# New Frontiers in The Solar System:

## An Integrated Exploration Strategy

Solar System Exploration Survey
Space Studies Board
National Research Council

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# Members of Survey

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Inner Planets Panel – **Carlé Pieters**
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)

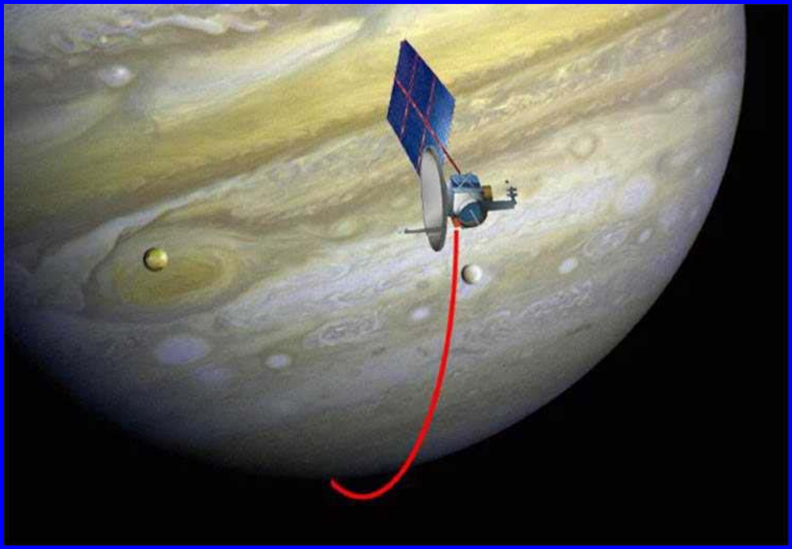
A close-orbiting polar spacecraft equipped with various instruments and a relay for three probes that make measurements below the 100+bar level.

- **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

# <u>Missions: Key Scientific Questions:</u>

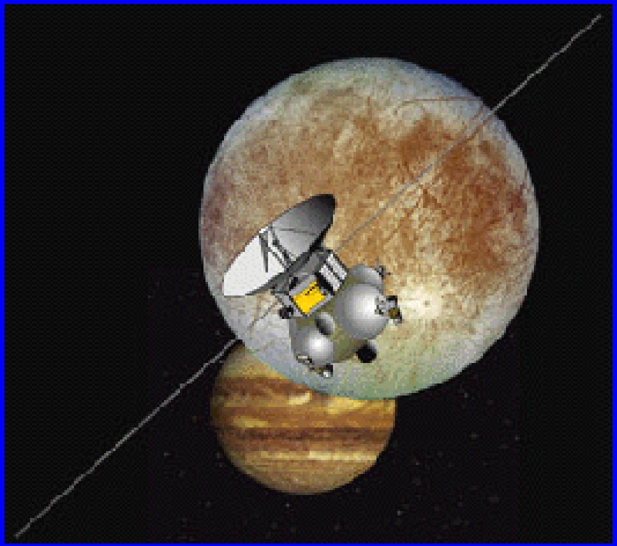
## Europa Geophysical Explorer (EGE)

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)

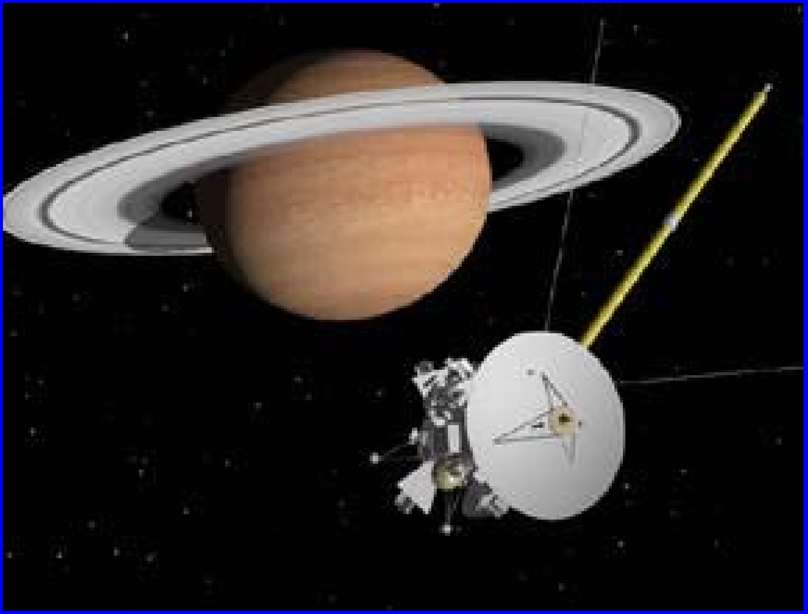
Extension of orbiter mission at Saturn

- **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)

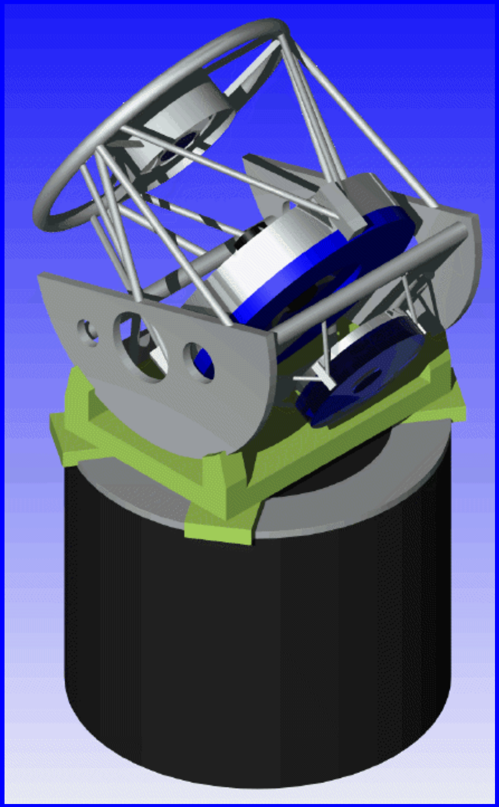
A facility to survey objects in the Kuiper Belt and comets and asteroids in near-Earth orbits.

- **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