

# The NASA Lunar Science Institute's Three-Year Report

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## Abstract

The NASA Lunar Science Institute (NLSI) is proud to present this summary of the accomplishments of its first three years of existence. This report contains an introduction to the Institute, executive summaries highlighting the accomplishments of NLSI's seven U.S. teams, and a bibliography of scientific publications produced during the time period covered by this report.

## 1. Introduction

The NLSI is an innovative virtual research organization that leverages expertise from the science and exploration communities to support NASA's goals in lunar science (as outlined by the National Research Council and relevant NASA studies) as well as human exploration beyond low Earth orbit. The Institute also contributes to building a lunar science community, training the next generation of lunar scientists, and communicating lunar science with educators and the public.

The short existence of the NLSI has seen a blooming of lunar science, fueled in part by data from several scientific missions to the Moon (Chang'e, Kaguya, Chandrayaan, Lunar Reconnaissance Orbiter [LRO], Lunar Cratering Observation and Sensing Satellite [LCROSS], and the Gravity Recovery and Interior Laboratory [GRAIL]). New professional organizations have been formed to support lunar science, and sessions on the Moon have proliferated at the Lunar and Planetary Science Conference, the NLSI-sponsored Lunar Science Forum, and meetings of scientific societies such as the AAS Division for Planetary Sciences and American Geophysical Union. The increase in the number of students who have gravitated toward careers in lunar science is especially gratifying. The Institute has substantially re-energized the lunar community.

## 1.1 NLSI History and Organization

The NLSI was founded in March 2008, and seven member teams (see Table 1) were selected a year later through a highly competitive, peer reviewed process from proposals submitted to NASA. The Institute is based on the premise that exploration and planetary science are fundamentally intertwined; exploration enables science, but basic scientific understanding is foundational to safe, effective, and efficient human exploration. While the focus is on the Moon, NLSI scientists also study lunar science within a broader context of both planetary science and future human exploration beyond low Earth orbit.

The NLSI is modeled on the successful NASA Astrobiology Institute (NAI), which pioneered the concept of a virtual scientific institute. Like NAI, NLSI consists of a distributed network of competitively selected teams, managed and directed by a small central office. The NLSI Central Office is located at NASA Ames Research Center, Moffett Field, Calif. A virtual Institute is complementary to both individual research and analysis grants and the establishment of a "bricks and mortar" organization. First, providing funding to existing research institutions leverages past investments ranging from research infrastructure to student training. Also, flexibility and stability—essential to maximizing efficiency across teams—are achieved through longer support periods with larger funding awards than provided through small R&A grants to a single researcher. Second, a virtual Institute integrates scientific research across both geography and disciplines; the products exceed the sum of the individual efforts and often cannot be foreseen. Third, a virtual Institute requires minimal overhead, with most of the resources going directly to the distributed research teams.

Each NLSI team brings together scientists from multiple organizations who have related capabilities and interests. The initial seven teams include more than 180 individual scientists and future researchers.

The Institute also partners with international organizations, both research institutions (Affiliate partners) and government-based organizations (Associate partners) on a no-exchange of funds basis. The current international teams represent Canada, Germany, Israel, Korea, The Netherlands, Saudi Arabia, and the United Kingdom.

## 2. NLSI Goals

The prime product of the NLSI is research, disseminated to the community through professional publications, conferences and other methods including virtual workshops and webinars. The three-year bibliography included in this summary provides concrete evidence of our scientific contributions. The Institute also serves as a community leader through sponsorship of conferences and activities focused on lunar science and exploration. The Institute is integrated with the NASA Advisory Council's Lunar Exploration Assessment Group (LEAG) through representation on the LEAG steering committee and executive group. In support of the virtual institute concept, NLSI is exploring innovative ways of using information technology for communications and scientific collaboration between geographically disparate teams. In addition to research, the Institute supports a robust program to communicate the excitement of science and exploration to teachers, students, and the public, and it develops programs to train the next generation of space science explorers.

For the NLSI, lunar science is broadly defined to include studies:

- *Of the Moon:* Investigating the composition, structure and history of the Moon as each relates to the evolution of the Earth, Moon and Solar System.
- *On the Moon:* Investigations of the effects of lunar material and the environment on terrestrial life and robotic equipment.
- *From the Moon:* Exploring science that is uniquely enabled by being on or near the Moon, including celestial and Earth observations.

The selection of the current teams was also based on NASA's interest in a series of key scientific questions.

Within this broad framework, the NLSI teams have the freedom to shift direction in response to changing scientific priorities and to take advantage of opportunities for new cross-team collaborations. The objective is to create a flexible, interactive institute that is responsive to both NASA's needs and to those created through new scientific discovery. The individual team reports that follow this introduction illustrate the flexibility and creativity of this approach. Many further details are available at the NLSI website at [lunarscience.nasa.gov](http://lunarscience.nasa.gov).

## 3. Key Scientific Questions for Lunar Science

- How did the Moon form and how did its interior structure arise?
- How has the impact history of the Earth-Moon system been recorded on the lunar surface?
- How have volcanic processes on the Moon been initiated over lunar history and how do the volcanic flows reflect the interior composition.
- How have solar processes and space weather altered the lunar surface over time and been recorded in the lunar regolith?
- How will the lunar environment (e.g., dust) affect surface operations and influence designs for living on the Moon?
- What are the environmental conditions and the volatile content of the lunar poles?
- How will increased human activities alter the lunar environment?
- How can life from Earth adapt to long stays on the Moon?
- How can the Moon be used as a platform to advance important science goals in astronomy, Earth observation, and basic physics?

## 4. Community Support

Following are examples of ways the NLSI as a whole has supported the lunar community and reached out to the public.

*Lunar Science Website.* As of the printing of this report, the website [lunarscience.nasa.gov](http://lunarscience.nasa.gov) is a dynamic repository of news about the Moon, with

stories changed almost daily (reflecting the wide current interest in the Moon). Other main sections include an overview of the NLSI, descriptions of current and planned lunar missions, summaries of EP/O activities, and a calendar of events (including the annual Lunar Science Forum). It also includes links to the individual websites maintained by each Team. The website has a readership in more than 150 countries around the world.

*Lunar Science Forum.* The NLSI has hosted, since 2008, the world's largest dedicated lunar conference in the form of an annual NASA Lunar Science Forum (LSF). The LSF features sessions relating to science "Of, On and From the Moon" in addition to exploration-centered initiatives, education, public outreach and commercial space ventures. The LSF is held at NASA Ames Research Center during the anniversary week of the Apollo 11 moon landing. Attendance has exceeded 500 each year. The associated LunGradCon is a dedicated side-conference for graduate students, which is organized and attended solely by lunar science graduate students. This conference is designed to provide an opportunity for networking, sharing scientific results, and exposure of the grad students to senior leadership within the lunar scientific community. Additionally, the Next Gen Lunar Scientists and Engineers hold an annual workshop at the LSF, which provides personal and professional development programs to assist early-career lunar scientists.

*Shoemaker Prize.* Each year, NLSI presents the Gene Shoemaker Distinguished Lunar Scientist Award and associated keynote lecture at the Lunar Science Forum. This medal recognizes individuals who have significantly advanced the field of lunar studies throughout their scientific careers. Past winners include Gene Shoemaker (posthumous), Don Wilhelms, Jeffrey Taylor and S. Ross Taylor.

*Other Science Communities.* The NLSI hosts several lunar "focus groups" that are open to all interested scientists. The current focus groups deal with Apollo Lunar surface Experiments Package (ALSEP) data recovery, Lunar Space Biology and Astrobiology, Lunar Dust Atmosphere and Plasma, South Pole-Aitkin (SPA) Basin, Lunar Bombardment History, and Lunar Commerce. Staff from NLSI Central, as well as our teams, regularly exhibit at professional meetings of the American Astronomical Society, the American Geophysical Union, the AAS Division for Planetary Science, the Lunar and Planetary Science

Conference, the European Planetary Science Congress, and other organizations as time and funds permit. NLSI was a cosponsor of the International Year for Astronomy. NLSI also regularly presents on-line public lectures, usually featuring scientists from NLSI teams, which are available to everyone through live video connections and are archived as podcasts.

*Education and Public Outreach.* Each NLSI Team has its own E/PO coordinator and program, as described on respective team websites. NLSI Central coordinates a variety of large education and public outreach efforts. NLSI works with Montana State University's "Geology of the Moon" on-line course for K-12 teachers, and sponsors the development of educational material for use by students and audiences with disabilities. One of NLSI's most successful efforts was the development of a tactile guide to lunar geology for the blind with accompanying text in Braille. NLSI is pioneering high-profile public outreach and citizen science programs emphasizing inspiring students and the public. This includes International Observe the Moon night, when tens of thousands of people around the world gather to view the Moon through telescopes and learn about our nearest neighbor in space. NLSI promotes campaigns with schools, amateur astronomers, and the Girl Scouts to help them make observations of the Moon that directly support NLSI research. Exploration Uplink has allowed over 10,000 students in sites as far away as South Africa to remotely control a robotic rover operating in a simulated lunar environment. NLSI also works closely with the E/PO programs of the various NASA lunar missions including LCROSS, LRO, GRAIL, and LADEE to present the public with an integrated view of NASA lunar science and exploration.

## 5. Tables

Table 1: NLSI Current US Teams

<b>Investigation Title</b>	<b>Team Leader</b>	<b>Institution</b>
Understanding the Formation and Bombardment History of the Moon	William Bottke	Southwest Research Institute, Boulder, CO
Exploring the Cosmos From the Moon	Jack Burns	University of Colorado, Boulder, CO
Science and Exploration of the Lunar Poles	Ben Bussey	Johns Hopkins University/ Applied Physics Lab, Laurel, MD
Dynamic Response of the Environment at the Moon	William Farrell	NASA Goddard Space Flight Center, Greenbelt, MD
Colorado Center for Lunar Dust and Atmospheric Studies	Mihaly Horanyi	University of Colorado, Boulder, CO
Impact Processes in the Origin and Evolution of the Moon: New Sample-Driven Perspectives	David Kring	Lunar and Planetary Institute, Houston, TX
The Moon as Cornerstone to the Terrestrial Planets	Carle Pieters	Brown University, Providence, RI