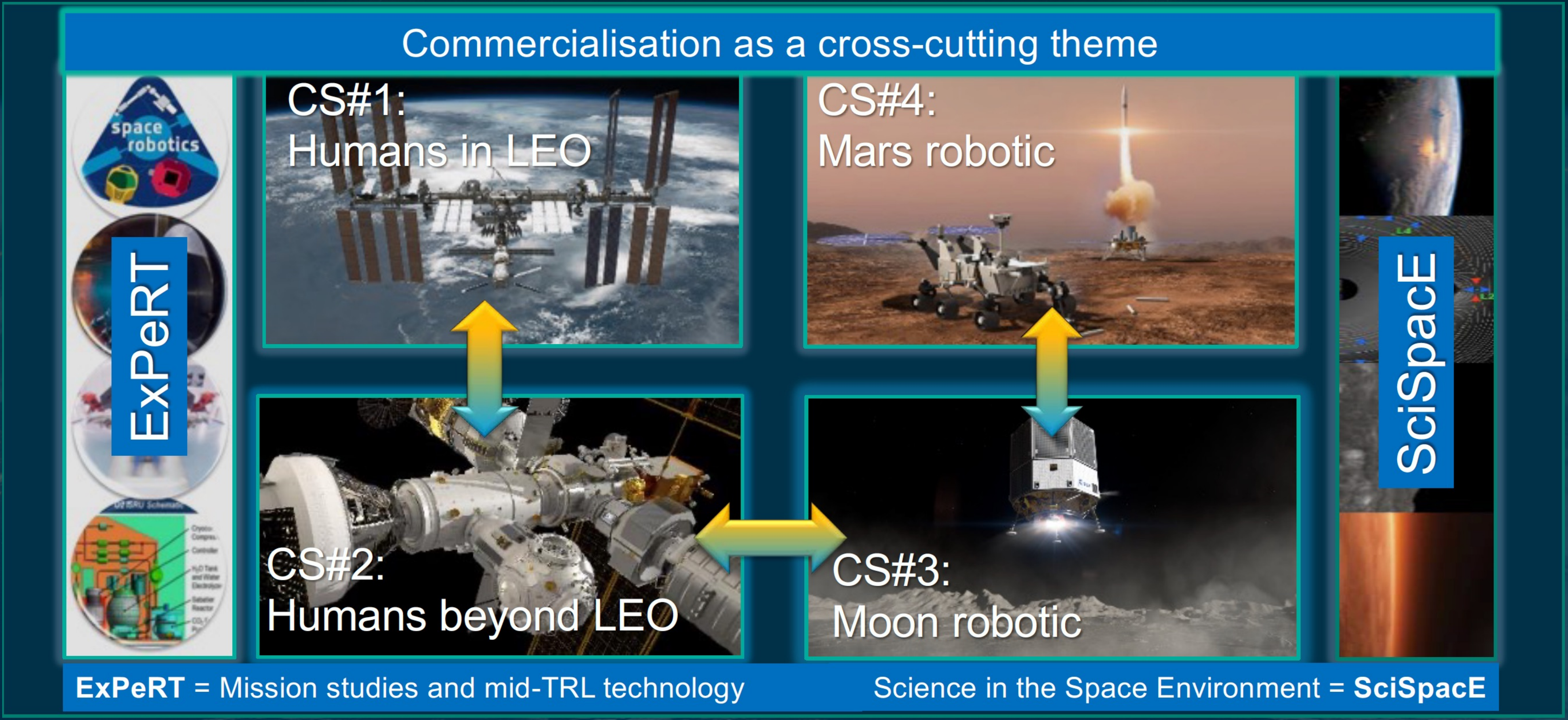
ExPeRT
Exploration Preparation, Research & Technology

Exploration Technologies for Future Missions

Advanced Space Technologies in Robotics and Automation (ASTRA)
20 October 2023

HRE-E (J. Alves)
Email: jorge.alves@esa.int

E3P – European Exploration Envelope Programme

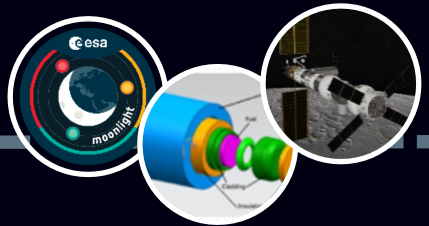



TERRAE NOVAE 2030+
Notional Strategy Roadmap
esa
2020 > 2030
ESA in mutual inter-dependence
2030 > 2040
European-led capabilities
ExoMars TGO
EDL and Rosalind Franklin rover
Sample Transfer Arm & Earth Return Orbiter
Mars Sample Return
Comms&Nav
Heavy Cargo&Astrobiology
Crew Habitation
Preparing to send humans to Mars
European Service Module
Deep space human transportation
Gateway
Deep space habitation & refuelling & communications
esa
moonlight
Cargo logistics/mobility
Science activities
Power Station
Living and working on the Moon
Core ISS Partner
Contribution Commercial Stations
Cargo up/down
Human transportation
Enabling capabilities - Inspirator
→ THE EUROPEAN SPACE AGENCY

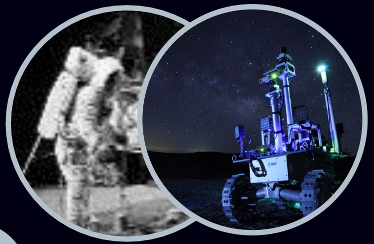
TERRAE NOVAE 2030+

Moon Notional Strategy Roadmap Mission Concepts

esa



Communication & Navigation, Gateway utilisation, RPS, analogues, exploration tools

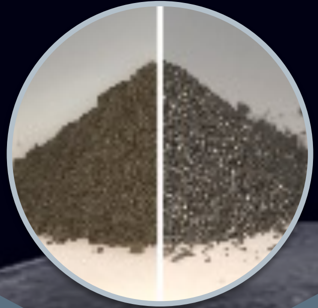


Cargo, science & ISRU demo

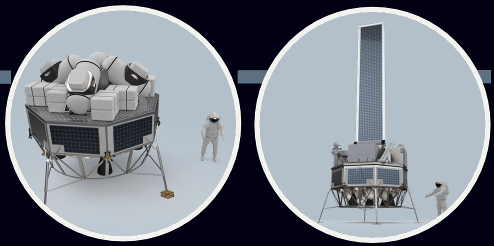
Large science mission & mobility platform

Power & comms station

ISRU pilot plant & excavation



Surface habitat or pressurized rover



European surface transportation (EL3/Argonaut) supporting science, cargo/utilities for human missions & infrastructure deployment

THE ARGONAUTS ARE COMING!

Lander Descent Element (LDE) Phase A/B1 studies conducted in Period 2

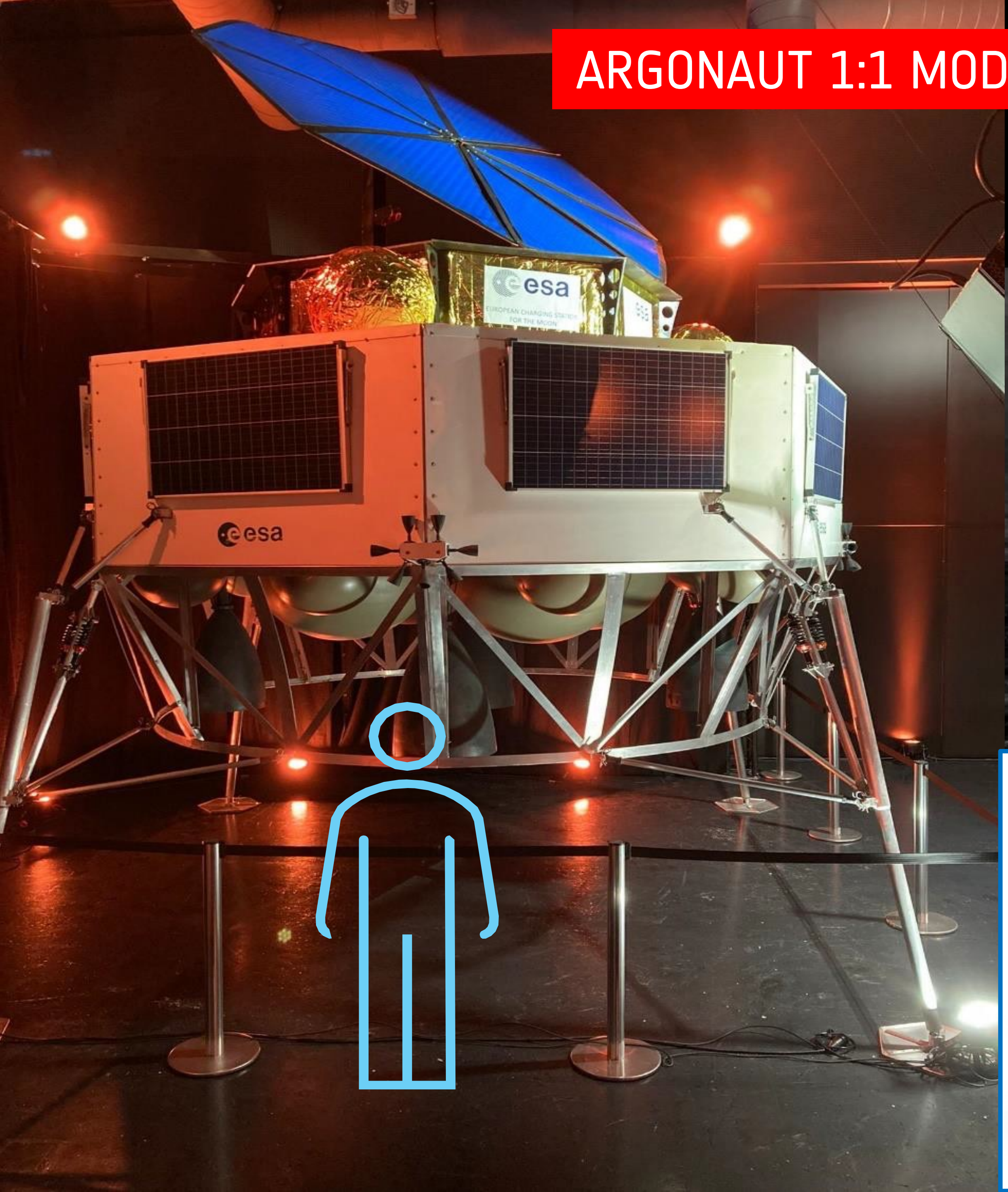
LDE Phase B2/C/D procurement approved at February IPC 2023, ITT issue in March 2023

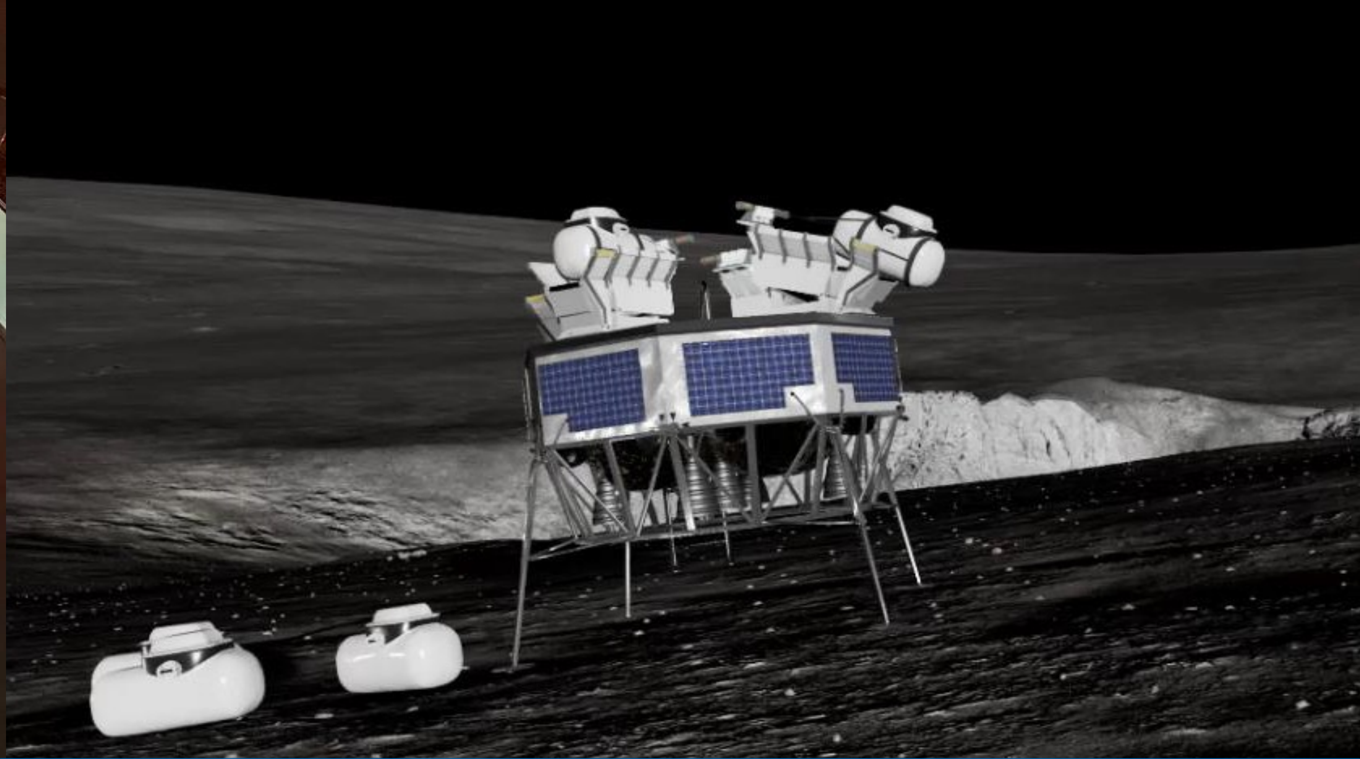
Engine pre-development to TRL5 proceeding with selection in December 2023

Argonaut Mission 1 to be studied & agreed with NASA by CM25

Current candidates: Logistic cargo, Utility human rover, + ‘hitchhiker’ ESA science/technology

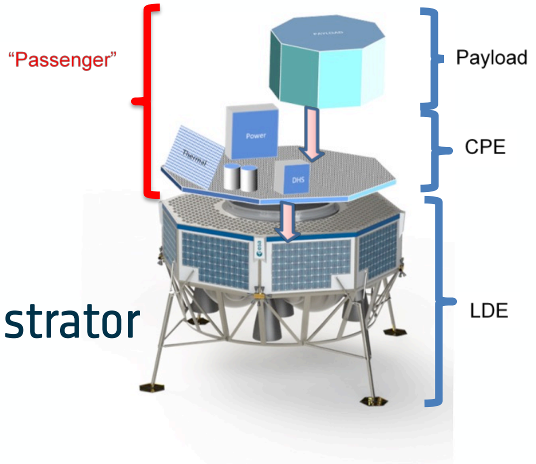
ARGONAUT 1:1 MODEL and VR



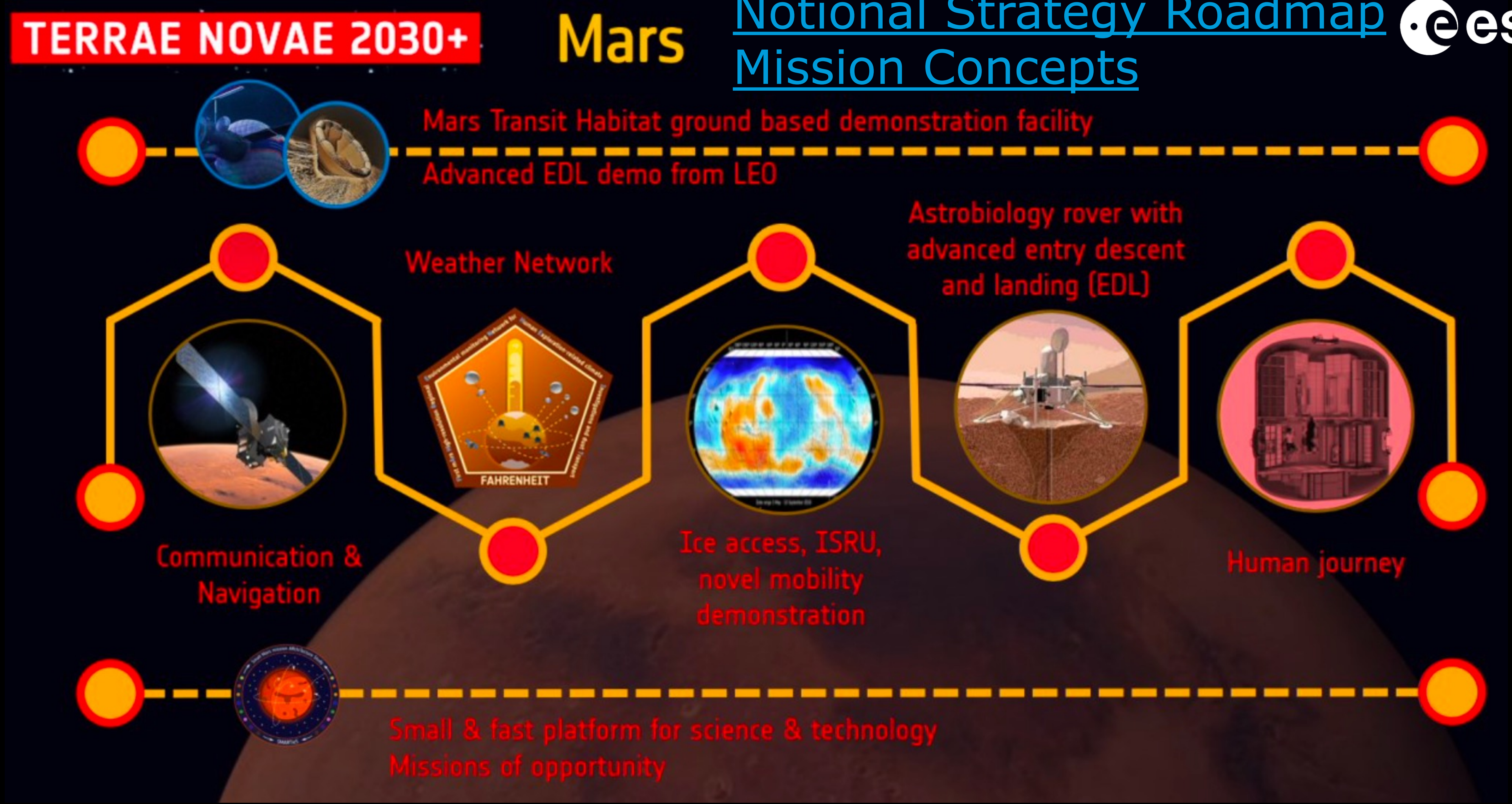


Many options for later missions:

- Cargo and Logistics
- Scientific missions
- Power charging station
- Space resources demonstrator
- ...



Notional Strategy Roadmap Mission Concepts



Exploration Preparation Research and Technology (ExPeRT)

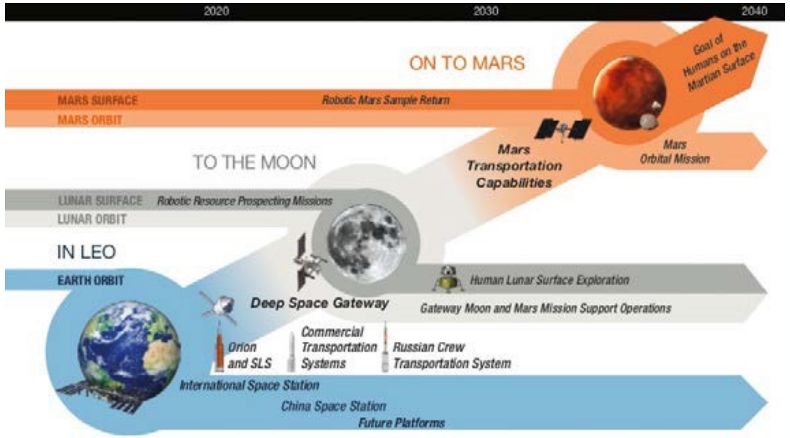
- By preparing the future, ExPeRT is **an enabling element for implementing the Terrae Novae 2030+ strategy**

- ExPeRT has the mandate to:
  - **Prepare & de-risk** future exploration missions, projects and associated technologies (Phase-0, Pre-Phase A, Phase A/B1);
  - Raise **critical technologies to TRL5** to facilitate selection and development of new exploration missions and projects;
  - Contribute to new **international partnerships** (both existing and new partners) to create future exploration opportunities;

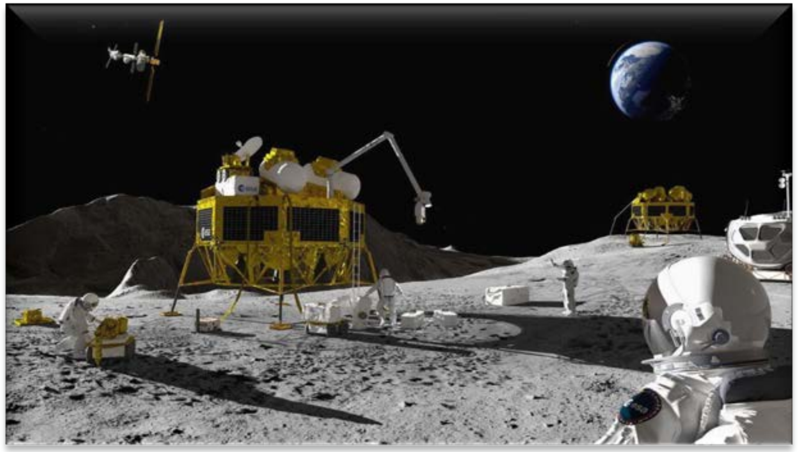
Hence allowing Europe **to be flexible** and to adapt to a fast-evolving international exploration context

Note: *Visit the ExPeRT webpage at www.esa.int/expert* (feedback is welcome!)

Exploration Technology Activities



Credit: ISECG/Global Exploration Roadmap



Technology-push activities

- Foster innovation and ideas from technical experts in ESA
- Potential for step-change or breakthrough (even disruption) in existing technologies and products
- Contributes to long-term performance targets, capability building

Mission-pull technology activities

- Application focused
- Responds to a specific identified exploration mission need
- Requirements are derived from completed mission studies
- Performance verification

Exploration Technology Requirements

esa

- HRE coordinates technology activities for Exploration with relevant ESA Directorates
- A fundamental element of this coordination process is represented by the timely definition of adequate user needs and technology requirements for future exploration missions
- ExPeRT provides technology-push and mission-pull technology requirements (TRQ) on annual basis
- Technology-push requirements defined by ExPeRT, are coordinated with ESA Competence Domain Leaders
- Mission-pull technology requirements in 2021, 2022, and 2023 were defined by ExPeRT for the TDE workplan based mainly on mission concept studies run at ESA's Concurrent Design Facility

The Exploration Technology Compendium provides an overview of activities in its main funding pillars:

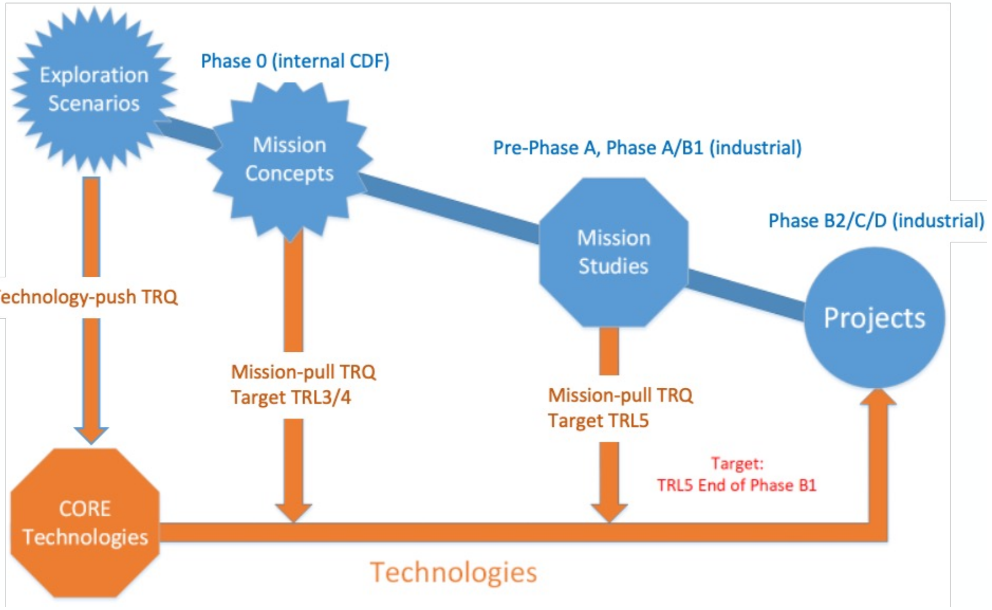
- Discovery and Spaceships TRL1 → TRL3 (Innovation and blue-sky research) – *not yet in the Compendium*
- TDE TRL2 →TRL4 (technology-push or mission-pull technology developments)
- GSTP TRL3 → TRL9 (product competitiveness or market-push)
- ExPeRT TRL3 → TRL5/6 (programme/mission-pull technology developments or core capability maturation)

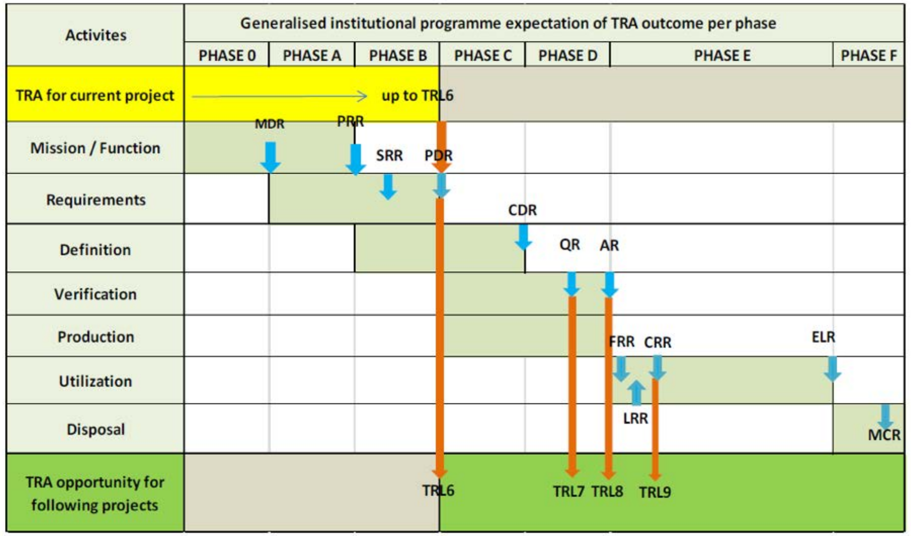
Technologies for Exploration

16 Technology Areas

Propulsion
Novel Energy Systems
Robotics and Mechanisms
Artificial Intelligence Applications
Advanced Life Support Systems
In-Situ Manufacturing
Crew Health Management
Space Resources Utilisation*roadmap
Radiation & Environmental Effects
Communication and Navigation
Subsurface Sampling/Deep Drilling
Guidance, Navigation and Control
Avionics
(re-)Entry, Descent and Landing
Thermal Control Systems
Mission Operations Data Systems

- Timely development of critical technologies essential to achieve optimum cost
- ESA requires TRL5 for new technologies by end of system Phase B1
- Principle of maximising open competition for the excellence of the products





Ref. ECSS-E-HB-11A

Exploration technology area: **Robotics and mechanisms**

These are technologies for surface or orbit applications at the Moon and Mars, inside and outside the International Space Station (ISS), autonomously or tele-operated, in the area of robotics and mechanisms for space exploration.

Background

ESA activities on robotics and mechanisms have developed key technologies in many areas of space exploration. Latest projects are:

- ISS European Robotic Arm (ERA)
- Moon PROSPECT instrument mechanisms and the METERON analogue experiments
- Mars Rosalind Franklin rover and the MSR Sample Transfer Arm
- Gateway ESPRIT refuelling mechanism
- the European Moon Rover System

Mars sample transfer arm, Leonardo

Applications

Robotic systems and mechanisms can benefit from synergies between orbital and surface applications from low Earth orbit to the Moon and Mars. Gravity is the main differentiator between the required applications. Key targets are manipulation and deployment systems (e.g. robotic arms), but surface technologies providing locomotion and autonomous operations in preparation for human infrastructures using in-situ resource utilisation (ISRU), are also relevant for the Moon and Mars.

PROSPECT Sample Processing and Analysis (ProSPA) carousel, Open University

Technology push

Areas for development that target breakthroughs in exploration, include:

Surface applications:
- long-range autonomy and localisation capabilities
- improved mobility in challenging terrains
- extended lifetime under extreme temperatures and resilience to dust
- manufacturing/construction and support for ISRU

Orbital applications:
- logistics and maintenance (manufacturing)
- robotic manipulation and assembly
- refuelling

Global Exploration Roadmap

Key enabling technologies are:

GER-019: Telerobotic control of systems with time delay
- distributed operations, sensors improvement, high speed visual capability, verification and validation

GER-020: Robots working side-by-side with suited crew
- standards, sensors feedback, autonomy of tasks

GER-048: Surface mobility systems
- rovers and mechanisms capability, resilience to dust, improved motion (non-wheeled)

GER-057: Low temperature mechanisms
- modularity, high g and extended lifetime

Rosalind Franklin rover

Exploration technology area: **Artificial intelligence application**

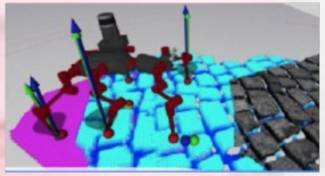
Artificial intelligence is an enabling technology for new exploration scenarios, changing the way spacecraft and missions are designed, implemented and operated. Autonomous systems for space exploration are key and can support varying levels of autonomy.

Background

Current developments include:

- long-range navigation with self-localisation
- robotic arm operations with onboard target detection
- flexible onboard plan execution
- object detection, localisation, analysis and classification
- smart constellation management
- astronaut health management
- failure detection, isolation and recovery (FDIR) and anomaly detection/identification

AI application for autonomous rover, DFKI



Applications

Artificial intelligence (AI) could enable navigation with a high degree of autonomy for traversing the Moon and Mars. For in-situ operations, machine learning techniques could support science objectives and feed useful information to ground science teams. Machine learning can also help to positively identify the onset of astronaut pathologies from collected data, allowing in-situ diagnosis. Human exploration at the Moon and Mars will benefit from augmented local capability of diagnosis.

Technology push

Areas for development that target breakthroughs in exploration, include:

- standardised interfaces for onboard autonomous systems
- autonomous on-board mission planning
- ground segment mixed-initiative planning with explanations
- collaborative robots
- AI-based data fusion
- autonomous science detection and targeting
- space medicine using augmented reality or virtual reality for crew health management

Global Exploration Roadmap

Key enabling technologies are:

GER-021 – Autonomous vehicle systems management

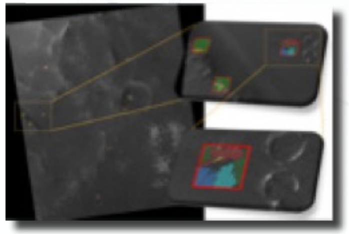
- enabling autonomous FDIR, decision-making capability, planning and execution on board

GER-022 – Autonomous rendezvous and docking (RdV&D)

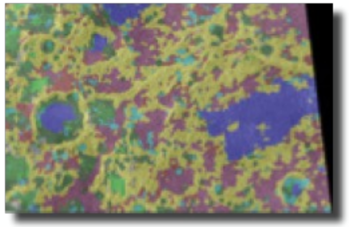
- maturation of technologies for autonomous RdV&D operations (International Rendezvous System Interoperability Standard)

GER-023 – Crew autonomy beyond LEO

- automate 90% of operations at destinations with > 6s delay
- provide automated tools for crew to make real-time decisions in off-nominal situations based on real-time data
- crew medical critical gaps identified in baseline modelling, diagnostic support, medications, training, and treatment



Small area annotated by geologist (teaching)



Framework with the capability to interpret remote sensing images using neural networks - large area annotated following Machine learning, CGI (previously SciSys)

Exploration technology area: **Subsurface sampling/deep drilling**

Drilling for access and sampling on the Moon and Mars at depth, in support of science, resource prospecting and utilisation.

Background

Subsurface sampling provides access for science as well as resource prospecting:

- SD2 drill on Philae (Rosetta mission)
- Rosalind Franklin rover drill
- PROSPECT drill

Technologies supporting instrumented drill:

- spectrometer heritage from Ma_MISS (Rosalind Franklin rover)
- permittivity sensor in ProSEED (PROSPECT)
- research ongoing for integration of imagers for subsurface multispectral imaging

Applications

Contextual information is required to inform decisions and adapt to the environment. Geological history, terrain characterisation, and the presence of water/volatiles or subsurface ice will be key for future habitats. This will require enhanced sensing capabilities, and autonomy (possibly with tele-operation on the Moon). Relevant applications and destinations are:

- ice and rock sampling for scientific analyses
- subsurface ice on Mars
- polar ice on the Moon
- ISRU prospecting ice or minerals

Technology push

Deeper access could uncover very different types of materials requiring casing for borehole stabilisation. Alternative techniques and the possible need to preserve the stratigraphy of the samples/cores/cuttings will be a driver of the target system. Main areas for development are:

- shallow drilling (e.g. for ISRU)
- drilling to depths from 5m to 10m+
- drill placement, and drilling control/teleoperation
- core sample extraction
- stratigraphic preservation
- down-hole measurements, sensor emplacement
- ice/volatile extraction
- borehole stabilisation
- planetary protection for special regions
- low temperature drilling

Global Exploration Roadmap

Critical technology for this area is a generic capability supporting science and in-situ resource utilisation (ISRU) rather than explicit requirements for the GER architecture defined in 2018.

Lunar PROSPECT drill, Leonardo.

Martian Rosalind Franklin drill, Leonardo

Thank you for your attention

→ THE EUROPEAN SPACE AGENCY