New Frontiers in The Solar System.

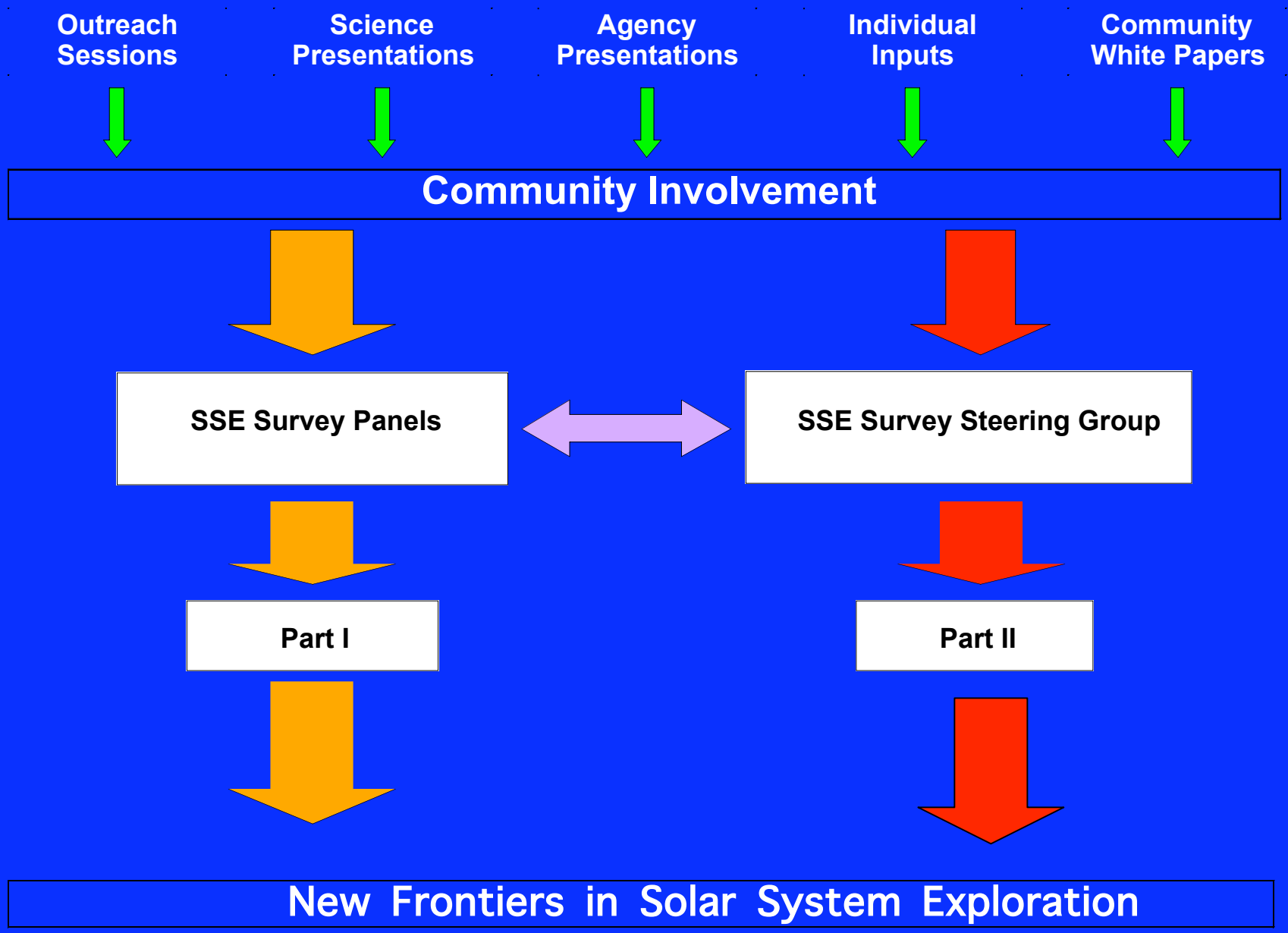
An Integrated Exploration Strategy

Solar System Exploration Survey
Space Studies Board
National Research Council

6 August, 2002

The Charge to the Survey:

- **Define a "big picture"** of solar system exploration - what it is, how it fits into other scientific endeavors, and why it is a compelling goal today.
- **Conduct a broad survey** of the current state of knowledge about our solar system today.
- **Identify the top-level scientific questions** that should provide the focus for solar system exploration today; these will be the key scientific inputs to the roadmapping activity to follow.
- **Draft a prioritized list** of the most promising avenues for flight investigations and supporting ground-based activities.


Outreach Sessions
Science Presentations
Agency Presentations
Individual Inputs
Community White Papers
Community Involvement
SSE Survey Panels
SSE Survey Steering Group
Part I
Part II
New Frontiers in Solar System Exploration

New Frontiers in the Solar System
Table of Contents

PART I

Primitive Bodies

Inner Solar System

Mars

Giant Planets

Large Satellites

PART II

Solar System Exploration Today: A Multi-Faceted Endeavor

Priority Questions for Solar System Exploration 2003-2013

Recommended Flight Missions and Supporting Investigations

Epilogue

The Selection and Prioritization Process:

Motivational Goals

▼

Scientific Goals

▼

Scientific Themes and 12 Key Scientific Questions

▼

Mission Selection

▼

Mission Prioritization

Why is Solar System Exploration a Compelling Activity Today:

- **Solar system exploration is that grand human endeavor** which reaches out through interplanetary space to discover the nature and origins of the system of planets in which we live, and to discover whether life exist beyond Earth.

- **It places *within our grasp* answers to questions of profound** human interest:

  - ***Are we alone?***
  - ***Where did we come from?***
  - ***What is our destiny?***

Relationship Between Motivational Questions and Scientific goals

- *Where did we come from?*
  - Learn how the Sun's retinue of planets and minor bodies originated and evolved.
  - Discover how the basic laws of physics and chemistry lead to the diverse phenomena observed in complex systems
- *What is our destiny?*
  - Explore the terrestrial space environment to discover what potential hazards to Earth may exist
  - Understand how physical and chemical processes determine the main characteristics of solar system bodies and their environments, illuminating the workings of Earth
- *Are we alone?*
  - Determine how life developed in the solar system, where it may have existed, whether extant life forms exist, and in what ways life modifies planetary environments

Scientific Themes for 2003 – 2013:

- The first billion years of solar system history
- Volatiles and organics: The stuff of life
- The origin and evolution of habitable worlds
- Processes: How planetary systems work

Themes → Key Scientific Questions → Missions

The first billion years of solar system history - - -

1. **What processes marked the initial stages of planet formation?**
   - **Comet surface sample return (CSSR)**
   - **Kuiper belt/Pluto (KBP)**
   - **South pole Aitken basin sample return (SPA-SR)**
2. **Over what period did the gas giants form, and how did the birth of the ice giants (Uranus, Neptune) differ from that of Jupiter and its gas-giant sibling, Saturn?**
   - **Jupiter polar orbiter with probes (JPOP)**
3. **How did the impactor flux decay during the solar system's youth, and in what ways(s) did this decline influence the timing of life's emergence on Earth?**
   - **Kuiper belt/Pluto (KBP)**
   - **South pole Aitken Basin sample return (SPA-SR)**

Themes → Key Scientific Questions → Missions

Volatiles and Organics: The stuff of life- - -

4. **What is the history of volatile compounds, especially water, across our solar system?**
   - **Comet Surface Sample Return (CSSR)**
   - **Jupiter Polar Orbiter with Probes (JPOP)**
5. **What is the nature of organic material in our solar system and how has this matter evolved?**
   - **Comet Surface Sample Return (CSSR)**
   - **Cassini Extended mission (CASx)**
6. **What global mechanisms affect the evolution of volatiles on planetary bodies?**
   - **Venus In-situ Explorer (VISE)**
   - **Mars Upper Atmosphere Explorer (MAO)**

Themes → Key Scientific Questions → Missions

The origin and evolution of habitable worlds- - -

7. **What planetary processes are responsible for generating and sustaining habitable worlds, and where are the habitable zones in our Solar System?**
   - **Europa Geophysical Explorer (EGE)**
   - **Mars Smart Lander (MSL) • Mars Sample Return (MSR)**

8. **Does (or did) life exist beyond the Earth?**
   - **Mars Sample Return (MSR)**

9. **Why have the terrestrial planets differed so dramatically in their evolutions?**
   - **Venus In-situ Explorer (VISE) • Mars Smart Lander (MSL)**
   - **Mars Long-lived Lander Network (MLN) • Mars Sample Return (MSR)**

10. **What hazards do solar system objects present to Earth's biosphere?**
    - **Large-aperture Synoptic Survey Telescope (LSST)**

Themes → Key Scientific Questions → Missions

Processes: How planetary systems work- - -

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

- **Kuiper Belt / Pluto (KBP)** • **South Pole Aitken Sample Return (SPA-SR)**
- **Cassini Extended mission (CASx)** • **Jupiter Polar Orbiter with Probes (JPOP)**
- **Venus In-situ Explorer (VISE)** • **Comet Surface Sample Return (CSSR)**
- **Europa Geophysical Explorer (EGE)**
- **Mars Smart Lander (MSL)** • **Mars Upper Atmosphere Orbiter (MAO)**
- **Mars Long-lived Lander Network (MLN)** • **Mars Sample Return (MSR)**

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

- **Kuiper Belt / Pluto** • **Jupiter Polar Orbiter with Probes (JPOP)**
- **Cassini Extended mission (CASx)**
- **Large-aperture Synoptic Survey Telescope (LSST)**

Criteria Used for Judging Priorities:

- **Scientific Merit:**
  - Might a reigning paradigm be overturned?
  - Will knowledge reset research directions?
  - Will measurements substantially broaden database?
- **Opportunity**
- **Technological readiness**

Solar System Mission Priorities:

- *Small Class (<$325M)*
  1. Discovery missions at one launch every 18 months
  2. Cassini Extended mission (CASx)
- *Medium Class (<$650M) – New Frontiers*
  1. Kuiper Belt/Pluto (KBP)
  2. South Pole Aitken Basin Sample Return (SPA-SR)
  3. Jupiter Polar Orbiter with Probes (JPOP)
  4. Venus In-situ Explorer (VISE)
  5. Comet Surface Sample Return (CSSR)
- *Large Class (>$650M)*
  1. Europa Geophysical Explorer (EGE)

Mission Priorities: Mars Flight Missions (beyond 2005):

- *Small Class (<$325M)*
  - **Mars Scout Line**
  - **Mars Upper Atmosphere Orbiter (MAO)**
- *Medium Class (<$650M)*
  - **Mars Smart Lander (MSL)**
  - **Mars Long-lived Lander Network (MLN)**
- *Large Class (>$650M)*
  - **Mars Sample Return preparation so that *its implementation can occur early in the decade 2013-2023* (MSR)**

Priorities for New Ground-Based Activities:

Enter an equal partnership with NSF to build and operate a

- **Large-aperture Synoptic Survey Telescope (LSST)**

Backups

An alternate science trace from the IAA study

Translating public questions…	*to science goals…*	*to exploration objectives…*	*at specific destinations.*
Where did we come from?	Determine how the universe of galaxies, stars and planets began and evolved.	Survey matter in the universe across the spectrum and to the beginning of time.	with telescopes at Sun-Earth Libration Point L2
		Observe and understand the process of planetary system formation in the galaxy.	with telescopes at Sun-Earth Libration Point L2
		Survey the diversity and composition of small bodies in the solar system.	on Near-Earth Objects
	Determine the origin and evolution of our own Earth and its biosphere.	Search for evidence leading to understanding the origin of the Earth-Moon system.	in the regolith and rocks of the Moon
		Search for samples from the earliest episodes in the history of the Earth.	in Earth meteorites found on the Moon
		Obtain evidence on the Sun's history and its effect on Earth through time.	in the regolith and rocks of the Moon
What will happen to us in the future?	Determine the nature of the space environment and any cosmic hazards to Earth.	Determine the history of asteroid and comet impacts on Earth.	in the local cratering record on the Moon
		Determine the bulk properties and internal structures of NEOs.	at and on Near-Earth Objects
	Determine the potential for establishing permanent human presence in space.	Determine the utility of resource production on the Moon including potential lunar ice.	on the Moon
		Determine the utility of NEOs as potential resources for materials in space.	on Near-Earth Objects
		Determine the feasibility of in-situ resource production on Mars.	on Mars
Are we alone in the universe?	Determine if there is or ever has been extra-terrestrial life in the solar system.	Determine the geological and climatological histories of Mars.	on Mars
		Determine the history of water and its present distribution and form on Mars.	on Mars
		Search for past and current life on Mars and in the subsurface ocean of Europa.	on Europa
	Determine if there are Earth-like planets with evidence for life around other stars.	Search for terrestrial-like planets around other stars.	with telescopes at Sun-Earth Libration Point L2
		Search for evidence of life in the observational properties of extra-solar planets.	with telescopes at Sun-Earth Libration Point L2