Science and Challenges of Lunar Sample Return

→ WORKSHOP OUTCOMES AND RECOMMENDATIONS

European Space Agency

In cooperation with:

A Statement from Participants to the Workshop

The Moon is an inspirational and scientifically important destination, which offers tremendous opportunities to those who make the decision to get there. New lunar samples can enable multiple scientific breakthroughs and inform future Solar System exploration endeavours. Accessing the Moon and retrieving samples is technologically feasible, and can be achieved within realistic budgetary and time constraints.

The more than 150 participants of the workshop urge the decision makers in ESA, its member states and the other space agencies worldwide to commit to a collaborative international lunar exploration programme that will provide access to the lunar surface and lead to state-of-the-art sample return missions within the next decade.

Workshop Outline

On the 18th and 19th February 2014 a workshop was held at the European Space Research and Technology Centre (ESTEC) in Noordwijk, The Netherlands on the "Science and Challenges of Lunar Sample Return". The workshop was organised by the Directorate of Human Space Flight and Operations of the European Space Agency, in cooperation with the Space Research Institute of the Russian Academy of Science (IKI) and the NASA Solar System Exploration Research Virtual Institute (SSERVI). The meeting was attended by more than 150 people from research, agencies and industry from Europe, Russia, the USA and other countries.

A new era of lunar exploration is underway, and new missions to the lunar surface are planned by various agencies and the private sector. Lunar Sample Return will be a major part of the activities to be performed by future robotic missions and by human missions when they resume.

This workshop was called to establish priorities for the science and investigations to be performed through analysis of new lunar samples, to identify locations from which these samples should be sourced and to highlight the major challenges associated with obtaining and preserving them to the point of analysis in terrestrial laboratories.

Key Messages

1. Lunar surface robotic missions followed by sample return missions represent the next major step in our return to the Moon and will result in important breakthroughs in our understanding of the Earth-Moon system and in fundamental science across multiple disciplines.
2. Missions to any lunar location distinct from those visited previously by the Apollo and Luna missions will result in high value samples. The highest priority sites for sample return are found within the lunar polar regions and the South Pole-Aitken basin.
3. Sample return should be considered as part of a coordinated exploration effort across multiple missions. Cooperation and coordination of missions (including internationally) will maximize the increase of knowledge from samples and provide the greatest return on investment.
4. Preserving the integrity of collected samples is paramount. Considerations of sample alteration, contamination, preservation and curation are of high importance and should be considered from the earliest mission phases.
5. Modern technologies provide sample return opportunities that were not available to the missions of the past. While complex and advanced missions are desirable, mission feasibility and cost constraints should be considered. Simpler, lower cost missions can also make very significant contributions and can be realised over meaningful timescales.
6. There is tremendous interest and enthusiasm for working with lunar samples among the present generation of students and young researchers from multiple disciplines. New lunar sample return missions provide a means of engaging, training and retaining scientific talented young scientists.
7. Advances in the capabilities of analytical instrumentation and modern laboratory protocols allow analyses of returned lunar samples that would not have been possible at any time in the past.

Science of Lunar Samples

A number of key research areas were identified, for which new lunar samples are required. Investigations have a broad scientific importance, addressing questions, which extend across multiple disciplines and represent the interests of a broad stakeholder community. Our existing sample collection is heavily biased as all existing samples were returned from the near side and low latitudes, within what we now know is a geochemically distinct terrain. New samples, representing the other lunar terrains are essential to understand the Moon.

Origin and evolution of the Earth and Moon.

The Earth and Moon are a binary system whose origin and history are intimately related. However recent findings related to indigenous volatile contents, isotopic systematics, and giant impact dynamic constraints may require modifications to the classic view that a Mars sized object impacting the early Earth is the origin of the Earth-Moon system as we see today. Analysis of lunar samples on Earth provides an essential means of testing formation models.

Bombardment and impact chronology of the Earth and Moon.

The Moon's ancient surface provides a unique reference in the inner Solar System for understanding the largest basin forming impacts, and the period of heavy bombardment, as well as the chronology of impacts that have occurred since. These events provide a context for the emergence and early evolution of life on Earth and have implications for early Solar System planetary dynamics and evolution. Radioisotope dating in terrestrial laboratories of well-selected and well-characterized samples from key locations provides the primary means of accurately determining this chronology.

Volatiles, ice and life precursor chemistry.

Volatiles at the lunar poles represent a time averaged sample of volatile sources through history, including the solar wind, asteroids and comets, and may reveal connections with the sources of terrestrial volatiles and organics, essential for life. Precursor chemistry in lunar ices may reveal connections with processes that generate such chemistry in deep space and the origins of life on Earth. Volatiles in the lunar interior, as recorded in magmatic lunar samples, can provide insight into the shared origins of volatiles in the Earth-Moon system. A comprehensive assessment of the chemistry and isotopic composition of these volatile reservoirs requires returned samples.

Fundamental planetary processes.

The Moon is a relatively simple geological body and so represents a near end member in terms of planetary evolution processes. As such it presents a reference point for understanding fundamental processes, including differentiation and volcanism, which can be extended to improve our understanding of these processes throughout the Solar System.

A Record of Solar System history.

The Moon's surface preserves remnants of the impactors that have struck it as well as material that has entered the Solar System during its multiple circuits around the galaxy. These samples, located only three days away, provide insights into processes that affected planetary bodies throughout the Solar System. Meteorites delivered to the Moon from the early Earth will also be present and may provide a unique window on the early history of our planet. Detecting and characterising this class of materials is only possible in terrestrial laboratories.

Environmental exposure for astrobiology.

Exposure of biological samples to the environment at the surface of the Moon and their return to Earth is a natural follow on to astrobiological experiments into the biological effects of space exposure in low Earth orbit on platforms including ISS. This has implications for understanding the transport of life through space and the biological effects of long duration space flight beyond low Earth orbit. Such effects are important for humans, for organisms, which may be employed in life support, for human-related microorganisms working in the body or for organisms living naturally within modules with a crew.

Exploration opportunities and hazards.

Lunar samples can provide insight into the utilisation potential of resources on the lunar surface and on the surfaces of other airless bodies (e.g., asteroids). These resources could enable sustainable exploration of the Moon and beyond, and may eventually offer benefits for terrestrial applications. Lunar samples can also provide information on hazards and effects of biological exposure to lunar dust or due to the properties of lunar dust and its interactions with surface systems. Lunar materials are also of interest as possible nutrient resources for bio-driven ecosystems, which might be used to support future Moon activities.

Current Expertise and Activities

The workshop was attended by representatives of both the science and exploration communities who are currently engaged in activities that are essential for the preparation of these missions.

Industrial work is on-going in Europe, Russia, the USA, Japan and China to develop the capabilities and technologies that will be required for lunar sample return. The technical ability to do lunar sample return missions exists.

Extensive work is being carried out on existing lunar samples in Europe, the USA, Russia and elsewhere that continues to produce ground-breaking science. As a result, significant expertise and technology has been developed for the handling and exploitation of these samples. In parallel, the vast new orbital dataset from recent missions are being exploited. The next steps, scientifically, require new samples. The established expertise from both current sample analysis and orbital data analyses will be enabling for the missions that provide those samples.

New sample return missions are required, soon, to bring these elements together and capitalise on the significant investments made.

Recommendations

Missions

Early robotic missions which access the surface, such as Luna-Resurs, should be followed by sample return missions such as MoonRise and Lunar Polar Sample Return. Such missions would return valuable new lunar samples and are important initial steps. For these early missions it is important to manage and constrain complexity such that they can be realised in an affordable and timely manner. At the same time it is important to develop the technologies required to access complex and challenging locations.

Mobility and precision landing provide enhanced scientific return by allowing access to carefully selected samples, which can be understood within their context and can be selected to provide the best possible science return. These should be considered in so far as missions remain affordable.

Humans at the surface will provide the greatest scientific benefits. No robotic mission conceived can approach the scientific productivity and flexibility demonstrated by human lunar missions. Bringing humans to the surface of the Moon should be a goal for human exploration programmes.

Human assisted sample return missions, where humans in cis-lunar space work with robotic assets at the surface, can provide an important intermediate step to human surface access, building on expertise developed through the International Space Station partnership. Such missions bring some of the benefits of having humans in-situ, while developing capabilities for application later. They offer a means of accessing far side locations and retuning significantly larger sample masses than can be achieved by robotic-only missions.

Coordination between missions in terms of landing sites, sample types, curation and analyses can lead to significant enhancements in scientific return compared to missions considered in isolation. No single mission will be all encompassing.

Sample return should be considered in the frame of a sustainable and on-going international lunar exploration efforts. In addition, the interoperability of capabilities and assets of various players can be used to enhance the overall operations and performance of missions.

Sample types

Samples from any new location, distinct from those visited by Apollo and Luna missions, will have a high scientific value. Those identified as having the highest priority are:

Samples containing volatiles from polar regions. These samples are most likely to be located in polar cold traps (e.g. Cabeus crater Permanently Shaded Region) though some indications exist that they persist more widely. They are almost certainly found in the subsurface at depths sufficient to protect them from the effects of space weathering and sublimation.

Samples which constrain the period of Late Heavy Bombardment, also called the Cataclysm. These samples need to be associated with the oldest (e.g. South Pole-Aitken basin) and youngest basins.

Samples representing key dates in the lunar chronology. The samples of highest priority are to be found primarily within or immediately around the lunar basins (e.g., at Copernicus and Tycho craters) and in the youngest terrains. It is essential that such samples are associated with a specific feature and epoch in the lunar chronology.

Samples representing products of planetary differentiation. Samples of lower crust and upper mantle material are of primary importance and are most likely to be located within the South Pole-Aitken Basin.

Samples preserving the record of the environment at a given epoch. These samples are to be found in the present day regolith and in deeper buried paleoregoliths, where overlying volcanic events or impact craters have buried surfaces exposed to the space environment in the distant past. It is recognised that such locations are unlikely to be accessed by early robotic missions but should be a target for future human missions.

Locations

Any new location, which is distinct from those visited by Apollo and Luna missions will yield new and valuable scientific results. Locations identified as being of the highest priority are:

The lunar poles, in particular the South Pole. The poles provide access to the cold traps that preserve volatiles including water ice and may contain complex organic compounds. The priority here is for areas of permanent shadow and where existing evidence supports the presence of such materials. Areas that are illuminated but where evidence of volatile enhancements exists can also be considered as a lower priority. Areas of particular interest include the areas in and around Cabeus crater and Amundsen crater. Parts of the South Polar region may also enable access to material from the South Pole-Aitkin basin.

South Pole-Aitken (SPA) Basin. This is the oldest and largest impact basin observable on the lunar surface, and is a touchstone for the bombardment history of the inner Solar System. Samples of impact melt from this basin can provide an important upper limit for the rest of lunar chronology. Younger basins superimposed on this one, in particular Schrödinger basin, could provide samples to delineate the youngest period of late heavy bombardment. These locations can also provide access to lower crust and upper mantle material. Permanently shaded regions here, although limited in scale, may provide access to volatiles. The return of samples from the interior of SPA basin, as proposed by the *MoonRise* mission, coupled with the return of samples from a south polar mission or from Schrödinger basin, both of which are located near the southern rim of SPA basin, would provide great synergy in scientific understanding of the samples and the geology and chronology of the SPA basin and the early bombardment history and dynamical history of the Solar System.

Tycho and Copernicus. Returning samples from Copernicus and Tycho is crucial for accurately defining the lunar chronology. There are only four data points that fix the lunar chronology at ages younger than about 3 Ga and two of them, Copernicus and Tycho, have not been directly sampled by the Apollo and Luna missions.

Paleoregoliths. Though challenging to sample because they are now buried or located beneath younger lava flows, later human missions should consider accessing and sampling from paleoregoliths, such as those located in Oceanus Procellarum, trapped between units of young lava flows.

Challenges

Accessing challenging locations. Some of the highest priority samples are likely to be found in challenging locations. Volatiles and ices are most readily obtained from the polar regions where missions must endure some of the lowest temperatures in the Solar System with limited or no solar illumination. Samples here will be taken from the subsurface and have poorly constrained physical properties. While many near side locations of importance can be identified many important and unique locations are located on the lunar far side, which poses challenges for communications. Geological samples of the highest priority may be obtained from geological features such as peak rings and volcanic structures that require highly capable mobility to access. A priority should be to develop the capabilities that allow access to and operations in these locations.

Context and representation. Samples must be collected and understood in terms of their geological context and their provenance at the point of sampling. Achieving this requires careful targeting and selection of samples. In some cases large number of small samples (e.g. rocklets in the regolith) may be sufficient to allow statistical arguments of their provenance to be applied. In more ideal cases samples should be selected on the basis of in situ imaging and other measurements to allow selection based on context and measurement. It is important to understand the extent to which a sample represents the wider environment locally and globally. A priority here should be to develop sampling strategies, sampling techniques and instrumentation to allow samples to be selected and extracted with the best possible understanding of their context and the extent to which they represent the target of investigations.

Sample preservation and contamination. Preserving a sample in a pristine and uncontaminated state is important if measurements are to be fully understood. Volatiles pose the greatest challenge for contamination by terrestrial species, surface bound volatiles are easily lost and ices should ideally be maintained at very low temperatures. Practically some contamination and alteration is unavoidable. The challenge is to limit this to acceptable levels while ensuring that any changes introduced are fully understood and quantified. A priority is to develop sampling strategies and capabilities, which access uncontaminated samples, minimise contamination and alteration of samples and fully characterise likely contamination and alteration mechanisms and effects. Sample contamination, alteration and provenance from sampling through to analysis, including curation, need to be considered from the earliest mission phases.

Summary

The workshop on the Science and Challenges of Lunar Sample Return demonstrated a widespread interest in the opportunities such missions present for scientific and exploration related investigations. The importance of currently planned missions, and prospects for future missions, eventually involving humans were highlighted. It was shown that new lunar samples are required to address major questions for exploration and science, supporting high-level and interdisciplinary science themes. Lunar sample return missions also have important science and technology synergies with missions to other destinations. It was also noted that a major contribution to the meeting was from young scientists and students, who demonstrated a drive and enthusiasm from the emerging generation of scientific talent, who will realise this benefits of new sample return missions.

The Moon is an important and enabling platform for space exploration and provides a unique window into the history of the Solar System, the Earth and the fundamental processes that drive the origin and evolution of planets. Sample Return in the coming decades is the best possible way to yield the extensive benefits and major breakthroughs that the lunar surface offers. It is important that steps are taken now to build on the existing global momentum in this area and ensure that a program of successful lunar sample return missions is formulated and executed.

Authors

This document was prepared following the workshop on the "Science and Challenges of Lunar Sample Return" by the scientific organising committee and panellists, listed below in alphabetical order.

Mahesh Anand, Open University, UK
James Carpenter, ESA ESTEC, The Netherlands
Marc Chaussidon, Institut de Physique du Globe de Paris, France
Ed Cloutis, University of Winnipeg, Canada
Ian Crawford, Birkbeck College, University of London, UK
Jean-Pierre De Vera, DLR Institute of Planetary Research, Germany
Amalia Finzi, Politechnico di Milano, Italy
Richard Fisackerly, ESA ESTEC, The Netherlands
Bernard Foing, ESA ESTEC, The Netherlands
Harald Hiesinger, Westfälische Wilhelms-Universität Münster, Germany
Harald Hoffman, DLR Institute of Planetary Research, Germany
Ralf Jaumann, DLR Institute of Planetary Research, Germany
Brad Jolliff, Washington University in St. Louis, USA
Katherine Joy, University of Manchester, UK
David Kring, Lunar and Planetary Institute, USA
Zita Martins, Imperial College London, UK
Igor Mitrofanov, Space Research Institute of the Russian Academy of Science, Russia
Clive Neal, University of Notre Dame, USA
Greg Schmidt, NASA Space Exploration Research Virtual Institute, USA
Chip Shearer, University of New Mexico, USA
Erin Tranfield, Instituto Gulbenkian de Ciência, Portugal
Wim van Westrenen, VU University Amsterdam, The Netherlands