New Frontiers in The Solar System:

An Integrated Exploration Strategy

Solar System Exploration Survey

Space Studies Board

National Research Council

9 July 2002

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Giant Planets Panel – **Reta Beebe**
Primitive Bodies Panel – **Dale Cruikshank**
Large Satellites Panel – **Alfred McEwen**
Ad hoc Astrobiology Panel (COEL)
- Jonathan Lunine/John Baross

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.

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***
  1. **Mars Scout Line**
  2. **Mars Upper Atmosphere Orbiter (MAO)**
- ***Medium Class***
  1. **Mars Smart Lander (MSL)**
  2. **Mars Long-lived Lander Network (MLN)**
- ***Large Class***
  1. **Mars Sample Return preparation so that *its implementation can occur early in the decade 2013-2023* (MSR)**

Lesson #1

Remember the three R's -

reliability, realism, readiness

Don't overload with ambitious science

Resist a science beauty contest at the Steering Group level

Put Mars back in the solar system

Missions: Key Scientific Questions:

Jupiter Polar Orbiter with Probes (JPOP)

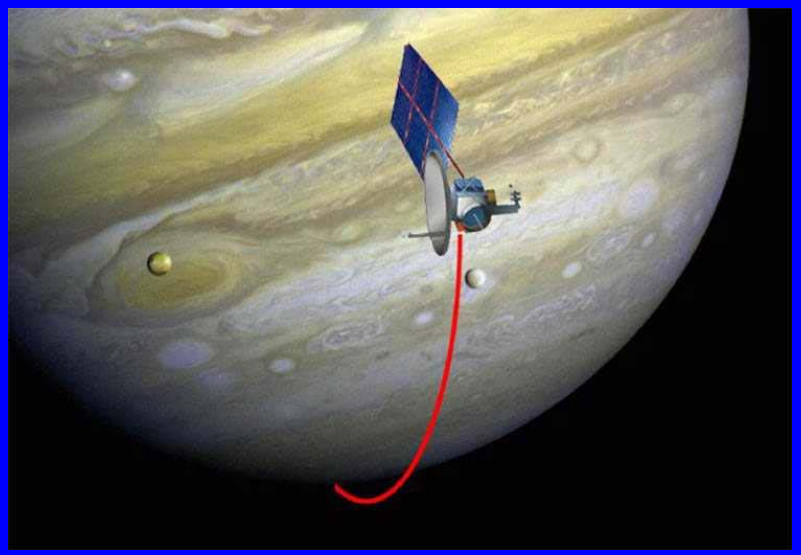
A close-orbiting polar spacecraft equipped with various instruments and a relay for three probes that make measurements below the 100+bar level.

- **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?**
- **What is the history of volatile compounds, especially water, across our solar system?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and *vice versa?***

Jupiter Polar Orbiter with Probes (JPOP)

GOALS:

- Determine if Jupiter has a central core to constrain models of its formation
- Determine the planetary water abundance
- Determine if the winds persist into Jupiter's interior or are confined to the weather layer
- Assess the structure of Jupiter's magnetic field to learn how the internal dynamo works
- Measure the polar magnetosphere to understand its rotation and relation to the aurora



Lesson #2

Prioritize based on cost realism and technical reliability

Don’t over-constrain the science

Leave room for innovation

Missions: Key Scientific Questions:

Kuiper Belt / Pluto (KBP)

A flyby mission of several Kuiper Belt objects, including Pluto/Charon, to discover their physical nature and determine the collisional history of the Kuiper Belt.

- **What processes marked the initial stages of planet formation?**
- **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?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and vice versa?**

Kuiper Belt / Pluto (KBP)

GOALS:

- **Investigate the diversity of the physical and compositional properties of Kuiper belt objects**
- **Perform a detailed reconnaissance of the properties of the Pluto-Charon system**
- **Assess the impact history of large (Pluto) and small KBOs**

Lesson #3

Speak with a unified voice

Read the white papers and use them

Represent the community

Allow competition and innovation

No need to empty the queue from 2002

Missions: Key Scientific Questions:

Europa Geophysical Explorer (EGE)

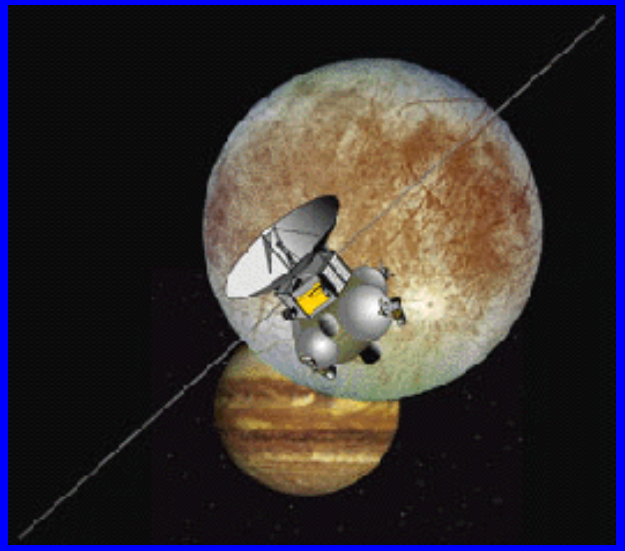
An orbiter of Jupiter's ice-encrusted satellite will seek the nature and depth of its ice shell and ocean.

- **What planetary processes are responsible for generating and sustaining habitable worlds, and where are the habitable zones in our Solar System?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**

Europa Geophysical Explorer (EGE)

GOALS:

- Assess the effects of tides on the satellite's ice shell to confirm the presence of a current global subsurface ocean.
- Characterize the properties of the ice shell and describe the three-dimensional distribution of subsurface liquid water.
- Elucidate the formation of surface features and seek sites of current or recent activity.
- Identify and map surface compositional materials with emphasis on compounds of astrobiological interest.
- Prepare for a future lander mission.



Lesson #4

Don’t forget the flagships

Higher cost is not bad if it is realistic

Factors of 2 – If your most costly mission is $N

you want to budget 1*N + 2*N/2 +4*N/4 + 8*N/8

Think beyond Europa – Titan? Enceladus?
Uranus? Neptune? GP probes?

Missions: Key Scientific Questions:

Cassini Extended Mission (CASx)

Extension of orbiter mission at Saturn

- **What is the nature of organic material in our solar system and how has this matter evolved?**
- **How do the processes that shape the contemporary character of planetary bodies operate and interact?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and *vice versa*?**

Cassini Extended Mission (CASx)

GOALS:

- Follow up on significant discoveries during the nominal mission
- Extension of spatial coverage on Titan through changing orbital geometry
- Extension of time coverage of dynamical phenomena at Saturn and Titan

Lesson #5

Support on-going missions like Cassini, New Horizons, Kepler

Support international partnerships

Support approved missions like Juno

Support the Discovery and New Frontiers lines

Ground Based Facilities: Key Scientific Questions:

Large-aperture Synoptic Survey Telescope (LSST)

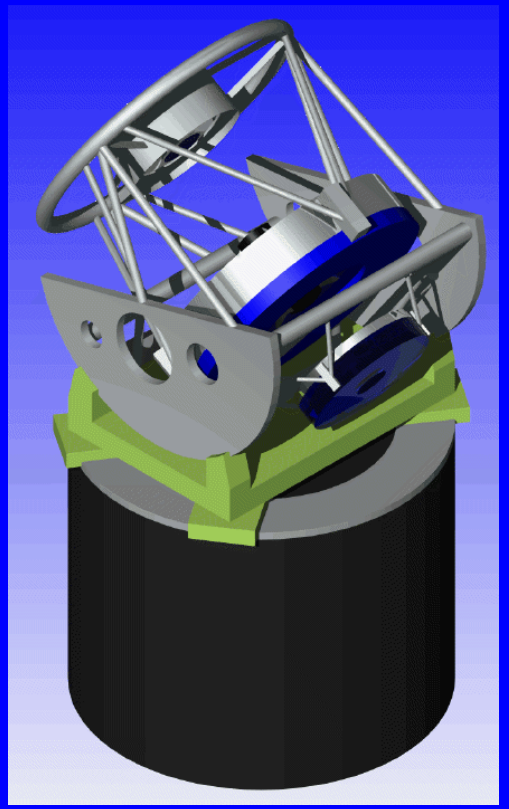
A facility to survey objects in the Kuiper Belt and comets and asteroids in near-Earth orbits.

- **What hazards do solar system objects present to Earth's biosphere?**
- **What does our solar system tell us about the development and evolution of extrasolar planetary systems, and vice versa?**

Large-aperture Synoptic Survey Telescope (LSST)

GOALS:

- To optically survey the entire available sky to m = 24 magnitudes every week or faster to:
  - Catalog and determine orbits for the population of Near Earth Objects down to 300-m diameter so as to assess the impact threat posed to Earth.
  - Determine the distribution of trans-Neptunian objects and other bodies in the outer solar system (Centaurs, Trojans, long-period comets)



Lesson #6

Support the Earth-based observers

Support extra-solar planetary research

Support theory and data analysis

Support the whole community

Mission Priority by Panel

Panel	Mission Concept Name	Cost Class
Primitive Bodies		
	Kuiper Belt-Pluto Explorer	Medium
	Comet Surface Sample Return	Medium
	Trojan/Centaur Reconnaissance Flyby	Medium
	Asteroid Rover/Sample Return	Medium
	Comet Cryogenic Sample Return	Large
	Discovery Missions	Small
Giant Planets		
	Cassini Extended Mission	Small
	Jupiter Polar Orbiter with Probes	Medium
	Neptune Orbiter with Probes	Large
	Saturn Ring Observer	Large
	Uranus Orbiter with Probes	Large
	Discovery Missions	Small
Large Satellites		
	Europa Geophysical Explorer	Large
	Europa Lander	Large
	Titan Explorer	Large
	Neptune Orbiter/Triton Explorer	Large
	Io Observer	Medium
	Ganymede Orbiter	Medium
	Discovery Missions	Small

- 27 missions identified by the Panels, listed in priority order.
- 16 missions and mission classes in **green** placed on short list by Steering Group.
- 13 missions included in final honed priority listings.
- 5 New Frontiers missions prioritized by Steering Group:
  - 3 prime
  - 2 included to account for uncertainties, encourage further growth, and indicate possible future directions.

Lesson #7

Spend more time than in 2002 on missions for the future

Spend less of your time re-writing the science questions from 2002

Don’t prioritize unless you have done the required studies

Primary Recommendations on Solar System Exploration Infrastructure (1):

- We recommend that NASA commit to significant new investment in **advanced technology** in order that future high-priority flight missions can succeed..

•Power: Advanced RTGs
•Power: In–space Nuclear power source
•Propulsion: Nuclear--powered electric propulsion
•Propulsion: Advanced electric engines
•Propulsion: Aerocapture
•Communications: Ka band
•Communications: Optical
•Architecture: Autonomy
•Avionics: Advanced packaging and miniaturization
•Instrumentation: Miniaturization
•Entry to landing: Autonomous entry, precision landing
•In-situ ops: Sample gathering, handling and analysis
•In-situ ops: Instrumentation
•Mobility: Autonomy
•Contamination: Forward-contamination avoidance
•Earth return: Ascent vehicles

Primary Recommendations on Solar System Exploration Infrastructure (2):

- We recommend an increase over the decade in the **R & A programs** at a rate above inflation to a level that parallels the increase in the number of missions, amount of data, and diversity of objects studied… We estimate that R & A programs should correspond to about 25% of the overall flight mission budget.
- We encourage NASA to continue the integration of **Astrobiology science** objectives with those of other disciplines. Astrobiological expertise should be called upon when identifying optimal mission strategies and design requirements for flight-qualified instruments that address key questions in astrobiology and planetary science.
- We recommend that, well before cosmic materials are returned from planetary missions, NASA establish a broad and vigorous **Sample Analysis Program** to support instrument development, laboratory facilities, and the training of researchers.

Recommendations on Mission Lines:

- We recommend continuance of the **Discovery** mission flight rate at the current level of one launch every 18 months…
- We strongly endorse the President's initiative on **New Frontiers** with competitively selected, medium-class missions with flights every 2 – 3 years…
- We recommend that **Flagship,** large class, missions be developed and flown at a rate of about one per decade…
- For many missions, particularly those of the **large class**, we recommend that NASA encourage and continue to pursue cooperative programs with other nations…
- For **large missions**, a broad cross-section of the community should be involved in the early planning stages…
- We recommend that early planning be done to provide adequate funding of **mission extensions,** particularly flagship missions and missions with international partners…

Lesson #8

Maintain continuity with the
2002 Decadal Survey
Do a better job on the infrastructure
If something is important, e.g., RTG's
say it loud and clear

Twelve Key Scientific Questions → Missions:

I. 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)**

Twelve Key Scientific Questions → Missions:

II. 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 Orbiter (MAO)**

Twelve Key Scientific Questions → Missions:

III. 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)**

Twelve Key Scientific Questions: Missions:

IV. 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)**

Lesson #9

Keep the key questions from 2002

Define the role of solar system exploration in extra-solar planetary research

The End