ESA’s Lunar Lander descending to the Moon’s surface (ESA/AOES Medialab)

→ DESTINATION MOON

The European Lunar Lander: opening a new era for exploration

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The Moon is a stepping stone on the path of human exploration beyond low Earth orbit. Taking this next step means demonstrating new technologies and learning more about this challenging environment. The European Lunar Lander intends to do just that.

A new face of our nearest neighbour is emerging from the exciting discoveries of recent and ongoing lunar missions from space agencies around the world. With over 10 orbital spacecraft and impactors making the journey to the Moon in the past decade, a wealth of new data has become available and has stimulated an exciting 'lunar revival'.

After over 30 years, the Moon is once again firmly in the spotlight as an exploration destination for both robotic missions and human explorers, especially its polar regions.

"The Moon's south polar region is a unique location in the Solar System: where Europe can demonstrate the technology and capabilities required for the future robotic and human exploration missions beyond the limits of low Earth orbit, to the Moon and ultimately to Mars," says ESA's Bruno Gardini.

A further wave of automated lander missions is planned for the next decade by various spacefaring countries, this time striving for access to the surface and performing direct measurements there. Europe has been preparing its own contribution and participation to this new phase of exploration, with work on lunar landing and associated technology development going on for several years.

Getting down to the lunar surface, however, is not as simple as it might seem. Indeed the Americans and the Russians succeeded several times during the 1960s and 1970s, but landing in today's perspective of exploration is a very different challenge from Apollo or Luna.

Landing now requires major advances in the levels of accuracy and autonomy. Such high performance is needed to target specific well-illuminated landing sites or locations of special scientific interest, and to ensure the proximity of robotic and human surface mission elements.

The European Lunar Lander has the primary objective of proving the technologies required to achieve the landing accuracy and safety needed to realise the exploration missions of the future. Once on the surface, the Lunar Lander will be the first 'explorer' to experience the conditions at the Moon's south pole region, which looks very different from the landing sites visited in the past.

It will capitalise on this achievement, deploying a suite of instruments and sensors to investigate the environment and its effects, providing key data to help inform the preparation of future exploration missions and systems.

"The Lunar Lander is a strategically important and exciting mission, not only because of its technical achievement in getting access to the lunar surface, but also because of the opportunities it provides to perform exploration at the landing site. It will take advantage of Europe's industrial and scientific expertise, and demonstrate Europe's capability as a reliable partner in a future international exploration scenario," says Bérengère Houdou, Lunar Lander Phase-B1 Project Manager.

The Lunar Lander mission is part of the activities of ESA's Directorate of Human Spaceflight and Operations, preparing the way for future human exploration. The prime contractor Astrium GmbH in Bremen, Germany, has gathered the expertise of more than 10 companies from six European countries.

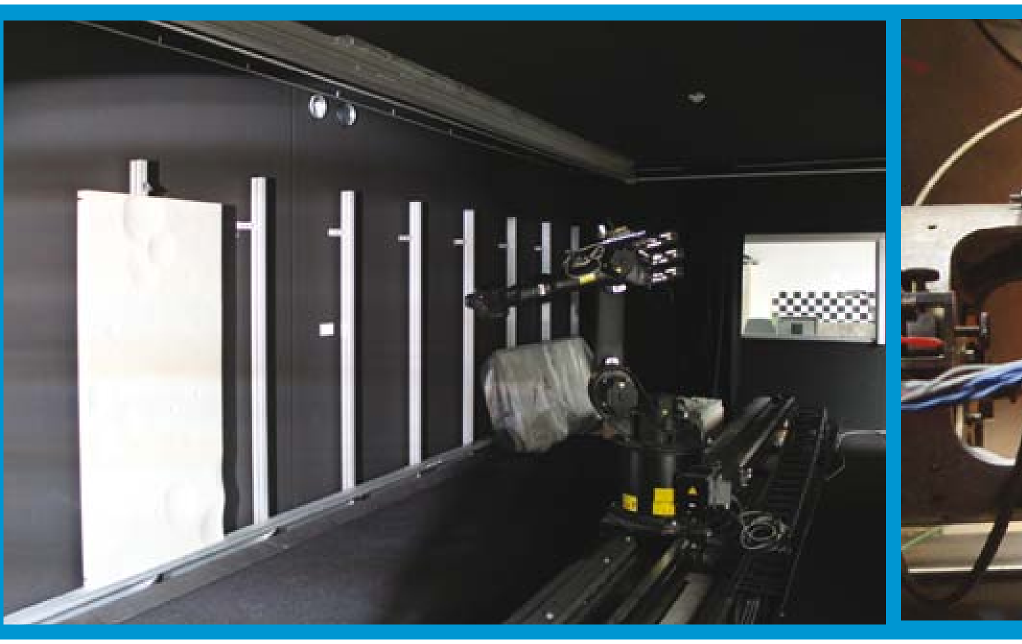
The project is currently in Phase-B1, which includes mission and system design as well as hardware 'breadboarding' and testing, all focused on building a spacecraft that can achieve an accurate and safe landing and then operate in the unique environment of the lunar poles.

A target for exploration

The availability or absence of sunlight plays a major role in space exploration activities and in creating the environmental conditions in which those activities take place. This is especially true on the Moon's surface, which for the most part experiences around 15 days of continuous illumination followed by the same period of continuous darkness.

→ Technology

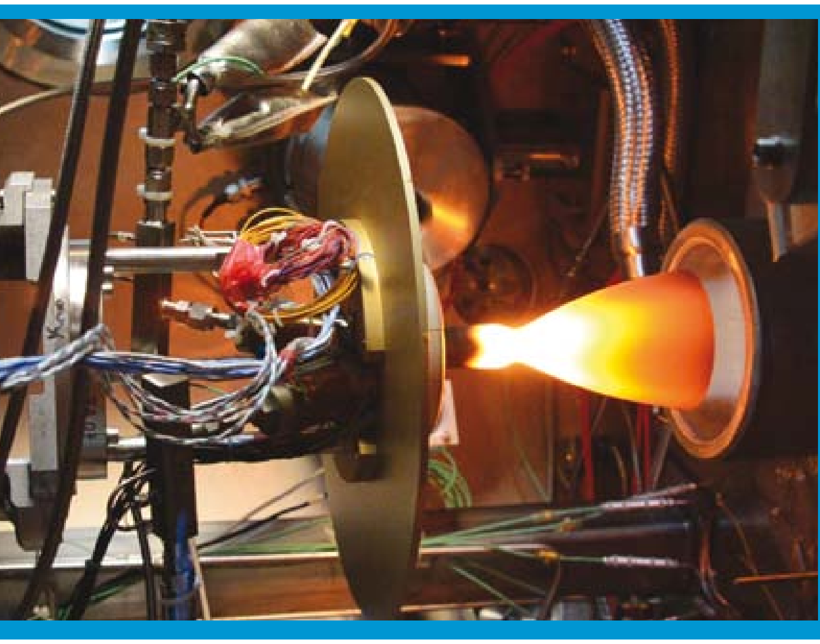
The Lunar Lander mission builds on hardware and technology that has been the focus of developments in ESA programmes such as Aurora and ATV, as well as in national programmes. Such activities include testing of navigation sensors and algorithms in DLR's TRON facility (left), hotfiring of the 200N ATV assist engine at Astrium's Lampoldshausen facility (centre) and drop testing of prototype landing legs at DLR's LAMA facility in Bremen (right)



↑ The lunar south pole as seen by the Japanese ‘Kayuga’ spacecraft in 2007 (JAXA)

While daytime temperatures at the surface can reach around 130°C, during the long lunar ‘night’ they can quickly reach lows of –160°C. For landers or other surface systems relying solely on solar power, batteries and standard thermal control hardware, surviving these conditions for a full 15-day lunar night poses an extreme and currently insurmountable challenge.

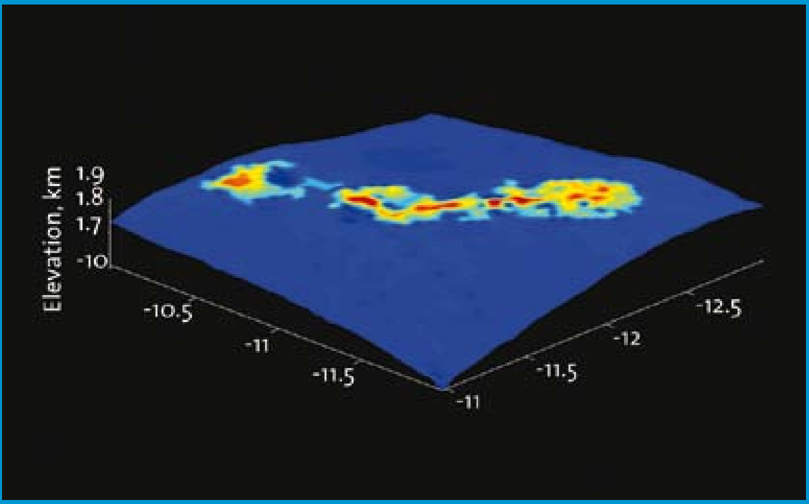
The lunar polar regions, however, offer a range of very different and unique illumination conditions. This is principally because of the combination of inclination of the Moon’s rotation axis (nearly perpendicular to the ecliptic) and the large variations in altitude of the terrain in the polar regions.



(NASA)

→ Site analyses

The Sun is always very low on the horizon when seen from the lunar south pole, meaning vast portions of the surface are immersed in darkness at a given time. Only those regions which are high enough with respect to the surrounding landscape, such as this ridge (above) imaged by the NASA Lunar Reconnaissance Orbiter (LRO), experience sunlight for long periods of time. The Lunar Lander team, in cooperation with several science teams, is studying these images alongside surface topographic data obtained by the LRO Laser Altimeter to identify areas on the surface which receive the longest periods of illumination (in colour, right) and which are relatively free of hazards – and which are therefore good landing site candidates.



This results both in local peaks, which can experience several months of near continuous sunlight, as well as polar craters, which are kept in virtually permanent darkness.

Surface sites offering the possibility for long periods of sunlight and solar power are attractive for both near-term robotic missions as well as the establishment of a longer-term human lunar presence. These regions are also proving, through the results of recent orbital missions, to be rich in resources, including water, which may be utilised locally to support exploration activities. Solar wind implanted volatiles, and water ice at the lunar poles also represent an important record of the history of the inner Solar System.

It is this combination of conditions and characteristics that mark out the lunar south pole region as one of the most important destinations for future exploration. But while attractive for exploration missions operationally and scientifically, the Moon's polar environment poses a number of important challenges that the Lunar Lander mission must face.

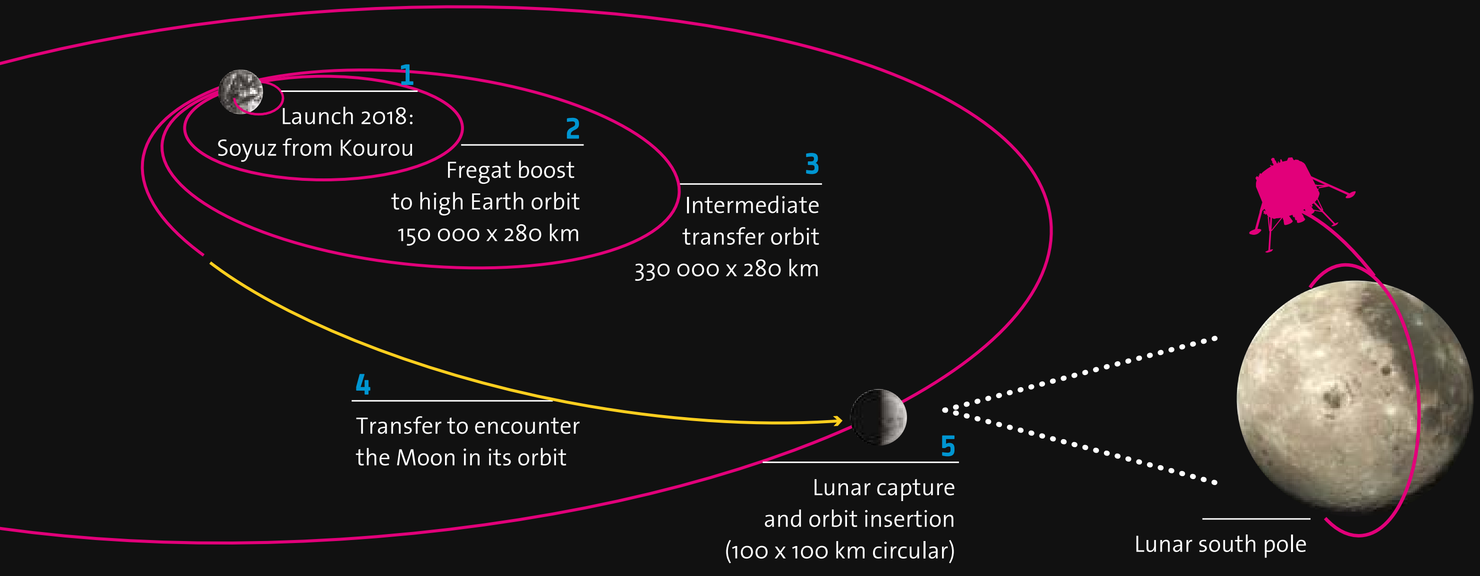
In terms of the Lunar Lander mission and its objectives, the demonstration of the technologies required to achieve a soft, safe and precise landing is paramount. However in order to offer an opportunity for surface exploration activities and investigations, the Lander targets those specific surface sites offering the possibility of several months near-continuous illumination.

The surface areas with good illumination conditions are, by their nature, limited to a few hundreds of metres. This has important impacts on the overall mission profile, and is why the landing accuracy and associated navigation technologies are so crucial.

The Lander must achieve this high performance completely autonomously, without intervention from ground.

→ FROM EARTH TO THE MOON

Launch to lunar orbit



1 Launch 2018: Soyuz from Kourou

2 Fregat boost to high Earth orbit 150 000 x 280 km

3 Intermediate transfer orbit 330 000 x 280 km

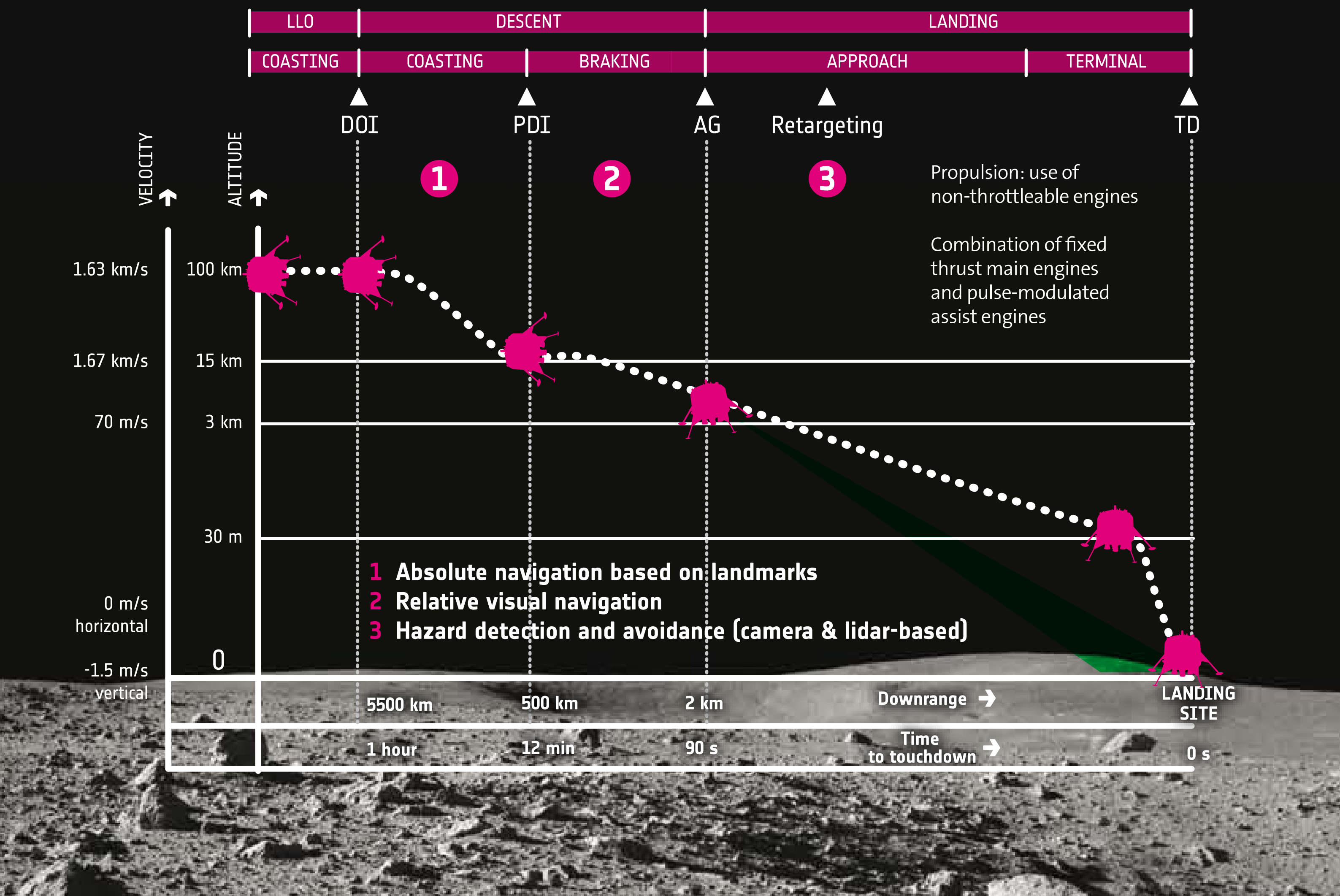
4 Transfer to encounter the Moon in its orbit

5 Lunar capture and orbit insertion (100 x 100 km circular)

Lunar south pole

Descent and landing profile

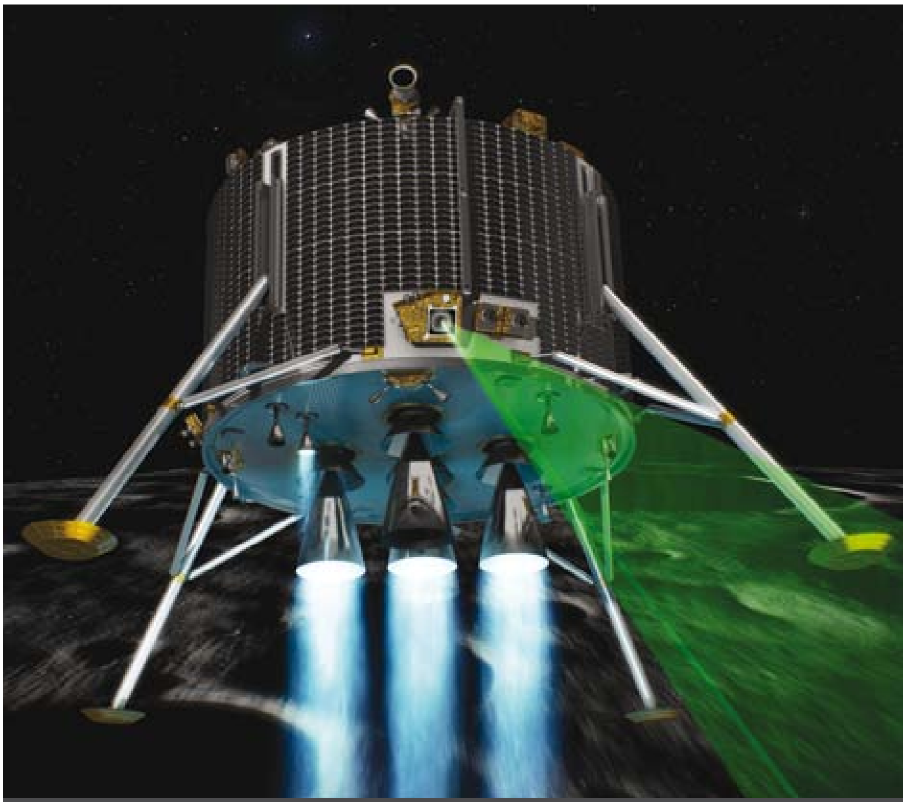
LLO	Low lunar orbit	AG	Approach Gate
DOI	Descent Orbit Initiation	TG	Terminal Gate
PDI	Propulsive Descent Initiation	TD	Touchdown



Propulsion: use of non-throttleable engines

Combination of fixed thrust main engines and pulse-modulated assist engines

1 Absolute navigation based on landmarks
2 Relative visual navigation
3 Hazard detection and avoidance (camera & lidar-based)



↑ Lunar Lander scanning the surface terrain for hazardous features such as slopes, boulders and shadows (ESA/AOES Medialab)

↑ Thrust is reduced for final phases of terminal descent (ESA/AOES Medialab)

Getting to the surface

Launched on a Soyuz ST-B in 2018 from Europe's Spaceport in Kourou, French Guiana, the Lunar Lander will spend several weeks travelling to the Moon in a number of highly elliptical orbits. While this takes time, this approach avoids the limitations on launch opportunity that would come from a direct injection to the Moon by the Soyuz.

Once captured in a circular low lunar orbit, at around 100 km above the surface, the Lander waits for the best alignment of its orbit with the Sun, Earth and lunar surface, to meet the requirements for communication and surface illumination.

The Lander executes a Descent Orbit Initiation burn, firing its engines over the Moon's north pole. It begins coasting for one final half-orbit, coming down from 100 km to 10 km altitude.

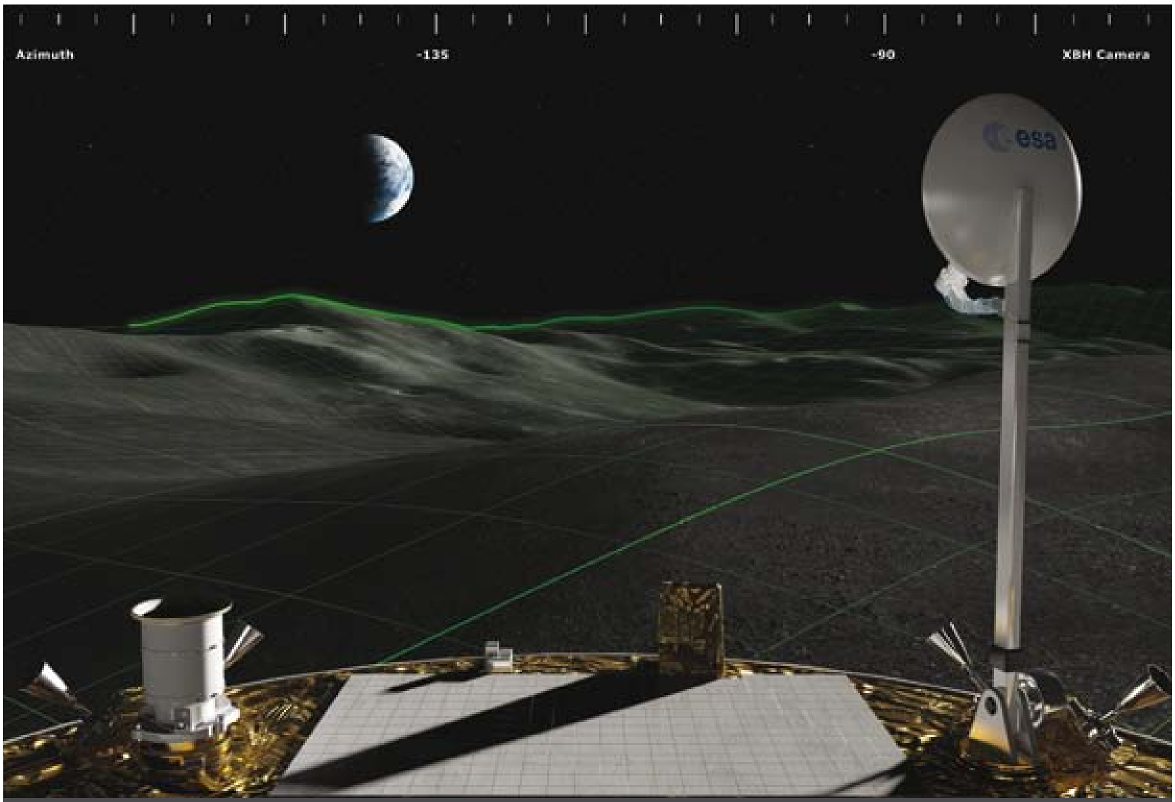
During this phase, the Lander uses Optical Absolute Navigation, an advanced technique involving the matching of landmarks (extracted from camera images acquired in real time during flight) with reference landmarks stored on board, to ensure an accurate estimation of its position autonomously.

As the Lander closes in on the south polar region, it initiates the Main Braking phase by firing all of its main engines at maximum thrust. During this braking, the Lander uses Optical Relative Navigation to track features using the onboard cameras. The Lander is able to monitor its relative velocity with respect to the surface and to ensure a precise trajectory during the final minutes of descent.

"Landing accuracy is key to the mission's objectives and to enabling future exploration, and is also strongly affected by the landscape of the sites we are targeting for illumination," says Diego De Rosa, Lunar Lander System Engineer.

On approach to the landing site, the Lander modulates the level of thrust from the engines, progressively shutting down the main engines and compensating with 'assist engines' operating in a 'pulsed mode'. The Lander is therefore able to precisely control its descent in a fuel-efficient way.

The engines on which the Lander relies reflect the drive to use European technologies and to use equipment that has already a good level of technical maturity. The five main engines are based on the European Apogee Motor (EAM)



↑ View of lunar horizon and back to Earth once on the surface (ESA/AOES Medialab)

and the six 'assist' engines are derived from thrusters used on the Automated Transfer Vehicle.

During the landing phase, the Lander has the capability to characterise the surface terrain in terms of hazardous features such as slopes, boulders and shadows, and to decide to retarget to a new hazard-free landing site if necessary.

The Lander's avionics play a central role in enabling the autonomy behind this decision-making and planning capability. Analysing sensor data, making decisions and implementing those decisions via commands to thrusters, represents a major challenge for both the Lander's hardware and software.

In the final moments, the Lander descends vertically to the surface and completes touchdown on its four landing legs. "The moment of touchdown on the Moon will represent many firsts, not only for Europe, including the demonstration of new enabling technologies, access to a key dynamic and diverse environment, and not least the beginning of a new era in exploration," says Richard Fisackerly, Lunar Lander System Engineer.

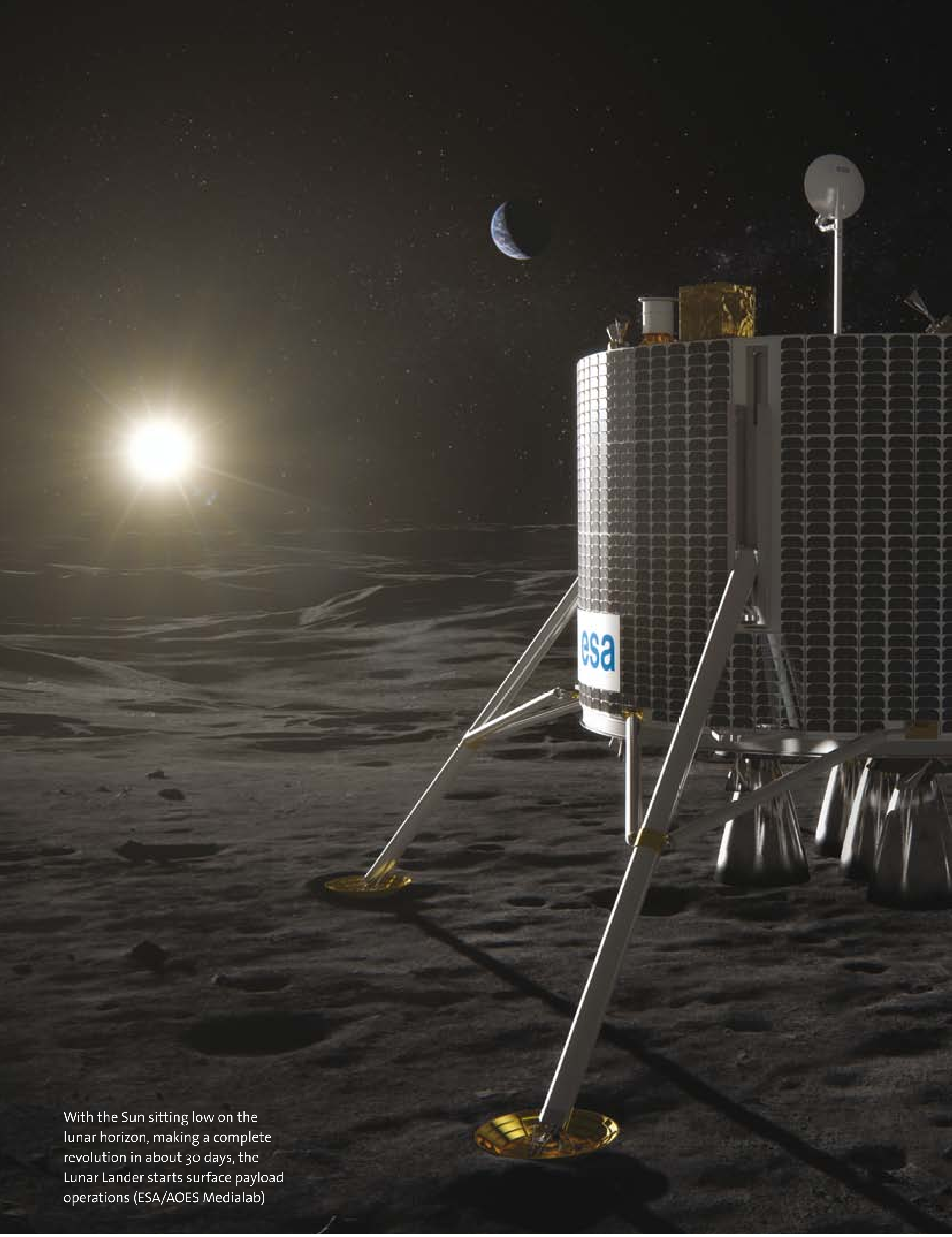
Operating in a harsh environment

When on the surface, the Lander will immediately deploy equipment such as the main antenna and the surface camera package. Only when the full data-set from the descent and landing phase has been received on Earth can the Lander turn its attention to exploring its new home at the lunar south pole.

With the Sun sitting low on the lunar horizon, making a complete revolution in about 30 days, the Lander will start surface payload operations.

Many of its instruments will characterise aspects of the lunar environment and its effects, for example, measuring and monitoring the properties of dust near the surface, local electric fields and plasma environment.

Along with the static monitoring instruments, the Lander also carries experiment packages that will analyse lunar surface samples. To acquire these samples, the Lander must deploy its robotic manipulator arm, which can be operated from the ground in near-real time because of the proximity of Earth.



With the Sun sitting low on the lunar horizon, making a complete revolution in about 30 days, the Lunar Lander starts surface payload operations (ESA/AOES Medialab)

The unique location of the lunar south pole imposes some important operational constraints. The Lander uses a direct-to-Earth link for receiving commands and sending back data, avoiding the need for a communications relay orbiter. However, the slight inclination of the Moon's orbit means that Earth appears to rise and set over the horizon on a 28-day cycle at the pole, meaning that the Lander has to be able to operate autonomously for around 14 days at a time.

"Given that we must exploit the 'season' of good illumination conditions to the utmost, the Lander must make best use of all its time on the surface, in making measurements of this important environment for exploration. This implies operating even during periods in which communication with Earth is not possible," says Richard Fisackerly.

Autonomous operations ensure that the mission continues even without communication with Earth, but the potential for darkness is a completely different challenge. The Sun sits low in the sky, grazing along only a few degrees above the horizon, so its visibility depends on the local topography and on the precise location of the landing site.

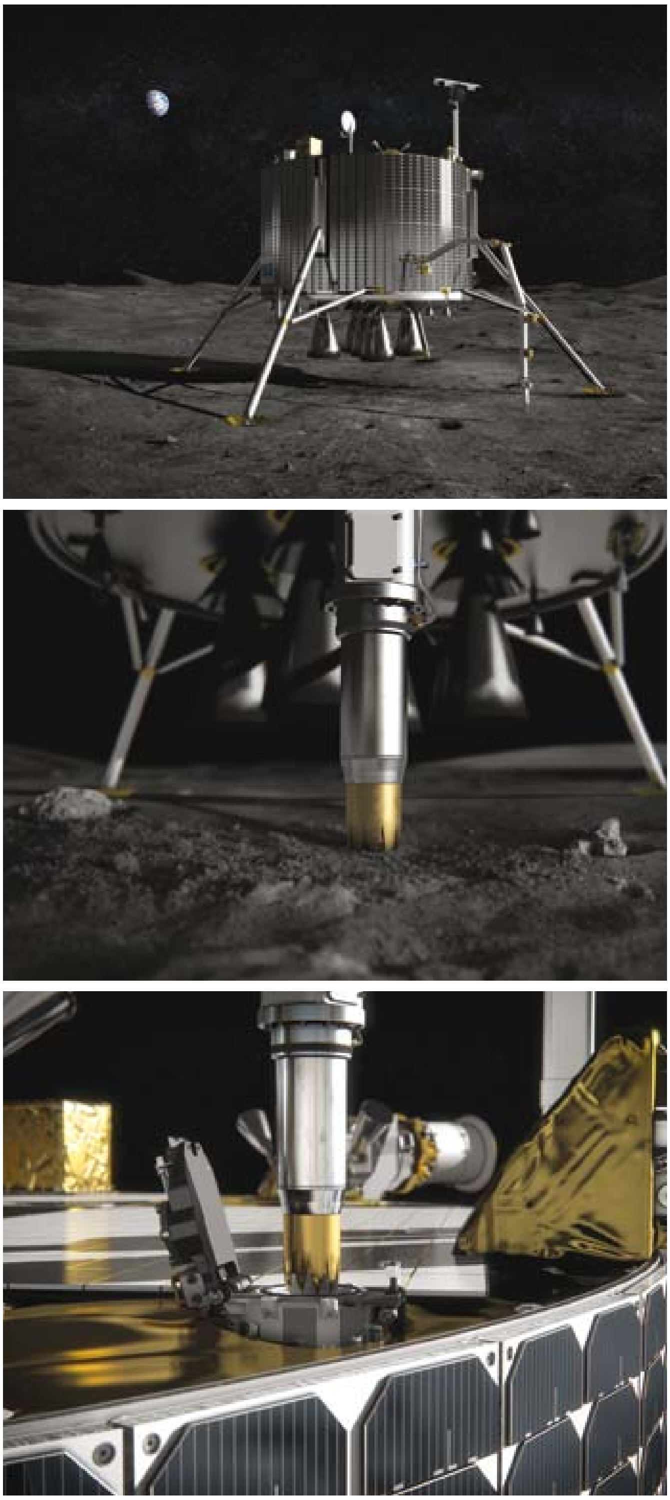
In trying to select the best possible landing sites with illumination for an extended period up to several months, mission planning places a strong emphasis on the analysis of topographic and image data. But it cannot be excluded that the Lander will experience short darkness periods, such as when the Sun passes behind a peak on the horizon or a large obstacle nearby.

"We predict these darkness periods to be in the order of tens of hours based on simulations performed before the mission. But it will only be after landing that the precise timing and duration of periods without illumination are known and can be used for planning of the operations.

The Lander must therefore be designed to maximise its robustness to darkness and low temperatures by building in a 'survival' or 'hibernation' mode," says Diego De Rosa. The Lander can be configured to endure several days of darkness, with critical temperature-sensitive equipment, such as batteries, electronics and communications systems, cocooned in the core of vehicle. This capability will allow the Lander to extend its period of surface operations for as long as possible.

Exploration enabling science

The Lander platform provides an opportunity to carry out investigations on the surface that enable future robotic and human exploration. Living and operating on the lunar surface in a sustainable way will be a major challenge, in which there are many fundamental unknowns.



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The Lander carries experiment packages that will analyse lunar surface samples. From top, the Lander deploys its robotic manipulator arm, then positions the sample collection device on the surface, and then returns it to the lander body to deposit the samples for analysis (ESA/AOES Medialab)

On-the-spot measurements provide a vital element in understanding these unknowns and a model payload has been put in place in the Phase-B1 study that addresses a range of important questions.

One major issue for exploration during the Apollo era was dust. Dust stuck to surfaces leading to thermal and mechanical problems, interfered with mechanisms, prevented proper sealing of vacuum seals and entered the crew compartments of manned spacecraft where it caused operational difficulties. More recently, the potential toxic effects of this material have also been realised.

Understanding the properties and behaviour of dust is therefore an important aspect of the Lunar Lander mission, and is supported by the sampling operations of the robotic arm coupled with microscopic investigations of dust particle properties.

Dust also plays an important role in the environment at the lunar surface, where solar ultraviolet radiation and high-energy particles, along with solar wind and magnetospheric plasmas, are incident directly on the dusty surface. This results in interactions that are complex and poorly understood, and which lead to a unique and challenging operating environment for exploration that may include strong electric fields, levitated dust and the global transport of dust particles.

The Lander's model payload includes a suite of instruments to measure the properties of this dusty plasma environment and provide insight into the underlying physics that drive it.

"From previous missions we know that lunar dust has major effects on surface systems from rovers, to life support systems, to radiators and solar panels, as well as the physiology of the astronauts themselves. However we have a poor understanding of the properties and behaviour of this dust *in situ* and its interactions with systems. In order to learn to mitigate the effects of dust and to live and work in this environment, we have to properly understand it. The Lunar Lander aims to address this," says James Carpenter, ESA's Lunar Lander project scientist.

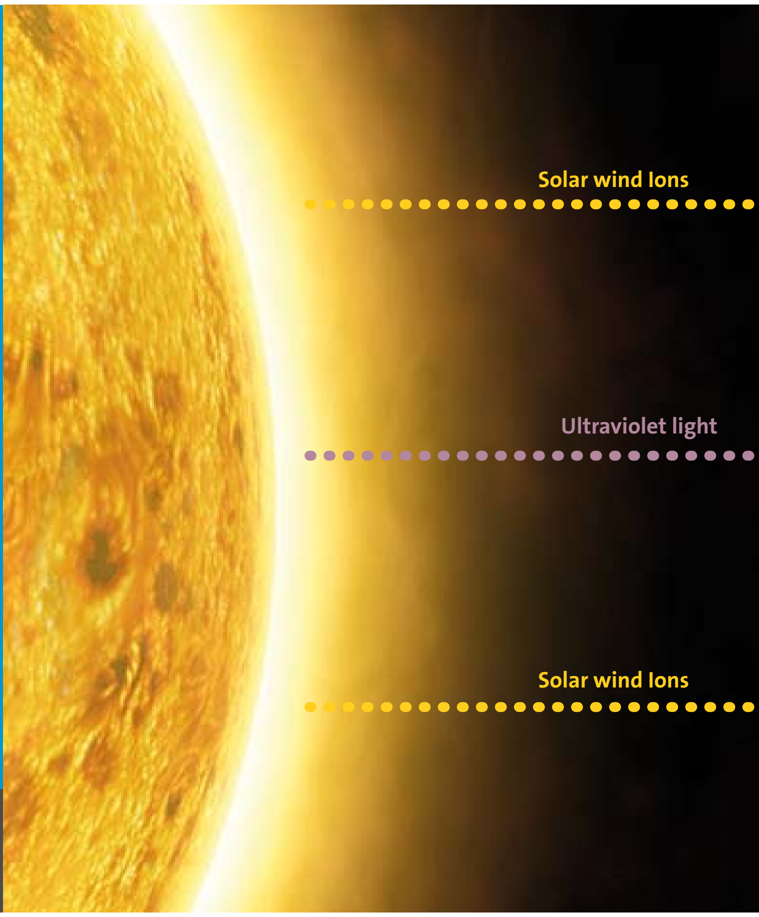
The lunar environment also offers opportunities for both science and future exploration. One example, which has become apparent in recent years following new scientific results, is the likely abundance of volatile materials, including water ice, at or near the surface.

→ Science to support exploration

The lunar surface is subject to incident ultraviolet radiation and charged particles from the Sun and Earth's magnetosphere. These particles charge the dusty lunar surface and may result in global and local transport mechanisms for charged lunar dust.

During the Apollo missions, lunar dust was found to be a big problem for operational activities. Dust stuck to surfaces and was abrasive, often preventing vacuum seals from operating correctly. Dust inside the pressurised modules could inhibit human activities and may pose a serious threat to health when inhaled.

The Lunar Dust Environment and Plasma Package (L-DEPP) is one candidate payload under study for the Lunar Lander mission. The experiment combines measurements of the complex local plasma and electromagnetic environment with investigations into the properties and behaviour of dust, and the effects of this environment on radio measurements.



→ Charging and electric fields experienced at the lunar surface

Understanding the nature of these volatiles, including their origins and the processes that affect them, is a first step in their potential use as resources for future missions. But this information will also provide insights into the history of the inner Solar System, with wide ranging implications for planetary sciences, Earth sciences and astrobiology.

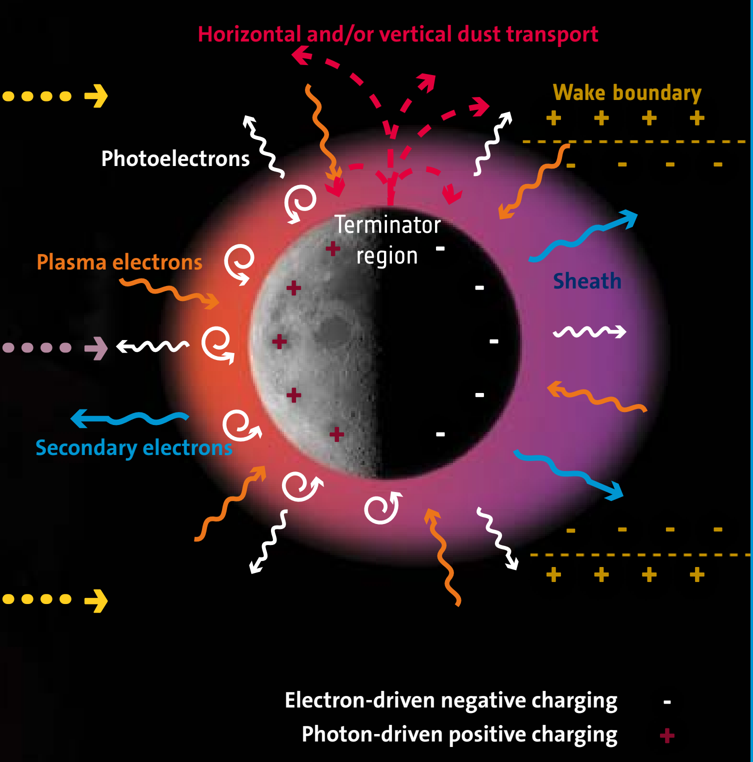
Rebirth of lunar exploration

The Lunar Lander mission prepares for the future, both technologically and in terms of enabling science. This fits within an international context that has seen a rebirth of interest in lunar exploration, a fleet of orbital missions gathering new data, and a drive to take the next step down to the surface.

For Europe and European industry in particular, this self-standing mission is an opportunity to take the lead in the precision landing technologies needed for the future, which can open the door to cooperation on more ambitious missions in the coming decade.

A decision on the next phase of the Lunar Lander mission will be made at the ESA Ministerial Council at the end of 2012. ■

↑ December 1972, Apollo 17 astronaut Harrison Schmitt experiences lunar dust (NASA)



↓ The Lunar Dust and Regolith Analysis Package (L-DAP) is one of several potential payloads under study for the Lunar Lander. The experiment investigates the properties and chemistry of dust and regolith grains for particles as small as tens of nanometres (SEA)