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ON GROUND TESTING FACILITIES NETWORK TO STEP FORWARD IN TRL ENHANCEMENT FOR MOON EXPLORATION

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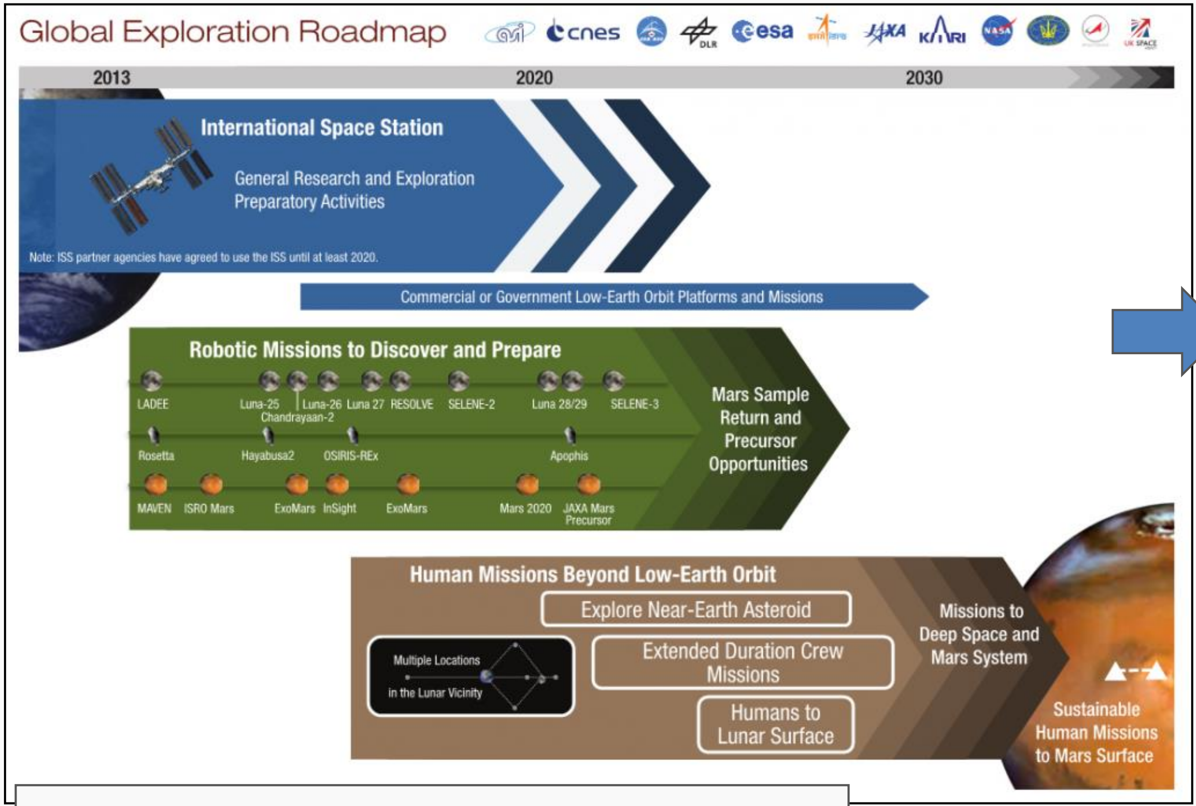
The Moon

The Moon is the natural and perfect step to **increase technology** and **knowledge** to safely and effectively enhance **space exploration** - Mars first - but, even interesting and attracting by itself, technologically, scientifically and commercially



From: ISECG Global Exploration Roadmap, 20/08/2013

The Moon Roadmap

- First, precursor **robotic missions**, both on-orbit and on-surface, *to craft the environment* and *get skills*
- Followed by **human presence** to further increase confidence and reliability on manned mission related techs and functionalities

The Moon opportunity: Techs & field of development

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Propulsion
- Electric
- Sails
- In situ

Ascent | Space segment

Materials
- Advanced materials (3D printing)
- Radiation protection
- Smart materials (healing)
- Inflatables
- In situ production

EDL | Ascent | ISRU | On surface segment | Human factors & Habitats

Power/TMTC
- Solar Cells
- Nuclear Systems
- Fuel Cells
- High efficiency batteries
- Microwave power tx

ISRU | Space segment | On surface segment | Human factors & Habitats

Thermal control
- Cryogenic T control

On surface segment

Robotics & Mechs
- Locomotion/long range paths
- Sample collection/distribution mechs (scope, mole, drill etc)
- in –situ soil analysis
- Sample curation/preservation
- Rendez-vous/docking (canister capture/ large orbiting infrastructures)
- Landing mechs (legs)
- Sensors

EDL | Ascent | ISRU | Space segment | On surface segment | Human factors & Habitats

GNC:
- Deep Space Nav
- EDL Navigation
- Precision Landing
- HDA & retargeting
- Surface Nav/path planning
- On orbit relative GNC

EDL | Ascent | Space segment | On surface segment | Human factors & Habitats

OB SW:
- Autonomy (planning/scheduling-FDIR)
- Opportunistic science
- absolute/relative GNC (vision based nav)
- Distributed multi-platform handling
- Man\robots coordination
- Data fusion

The Moon opportunity: testing philosophy

TECH ↔ **FIELD**

TECH
- Propulsion
- Materials
- Power\TMTC
- Thermal control
- Robotics & Mechs
- GNC
- OB SW

FIELD
- EDL
- Ascent
- ISRU
- Space segment
- On surface segment
- Human factors & Habitats

- Each field asks for a set of techs development and fields may be common for different missions but must be coherently designed according to each mission reqs & objs

  → *benefit on building blocks I/F standardization*

- Being techs & fields numerous and complex

  →*effort should be stressed on setting significant **tests on ground** at the most for cost/time saving, repeatability, fast issue identification/solving*

Following the ESA example on going projects PILOT, PROSPECT, SPECTRUM

Needs for a common development platform

- To address all the challenges involved in future planetary exploration **sharing** human and financial **resources** seems to be the winning path to win the exploration challenge, addressing efficiently available financial and human resources.
- Collaboration needs to step forward to guarantee efficient integration of different concepts from different players: a **platform** shared by each involved entity seems necessary
- In such open platform (hardware, software, knowledge but also experimental facilities), **peculiar skills** and premises (new or existing) of each player **should contribute** in that field for a particular mission/project.
- Other participants acquire know-how as minor contributors in that field.

HD and Landing experimental facility@ PoliMi

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Part of the shared platform may consist of a **network of testing facilities** focused on new needs for on ground testing for EDL, robotics (sampling & surface vehicles), OB-SW

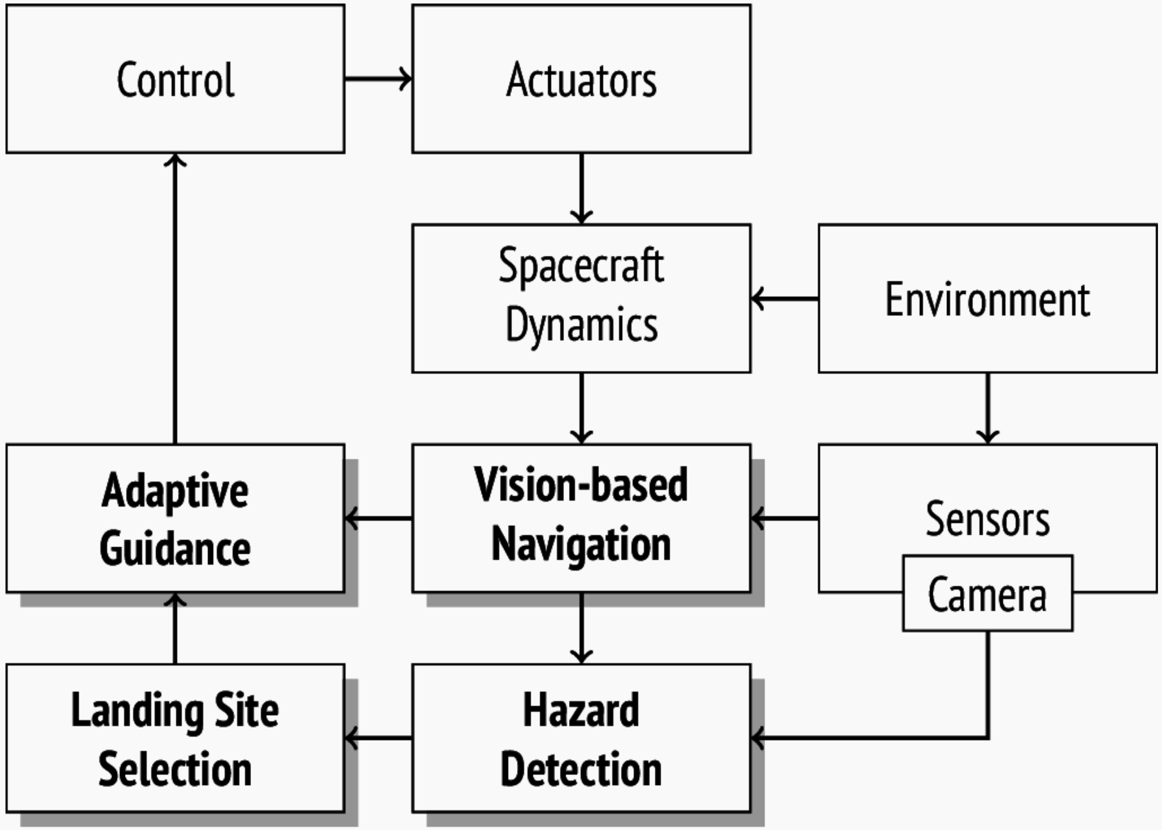
PoliMi-DAER since some time is **developing building blocks** for on board **HD** and **GNC** for landing on planets and small bodies single camera based, being EDL techs crucial for most of the exploration mission.

We are setting up an **experimental facility**

→to step forward in TRL enhancement and run experimental calibration-verification and validation of the in-house developed algorithms.

→ to share, if needed, the facility with entity interested into, for system V&V, as part of a common but distributed testing framework for exploration.

HD and Landing experimental facility@ PoliMi



In bold: building blocks under development @ Politecnico di Milano DAER

facility@ PoliMi: retargeting

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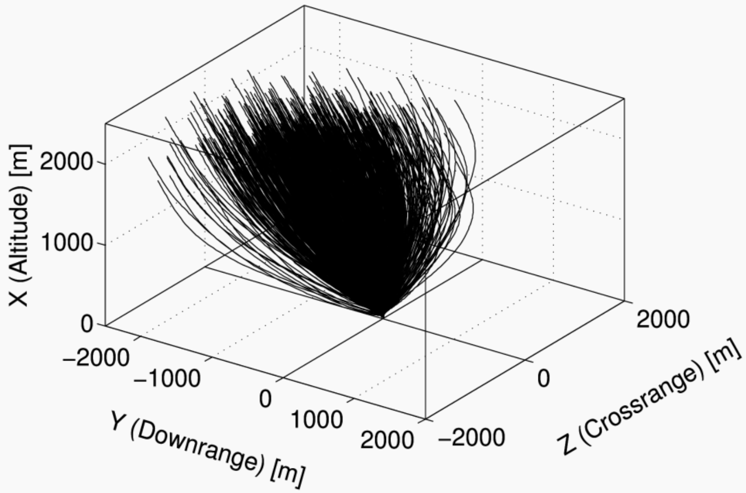
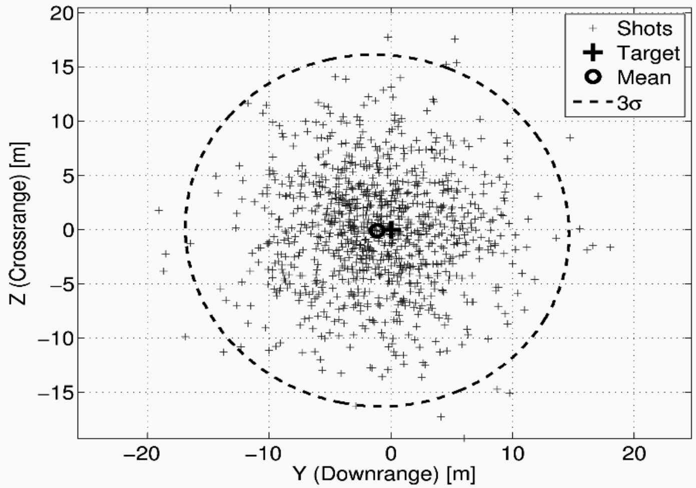
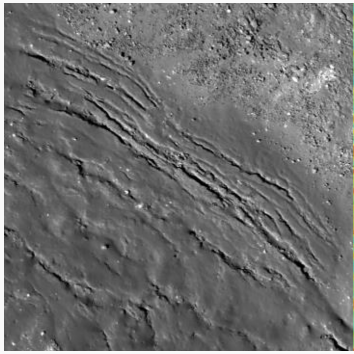




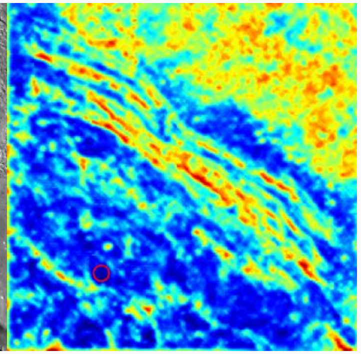
Moon landing adaptive guidance MC test case.
Diversion ordered at altitude 2000m, 600m (1σ);
dispersion at touchdown <16m (3σ)

P. Lunghi, M. Lavagna, and R. Armellin, “A semi-analytical guidance algorithm for autonomous landing,” *Advances in Space Research*, Vol. 55, N. 11, 2015, pp. 2719-2738

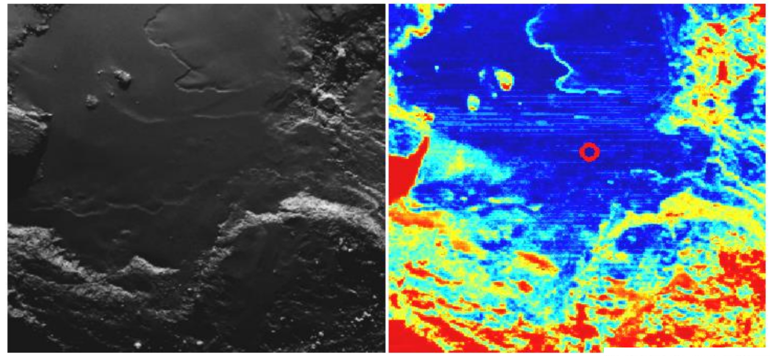
facility@ PoliMi: HDA & landing site selection



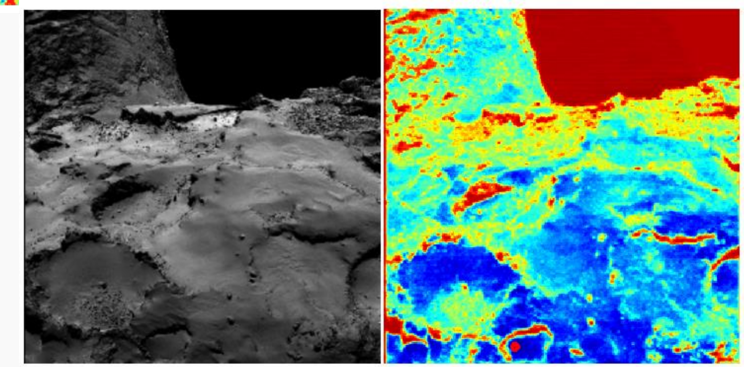
Larmor Q crater floor
Image width ~800m
1024x1024 px



Hd map and identified target landing site: red circle radius =60.7 m



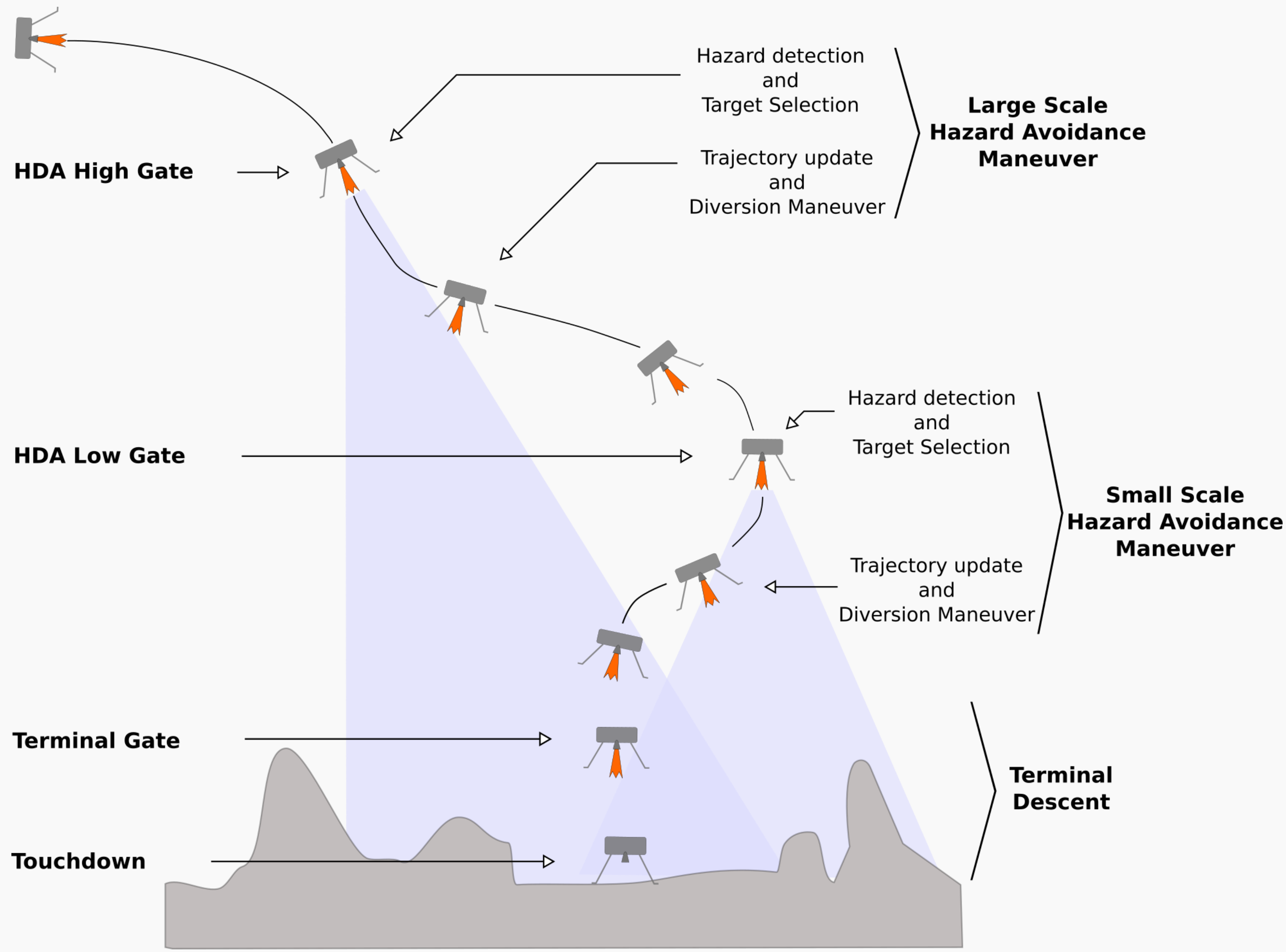
Imhotep landing region from NavCam – Rosetta s\c



Backup landing region from NavCam – Rosetta s\c

- P. Lunghi, M.Ciarambino, M. Lavagna, “Multilayer Perceptron Hazard Detector for Vision-Based Autonomous Planetary Landing”, *AAS/AIAA Astrodynamics Specialist Conference 2015, Vail, CO2015*
- P. Lunghi and M. Lavagna, “ Autonomous vision-based hazard map generator for planetary landing phases,” *in 65th International Astronautical Congress (IAC), 2014*.

Experimental scenario: reference HD maneuvers



HD and Landing experimental facility@PoliMi

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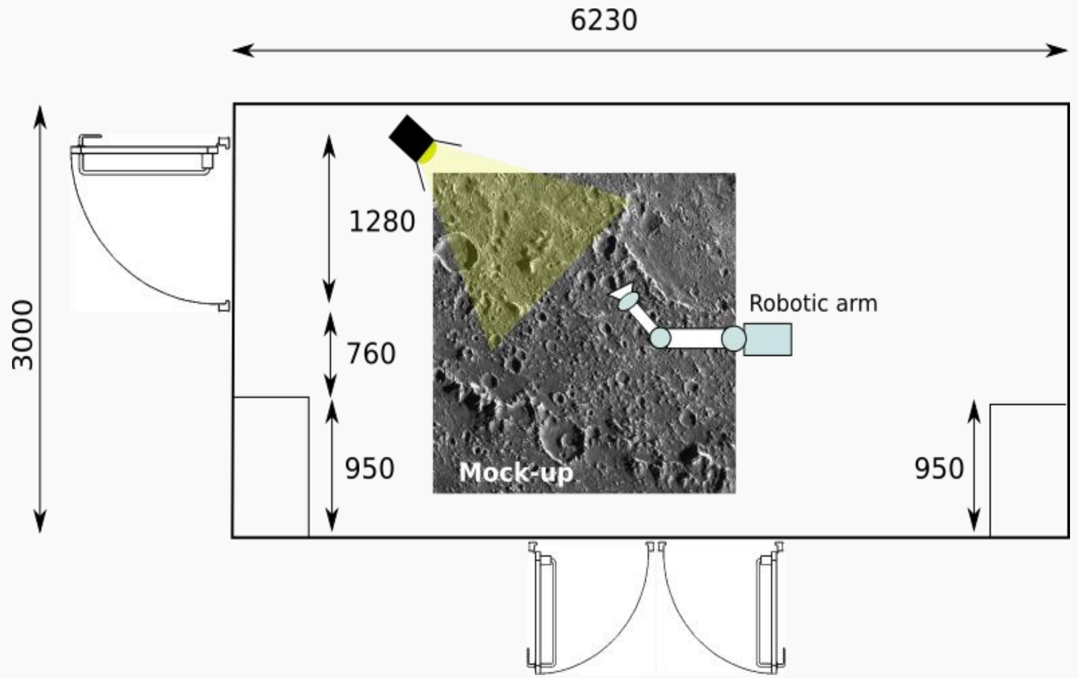
Motivations

- available mission datasets lack of sensor metedata and telemetry needed to run the algorithms
- synthetic images have been used and they need to be validated
- assessments of single subsystems dependencies in closed loop simulations
- TRL increase of optical breadboard up to 4



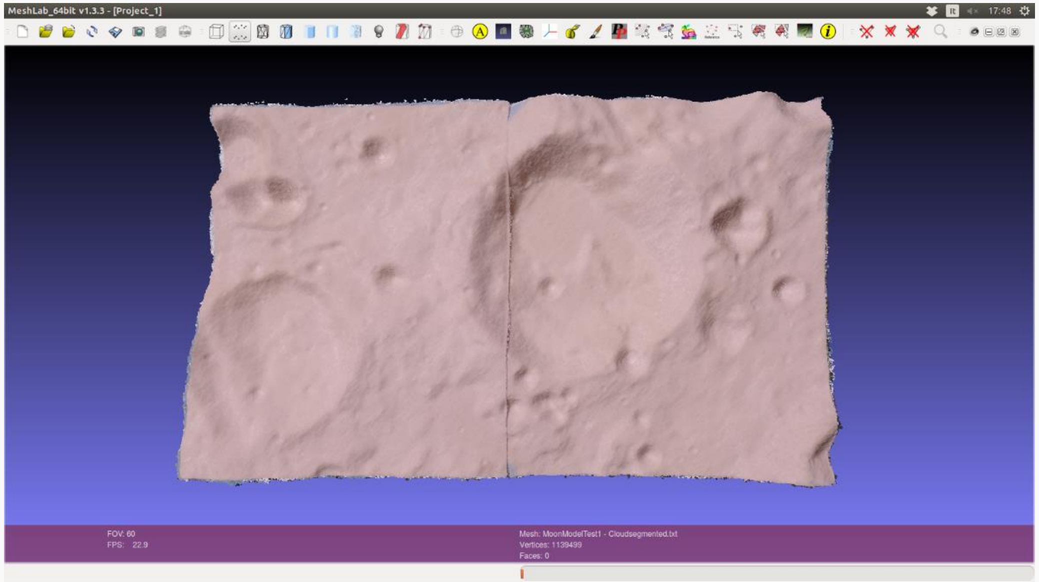
First application for the facility is to verify, validate and test an hazard detector in lunar environment

- 1 Lunar terrain 3D mockup
- Robotic arm
- Lightning system
- Sensors assembly
- Control PC
- Test PC

Lunar Mockup

- Diorama (2,4x2m) **manufactured at PoliMi** through numerical controlled milling machine
- Material: RenShape BM5460 urethane foam.
- Scale is 2000:1 (hazard detection starts at 2000 m).
- 10 m of accuracy at touchdown=5 mm in scale. Diorama resolution needs min 0.5 mm
- DEM to create the diorama is on LRO data adding craters, boulders, fractal noise following lunar statistical distribution: DEM resolution is increased to 0.25 m/px.

Lunar surface sample milled with a 5 mm spherical cutter and a milling step of 0.2 mm



Lunar sample cloud points reconstructed through *dense matching* technique.

Robotic arm, sensors assembly, illumination

7 DoF Mitsubishi PA-10/7C

to simulate lander dynamics

Mass	40 kg
Payload mass	10 kg
Speed about shoulder	28.5° /s
Speed about elbow	57° /s
Speed about wrist	180° /s
Spatial envelope	1.03 m
Number of DoF	7
Position repeatability	0.1 mm

•**Sensors assembly** mounted on the end effector:

•Camera: 8-bit greyscale, 1Mpx resolution, ~50° FoV

•Ranging sensor to simulate LASER altimeter

•IMU is simulated

Light source:

•CAME-TV LED array of 1024x1024 LEDs.
•Narrow beam angle
•High Color Rendering Index (CRI)
•Light temperature from 3200 to 5600 K

Dimming system:

•Matte black structure.
•Prevents external light and internal
•Reflections to interfere with the simulation
•Fabric or thick paper can be used

Final remarks

- On ground test facilities are fundamental and effective tools to support tech development for Moon/planetary exploration
- Functionalities and performance to be tested are peculiar for this application (e.g. sampling/curation, precision landing, human\robot interaction, etc) therefore new dedicated facilities are required.
- Synergies in developing and exploiting distributed labs facilities is suggested as winning strategy for fast, cheap and effective TRL increase
- The HDA-DL field may be a starting point as some facilities already exist or they are under development (TRON, DLR - Bremen, VBNF - TAS-I, Turin, Platform – art - GMV, Madrid, VisiLab - ESA, PoliMi)