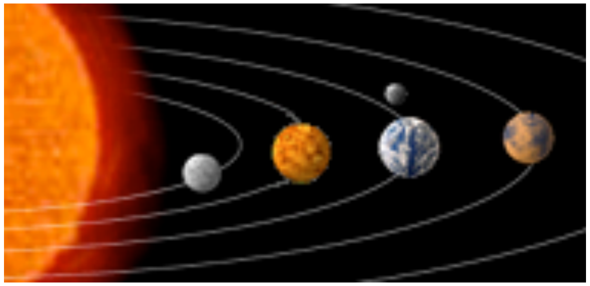
Decadal Survey, 2003, and Exploration of the Moon



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Charge from the Chair

- Describe the scientific rationale that led to high rankings for South Pole-Aitken Basin Sample Return, Exploration of the Lunar Poles, and Geophysical Networks in the last NRC decadal survey (2003).
- **The key:** address science issues that are relevant to “Solar System Questions” and not just “Science of the Moon”

Lunar Science for the Solar System

- Because of the great age of its surface, the Moon is a recorder of <u>early Solar System history.</u>

- Moon is a recorder of the <u>impact process</u> as well as <u>the impact flux.</u>

- Moon is a recorder of <u>early planetary differentiation</u> and is a cornerstone of current comparative planetology.

Guiding Principles

SSE Survey's criteria for judging scientific priority or exploration questions:

- Scientific merit
- "Opportunity" (some favorable circumstance)
- Technological readiness

Scientific merit measured by the following (in order of importance):

1. Potential of creating or changing a paradigm
2. New knowledge with a pivotal effect on the direction of future research
3. Knowledge gained substantially strengthens the factual base of our understanding

Key Scientific Questions that Underpin Exploration Strategy

Four broad cross-cutting themes:

1) The First Billion Years of Solar System History
2) Volatiles and Organics: The Stuff of Life
3) The Origin and Evolution of Habitable Worlds
4) Processes: How Planetary Systems Work

The First Billion Years

1. What processes marked the initial stages of planet and satellite formation?
2. How long did it take the gas giant Jupiter to form, and how was the formation of the ice giants (Uranus and Neptune) different from that of Jupiter and Saturn?
3. How did the impactor flux decay during the solar system’s youth, and in what ways did this decline influence the timing of life’s emergence on Earth?

Clear relevance for SPA Sample Return

Volatiles and Organics

4. What is the history of volatile compounds, especially water, across the solar system?

5. What is the nature and history of organic material in the solar system?

6. What global mechanisms affect the evolution of volatiles on planetary bodies?

Clear relevance for Lunar Polar Volatiles

Origin and Evolution of Habitable Zones

7. Where are the habitable zones for life in the solar system, and what are the planetary processes responsible for producing and sustaining habitable worlds?
8. Does (or did) life exist beyond Earth?
9. Why did the terrestrial planets differ so dramatically in their evolution?
10. What hazards do solar system objects present to Earth's biosphere?

Processes: How do Planetary Systems Work?

11. How do the processes that shape the contemporary character of planetary bodies operate and interact?

12. What does the solar system tell us about the development and evolution of extrasolar planetary systems and vice versa?

Early differentiation and impact processes recorded and accessible on the Moon

Mission Concepts Proposed by the SSE Survey's Panels

Inner Planets Panel

Mission Concept Name	Cost Class
Venus In Situ Explorer	Medium
South Pole-Aitken Basin Sample Return	Medium
Geophysical Network Science	Medium
Venus Sample Return	Large
Mercury Sample Return	Large
Discovery missions	Small

Building on Previous Discoveries

South Pole-Aitken Basin Sample Return

- Impact record & lunar chronology from Apollo
- Orbital remote sensing over SPA

Exploring Lunar Polar Volatiles

- Remote sensing suggesting volatile enhancement in permanently shaded craters at poles
- Known extremely low indigenous volatile contents

Lunar Geophysical Network

- Apollo (limited) seismic network
- Crust and mantle components known from Apollo

SPA Basin Sample Return

- Lunar impact record used for surface ages throughout Solar System. However, uncertainty exists in early flux:
  - Early Flux decay exponential following accretion, or Cataclysm?
  - Profound implications for terrestrial planets, especially for conditions under which life emerged on early Earth
- To understand the conditions on early Earth, we must establish the age of Moon’s oldest surface units.
  - Dating samples returned from the interior of SPA Basin would establish a benchmark date for this earliest chronology.
- Age of SPA impact event is a vital point of reference for the cratering rate during earliest history of Moon and Earth.

Exploring Polar Volatiles

- Investigation of polar volatiles to:
  - characterize composition, molecular forms/mineralogy, and extent, depth (spatial distribution)
  - verify deposits -- determine relationship to permanent shadow
  - determine sources (solar wind, cometary, meteorite)
  - determine history (recent versus ancient)
- Understand processes of volatile migration and deposition on airless bodies
- Determine resource potential

Lunar Geophysical Network

- Seismic and heat flow to determine
  - internal structure
  - distribution of heat-producing elements
  - lateral and vertical heterogeneity of crust and mantle
  - possible existence of an iron-rich core
- Geophysical network science would address
  - how small planetary bodies differentiate
  - how the bulk composition of the Moon is related to the composition of Earth
  - how planetary compositions are related to nebular condensation and planetary accretion processes

Lunar Geophysical Network

BOX 8.1
Deferred High-Priority Flight Missions

The SSE Survey deemed the following mission concepts worthy of flight and accorded them a high priority. However, for reasons of mission sequencing, technological readiness, or budget, they did not make the final cut for the coming decade:

Medium Class
- Geophysical Network Science
- Trojan/Centaur Reconnaissance Flyby
- Asteroid Rover/Sample Return
- Io Observer
- Ganymede Observer

Large Class
- Europa Lander
- Titan Explorer
- Neptune Orbiter with Probes
- Neptune Orbiter/Triton Explorer
- Uranus Orbiter with Probes
- Saturn Ring Observer
- Venus Sample Return
- Mercury Sample Return
- Comet Cryogenic Sample Return

Discovery-class Issues

Geophysical investigations to determine internal structure, thermal evolution, and lateral/vertical heterogeneity (GRAIL)

Sample-return & dating youngest lava flows - relevant to extent of volcanism and calibration of impact flux

Investigation of polar volatiles - verify deposits, determine sources, and understand processes of volatile migration and deposition (LCROSS, LRO-LEND)

High-resolution topography - address geophysical properties and thermal evolution of crust and mantle (LRO LOLA, mini-SAR, mini-RF)

Mapping mineralogy to understand petrologic relationships within and origins of geologic units (Moon Mineralogy Mapper)

Discovery-class Issues

Targeted area studies to address impact chronology, including spikes and periodicity in the record

Composition of Moon's surface to characterize distribution of materials and understand formation, differentiation, and bulk composition

High-resolution imaging for 3-D definition of surface morphology to interpret local and regional geology, resource evaluation, and Moon-base planning (LRO LROC)

Geological site characterization to interpret geological evolution at key locations and understand interplay between tectonic, impact, and volcanic processes

Summary of Key Points

- Address Questions of Solar System Relevance
- Potential to alter Paradigm
- Applies to multiple questions and objectives
- Builds on existing and new discoveries
- Technological Risk: low/well understood
- Cost is low or opportunistic