National Aeronautics and Space Administration

NASA LUNAR SCIENCE INSTITUTE

2010 ANNUAL REPORT

NASA LUNAR SCIENCE INSTITUTE

INTRODUCTION

The NASA Lunar Science Institute supplements and extends existing NASA lunar science programs. Supported by the NASA Science Mission Directorate (SMD) and the Exploration Systems Mission Directorate (ESMD), the NLSI coordinates dispersed teams across the nation to help lead the agency's lunar research activities.

The Mission of the NLSI and its member investigators is to advance the field of lunar science by:

1) carrying out and supporting collaborative research in lunar science, investigating the Moon itself and using the Moon as a unique platform for other investigations;

2) providing scientific and technical perspectives to NASA on its lunar research programs, including developing investigations for current and future space missions;

3) supporting development of the lunar science community and training the next generation of lunar science researchers; and

4) supporting Education and Public Outreach by providing scientific content for K-14 education programs, and communicating directly with the public.

The development of new instrumentation concepts includes the laboratory fabrication and test of the Electrostatic Lunar Dust Experiment (ELDA), capable of detecting slow-moving (< 100 m/s) dust particles, and a Dust Telescope (DT), which is a combination of a dust trajectory sensor, and a chemical composition analyzer to measure hypervelocity (>> km/s) interplanetary and interstellar dust impacts on the lunar surface.

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Partnerships

- International Observe the Moon Night
- My Moon
- Moon Zoo
- Next Generation Lunar Scientists and Engineers
- Center for Astronomy Education for College Teachers
- Astronomical Society of the Pacific
- International Year of Astronomy
- Astronomers Without Borders
- Solar System Ambassador Program
- Museum Alliance Program
- Museum and Visualization Alliance for a high-leverage opportunity and for greater distribution.
- The JPL and Johnson Space Center ongoing program with the Girl Scouts of America

Formal Education

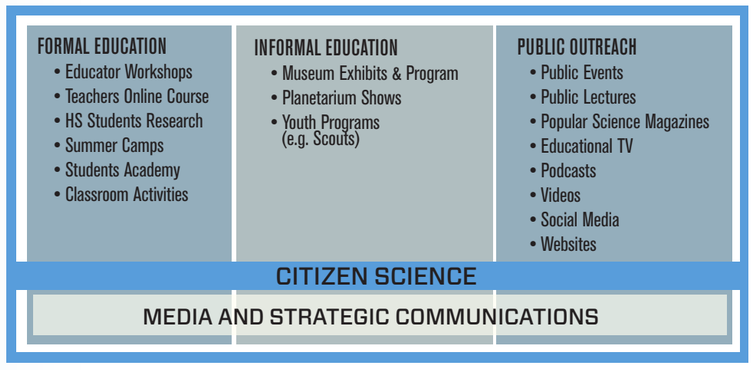
- High school research experiences through online mentoring
- High school student research with the Summer Science Program, Inc.
- Educator "Of the Moon, On the Moon, From the Moon" Institutes = 2 day workshops, grade 6-12
- High School Teacher Workshops
- Online Course for Teachers: Lunar Geology

Lunar Grad Con

A lunar science conference for graduate/undergraduate students held before the Lunar Science Forum, is an opportunity for Lunar Science Graduate students to connect and give oral and poster presentations on their own research to a group of their peers. Lunar Grad Con is open to anyone, especially undergrads, grads, postdocs, people early in their career, or anyone new to lunar science.

Next Generation Lunar Scientists and Engineers

Next Gen is preparing the next generation to encourage immediate integration into the lunar community, and to increase and encourage effective communication among and between scientists, engineers, and the public. It is open to undergrads, grads, postdocs, early career, or anyone new to lunar science and engineering.
http://nextgenlunar.arc.nasa.gov/



Moon Zoo

- Directly engages the public in identifying geological (& sometimes technological) features on the Moon.
- Users can explore educational content, including video tutorials, articles, glossary terms, and flash interactive activities.
- There also is a blog and a forum to encourage collaboration and social learning, and a twitter feed for general communications.

Over 2 million craters / areas of interest annotated as of June 15, 2010. Averaging 5,000+ users per day, >14,000 participants so far!

International Observe the Moon Night, 503 Events in 52 countries

Engaging lunar science and education communities, partner networks, amateur astronomers, space enthusiasts, and general public in an annual lunar observation campaign that shares excitement of lunar science and exploration.

- Enable public to maintain curiosity about the Moon and gain better understanding of Moon's formation, evolution, and place in night sky
- Lunar Photography contest

Program Partners include: Lunar Reconnaissance Orbiter Education and Public Outreach; NASA Lunar Science Institute; Lunar Planetary Institute; Ames Research Center; Marshall Space Flight Center; The Astronomical Society of the Pacific; The Astronomers without Borders Group; Bryce Canyon National Park; and various international partners in 52 countries.

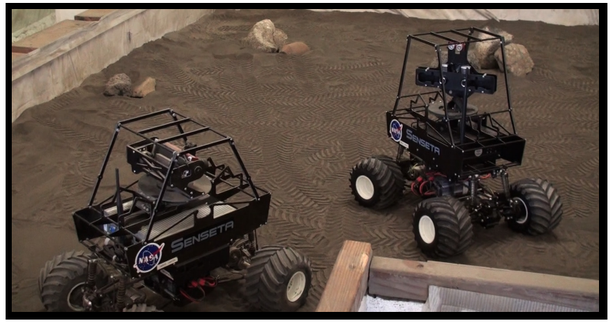
Director Seminars Series

NLSI has a monthly virtual seminar series that allows anyone with a telephone and internet connection to learn from world class lunar scientists. Participants use Adobe Connect for slide sharing and chat, and either video conferencing or teleconferencing options. Support capabilities range from HD to web cams.

- Regular seminar attendance from all NLSI domestic teams, international partners and other non-partner institutions.
- Twenty to thirty sites connect via teleconference options.
- Talks are archived, with the presentations, for anyone to access.

Exploration Uplink

Exploration Uplink was able to reach over 4,000 students with a hands-on tele-robotic exploration experience. This was accomplished over a series of 21 events, four of which were international. The international events were conducted in Canada, South Africa and South Korea in support of developing new international partnerships. Exploration Uplink accomplished this by allowing students to operate a NASA field science rover via a web browser, exploring a simulated lunar environment at NASA Ames Research Center. In addition to reaching out to students, Exploration Uplink was able to demonstrate new capabilities this year; deployment to field locations during Desert-RATS and a spectrometer payload. The future aim of Exploration Uplink is to allow middle school and high school students to participate directly in NASA field science missions by operating rovers that provide data to the primary mission.



Social Media

- Facebook, Twitter, and blogs are used to communicate science results as well as student and teacher experiences to the public
- "As it Happened: How We Went to the Moon" vodcasts
- Series of 11 episodes following the Apollo Missions.
- "NLSI Podcasts Series"
- Various Interviews NLSI Scientists

twitter.com/nasa_lunar
moourl.com/nlsifb
vimeo.com/nlsi

Lunar Science Forum

The Lunar Science Forum is an annual three day event organized by the NASA Lunar Science Institute that reports on recent science results from current lunar missions and discusses future opportunities for lunar science. The 2010 Forum had ~650 attendees from 31 States with international guests from 15 different countries, including delegates from current international lunar missions Kaguya from the Japan Aerospace Exploration Agency (JAXA), Chandrayaan-1 of the Indian Space Research Organisation (ISRO), and Chang'e-1 from China's National Space Administration (CNSA). Representatives from NASA's lunar missions were also in attendance, with Richard Vondrak discussing the preliminary science results of the Lunar Reconnaissance Orbiter (LRO) mission, and Principal Investigator Tony Colaprete detailing the upcoming LCROSS impact.

Shoemaker Award

The Shoemaker Distinguished Lunar Scientist Award is an annual award given to a scientist who has significantly contributed to the field of Lunar Science throughout the course of their scientific career. The first Distinguished Lunar Scientist Award was given posthumously to Dr. Gene Shoemaker and presented to his wife Carolyn for his many contributions to the lunar geological sciences. This year's honoree, Dr. Don Wilhelms, was given the award on the first night of the Lunar Science Forum, where he then gave a short scientific talk to the Forum attendees.

"Shoemaker was a great scientist and a great influence on the Apollo program-- he got science into the lunar program that wouldn't have been there otherwise-- so I'm very pleased to be associated with him, having worked with him and now getting the award with his name on it" Wilhelms said after receiving the medal.

Oral Presentations

As in past years, science sessions were structured to report on both recent results and future opportunities for lunar science, education and outreach. Presentations on elements of education and public outreach were included to better understand how lunar exploration can be used to stimulate public interest in space exploration and improve science literacy.

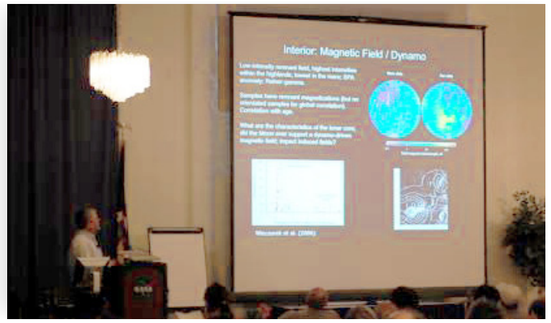
Invited and contributed oral and poster presentations, together with breakout sessions planning for future lunar science, included interesting presentations given by premier scientists from around the world. The session summaries, along with the abstracts, list of organizers, and participants, can be found at http://lunarscience2010.arc.nasa.gov/

Poster Presentations

The student poster competition was pleased to sponsor the Student Poster Competition. This event provided motivation, encouragement, and most of all, recognition to the most promising lunar scientists of the future. There were 1st, 2nd and 3rd place selections with awards of $1,500, $1000 and $500 respectively. Selections were made by votes of a committee of scientists and NLSI management.

NLSI had more than two dozen submissions from graduate and undergraduate students from both U.S. and Non-U.S. degree programs. The contest was very competitive with high-quality submissions. Selection criteria included the originality of the research, quality and clarity of the presentation—including accessibility to the non-expert, and impact to the field of lunar science.

This year, third place went to Laura Kruger from Coloradu University, with Matthew Siegler from UCLA taking second place. Tied for first place was Elise Rumpf from University of Hawaii and Paul Hayne from UCLA. With some good fortune, they were both awarded the full prize purse!



Lunar Science Research results presented in the Main Ballroom.

Student poster competition award winners. From left to right: D. Morrison, B. Bailey, A. Dove, G. Schmidt, D. Stitt, J. Green (Director, Planetary Science Division).

Collaborative Technologies

In building a robust and globally distributed research community, it is crucial to provide accessible, integrated and easy to use communication and collaboration solutions. The NASA Lunar Science Institute (NLSI) advances collaborative science through the innovative use of technology and user-centric approach. Research team members can have host accounts and training for collaborative technologies provided by NLSI as well as recommendations on best practices for the implementation of these tools. This approach lowers the barriers to entry increases technology adoption and empowers NLSI members to collaborate within their communities. Partnering with experts in science visualization, human factors, design, advanced networking and computer science, Ames Research Center and NLSI is demonstrating new ways of working in the information age.

Some of the tools we use on a regular basis are:
Videoconferencing: The NLSI Multipoint Video Control Unit (MCU) supports up to 30 high definition video connections at once in various configurations. ISDN, telephones and Skype can be integrated into the system, allowing for maximum connectivity to end users in almost any environment from room-based systems to laptops. Videoconferencing can be managed, audio levels controlled and interfaces customized by team members through a web browser without assistance from NASA staff.

Real-Time Meeting Software: Adobe Connect allows users to connect and collaborate with colleagues around the world. NLSI Central has integrated videoconferencing systems into Adobe Connect to produce a seamless user experience. Supporting file sharing, desktop sharing, chat rooms, VoIP, webcams, meeting recordings, persistent meeting spaces and more, Connect is easily accessible through a web browser. Meetings and seminars are easily archived for playback at anytime. Between February and November 2010, 60 NLSI Adobe Connect host accounts have been created to run more than 1500 hours of meetings and seminars.

Secure Workgroups: NASA provided Secure Workgroups provides an online community workspace approved for both low and moderate security levels. Group members can share files, calendars, database, discussion forums, email lists, member profiles and more in an easy to use interface. Community moderators can customize the interface, design, tools and access permissions.

NLSI's hyperwall is a matrix of High Definition screens powered by a multi-node network of high performance computers. Lunar scientists use the hyperwall for image comparisions and data mining, and to demo science and technology to peers and students.

From the Lunar and Planetary Institute team:
We find the Adobe Connect technology very useful for CLSE team meetings which include U.S. and international partners who are not always able to join us locally. An important goal of team meetings is meaningful discussion, so that collective expertise in the group can be used to assist specific projects and bring younger investigators up-to-speed with lunar sample issues. The technology certainly makes achieving this goal much more attainable for a team located throughout the world.

Additionally, we broadcast the monthly NLSI Seminar Series at the LPI for all local team members to come to LPI and participate in those talks together. It also allows younger researchers the ability to ask questions and gain exposure to the larger lunar science community.

From Jack Burns team, University of Colorado at Boulder:
The Lunar University Network for Astrophysics Research (LUNAR) uses Polycom videoconferencing for most of our meetings with our collaborating institutions and the NLSI. We also use our videoconferencing system in conjunction with Adobe Connect to broadcast and record our monthly LUNAR Webinar series as well as a graduate Lunar Science Seminar hosted by three of the seven NLSI team leaders (Dr. Jack Burns, Dr. Mihaly Horanyi and Dr. Bill Bottke). All of these webinars & seminars we have hosted are available on line at http://lunar.colorado.edu

E/PO Activities at APL

The Unknown Moon High School Educators Workshop program is a week-long immersion focused on a clear progression of lunar educational experiences and opportunities for students, teachers, and faculty. We have found that longer immersion leads to a greater depth of knowledge and learning than a 1-day workshop. These programs are based on the highly successful LPI teacher workshops for middle school and high school educators and complement their teacher offerings. This year, 27 high school faculty participated in the Unknown Moon Institute July 12-16 at the Lunar and Planetary Institute in Houston, TX.

Space Academy Program The "Unknown Moon" was the focus of a "Space Academy" educational event hosted by APL. The Space Academy series was created by the APL E/PO office and is co-sponsored by Comcast Cable, the Discovery Networks, and APL. Space Academy gives middle school students a close-up look at NASA's missions and enables them meet the scientists and engineers who work on them. Students study the mission and space related careers through classroom activities and videos developed by the Discovery Networks and APL. They participate in press conferences with mission panelists, moderated by an APL public relations representative. Student "reporters" ask panelists questions as if they were at an official NASA press conference.

Using styrofoam balls to help teach students about phases of the moon.

Participants in a workshop for homeschool students and their parents/teachers learn about the impact cratering process by making their own craters and observing the results.

E/PO Activities at CLOE

SSP encourages high-achieving high school students from across the nation and around the world to stay in the science career pipeline by involving them in an intensive six-week summer authentic research experience. The CLOE team is collaborating with SSP to a) develop two-day lunar research projects that involve computer modeling and b) to implement these projects with the students during the summer. During the project, over 200 students will be immersed in CLOE and NLSI science.

Explore the Moon! is a library program in which CLOE education specialists and scientists are creating modules of activities to be used in informal learning environment programs. Ninety children's and youth librarians, serving underserved and underrepresented audiences in CO/WY, ND/SD, and MT/ID, will be trained during three two-day workshops to use the modules. Ultimately they will engage 5400 children annually in CLOE and NLSI science.

E/PO Activities at CCLDAS

The primary product of the CCLDAS E/PO program was a professional development workshop for the media held May of 2010. 15-20 journalists, along with 6-8 scientists attended this 2 day workshop, designed to explore the current state of lunar system science and exploration.

NLSI TEAM E/PO

E/PO Activities at DREAM

DREAM's education and public outreach (E/PO) program is focused on student and teacher participation with scientists. The primary component of the DREAM E/PO program is two Lunar Extreme Workshops (LEWs) and the supporting materials developed for each LEW. The LEWs, which will be held in 2011 and 2012, will bring together scientists and modelers from the DREAM team with advanced high school students and their teachers. The LEWs will allow student and teacher participants to interact directly with scientists and to experience the process of science in action. Participation in LEWs and pre-LEW training will expose students to science, technology, engineering, and math (STEM) careers and engage them in learning new STEM content.

Participants in a workshop for homeschool students and their parents/teachers learn about the impact cratering process by making their own craters and observing the results.

E/PO Activities at CLSE

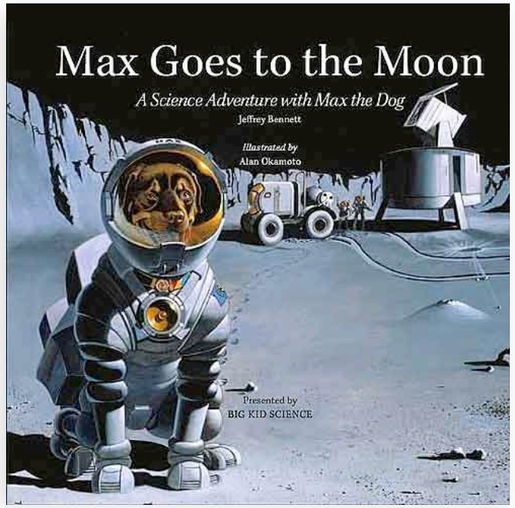
The LPI/JSC NLSI team is creating a series of library exhibits to share NLSI and NASA lunar science and exploration with the general public through a nation-wide network of librarians. To date, six exhibits are in the development process: 1) Treasure Hunt in Earth's Attic: Like an attic of ancient treasures, the Moon preserves Earth's lost history (in press); 2) Cosmic Decoder Ring: The Moon's well-preserved craters can decode ancient surfaces of the solar system (in press); 3) No Moon Light on Early Earth: Lunar scientists are illuminating how our Moon formed (in review); 4) Where To? NLSI Student Interns identify the best places to answer challenging questions about the Moon – and Earth (in development); 5) Lunar Cataclysm: Were early Earth and Moon bombarded by sudden burst of asteroid impacts? (in development); 6) Earth Without Moon: How would our lives be different without our Moon? (in development)

Each exhibit is accompanied by facilitator background information, a suggested hands-on activity to accompany the display, recommended NASA lunar educational activities and resources, and a guest book to collect visitors' impressions.

E/PO Activities at LUNAR

Planetarium Show: "Max Goes to the Moon"

The plot of the show is based on the award-winning book, "Max Goes to the Moon." This show is aimed at an audience between the grades K-5. Max, a real dog belonging to author and scriptwriter Jeff Bennett, helps make tangible to children the story line of preparations needed for going to the moon. A nice touch is the idea that Max's first lunar paw print will be preserved just like Armstrong's first lunar footprint.



This is the cover of the award winning children's book by Dr. Jeff Bennett.

Summary

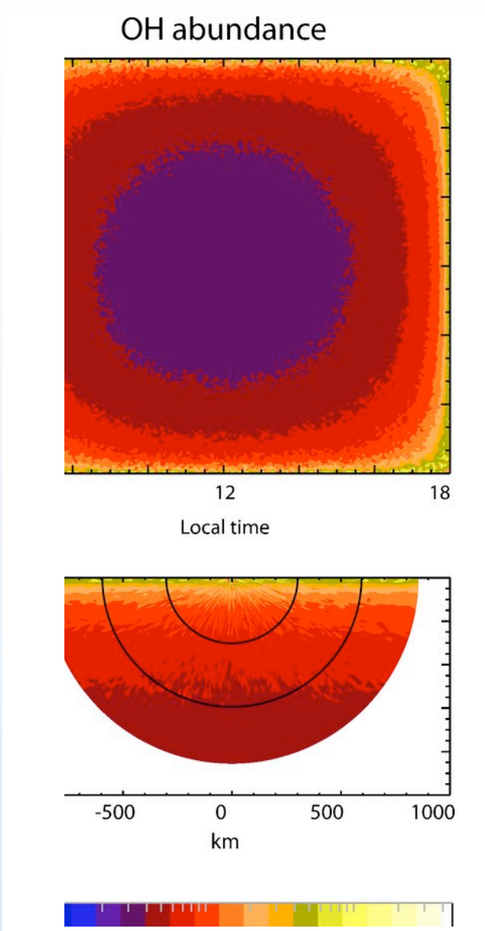
Recent results have revealed that there is water on the Moon. However very basic questions about the water are lingering. How did the water get there? How much water is there? How is the water observed in daylight related to the water in the cold traps? This project seeks to understand the mechanisms for emplacement and retention of volatiles at the lunar poles. After the LCROSS satellite purposefully impacted into an extremely cold, hydrogen rich crater, we modeled how water would be released by the impact. We provided our model results to the LCROSS team to compare with the observations. Because different observers were looking from different directions, it is hard to compare one observation to another. However, when there is a model of the whole vapor cloud that can be used to relate one observation to another, researchers can better constrain how much material was released, and what the physical state of it was when it was released.

Project Progress

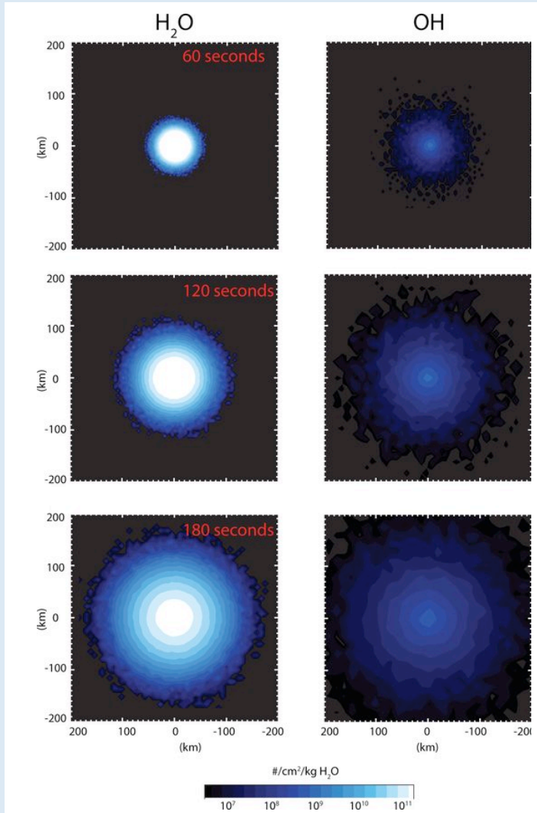
We provide a modeling framework for the assembly and interpretation of data from the LCROSS impact into the Cabeus crater in the southern polar region of the Moon. Through model-data comparisons, we have determined that H2 observed by the LAMP instrument on Lunar Reconnaissance Orbiter was released directly as H2, and was not produced from H2O molecules broken up by sunlight. However, there might be some H2 produced that way that is far less detectable than OH molecules that were observed, and probably produced by breaking up of H2O. Further, we find that the H2 was released more like a gas cloud than following the cone-shaped solid ejecta. This research effort focused on water and its daughters.

Depending on how the H2 gas is produced after the LCROSS impact, the evolving gas cloud appears very different. These figures show the cross form of the gas cloud at 90 seconds after impact as seen by the LAMP instrument on the Lunar Reconnaissance Orbiter, as it flew past the LCROSS impact site. The photodissociated H2 cloud (top) is far less dense than H2 produced directly on impact. The isotropic release (middle) fits the LAMP data well. The scenario where the gas follows the solid ejecta in a cone shape (bottom) does not get the gas to the right place for LAMP to observe it when it did.

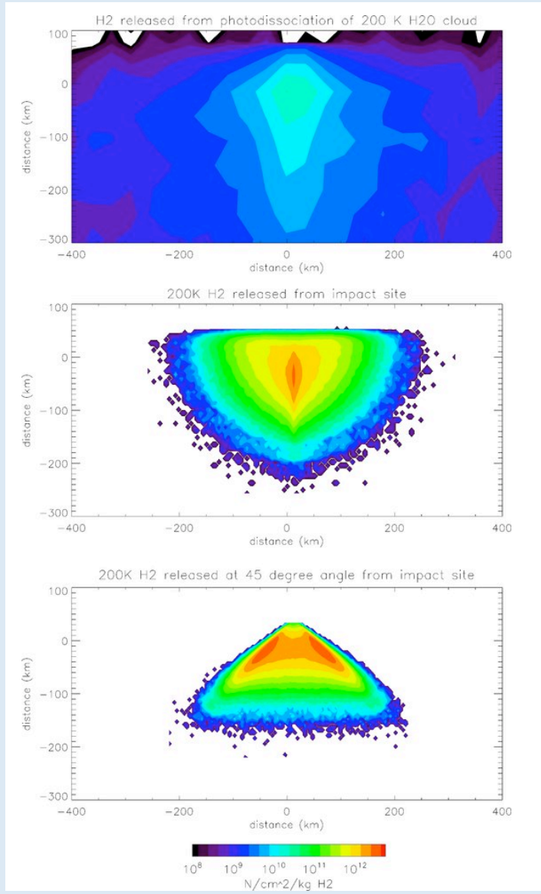
Multiple spacecraft have recently reported that there is OH and H2O on the surface of the moon in places that were considered to be too hot to have H2O remain for long periods of time. This shows the model predictions of the surface concentration of OH produced and maintained as follows: the solar wind implants hydrogen into the regolith. The H finds an O near a defect site, combines, and is released from the surface into the lunar atmosphere. When the OH comes back down, it reabsorbs and sticks for a time dependent on the destructive UV light flux, then is rereleased for another hop in the atmosphere. This process contributes to the observed OH coating on the surface, and comes close to reproducing the daily migration observed.



These models predict OH abundances as a function of time, depth and latitude over a lunar day.



These are the model results of how the gas cloud produced by the LCROSS impact would look from the following spacecraft's viewpoint looking down on the expanding cloud. The simulations show the water (H2O) vapor and its daughter hydroxyl (OH) ovver the first few minutes after impact.



These models show the amount of elemented Hydrogen (H2) released from the regolith following the warming pattern produced by the LCROSS impact.

Summary

One of the major discoveries of the Apollo program was that the Moon was once covered in a global layer of molten rock several hundred kilometers deep. The gradual cooling of this magma ocean led to the formation of the crust that we see today and a mantle of denser rock beneath it. By analyzing Apollo samples, our team has made ground breaking contributions to understanding the depth of the ocean, and how water was involved in this early cooling phase of lunar history. We have also formed models of how the unusually pure major rock type of the crust formed at this time. All of these discoveries are helping to build a more complete picture of one of the most important thermal event in our Moon's history.

Project Progress

1. Evolution of the Lunar Magma Ocean

The magma ocean epoch of lunar history represents a major global-scale thermal event that led to the formation of the lunar mantle and crust. Therefore, an understanding of this phase of lunar evolution is critical to interpreting the geology, geophysics, and geochemistry of the Moon we see today. As illustrated below, the Brown-MIT team is making fundamental contributions to understanding this critical portion of lunar evolution.

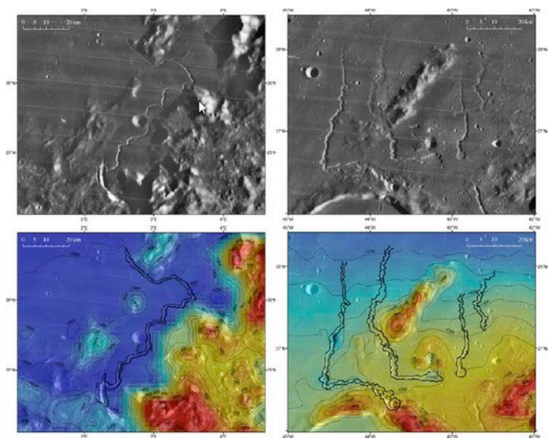
2. Post magma ocean structure and evolution

After formation of a global anorthositic crust, numerous large-scale events began to affect its structure. Two of the most critical events have been the extrusion of the mare basalts and the disruption of the surface by impact craters. The Brown-MIT team has recently published several key papers on the structure and formation of the largest craters in the Moon. These studies will yield insight into how large craters form everywhere in the solar system. Brown has also been collaborating with Lancaster University (UK) to better understand the how lava erupts on the lunar surface and forms the dark mare features we see today.

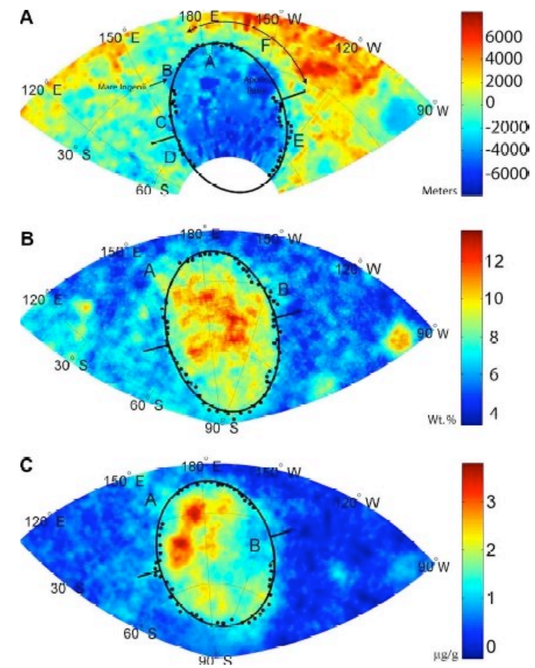
3. Deciphering the Crustal Record

The lunar crust provides one of the most pristine records of crustal evolution in the solar system. It is a natural laboratory with which to study chemical and physical processes that affect planetary surfaces over the age of the solar system.

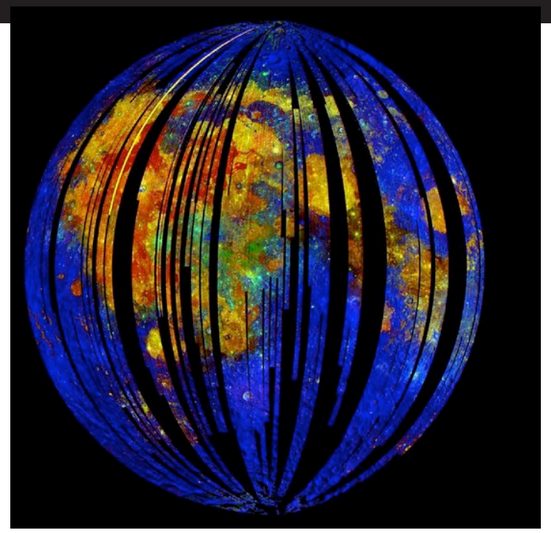
Our NLSI approach to studying the lunar crust bridges traditionally distinct perspectives and scales. Our interest spans the chemistry and petrology of a thin section to the local and regional composition seen by remote sensors. Our overall objective is use diverse types of information (composition, mineralogy, morphology, geophysics) to address and test fundamental science questions about the formation, evolution, and current state of the crust. The 12 peer-reviewed papers and 24 abstracts/presentations associated with this undertaking that have resulted during this first year attests to the scope and high level of activity of this project. Specific research activities are all mentioned in the citations, and we highlight a few examples here.



Lunar Orbiter (LO) images of Hadley Rille (top left) and Rimae Prinz, including Prinz, Beethoven, Handel, and Telemann (top right). Kaguya Laser Altimeter (LALT) data with vertical resolution of 5m for these areas are shown in the color sliced images below them.

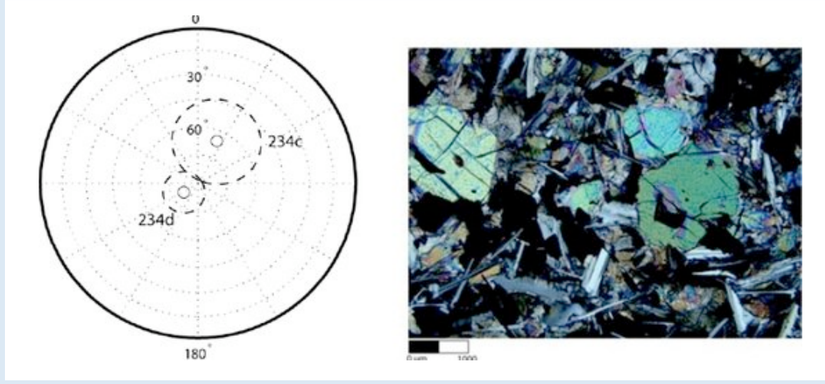


Above: Topography (A), thorium (B), and iron (C) in the lunar South Pole-Aitken basin. The ellipses define the crater's structure.



Global compositional properties of the nearside lunar crust. This color composite image [Isaacson et al., DPS, 2009a] is derived from M3 data to illustrate the fundamental compositional difference between the mafic-rich mare and the feldspathic highlands. Red and green capture the integrated strength of mafic absorptions near 1 µm and 2 µm respectively, while blue reflects surface albedo at 1.5 µm. This simple color display highlights the compositional diversity of mafic-rich basaltic materials across the maria.

Directions of characteristic components of the magnetization in Apollo 11 samples 10020,234c and 10020,234d, which are mutually oriented to each other. Dashed circles are maximum angular deviations of the fit. The closeness of the two magnetization directions suggests both pieces were magnetized in an ancient field. Right: optical photograph in crossed polars showing unfractured plagioclase laths and the pristine, unshocked nature of sample 10020.



CCLDAS

Introduction

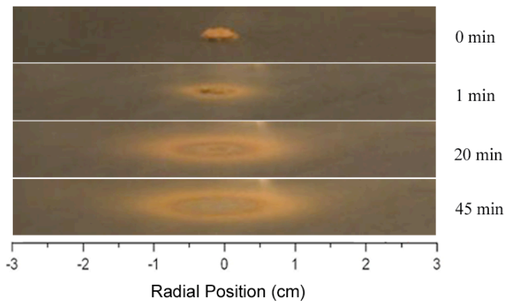
The Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS) is focused on: a) experimental and theoretical investigations of dusty plasma and impact processes; b) the development of new instrument concepts for future in situ dust and plasma measurements on the surface and in orbit about the Moon; and c) a complementary program of education and community development. CCLDAS is addressing basic physical and applied lunar science questions, including the long-term usability of mechanical and optical devices on the Moon. CCLDAS is supporting the development of the Lunar Dust Experiment (LDEX), an in situ impact dust detector to be flown on the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission scheduled to be launched in 2012.

Lunar Environment Impact Laboratory

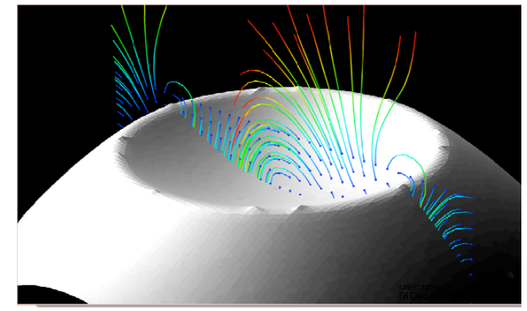
The objective of the LEIL facility is to accelerate micron-sized grains, which will provide a unique research tool to generate high-velocity dust impacts, closely reproducing the effects of micrometeoroid impacts onto the lunar surface. The LEIL facility, including the accelerator itself and the accompanying target chambers, will be capable of simulating the lunar surface environment, including variable plasma conditions, solar wind, UV radiation, and dust impacts. The core of the accelerator facility is the 3 MV ion accelerator, which is a "pelletron" linear ion accelerator (conceptually similar to a Van de Graff).

Duane Dusty Plasma Laboratory

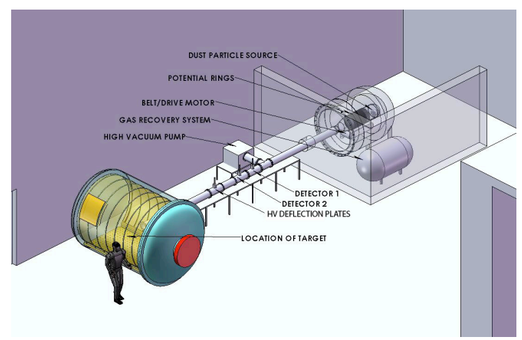
A series of tabletop experiments are currently operating to address dust charging on surfaces in a plasma, the adhesion of dust to surfaces, and the formation and characterization of a UV-generated photoelectron sheath, which is expected to be present under solar illumination of the lunar surface. Experiments on dust transport in plasma to investigate the origin of the lunar horizon glow were completed, motivated by the long-standing open questions about the physics of electrostatic lunar dust transport. We found that dust grains placed on a conducting surface, which is biased more negatively than its floating potential, charge positively, and an initial pile of dust spreads to form a dust ring (FIGURE 2). Dust particles were observed to land on insulating blocks, indicating the height of their hopping motion. The measured electrostatic potential distribution above the dust pile shows that an outward-pointing electric field near the edge of the pile is responsible for spreading the positively charged grains. A non-monotonic potential dip was measured in the sheath above an insulating patch, indicating a localized upward electric field causing the dust lift-off from the surface (Wang, et al., 2009). New experiments are being completed to include the effects of electron beams, leading to enhanced differential charging between a non-conducting dust pile and a conducting surface, which results in efficient dust mobilization (Wang et al., 2010).



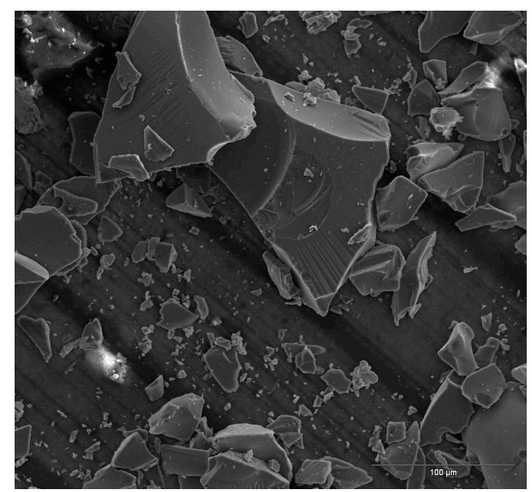
The experimental setup to study dust transport in plasmas produced these images of dust spreading at 1, 20, and 45 min after the plasma is turned on.



3D plot of the electric field structure over a partially illuminated crater. The electric field lines start from the positively charged illuminated regions and terminate at the negatively charged shadowed regions.



Schematic layout of the dust accelerator and the impact chamber to house UV, electron, and ion sources to simulate the variable plasma conditions on the lunar surface. The dust accelerator is used to simulate the effects of dust impacts with speeds >> 10 km/s for micron sized projectiles. The facility will be also used to test and calibrate plasma and dust instruments, including the Lunar Dust EXperiment (LDEX) for the LADEE mission. The facility is scheduled to come online by early 2011, and will be available for the lunar community for impact studies.



Zybek Advanced Products has developed novel approaches to produce copious amounts of lunar simulant particles. The production method uses extreme pressure gradients to cause particulates to break along grain boundaries, reproducing the sharp edge structures of the lunar regolith material.

Theory and modeling

We have developed both 1D and 3D plasma simulation codes to a) help the analysis and interpretation of our laboratory experiments, and b) model realistic plasma conditions and geometries for the lunar surface environment. 1D studies included the effects of non-Maxwellian energy distribution of the emitted photoelectrons and properties of the incoming solar wind plasma flow (Poppe and Horanyi, 2010). Initial 3D simulations using the VORPAL code developed by our partners at the company Tech-X were used to verify 1D simulation results and to examine the effects of partial illumination of craters

Lunar simulant production

To produce lunar simulant components for NASA and the USGS, CCLDAS partner Zybek Advanced Products (ZAP) has a developed a process for creating synthetic minerals from commercially available oxides. Examples of synthetic minerals ZAP has produced include: Sapphire, ruby, anorthite, augite, pigeonite, and enstatite using commercially-available batch ingredients (i.e., CaO, Al2O3, SiO2). The batch ingredients are combined in solid form and then brought to molten temperatures by the proprietary remotely-coupled transferred arc plasmas. The cooling is then controlled to promote crystal growth or quenched to produce glass. Current production capability is multiple tons per day. The simulant material can be ground to micron-sized particles with sharp surface structures, similar to the lunar regolith material.

In the spring of 2009, our group started the multi-institution Center for Lunar Origin and Evolution (CLOE) as part of the new NASA Lunar Science Institute. CLOE's main objective is to explore how our planetary system formed and evolved and how this record bears on both the geophysical/geochemical make-up of the Moon and the lunar cratering record. In this manner, our team is well positioned to inform the planetary science community what the Moon can tell us about the origin and history of the rest of the solar system.

CLOE's scientific research comprises three main scientific themes. In Theme 1, "Formation of the Moon", we are modeling the evolution of the moon from its origin in a giant impact on Earth through to the end of the Moon's accumulation. In time, our modeling work will have the unique ability to validate, or invalidate, the widely-accepted giant impact model of the Moon's formation through direct comparison with existing and future observational constraints. In Theme 2, "Observational Constraints on the Bombardment History of the Moon", we are employing inventive techniques to deduce new physical constraints on the lunar impact rate over the last 4.5 billion years. Over the course of this grant, this will involve an analysis of terrestrial and lunar zircons (as well as other key minerals) that are sensitive to, and have information on, the record of ancient impacts on the Earth-Moon system. The goal is to use lunar and meteoritic samples to establish an early lunar bombardment chronology. Similarly, another critical aspect of Theme 2 is new crater counts of ancient terrains on the Moon using an innovative method for analyzing lunar crater statistics. Finally, in Theme 3, "Modeling Lunar Impact Rates", our goal is to develop the most complete model to date of the lunar cratering rate from the most ancient lunar times to the present. Our impact rates rely on new state-of-the-art dynamical simulations of the evolution of the leftovers of accretion as well as those for primordial comet and asteroid populations. All of this is intimately linked to our understanding of the formation of the planets.

Theme 1: Formation of the Moon

The giant impact theory for the Moon's origin proposes that the Moon formed from debris ejected into orbit around the Earth when the early Earth collided with another planet-sized object. A first step in understanding the origin of the Moon within this paradigm is to develop computer simulations of collisions between planet-sized objects. Such simulations must account for a variety of physical processes, including gravity, pressure forces, and phase changes of the planetary materials as they are melted and/or vaporized by the impact. The overall goal is to deduce the properties of the collision that formed the Moon by comparing simulation output to constraints based on the known properties of the Earth and Moon.

From these models, we can begin to analyze key outstanding questions, such as: (i) would we expect an impact-produced Moon to be derived from material that originated in the Earth or in the impactor; (ii) can we determine the precise nature of the evolution of the protolunar disk and the accretion of the Moon (and make a Moon that matches constraints), and (iii) can we determine the initial thermal state of the Moon that led to a magma ocean. These issues are critical to interpreting various compositional relationships between terrestrial and lunar materials.

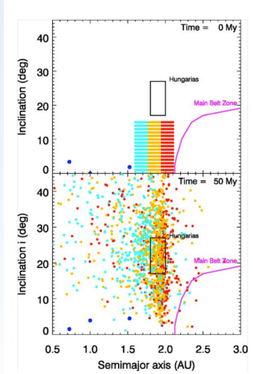
Theme 2: Observational Constraints on the Bombardment History of the Moon

As described above, in this Theme, we discuss our work from two broad projects aimed at providing new constraints on the bombardment history of the Moon.

Bombardment Thermochronometry of the Early Moon, Earth, and Asteroids

We have modeled the thermal effects of a broad range of impactors to the Moon following the methods outlines in Abramov and Mojzsis (2009) by: (1) Populating the model lunar and martian surface with craters within specified mass, time, and size-frequency distribution constraints using the modified stochastic cratering model of Richardson et al., (2005), (2) associating a post-impact temperature distribution with each model crater, and (3) introducing thermal fields associated with each impact into a 3-dimensional model of the Moon's lithosphere, and then allowing the model crater to cool by conduction in the subsurface and through radiation/convection at the surface. Our output shows the fraction of the Moon's surface, near-surface, and crust that was molten or thermally metamorphosed as a result of impact bombardments, the average length of time a given location remained molten, predictions of radiometric age distributions, and predictions of expected geochemical changes due to impacts. We are using these data now to prepare for our Pb-, Ti-, and REE-loss analyses in lunar zircons and apatites.

Scattering of the E-Belt indicates timing of Late-Heavy bombardment. The top plot shows our initial conditions for one example of the E-belt. The particles have been color-coded for identification purposes. The bottom plot shows the E-belt particles at 50 My within a run where Mars' eccentricity has been excited ($e_{\rm MAX} \sim 0.23$) and inserted into a system with Venus-Neptune on standard orbits. As shown by the plot, the test particles are unstable and readily go away. A substantial fraction go on to hit Earth and Moon, with the collision probabilities 4-6 times that of objects escaping from the inner main belt.



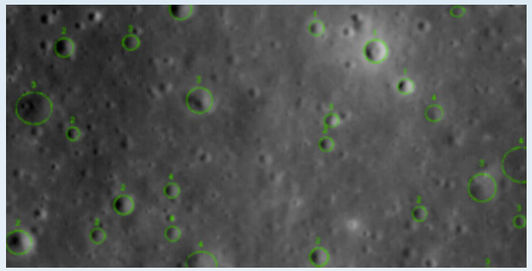
Relative Lunar Cratering Chronology

The goals of this project are to analyze the Moon's impact cratering record to better understand its bombardment history, chiefly from the later portions of the Late Heavy Bombardment until the present. To accomplish this goal, we have started to determine and compare crater distributions for lunar surfaces of different ages. The crater distributions are compiled by counting smaller craters within larger craters on Lunar Orbiter and Lunar Reconnaissance Orbiter spacecraft images.

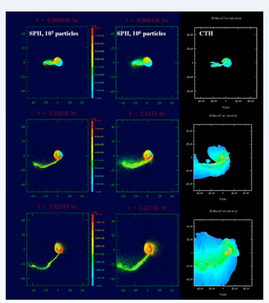
Theme 3: Determining Lunar Impact Rates

The late heavy bombardment of the Moon, which produced at least 40 craters with diameters larger than 300 km between 3.8-4.5 billion years ago (i.e., basins), was likely produced by a combination of (i) the leftover planetesimals from solar system accretion, (ii) asteroids from the primordial asteroid belt, and (iii) comets from the primordial comet population located beyond the orbits of the Jovian planets. It has been suggested that many, perhaps most lunar basins were produced as a direct or indirect result of the so-called Nice model, in which 4 billion years ago, the Jovian planets migrated from their original orbits between 5-15 AU to their current orbits between 5-30 AU and destabilized small bodies reservoirs across the solar system. The Nice model is compelling because it can quantitatively explain many long-standing dynamical aspects of the solar system (e.g., the orbits of the Jovian planets, the orbits of bodies in several different small body reservoirs in the outer solar system: Trojans of Jupiter and Neptune, the Kuiper belt and scattered disk, the irregular satellites of the giant planets). These accomplishments are unique among models of outer solar system formation.

A possible problem with creating most of the lunar bombardment via the Nice model, however, is that previous work has assumed the primordial asteroid belt was 10-20 times its current mass prior to 4 billion years ago. New modeling work by our team members indicates this is unlikely to be true. To deal with this apparent mass deficit, why we have an asteroid belt in the first place, and many other important issues related to bombardment constraints, we have been re-examining some of the basic tenets of planet formation and the Nice model in order to predict the nature and evolution of the planetesimal, asteroid belt and comet populations.



Measured craters on selected region of Lunar Reconnaissance Orbiter Narrow Angle Camera Image #nac100001055. Resolution is 1.07 m/pixel and location is ~ 4°S, 17°W. Green circles indicate the measured size of the craters and numbers indicate the crater degradation state (1 = fresh to 4 = most degraded). The largest crater measured has diameter ~ 95 m.



Results from 3 simulations of a giant impact in which the total mass is 1.02 Earth masses, the impactor-to-total mass ratio is 0.13, the impact speed is equal to the mutual escape velocity, and the angular momentum is 1.25 times that of the current Earth-Moon system. Color scales with temperature in degrees K. The first and second columns show low and high resolution SPH simulations, respectively, while the third shows a CTH simulation.

While the Moon is often considered a stagnant "dead" body, it actually percolates with activity – as the recent Chandrayaan M-cubed results suggest. The lunar surface is in constant interaction with its environment, acting as an obstacle to inflowing plasma and continually releasing solar-stimulated atomic neutrals. These interactions create a super-surface layering about the Moon containing (1) a plasma interaction region that includes a near-surface plasma sheath and an extended, trailing solar wind plasma wake and (2) a neutral surface boundary exosphere and exo-ionosphere that extends hundreds of miles above the surface. Apollo-era studies of these two systems revealed their presence and the tantalizing possibility of a very complicated and dynamic neutral-ion-volatile-plasma-dust environment.

The NLSI Dynamic Response of the Environment At the Moon (DREAM) team consists of two primary and ten expert partners embarking on an advanced study of these two seemingly separate environmental systems. DREAM's theory-modeling-data validation study focuses on advancing the knowledge base of the systems, understanding the systems' response to the variable solar drivers, finding common linkages between the two systems, and to test these modeled systems via extreme events.

The essence of DREAM is to address the fundamental question: "How does the highly-variable solar energy and matter incident at the surface interface affect the dynamics of lunar volatiles, ionosphere, plasma, and dust?" To answer this, DREAM has formulated 4 primary science objectives:

1. Advance understanding of the surface release and loss of the neutral gas exosphere over small to large spatial scales and a broad range of driver intensities.

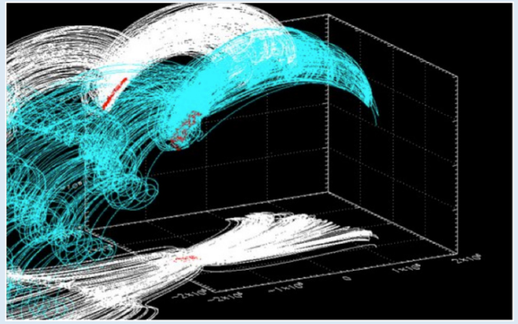
2. Advance understanding of the enveloping plasma interaction region over small to large spatial scales and over a broad range of driver intensities.

3. Identify common links between the neutral and plasma systems and test these linkages by modeling extreme environmental events.

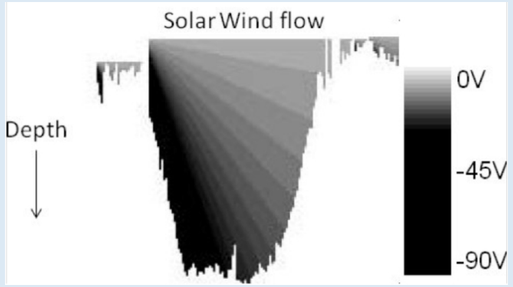
4. Apply this new-found environmental knowledge to guide decision-making for future missions, assess the Moon as an observational platform, and aid in human exploration.

In the first year of DREAM, a number of key advancements were made in the understanding of the neutral gas exosphere (Objective 1). Some highlights of DREAM applications include the following (and are presented in greater detail in the attached progress reports): 1) In support of both DREAM and the LADEE mission, Co-I Richard Hodges is developing the LExS neutral gas code to ultimately be distributed to the entire community. Currently, the code is being applied by the LADEE NMS team to fine-tune the predicted species that should be detected by that instrument. 2) Co-I Rosemary Killen obtained time on the McMath-Pierce telescope to search for a sodium plume during the LCROSS impacts. In fact a plume was observed by this ground based telescope suggesting that about ~1 kg of sodium was released at impact. The number density of observed sodium matches almost exactly the number obtained by the LCROSS impact team. Co-I's Rosemary Killen, Dana Hurley, and Tony Colaprete are now modeling that exospheric transport of the transient sodium plume using a neutral gas Monte Carlo code and thermal information provided by LCROSS impact studies (~1000K thermal expansion). Killen's and Hurley's work are funded primarily under DREAM. It is a nice example of institute funding in the form of a larger block grant that subsequently allowed a quick response to unanticipated/unplanned events. The use of McMath-Pierce's 62 inch telescope for LCROSS observation was in fact considered by Killen well after the DREAM proposal was in place – but the available resources provide a fast response that enabled and expanded the observations (resources available in an afternoon), instead of having to write and wait on a separate LASER proposal for support. 3) Co-I Menelaos Sarantos completed a study showing that the sodium emission from the lunar surface is created primarily by photon-stimulated desorption, but also enhanced by the influx of solar wind protons. The comprehensive study examined all ground based observations to date and correlated activity with location in the magnetosphere (low ion concentration) and solar wind (high ion concentration). A clear and distinct ~2-3 times increase in Na emission rate was clearly observed upon entry into the solar win ion flow.

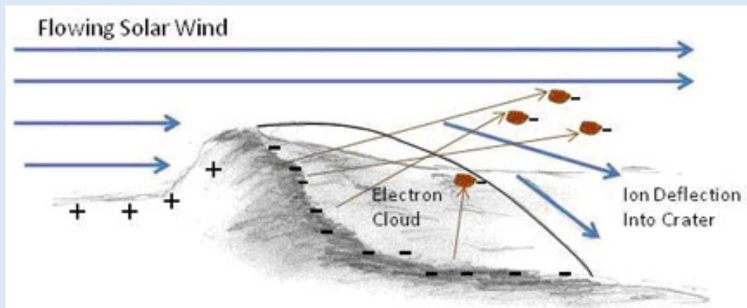
A number of key advancements were made in the understanding of the plasma interaction and ionized gas flow at the Moon (Objective 2). Some highlights include the following (and included in more detail in the attached progress reports): 1) PI William Farrell and Co-I Tim Stubbs further advanced and published a model of the solar wind expansion into lunar polar craters. The model applies both an ambipolar expansion process like that occurring in the plasma wake of the space shuttle and surface-sheath charging model to predict proton and electron flux levels at the bottom of the crater floor. The model finds that the surface should become strongly negatively charged at the leeward edge of a polar crater – that edge directly under the flow. 2) Co-I Tim Stubbs and Dave Glenar published a prediction of the dust flux, sodium neutral gas flux, and light scattering expected during the LADEE mission. The results will fine-tune the LADEE UVS observations of the horizon glow – and will aid in determining if this glow is created by gas or dust (which is a key LADEE objective). They especially found at wavelengths below 350 nm that the lunar dust scattering from smaller particles should dominate over zodiacal light- providing a unique spectral range for the detection of any lofted dust from the lunar surface. The work is funded under DREAM and provided to LADEE in support. 3) Co-I Jasper Halekas and Greg Delory have been in close contact with DREAM collaborator Prof. Yoshi Saito in support of joint Kaguya electron and ion studies. In May of 2009, Halekas and Delory visited JAXA and had a set of very successfully discussion on joint topics where DREAM could provide modeling analysis to aid in Prof. Saito's team analysis of the unique Kaguya MAP-PACE observations through the polar wake region.



Ion trajectories that can reach the nightside lunar wake at the time that an anomalous burst of electrons was observed by the Lunar Prospector spacecraft. Target location shown in red, ion trajectories in blue, and projections of ion trajectories in white.



The modeled ambipolar potential within Shoemaker crater. This potential draws ions and retards electron flow into the crater. The solar wind is assumed to be at nominal conditions (density at 5 particles per cc, 10 eV temperature, and 400 km/second flow speed).



This figure shows the lunar surface potential and solar wind interactions with charged and neutral particles.

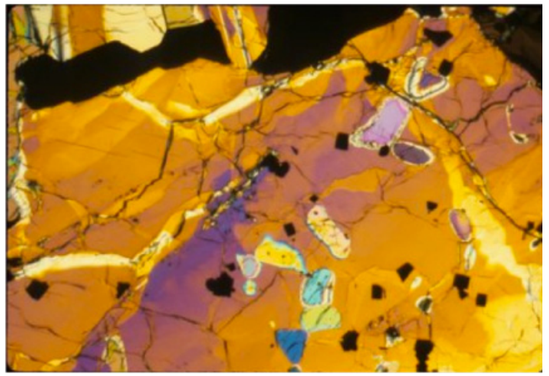
The Lunar and Planetary Institute (LPI) and the Johnson Space Center (JSC) have a long and successful history of collaborative research and exploration activities that began with the Apollo program. The LPI and JSC have harnessed that heritage to build the new Center for Lunar Science and Exploration (CLSE) to better support our nation's lunar science and exploration activities.

The CLSE, as part of the NASA Lunar Science Institute (NLSI) and is designed to:

1. Develop a core, multi-institutional lunar science program that addresses the highest science priorities identified by the National Research Council (NRC) for NASA;
2. Provide scientific and technical expertise to NASA that will infuse its lunar research programs, including developing investigations that influence current and future space missions;
3. Support the development of a lunar science community that both captures the surviving Apollo experience and trains the next generation of lunar science researchers; and
4. Use that core lunar science to develop education and public outreach programs that will energize and capture the imagination of K-14 audiences and the general public.

To meet those objectives, we developed programs for scientific research, exploration, training, and education and public outreach. Each of those programs and Yr1 activities are presented here.

Science. The NLSI program fosters collaborative, multi-institutional work that takes advantage of long-distance networking technologies. We have, thus, organized a team that involves faculty, students, and analytical facilities at Rice University, the University of Arizona, University of Houston, University of Maryland, and University of Notre Dame. We have also established international partnerships with faculty, students, and analytical facilities in the United Kingdom, Japan, and Australia. See http://www.lpi.usra.edu/nlsi/teamMembers/ for a complete list of team members. This collaborative program is built around the Apollo sample collection, which provides the highest-fidelity view of the lunar surface for a new generation of lunar scientists. The team's science theme is driven by the highest-priority science concept (the bombardment history of the inner solar system is uniquely revealed on the Moon) and highest-priority goal (to test the lunar cataclysm hypothesis) that were identified by the National Research Council (2007) for NASA's Science Mission Directorate (SMD). This investigative theme will carry us



Microscopic views of lunar samples collected by the Apollo astronauts are valuable assets for the science and exploration communities. They also provide eye-catching artwork, much like stained-glass, that fascinates the general public. This particular image illustrates Apollo sample 12005, which is from a lava flow on the lunar surface. The width of the view is 2.1 millimeters. The view was captured on a petrographic microscope and illuminated with cross-polarized light.

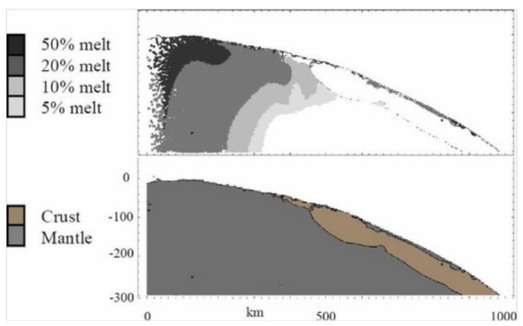


Figure 1: Example results for a 150 km diameter impact at 10 km/sec. Two distinct zones are created by the impact, (top) an ~800 km diameter mantle melt pool with no crust present, and (bottom) an outer zone where crustal material underlies partially molten mantle out to a distance of about ~1000 km.

from the earliest moments of the Moon's origin through the immensely important basin-forming epoch to new analyses of impact contributions to the lunar regolith.

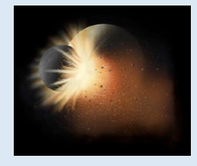
Our team surveyed the entire Apollo collection, conducted preliminary analyses of about two dozen samples, and began detailed analyses of them. The samples were selected to test the giant impact hypothesis for the Earth-Moon origin and the lunar cataclysm hypothesis for the early bombardment of the Earth-Moon system (and its implications for the entire solar system). This involved an important training component that gave two graduate students and two post-doctoral researchers experience in the Lunar Curatorial

Facility. We completed our first model calculation of the formation of the largest and oldest impact basin on the Moon, the South Pole-Aitken Basin. The model results reveal a fascinating amount of displacement of the crust and mantle of the Moon that may guide future scientific exploration of the lunar surface including future sample-return missions. We produced analyses of modified impact melts that we received in the form of lunar meteorites. Those analyses reveal a diversity of lunar crust lithologies not previously deduced from Apollo sample analyses. Our team began a re-evaluation of the Apollo 16 landing site geology that will better define the links between samples and basin-forming events. Our first report was published and suggests some material previously attributed to the Nectaris basin may, instead, be associated with the Imbrium basin. These types of studies (which are continuing) are needed to identify future sample sites on the Moon that will define the tempo of impact events during the planet-altering basin-forming epoch in the Earth-Moon system.

Exploration. The Center's activities are integrated with the Constellation Systems Program, particularly the Office of Lunar and Planetary Exploration. The team's experience with lunar surface samples, impact cratered terrains, and volcanic terrains are helping to integrate science and exploration activities and develop operational procedures for future lunar surface activities. In Yr 1:

- Our team participated in a robotic precursor mission simulation that occurred at the Black Point Lava Flow lunar analogue test site. Those activities included the design of traverses at the test site and implementation of the mission from a Science Operations Room at NLSI Central at the Ames Research Center.
- Our team participated in a human exploration mission simulation at the Black Point Lava Flow lunar analogue test site. Those activities included traverse plans for crew and the Lunar Electric Rover and implementation of the mission from a Science Operations Room.
- Our team compiled samples and course materials that will be used to teach lunar geological processes, including impact cratering, to the new class of astronauts. The goal is to enhance the synergy (and, thus, productivity) between science and exploration in future missions.
- A subset of the team is engaged in the development of robotic mission concepts, including a Lunar Reconnaissance Lander (at LPI) and a payload for Beagle 2 (at JSC).

CLSE team members helped design geological traverses for the lunar and Mars analogue test program so that mission operation concepts, science operation concepts, and hardware could be tested for future missions with crew. In Yr1, those mission simulations involved the Lunar Electric Rover and crew in a 14-day-long mission. (Images The leading hypothesis for the origin of the Moon involves a huge collision between the Earth and a planet half its size. Some of that colliding material was added to the Earth, but a large fraction of the impact debris went into orbit around the Earth. The orbiting material accreted together to form the Moon. The CLSE team will be testing that hypothesis by examining the chemical composition of samples from the Moon and the ages of those samples. Image Credit: NASA Johnson Space Center.

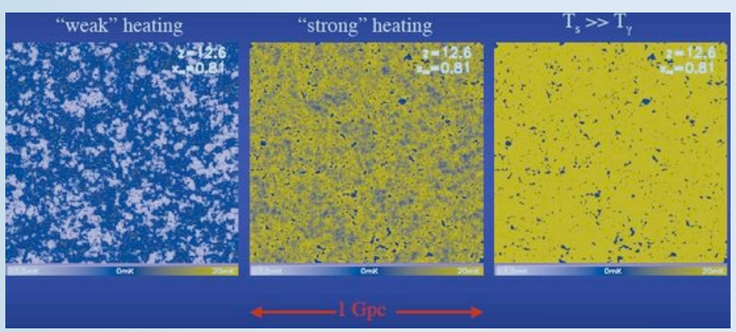


The leading hypothesis for the origin of the Moon involves a huge collision between the Earth and a planet half its size. Some of that colliding material was added to the Earth, but a large fraction of the impact debris went into orbit around the Earth. The orbiting material accreted together to form the Moon. The CLSE team will be testing that hypothesis by examining the chemical composition of samples from the Moon and the ages of those samples. (Image Credit: Lunar and Planetary Institute)

The Lunar University Network for Astrophysics Research (LUNAR), a consortium of top research institutions led by the University of Colorado, is performing research, education, outreach, and community development to advance Astrophysics From the Moon. 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 far side, shielded from terrestrial radio emissions, a radio telescope on the Moon will be an unparalleled heliospheric and astrophysical observatory. Crucial stages in particle acceleration near the Sun can be imaged and tracked. The evolution of the Universe during and before the formation of the first stars can be traced for the first time, yielding high precision cosmological constraints. LUNAR is pioneering important new astrophysical research by "using the Moon as a unique platform"; it broadens the participation in the NLSI by incorporating physical sciences from the Moon; it unites astrophysics and the Moon, which are individually both compelling means of motivating students and the public at large; and the required technology development is synergistic with other lunar science programs.

Key Project - Low Frequency Cosmology and Astrophysics: This project has the goal of advancing the science and technology required to track the evolution of the Universe and enabling the use of the Moon as a platform for conducting science. Over the past year, work within the Low-frequency Cosmology and Astrophysics Key Project has begun to refine predictions of the strength of the hydrogen signal from the Dark Ages. The most abundant element in the Universe is hydrogen, and it is the raw material from which stars form. After the Big Bang, there was a short interval known as the Dark Ages, perhaps a few hundred million years long, before the formation of the first stars, in which hydrogen was spread relatively uniformly throughout the Universe. Probing the evolution of the Universe during the Dark Ages and as the first stars form is uniquely possible by a low radio frequency telescope on the far side of the Moon. The proposed Lunar Radio Array telescope will be extremely powerful, and the team has explored secondary observations, such as searching for extra-solar planets, that might be possible. The team has also started to design, model, and construct antenna concepts that might be used for a lunar radio telescope. The modeling and testing has included computer modeling, conducting experiments to simulate the harsh conditions with which antennas will experience on the Moon, and testing how well the antennas can receive the intended hydrogen signal.

Theoretical Tools: Work in Year 1 included simulating the signals that will potentially be observed by the Lunar Radio Array to assess the (astrophysical) foregrounds with which the analysis of the signals will have to contend to expanding upon the potential secondary science observations that might be undertaken by the Lunar Radio Array. As a part of our simulations we began to build a fast, portable code to generate hydrogen maps of the high-redshift early universe, useful even with limited computing capacity. This is ideal for generating a wide range of predictions about low frequency radio signal that we seek. For the first time, this code includes all the relevant thermal processes.



Example maps resulting from this analysis and illustrates the importance of properly tracking heating to the 21-cm signal. Finally, Furlanetto acquired a new computer cluster that will be used to generate more detailed models in the future.

Furthermore, we completed a computer code that provides a comprehensive description of the full evolution of the radio signal throughout the entire cosmic history between ten million years after the Big Bang and the present time. This code allows us to explore the important scientific advantages of a lunar observatory over ground-based radio arrays. Another simulation that is helping to constrain our knowledge of foreground signals is modeling the early epoch of X-ray preheating near the end of the Dark Ages by inserting X-ray sources in the cosmological simulations that will heat and ionize regions around a population of early quasars. This is a first stage to a full modeling of reionization, which will include stellar/galactic sources of ultraviolet photons, in addition to the X-rays generated at quasars.

Array Concept & Algorithm Development: Work in Year 1 further solidified the requirements for the Lunar Radio Array. One such advance was developing the scientific requirements for the Lunar Radio Array with a specific focus on developing the array design. The robustness of the array design to failures of individual elements within a single station was explored. Aside from the designing of hardware, we worked on issues relating to low frequency measurements of the hydrogen radio signal from the epoch when the first stars/galaxies form. This work involved simulations of dynamic range limitations and calibration requirements for future low frequency arrays.

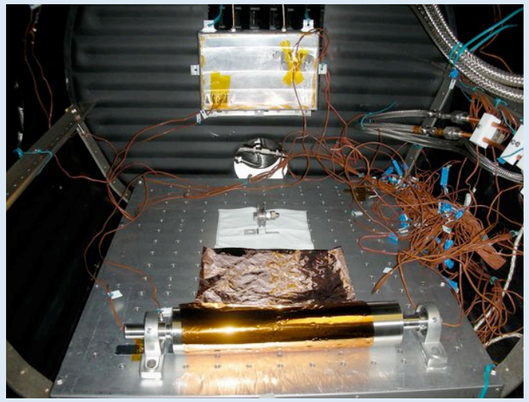
Technology Development (Science Antenna): The Lunar Radio Array will require a large number of science antennas, so that high sensitivity per unit mass is a key requirement. Two antenna concepts are being explored:

- A helical antenna for use in the Self-Tending Array Node and Communication Element (STANCE); and
- A polyimide film-based dipole antenna.

Work in Year 1 focused on the electromagnetic performance of both concepts as well as developing the capability to conduct environmental testing of polyimide film in lunar-like conditions. We have focused on the development of the helical antenna in the (STANCE) concept. Over the past year, the work has been focused on improving the electromagnetic performance of the helix along with developing a system for accurately measuring the beam pattern of the antenna in situ.

There has also been significant development of the infrastructure to conduct simulated lunar environmental testing of polyimide film, which may serve as the backbone for Lunar Radio Array antennas. The array will be rolled up during transport to the Moon, much like a carpet, and then unrolled by astronauts or robots once there. The radio antenna will be exposed to the harsh environment for many months. We are recreating these conditions in a laboratory vacuum chamber in order to ascertain whether the polyimide film exhibits any changes, such as in tensile strength or electrical conductivity.

There has also been development work on self-deploying antennas, which require minimum structure to save mass, as well as pack tightly to allow thousands to be carried in one payload. A helical antenna can be compressed to a small volume, but, to regain its original height, additional supporting structures must be included, easily doubling the mass and volume. The use of memory shape metals can greatly reduce or even eliminate the need for support, as they have sufficient elasticity to spring back to tall heights in the low lunar gravity.



This is an image of our experiment in a thermal vacuum chamber at CU Boulder. We are testing the Kapton Polyimide film in simulated lunations.

INTERNATIONAL

International Partnerships

NLSI has developed a partnership program with the other international science organizations to provide collaborative opportunities for its researchers within the global science community. International partners are invited to participate in all aspects of the Institute's activities and programs on a no-exchange-of-funds basis.

Gordon Osinski
Canadian Lunar Research Network (CLRN)
University of Western Ontario,
http://clrn.uwo.ca/
CLRN Coordinator Dr. Irene Antonenko

Canada ***Partnership signed July 2008***

As NLSI's first Affiliate partner, the Canadian Lunar Research Network is comprised of 14 institutions, including two industrial collaborators. Their research focuses on lunar dust and regolith and the effect on robotic and human exploration systems, isotopic analyses of lunar materials, shock processes in lunar samples and terrestrial analog samples, and impact ejecta emplacement processes.

Seongim Choi
Korea Advanced Institute of Science and Technology (KAIST)
In collaboration with Korea Aerospace Research Institute (KARI)
http://www.kaist.edu/edu.html ytim@kaist.ac.kr

Korea ***Partnership signed November 2008***

This Affiliate partnership has focused on small satellite missions, and is growing to include lunar science from orbit, including plasma and magnetic field studies around the Moon. There have been two lunar post-doctoral researchers from Korea to date, and the partnership includes both the KAIST and Kyung Hee University.

Mahesh Anand
United Kingdom
Open University
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United Kingdom ***Partnership signed January 2009***

The Affiliate partnership with the United Kingdom is founded on the strong legacy of sample-based lunar science in the UK since the Apollo days. The partnership has focused on bringing lunar scientists around the world together to discuss mission science concepts, creating a strong international lunar presence at the European Planetary Science Conference, and focusing on innovative educational tools such as the virtual microscope.

Haithem Altwaijry
Saudi Arabia
King Abdulaziz City for Science & Technology (KACST)
http://www.kacst.edu.sa/en/depts/nlneosc/Pages/home.aspx
haltwaijry@kacst.edu.sa

Saudi Arabia ***Partnership signed in December 2009***

This Affiliate partnership led to the Saudi Lunar and NEO Science Center, established under KACST. This team has an interest in spacecraft missions (partnership with Stanford), astrophysics and NEO studies. This team is developing a collaboration with an existing NLSI team around lunar laser ranging.

Shlomi Arnon
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shlomi@ee.bgu.ac.il

Israel ***Partnership signed in January 2010***

The Affiliate partnership with Israel involves the Israel Network for Lunar Science and Exploration. This team focuses on lunar science related technology (optical communications and robotics) and some interest in planetary science. The team includes involvement with the Israeli Space Agency.

Wim van Westrenen
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Netherlands ***Partnership signed in August 2010***

The Affiliate partnership with the Netherlands covers the range of science on, of, and from the Moon. This group includes nine partnering institutions, with specific interests of experimental lunar interior science, instrument development for various types of missions, and astronomy related research from the Moo.

National Aeronautics and Space Administration

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