MoonRise

SPA Basin Sample Return Mission for Solar System Science

B. Jolliff  C. Shearer
D. Papanastassiou
L. Alkalai  L. Borg
D. Carrier  B. Cohen
M. Duke  L. Gaddis
J. Head  H. Hiesinger
J. Hurowitz  S. Jacobsen
R. Jaumann  R. Korotev
G. Lofgren  H. J. Melosh
M. Norman  L. Nyquist
G. Osinski  N. Petro
C. Pieters  C. Runyon
T. Swindle  G. J. Taylor
P. Warren  M. Wieczorek
and the MoonRise Team

LEAG Meeting
Washington, DC, Sept. 15, 2010
South Pole-Aitken Basin

Window to deep Crust of the Moon

Window to early Solar System History
**MoonRise**

- Determines the age of a key event in Solar System history.
  - Test of the Cataclysm hypothesis for early bombardment of Earth-Moon System
  - Test of hypotheses for early orbital dynamics of gas giant planets

* MoonRise tests these hypotheses by determining the age of the oldest impact melts and thus the age of the SPA Basin formation.

**MoonRise will profoundly affect our understanding of the origins and early years of life on Earth.**
MoonRise addresses key Solar-System Science

- Apollo samples show that Moon and Earth experienced a late, heavy bombardment or “Terminal Cataclysm”
  ~ 3.8 to 4.0 billion years ago

- Current dynamical models indicate that a shift in orbits of the gas giants could have caused the injection of asteroids and comets into the inner Solar System at about 500 m.y. following planetary accretion.

- Materials of the SPA Basin hold the key to the impact Cataclysm and thus what happened on the Earth and Moon in their first ~500 million years.

Solar System relevance:
- Test models of orbital dynamics in the early Solar System
- What caused the release of small orbiting bodies to the Inner Solar System?
- What were the effects on the development of habitable environments and life on Earth?
– Established sample return from South Pole-Aitken Basin as a top priority for exploration of the inner Solar System

– Reaffirmed importance of SPA for lunar and Solar System science.

New Opportunities for Solar System Exploration (NOSSE), NRC, March 2008  
– Validated the Planetary Science Decadal Survey and listed five science goals for the (SPA-SR) mission that parallel Moonrise science themes.
The impact history of the Moon has significant implications that go far beyond simply excavating the surface of a dry and lifeless world. The age distribution of lunar impact breccias inspired the idea of a catastrophic influx of asteroids and comets about 4 billion years ago and motivated new models of planetary dynamics. A late bombardment may have regulated environmental conditions on the early Earth and Mars and influenced the course of biologic evolution. The cataclysm hypothesis is controversial, however, and far from proven. Lunar explorers face the difficult task of establishing absolute ages of ancient impact basins and the sources for the impactors.

Marc D. Norman, Feb. 2009
Research School of Earth Sciences,
Australian National University

HIGHEST-PRIORITY SCIENCE GOALS FOR LUNAR EXPLORATION (SPACE STUDIES BOARD 2007)

1a. Test the cataclysm hypothesis by determining the spacing in time of the creation of the lunar basins

1b. Anchor the early Earth–Moon impact flux curve by determining the age of the oldest lunar basin (South Pole–Aitken basin)
MoonRise Goals address three broad Planetary Science issues

1) Impact history of inner Solar System
   - Test Cataclysm Hypothesis
   - Illuminate first 500 million years of Solar System history

2) Large basin impact events and effects
   - Understand basin formation processes
   - What is their role in the evolution of planetary surfaces?

3) Interior differentiation of planetary bodies
   - Learn how planetary crusts and mantles formed

Moon uniquely preserves a record of these events in its rocks and regolith.
MoonRise has five specific objectives to address Science themes

1) **Determine impact chronology**
   - Age of SPA addresses early Earth-Moon system (& inner Solar System) Cataclysm.

   - **Largest, oldest visible basin**
     - Over 40 basins between ages of SPA & Orientale

   - **Exceptional test of Cataclysm hypothesis**
     - Large, so produced vast quantities of melt
     - Distant from Apollo
     - 4.0 Ga → Cataclysm
     - 4.3 Ga → No cataclysm

   - **Determine basin chronology, not just the age of SPA**
MoonRise has five specific objectives to address Science themes

1) **Determine impact chronology**
   - Age of SPA addresses early Earth-Moon system (& inner Solar System) Cataclysm.

2) **Investigate crust - mantle transition**
   - How did the lunar crust form?
   - Samples derived from deep crust and/or upper mantle.

---

![Diagram of SPA Basin Center](image)

- **SPA Basin Center**
- **NE**
- **SE**
- **Apollo Basin**
- **Maria**
- **Crater Ejecta**
- **Cryptomare**
- **Basin Ejecta**
- **South Pole-Aitken Basin Rim**
- **Mantle Uplift**
- **Upper Crust**
- **Lower Crust**
- **Megaregolith**

*from Head et al. (1993) JGR 98.*
MoonRise has five specific objectives to address Science themes

1) Determine impact chronology
   – Age of SPA addresses early Earth-Moon system (& inner Solar System) Cataclysm.

2) Investigate crust - mantle transition
   – How did the lunar crust form?
   – Samples derived from deep crust and/or upper mantle.

3) Giant impact-basin-forming processes
   – How deep did the impactor penetrate?
   – What were effects on early-formed crust?
MoonRise has five specific objectives to address Science themes

1) Determine impact chronology
   - Age of SPA addresses early Earth-Moon system (& inner Solar System) Cataclysm.

2) Investigate crust - mantle transition
   - How did the lunar crust form?
   - Samples derived from deep crust and/or upper mantle.

3) Giant impact-basin processes
   - How deep did the impactor penetrate?
   - What was the effect on the crust?

4) Thorium distribution and thermal evolution
   - Tracer of differentiation processes
   - Role of heat-producing elements in Moon’s interior and internal evolution

LP-GRS Thorium (half degree)
MoonRise has five specific objectives to address Science themes

1) Determine impact chronology
   - Age of SPA addresses early Earth-Moon system (& inner Solar System) Cataclysm.

2) Investigate crust - mantle transition
   - How did the lunar crust form?
   - Samples derived from deep crust and/or upper mantle.

3) Giant impact-basin processes
   - How deep did the impactor penetrate?
   - What was the effect on the crust?

4) Thorium distribution and thermal evolution
   - Tracer of differentiation processes
   - Role of heat-producing elements in Moon’s interior

5) Basalts as mantle probes
   - How do far-side basalts and their mantle sources differ from those sampled on the near side?
   - Direct information on far-side mantle beneath SPA Basin
MoonRise accomplishes key Lunar Science

- Probes materials formed deep in the Moon to learn how crusts and mantles of the terrestrial planets formed and how giant impacts modified early formed crust.

- First surface mission to far side of the Moon
  - Provides sampling and ground truth far from the Earth-facing side landing locations of the Apollo missions – greatly expanding knowledge of Moon’s differentiation and diversity of materials.
• 2016: MoonRise launches to the Moon.
• The Lander will descend into the interior of the South Pole-Aitken Basin on the Moon’s far side
• A dedicated satellite provides communications.
• On the surface, MoonRise scoops and sieves a volume of soil near the lander to collect thousands of rock fragments.
  – Regolith is well mixed and rock fragments contained in regolith are representative of the landing region and SPA basin interior.
• Multispectral Context Imager acquires a surface panorama and images the sample collection work volume.
• Sample materials are transferred to the sample return canister (SRC) for return to Earth.
• Ascent Vehicle launches from the Moon…
MoonRise Mission Overview

- Ascent Vehicle returns the SRC to Earth where it is recovered at the Utah Test Range and transported to the NASA/JSC Curatorial Facility.
- At JSC, samples undergo a thorough Preliminary Examination (PE).
  - Catalog of samples will be produced for online access.
  - PE includes non-invasive micro-XRF for rock classification.
- Samples distributed for analysis
  - Rock and soil samples will be analyzed in state-of-the-art laboratories.
  - Geochemistry, mineralogy, petrology, geochronology, spectroscopy
- MoonRise samples will be made available for study by the scientific community worldwide and for many years into the future.
Sieve to concentrate rock fragments and collect unsieved regolith for context

Rock fragments carry unique, individual histories of igneous, impact, and volcanic events.

Rock fragments (2–10% by mass of regolith) – represent local and distant events – rock types are diverse because of impact mixing.

Sampling requirements:

- Sieve regolith to increase number of rocks, thus science potential 10–50x
- Unsieved regolith for comparison with orbital data
- 900-950 g sieved; 50-100 g unsieved
1. The enriched FeO signature of the SPA Basin interior reflects the major compositional region that is targeted for the MoonRise mission.

2. Shaded areas mark keepout sites based on science criteria and proximity to obvious landing hazards (craters, rough topography). Remaining areas (green) meet science criteria.

3. Vast regions of the SPA Basin interior meet the science criteria and can accommodate the MoonRise landing ellipse.
MoonRise: Feeding forward to future planetary exploration

- **MoonRise** is a *pathfinder* for automated sample return from planets and moons in the Solar System.

- **MoonRise** will develop a medium-size lunar lander that can deliver a large scientific payload (~ 900 kg) to the lunar surface for potential future NASA lunar robotic missions.

- **MoonRise** in-situ & sample-return mission represents a key milestone in the international scientific exploration of the Moon.

  - Robotic sample return from planetary surfaces
  - Sophisticated robotic manipulation and processing of materials on a planetary surface
  - Delivering large robotic payloads to an airless planetary body
MoonRise: Exploring the Moon as a witness to early Solar System Events

Addresses key objectives for Planetary Science!

- Impact Cataclysm
- Dynamics of the Outer Solar System
- Effects of Giant Impacts on Planetary Evolution
- Origin of the Earth-Moon system
- Planetary Environments for the Origin and Evolution of Life
- Differentiation and Thermal History of the Terrestrial Planets

Advance scientific knowledge of Solar System history and processes.

Implications for the history of Earth at a pivotal time in the development of its habitable environments and the origin and survival of Earth’s early life.

How the Solar System evolved to its current diverse state.
• **How to provide geologic context for samples**
  – Remote sensing from new and on-going missions coupled with high-resolution topography to determine local geologic context.
  – High-quality descent and on-surface imaging to tie in landing site.

• **How to ensure we collect samples of SPA basin impact melt**
  – Strategy based on impact and ejecta distribution statistics points to center of Basin as best location to collect samples to date SPA Basin formation.
  – Center of SPA Basin retains compositional signature of SPA.

• **Rock samples too small to be representative or to be properly interpreted?**
  – Strength is in numbers; Many rock fragments for age dating and chemical analysis
  – Analysis of many samples enables us to determine inter-sample relationships (experience from Apollo).
  – Statistics of isotopic ages provides not only an age determination for SPA event, but also for other smaller, later basin events within SPA (“Basin Chronology”).
MoonRise leverages new lunar orbital datasets with US and International Partners

- MoonRise is a logical next step in exploration now that recent orbital missions have provided imaging and compositional data to support selection of sites that are optimal for science and safe for landing.
- Scientific Community will have input to site selection.

Kaguya Terrain Camera

Near global coverage obtained prior to end of mission June 11, 2009
Multi-band Imager for mineralogy

Moon Mineralogy Mapper
-- Global Coverage
-- Global mode 140 m/pix
-- Mineralogy of SPA Basin

Chandrayaan

LRO

Narrow-angle Camera, ~50 cm/pix
[NASA / GSFC / Arizona State University]
Returning the samples to Earth

SAMPLE RETURN

Sample Return Capsule

Sample Curation and Preliminary Examination

SAMPLE ANALYSIS

Mineralogy / Petrology
Petrographic Microscopy, Electron Microprobe Analysis

Chemistry
Inductively-Coupled Plasma Mass Spectrometry (ICP-MS)

Geochronology
Thermal Ionization Mass Spectrometry (TIMS)

40Ar/39Ar Analysis
Noble Gas Mass Spectrometry

Optical Spectroscopy
UV-VIS-IR Reflectance Spectroscopy

Mineral Trace Elements
Ion Microprobe

Rock Trace-Element Geochemistry
Neutron Activation Analysis Gamma Ray Spectrometry
Acquisition, processing, preliminary examination, team sample analysis

**Acquisition**

1 kg of sieved and bulk regolith.

Concentrating rock fragments in the range of 3 to 20 mm in size.

**Sample Processing**

- **>7 mm samples**
  - 25% will be available to MR science team.
  - No more than 50% will be consumed by MR science team.

- **3-7 mm samples**
  - 25% will be available to MR science team.

- **<3 mm samples**
  - PE will follow the 3-20 mm fragments

**Preliminary Examination**

(6 months, 100/day)

- (1) dusted,
- (2) sorted by albedo,
- (3) individually numbered,
- (4) weighed,
- (5) photographed,
- (6) described using binocular microscope observations,
- (7) analyzed (for major element characteristics)
- Using an XRF micro-analyzer, and
- (8) cataloged.

**Science Team Sample Analysis**

(6-24 months)

Sample analyses that cross-cut science objectives of science teams.

Multiple analyses of individual samples.