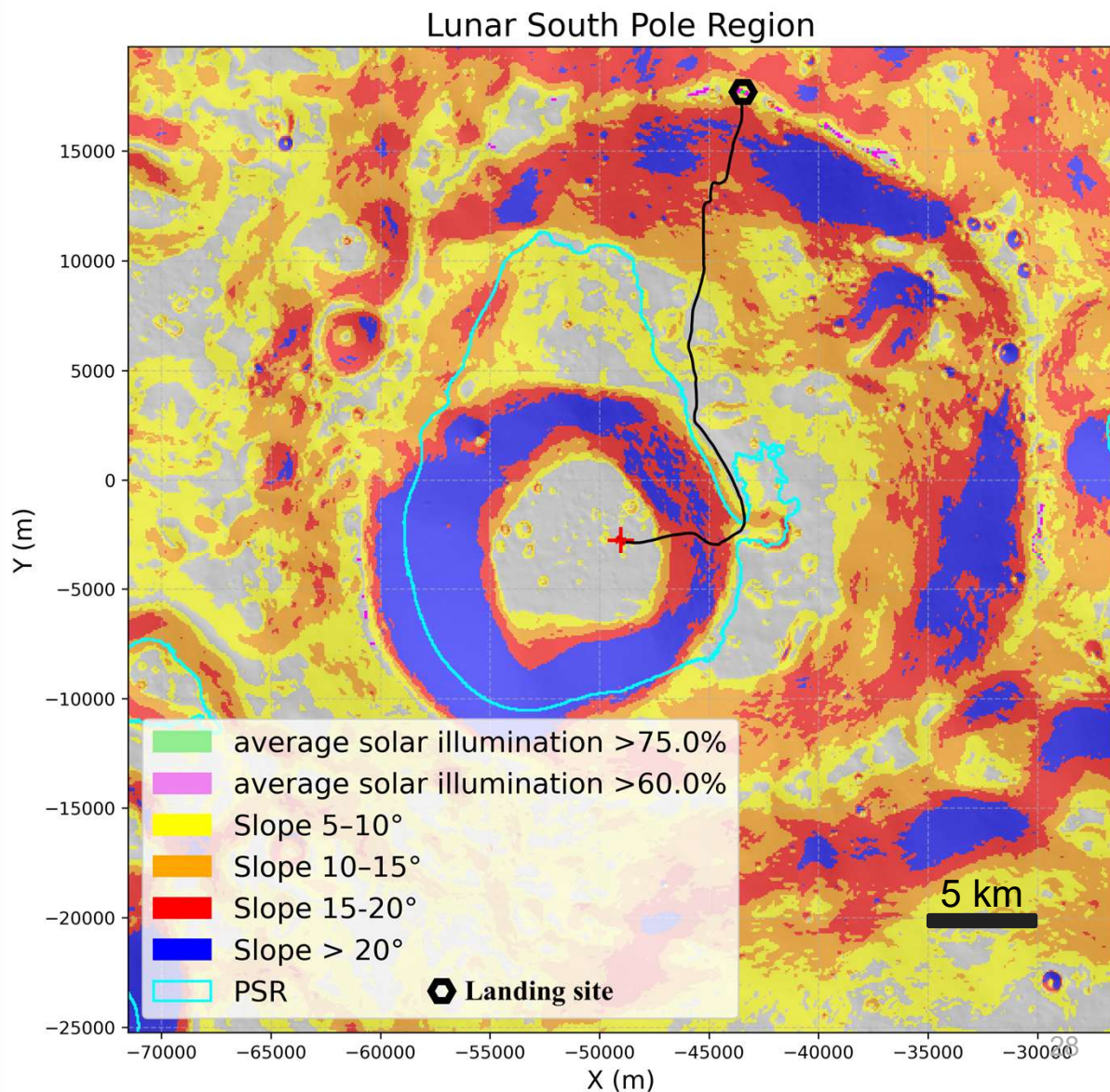
Illumination conditions 2 m above ground at landing site, simulated over 1 year

¹ Value from simulation conducted by Dr. Philipp Gläser

Alt. South Pole PSR de Gerlache Crater

- 76% min avg illumination
- Higher deployment risk
 - 18 km landing site - PSR
 - Close to 20 deg slopes
- Higher risk of anthropogenic noise vs. more rides

Higher-resolution analysis
desirable



Mission Profile

Mission Profile: L-class

Resource

- Time >10 years
- Mass 1.5 tons
- Financial €1.1 billion

Technical

- Vibration Ultra-Low
- Thermal Broad range of temperatures
- Power Heavily constrained
- Comm. Limited relay visibility

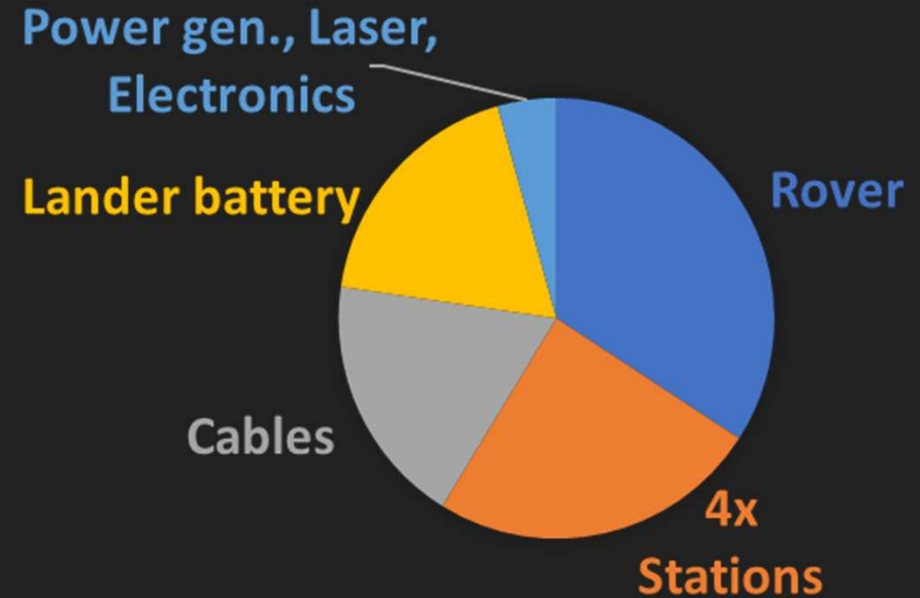
Other

- Environment Accessible PSR
- Lifetime 10 years

Mass Budget

Estimates based on

- Cryocooler and IMU Design
- The New SMAD (Wertz et al., 2011)
- Current Lunar Rover Concepts

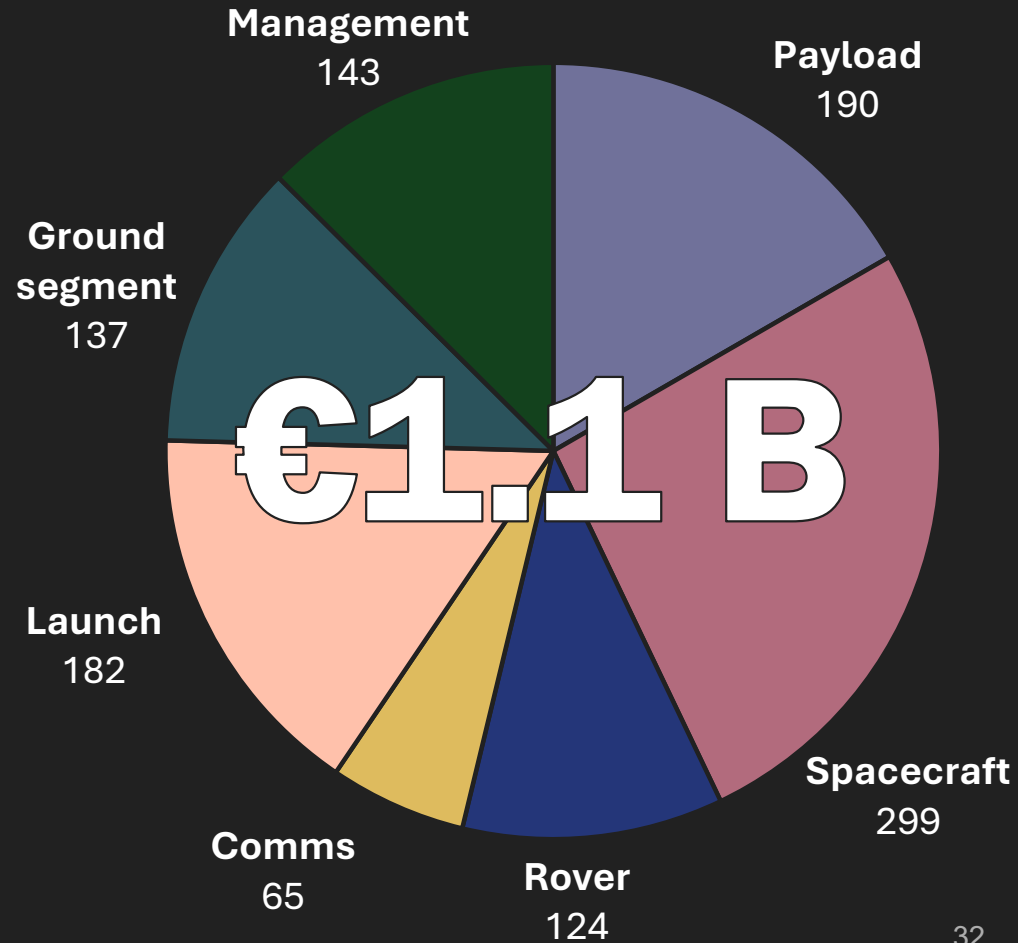


Distribution of 1.46 t
margined lander payload

Cost

Estimates in Mio. € based on

- NASA Instrument Cost Model
- The New SMAD (Wertz et al., 2011)
- Previous L-class missions



Major Risks and Lowest TRL

Subsystem	Major Risk	Rating	Lowest-TRL Component
Lander	Plume-Surface Interaction	High	Argonaut Lander 4
Rover	Immobilization	Med	FLEX Rover 6
Seismic Stations	Seismic noise too high	Med	Sensor 4
Thermal	Not cold enough	High	JT sorption cooler 5
Power	Single-cable failure	High	Power converters in low K 5
Communications	Existence of Relay	Med	Powerline Communications 5
Computing	Radiation storage faults	Med	Cryo-CMOS 4

Thank You