Lunar Science: Window to the Past and Stepping Stone to the Future

Statement of the NASA Lunar Science Institute Executive Council to the Augustine Commission, July 2009

David Morrison, chair: NLSI Director
William Bottke, Southwest Research Institute
Jack Burns, University of Colorado
Ben Bussey, Applied Physics Lab/JHU
William Farrell, Goddard Space Flight Center
Mihaly Horanyi, University of Colorado
David Kring, Lunar and Planetary Institute
Carle Pieters, Brown University
Gregory Schmidt, NLSI Deputy Director

Exploration has always led to new scientific insights—indeed, it is difficult to disconnect science from exploration. The very nature of exploration leads to new discoveries that break down old paradigms and enable new scientific understanding. Especially with respect to the Moon, human and scientific exploration remain synergistic and indistinguishable. The NASA Lunar Science Institute (NLSI) brings together scientists and engineers from the academic community and NASA Centers to advance lunar science, support both human and robotic missions to the Moon, train the next generation of lunar scientists, and communicate the excitement of this scientific exploration to the public (http://lunarscience.nasa.gov).

Our initial forays to the Moon by both robotic explorers (Luna, Ranger, Lunar Orbiter, Surveyor, Lunokhod) and astronauts (12 of whom walked on the Moon) extended the human boundaries for the first time to another world. This exploration probed not only the evolution and nature of the Moon itself, but perhaps more importantly, has begun to illuminate its role as a witness to the history of the solar system. Today we are in the same stage of lunar exploration as we were when we began the exploration of the other great frontiers of humanity. We know enough to ask key questions and to appreciate the significance of the anticipated answers, but are blind to the unknown.

From the science perspective, Apollo only skimmed the surface. Only a tiny portion of the Moon (nearside mid-latitudes) was explored during short visits by Apollo astronauts. With the current advanced orbiters sent to the Moon by the United States, Europe, Japan, China, and India, we are opening a new era of lunar studies.

In the 2007 National Research Council report, the "Scientific Context for Exploration of the Moon" [SCEM], the NRC committee states unanimously that the Moon has "profound scientific value" and is "priceless to planetary scientists." Furthermore, "only by returning to the Moon to carry out new scientific explorations can we… learn the secrets that the Moon alone has kept for eons." Unveiling these secrets provides a driving science-based reason to return to the Moon. We are poised on a new era of exploration and scientific discovery to unlock the Moon's mysteries and exploit it as a tool for understanding our own planet. The Moon is a fascinating cosmic body, but what makes it really special is that it is not any moon, it is *Our Moon.*

The Moon is a witness plate to the Solar System's past—and Earth's present

The decades since the Apollo missions have allowed scientific assimilation and integration of the large body of lunar data collected during that era, resulting in a new scientific framework and set of hypotheses for the formation of the Moon and its geological and impact history. The key to determining our future is understanding our past. Wind and water erosion, volcanoes, and subduction of the Earth's crust have all but erased our planet's impact and geochemical history, while the Moon provides the most logical and accessible record of the early Earth-Moon system.

One of the grand intellectual legacies of the Apollo program is the suggestion that the Earth-Moon system was severely bombarded 4 billion years ago in an event called the lunar cataclysm. Post-Apollo analyses suggest this event affected every nook and cranny of the solar system and may have been prompted by a dramatic reorganization of the orbits of the giant gas planets. Because of its fundamentally important implications for all planetary science, a test of this hypothesis is the NRC-SCEM's highest science priority for lunar exploration. A key component of that analysis will be a study of the South Pole-Aitken Basin, which is the oldest and largest basin on the Moon. It could provide samples to date the initiation of basin-forming events in the inner solar system and also components of rock with mantle composition to help us constrain our understanding of the interior composition of both Earth and Moon. Placing impact basins in chronological order, which requires a set of sample return missions, is intimately tied to the question of the role of impacts and the start of life here on Earth. A South Pole-Aitken basin sample return mission was a high priority in the 2003 NRC decadal survey report, "New Frontiers in the Solar System: An Integrated Exploration Strategy".

Additionally, the Moon serves as a witness plate for contemporary impact rates in the Earth-Moon system. Comparison of limited meter-resolution images from the Lunar Orbiter and LRO (separated by 43 years in time) will provide direct measures of cratering rates. These data sets also offer a splendid opportunity for "citizen science" in the search for changes between the two image sets.

The Moon is a critical stepping stone for human exploration of the Solar System

The Moon is a first step toward future human exploration of our own solar system, which will likely include the near Earth asteroids, the moons of Mars, and ultimately the martian surface. The Moon boasts several key attributes that make it the perfect test bed for planetary exploration: proximity, reduced gravity, minimal atmosphere for easy landing and return. It will be the place to first develop new methods for in-situ resource utilization (ISRU) that can later be used for asteroids and Mars. Additionally, scientific determination of the physical, chemical and optical properties of the lunar regolith are critical for development of machinery for regolith construction and manipulation. The conditions on the Moon change dramatically between illuminated and dark regions or as the Moon cuts across the magnetotail of the Earth. Additionally, both the long-term solar cycle effects and the short term variability in solar conditions can alter the surface dust

and plasma environment. These are amongst many problems to be solved in building a human presence on the Moon.

The Moon is an ideal platform to mature partnerships between human and robotic explorers. Working with the NASA Lunar Science Institute (NLSI), the NASA Lunar Robotic Recon Team just completed an exercise at NASA Ames where humans and robots worked side by side in the field to promote maximum efficiency in exploration and scientific goals (http://lunarscience.nasa.gov/roboticrecon). The Moon also provides an important laboratory for testing the effects of long-term space conditions on living systems. The combination of ionizing radiation, reduced gravity, exposure to lunar dust and other variables can be tested on key indicator species and cell cultures in order to understand the deleterious effects of space exposure and to develop countermeasures. As long-term human exploration will eventually require growing food, it is important to focus not only on human biology but the biology of the plants, animals, and microbial ecosystems we will carry with us.

Lunar observatories can provide unique insights into the universe

The Moon is a unique platform for fundamental astrophysical measurements of gravitation, the Sun, and the universe. Lunar Laser Ranging of the Earth-Moon distance provides extremely high precision constraints on General Relativity and alternative models of gravity. Lacking a permanent ionosphere and, on the Moon's far side, shielded from terrestrial radio emissions, a radio telescope on the Moon could be an unparalleled heliospheric and astrophysical observatory. With such a telescope, critical information on an epoch of the evolution of the universe during and before the formation of the first stars could be obtained for the first time, and crucial stages in particle acceleration near the Sun could be imaged and tracked. The Moon could also provide an important vantage point for Earth observations – unlike LEO, one may observe the entire disc of the Earth at one time, and unlike GEO, one may observe the entire Earth as it rotates. This gives an important opportunity for monitoring atmospheric chemistry and plume transport, whole-Earth thermal infrared measurements and (with a more significant infrastructure investment) radar interferometry for atmospheric velocity field measurements.

Lunar missions will inspire the next generation of scientists and engineers

Apollo-era expeditions encouraged imagination in our youth, fueled American ingenuity and inspired a generation of scientists and engineers. Unfortunately, the apparent lack of public interest in today's NASA indicates that they do not understand or are not inspired by the current path we are taking. To that end, two of the NLSI's central missions involve inspiring young people and training the next generation of lunar scientists. From promoting STEM research in undergraduate institutions to supporting graduate student lunar research, it is our mission to reinvigorate and capture the public's interest in science and exploration. Several ongoing programs to help attain this goal revolve around lunar science, including the NLSI Postdoctoral Fellowship Program, the NASA Academy summer group project on biology and lunar regolith simulant, strong support of the International Year of Astronomy, the Lunar Regolith Challenge (part of the Centennial

Challenges program), the Summer Lunar Interns program, comprehensive websites and lesson plan development for teachers, and many more. Exploring our nearest astronomical neighbor inspires the world, and programs such as the LCROSS campaign to observe the spacecraft impact on the lunar South Pole engage amateur astronomers globally. NASA has a critical role in helping inspire another generation through the excitement of our return to the Moon, and NLSI is working with institutions around the world in a vigorous approach toward bringing this excitement to fruition. As noted in the National Academies report "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (2007)," "History is the story of people mobilizing intellectual and practical talents to meet demanding challenges... After the launch of Sputnik in 1957, we accepted the challenge of the space race, landed 12 Americans on the moon, and fortified our science and technology capacity." Just as it did in the 1960s, a renewed focus on lunar science and exploration can inspire all of us and mobilize the nation's talent to meet the new challenges of the 21st century.

Lunar science and exploration offers opportunities for international cooperation

The world is returning to the Moon. China (Chang'e), Japan (Kaguya/Selene) and India (Chandrayaan-1) have all mounted highly successful orbital missions, and each of these countries is planning for robotic landed missions. There is a great opportunity for a new international effort to engage with other space-faring nations in lunar science and exploration. The International Lunar Network (ILN), led by the U.S., is a prime example. The ILN will establish a second-generation geophysical network to address important scientific question through a series of landed missions. The ILN members are contributing towards this multinational effort to develop coordinated spacecraft, instrumentation and infrastructure (http://iln.arc.nasa.gov), in response to high ranking for network science in the last Planetary Science Decadal study by the NRC.

International cooperation on the Moon benefits all; as an example, the Chandrayaan-1 mission currently in lunar orbit includes international experiments, two with strong ties to the NLSI. The NLSI also has its own vigorous international science program, with three current partners and an additional 10 under negotiation. As stated in the NRC SCEM, "strong ties with international programs are essential" and NASA "should explicitly plan and carry out activities with the international community for scientific exploration of the Moon in a coordinated and cooperative manner."

Lunar science can serve development of lunar commerce

The announcement of the Google Lunar X-prize in September 2007 galvanized the nascent entrepreneurial space community. Today 19 international teams are registered in this competition, which will award $30M in prizes to the first team to safely land a robot on the surface of the Moon, travel 500 meters over the lunar surface, and send images and data back to the Earth. Just as previous X-prize competitions have spurred development of new industries, this competition will encourage the development of a commercial lunar industry. Already, the policy framework is under development to allow NASA to buy services and "rides" to the Moon from the Google X-prize and other commercial lunar

companies, once they have proven their abilities to land on the Moon. With sufficient demand from the government, industry and academic sectors, these companies could provide end-to-end services at less cost than current government-led payload development. Aggregating payloads would allow purchase of only the service needed, and for well-defined experiments at high technology readiness level, commercial data buys (where payment is made only when data is delivered) could be made. A high demand from the international science community could thus lead to increased mission frequency and lower cost. NLSI is pursuing opportunities to contribute modest science payloads to these private missions to the Moon.

Conclusion

Noted Apollo historian Andrew Chaikin called the Moon the "jewel in the crown." The value of having this planetary body so accessible for scientific research and exploration is truly beyond measure. Important clues to the beginning and evolution of life on Earth are embedded within events recorded on the Moon's surface. Such information is of great importance to humanity and is retrievable by an active human and robotic exploration program. Revealing the scientific treasures that we have only begun to glimpse will deepen our understanding not only of the Moon itself, but of the Solar System and the Earth's place within it. The NLSI is committed to uncovering the many hidden gems the Moon has to offer, and to sharing the excitement of these discoveries with the public. The Moon offers a unique window into our own past and beckons as the next step into our future as a space-faring species.