POLITECNICO DI TORINO
Department of Mechanical and Aerospace Engineering

Protezione naturale dalle radiazioni in ambiente lunare: Lava tubes e loro esplorazione

1859

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17th March, 2023

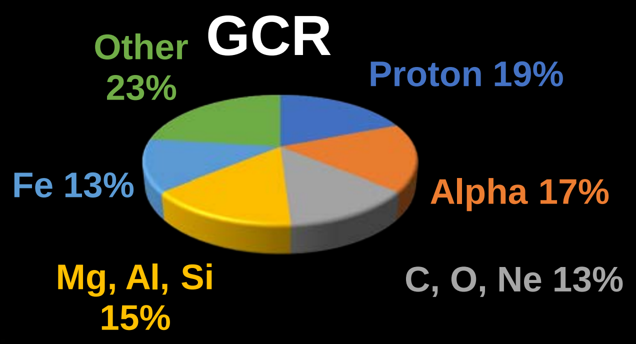
Our next steps on the Moon

CONTEXT

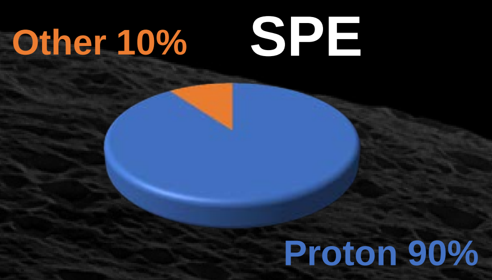
- The Artemis program's long-term goal is to establish a permanent base camp on the Moon

RADIATION ENVIRONMENT [1]

- Constant exposure to Galactic Cosmic Rays (GCRs)
- Chronic exposure to GCRs may have late health effects:
  - Induction of cataract
  - Cancer
  - Degenerative diseases of the central nervous system
- Sporadic Solar Particle Events (SPE)
- Exposure to SEPs with insufficient shielding may cause severe acute effects
- Neutral particles (neutrons and gamma rays) from interaction with lunar soil



Relative contribution to the dose equivalent behind 3 g/cm^2 Al for space radiation outside Earth magnetic field [2]



Radiation on the lunar surface

EQUIVALENT DOSE MEASUREMENTS [1]

- China's Chang'E 4 lander soft landed on the far side of the Moon on 3 January 2019.
- The Lunar Lander Neutrons and Dosimetry experiment aboard Chang'E 4 has made measurements of the radiation exposure on the lunar surface.

Chang'e 4 lander

GCRs contribute

1397 μSv/day
(~500 mSv/year)

Shielding of ~1g/cm^2
Solar minimum w/o SEP events

ISS same time period

$\underbrace{523\ \mu Sv/day}_{GCR} + \underbrace{208\ \mu Sv/day}_{SAA} = 731\ \mu Sv/day$

2.6 times more than ISS equivalent dose

Human habitats on the Moon

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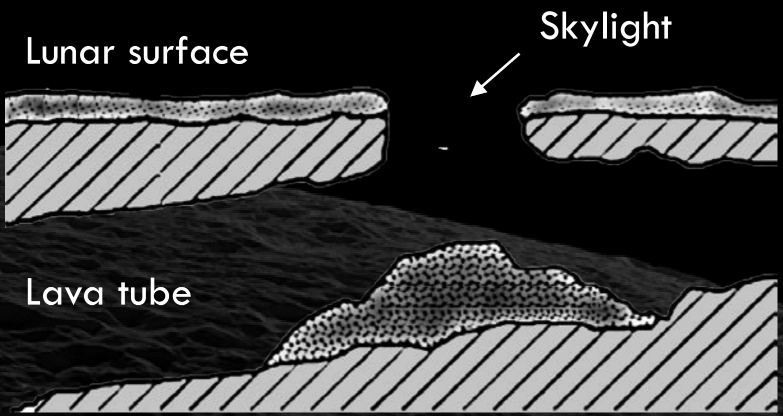
ON THE SURFACE

- Future habitats on the surface involve partial burying under layers of lunar regolith
- The contribution of charged particles to the equivalent dose decreases as the thickness of the regolith increases, but the flux of thermal and epithermal neutrons increases significantly up to a depth of approx. 1m [3].

ESA's lunar habitat concept

UNDER THE SURFACE

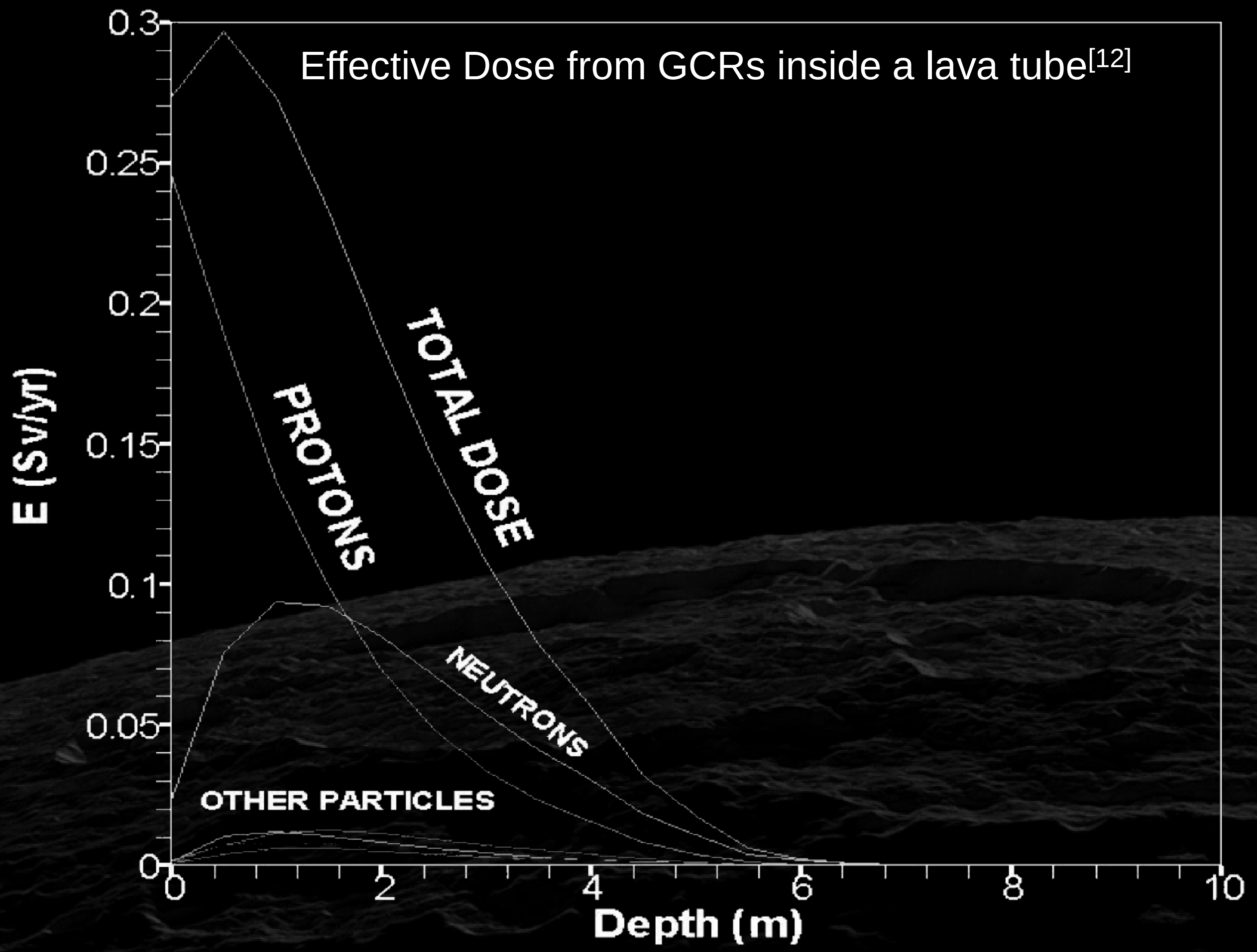
- **Lava tubes**: drained conduits of basaltic lava flows
- Since the early seventies, several authors[4]-[7] have discussed the possibility that lunar rilles on the Moon may in fact be collapsed lava tubes.
- Thanks to the data collected by the Chandrayaan-1[8], SELENE[9] and GRAIL[10] missions, it has been possible to estimate their size at hundreds of meters in diameter and tens of kilometers in length.
- Lunar lava tubes would provide shelter from:
  - Energetic particles and cosmic radiations
  - Micrometeoroids
  - Impact crater ejecta
  - Extreme temperature variations (~15°C costant[11])



Schematic section of a lunar lava tube

Radiation inside a lunar lava tube

- After 6 m of depth, no effects of radiation due to or induced by GCRs are observable
- After far less than 1 m no effects of radiation due to or induced by SPE particles are observable

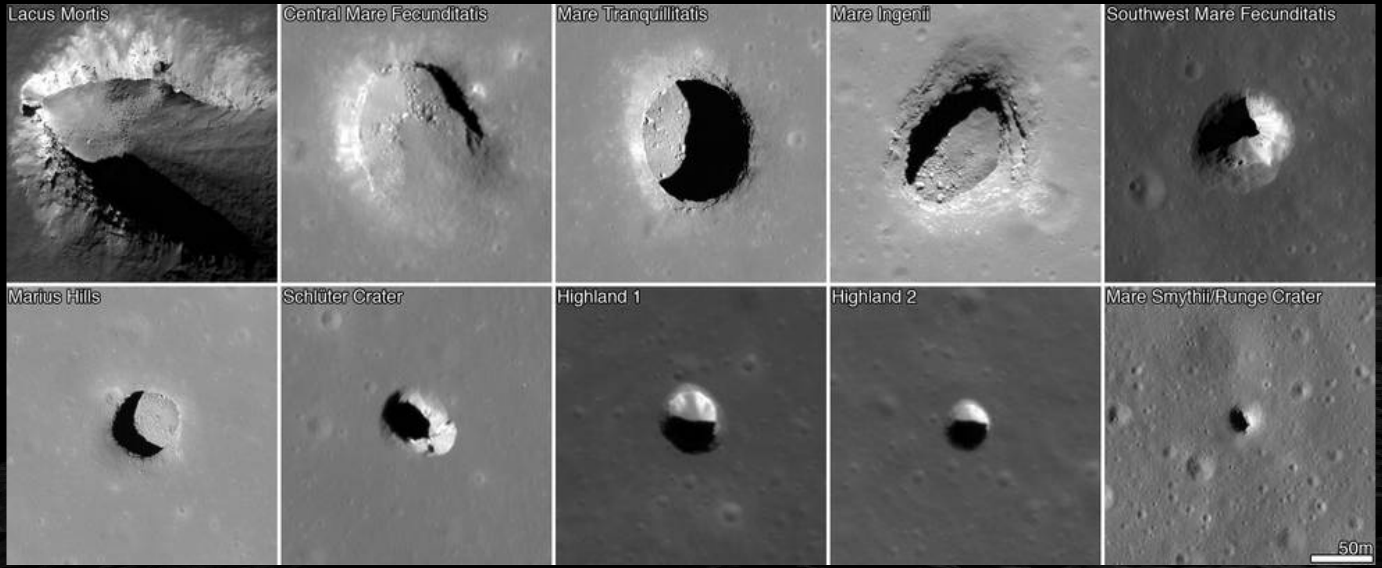


Ten-Year Career Effective Dose Limits (NCRP, 2000)[13]

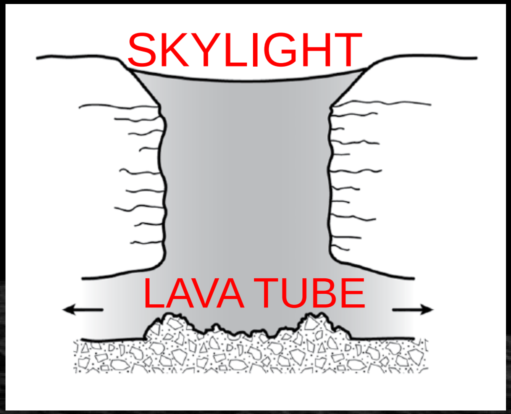
Age at exposure (y)	Female (Sv)	Male (Sv)
25	0.4	0.7
35	0.6	1.0
45	0.9	1.5
55	1.7	3.0

Skylights or just lunar pits ?

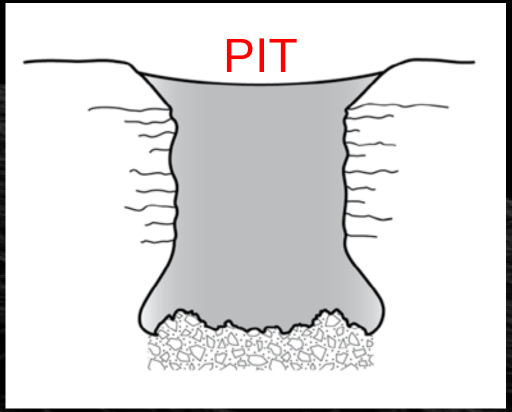
- A possible access to lava tubes are skylights, vertical shafts between the subsurface voids and the lunar surface.
- In 2009, a lunar pit with a diameter of 65 m, located in the Marius Hills region, was the first to be identified as a possible skylight. After that, nearly 300 potential skylights were identified, 21 of which located outside impact melt ponds[14]
- Four pits have contexts suggestive of lava tubes, the Mare Tranquillitatis Pit is probably the best candidate for a first scouting mission



LRO images of some lunar mare pits (potential skylights)



Model of a pit formation as collapse into lava tube M.S. Robinson et al. (2022)



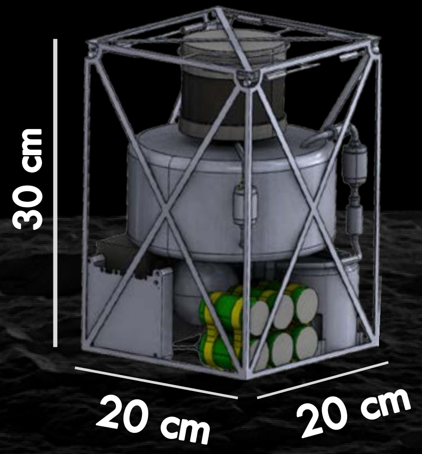
Model of a pit formation as collapse into near surface magma chamber M.S. Robinson et al. (2022)

LuNaDrone

- Robinson et al. (2022) recommend a low-cost precursor mission involving simple flying vehicles for pit initial reconnaissance
- The LuNaDrone project was launched in early 2020 thanks to the vision of Gen. Roberto Vittori
- The LuNaDrone team, which was formed within the Politecnico di Torino, is now leading the design and development of LuNaDrone with the valuable support of Italian SMEs
- Research activities related to the LuNaDrone project have been ongoing since 2020 and include master's thesis activities and a dedicated PhD at the Politecnico di Torino

SPACECRAFT OVERVIEW

MAX WET MASS	15 kg
MAX VOLUME (STOWAGE)	12 U
MAIN PROPULSION	H2O2 (92%) MONOPROP
NAVIGATION	RANGE-VISUAL-INERTIAL
POWER	Li-primary cells



LuNaDrone rapresentation


Ispace Series 1 Lander

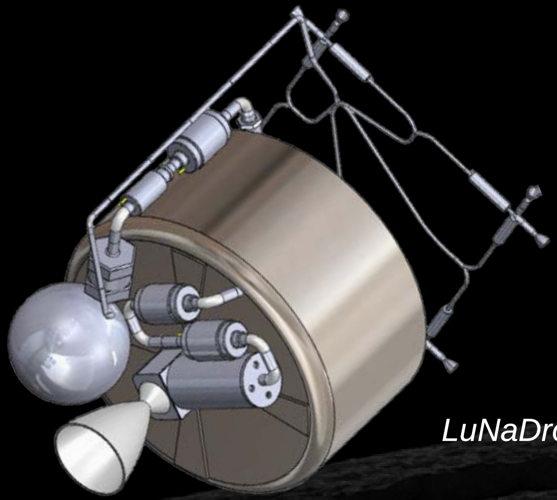
Astrobotic's Peregrine


Intuitive Machines "Nova-C"

Technology

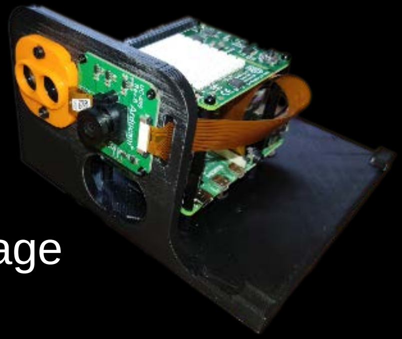
PROPULSION SYSTEM

- 92% Hydrogen Peroxide
- 1 main HTP monopropellant thruster
- 8 smaller thrusters for RCS
- Pressure fed, bang-bang control



LuNaDrone PropSys CAD

NAVIGATION SYSTEM



- No external assistance for navigation
- EKF based range-visual-inertial odometry
- Extremely light and compact sensor package

LuNaDrone flight profile

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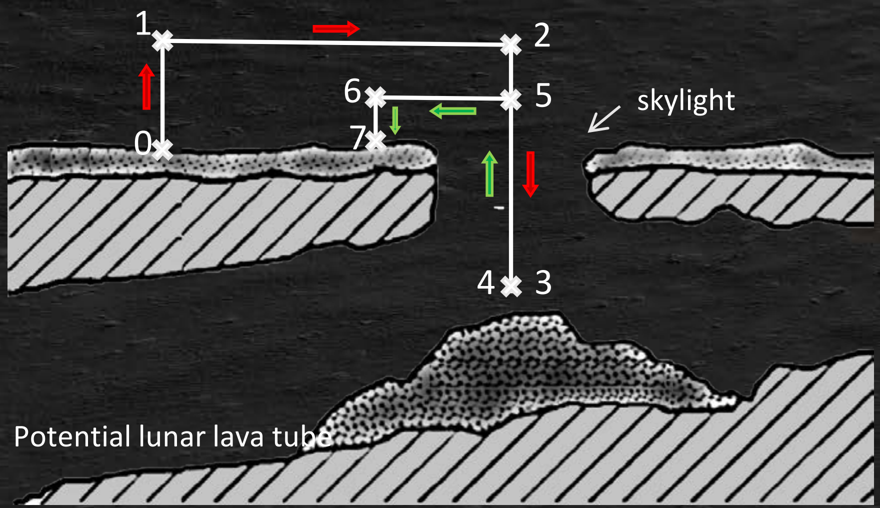
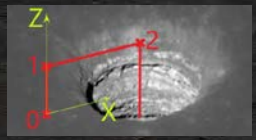
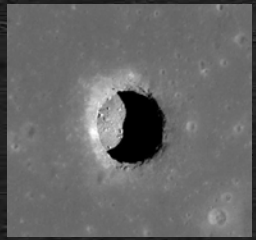
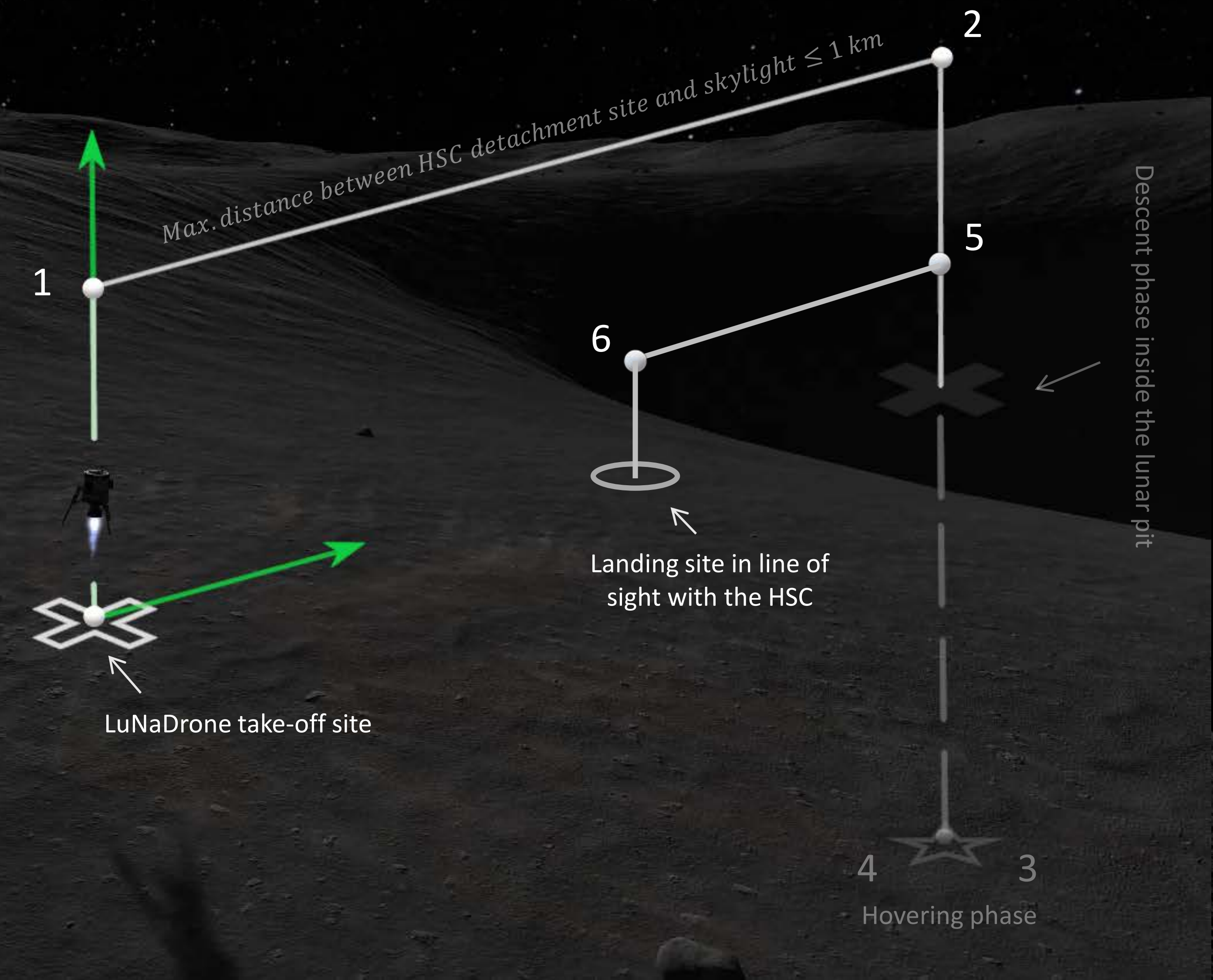
SURFACE MISSION PHASES

Detachment from the HSC	- On-board systems diagnostics - Flight profile update - Umbilical detachment - Mechanical detachment
Flight phase	- Reaching the skylight - Science phase/images acquisition - Skylight egress and landing
Scientific data transmission	- Data transmission to the HSC
Disposal phase	







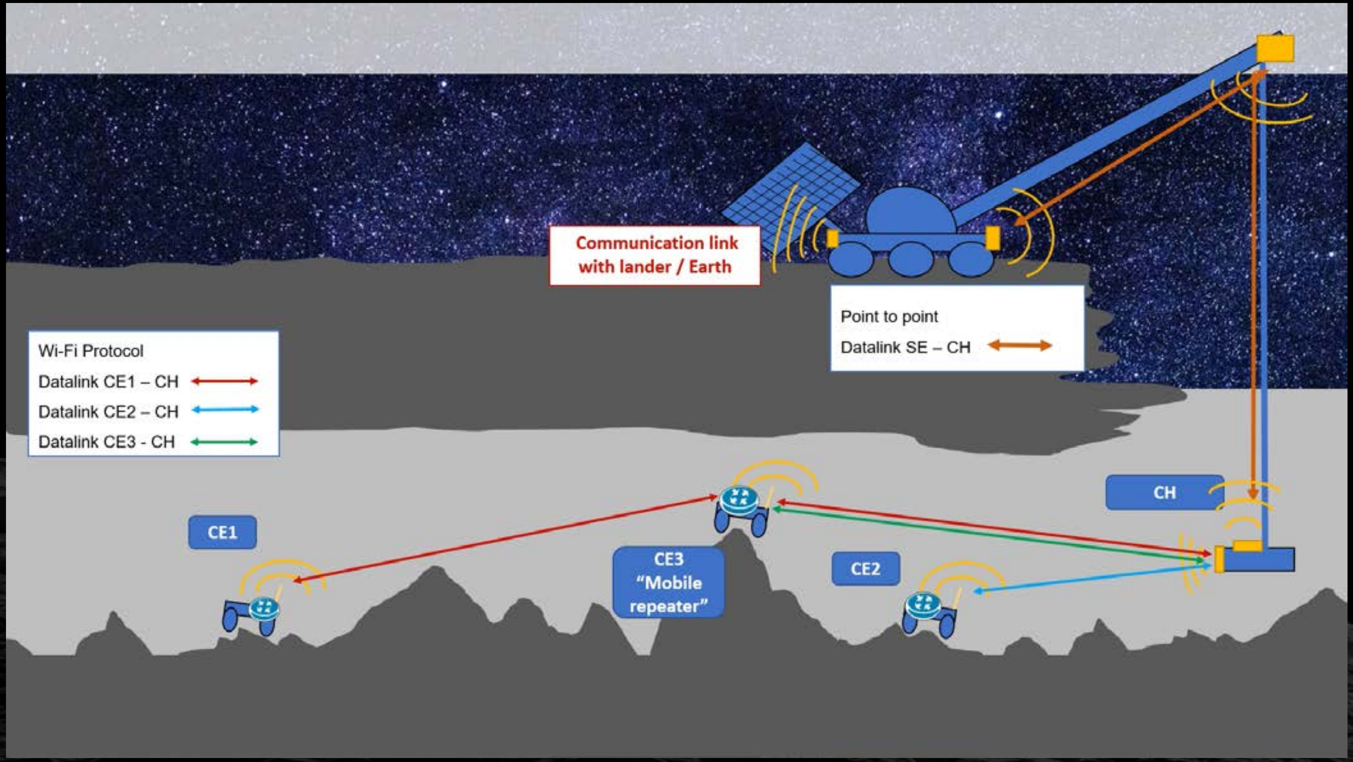


ESA approach to explore lunar lava tubes

- In response to the call for ideas for a lunar cave mission launched by ESA in 2019, the University of Oviedo has proposed a rover-mounted robotic crane, called RoboCrane, that would be responsible for the deployment of exploring robots into the lunar pit.

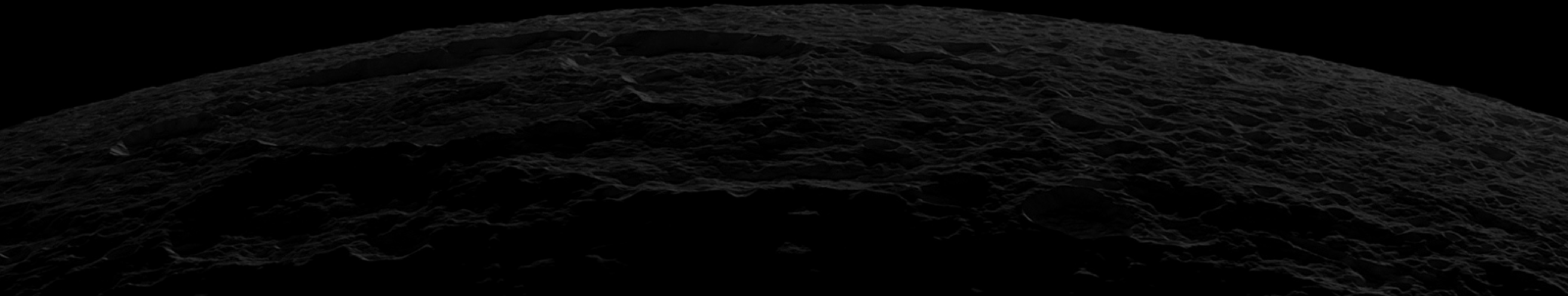
- Taking into account the rover's mass, the RoboCrane system would have a mass well in excess of 500 kg, making it compatible only with large landers such as the EL3. In contrast, with its 15 kg and 12U, LuNaDrone would be compatible even with smaller landers, making it much more flexible and suitable for missions that will take place in the near future.

- RoboCrane can ensure a slower descent into the lunar pit, allowing more scientific data to be acquired.



https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/ESA_plans_mission_to_explore_lunar_caves

THANK YOU FOR YOUR
ATTENTION



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