solar System Exploration Road Map

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ABSTRACT

NASA has commissioned a group of scientists, eng ineers, educators and technologists to prepare a "Road Map" for Solar Syste m exploration which covers the next 15-20 years. This Road Map is expected to serve as a guide for the continuation of Solar System exploration and future space science activities supported by NASA. The Road Map is currently in draft form, however, it is sufficiently developed al this time to be able to describe the process used to ge ne rate it, and to give an overview of the current plan. A discussion of the planning process and a status report 011 the Road Map for Solar System exploration for the next two decades is described in this paper, Emphasis in this paper is on the science goals.

INTRODUCTION

Solar system exploration, using robotic and ma n ned spacecraft, has been ongoing for more than 35 years. Starting with robotic spacecraft launched by the former U.S.S.R. to the moon in January 1959, and reaching beyond to every planet from Mercury to Neptune, to a number of satellites, and to a comet, mankind is close to having complet ed its initial survey of the Solar Sys tem. Most of the robotic planetary spacecraft 11s(?(1 to date have been launched by the United States, however in recent ye ars planetary exploration has truly become an international endeavor. A better understanding of our Solar System and the world wc live in has resulted from these activities; also, many ne w insights, important quest ions and challenges have been raised along the way. These results have benefited all mankind,

As a follow up to the p relude of the first 35 years of Solar System exploration, NASA's office of Space Science(OSS) recently appointed a large team of scientists, engineers, educators, and technolo gists to prepare a "Road Map" for Solar System Exploration which covers the next 15-20 years. This Road Map is expected to serve as a guide for the development of future Space science activities within the United States. Guidelines for the development of the Road Map arc that it should be exciting, scientifically rewarding, and affordable. The Road Map should also identify the key scientific issue. s to be addressed and the missions and technologies needed. 1)1". Charles Elachi from the Jet Propulsion Laboratory was asked to lead the activity. A status report of the Road Map planning activity is described in this paper.

STUDY PROCESS

The charter for the Road Map development activity, given below, provided the guiding principles for the Road Map activity,

Develop a visionary but affordable mission and technology development Road Map, for the exploration of the Solar System, in the 2000 to 2012 time frame. This should *include the undertaking of the next evolutionary step of extensive in-situ exploration and sample return from acce ssible bodies, in addition to completion of the ove rall survey. Therefore emphas is sho uld be placed on planetary mobility (local and global), in-situ sample studies (surface and atmo sphere) and sample return. The Road Map should de fine ground technology demo s as well as flight demos that could be accomplisw:ith presently planned US miss ion s/progra ms (New Millennium, Mars 2001/2003, Discovery, etc.) as well as interna tional mission s. 1'11(team activity should involve a broad spectrum of the science commun ity, the industrial community as well as interested public. It should use as a guiding frame work, the recent Complex R ep ort, the N R C report on "Managing the Space Sc ience", the Code S strategic plan, and the on-going SSES planning activity.*

'1'() achieve the goals set forth in the Charter, Dr. Elachi formed two working, team s composed of scientists, eng inee rs and industry participants. Each o f these teams prepared independent and detailed Road Map options. Suggestions were also solicited from the entire science community, at a science workshop held at the California Institute of Technology, March 4-5, 1996; dozens 0 1 respondents proposed science measurements or missions for inclusion in the Road Map. Road Map materials

A panel of distinguished scientists and eng ineers reviewed the two independent options and other inputs from which they assembled a single Road Map. Some members of the Space Science Board, the Committee on Planetary Exploration (COMPLEX), and the Solar System Exploration Subcommittee (S SES) were included on in order that the final Road Map would be closely linked to the formal NASA planning process. These organizations also provided extensive formal review of the draft. The final Road Map will be input into the SSES-NASA strategic plan for Solar System exploration.

SPACE SCIENCE THEMES

General guidance for the Road Map activity was provided by the four science themes within the NASA Office of Space Science(OSS). These themes correspond to the fundamental intellectual questions which OSS seeks to answer. The four themes are:

Planetary System Origin and Evolution: How are the characteristics of' different planets related? what processes shape the nature of planets? Which processes arc currently taking place? What can we learn about Earth by studying other planetary bodies? Arc there terlc.stlial-like planets around other slat's?

Origin and Distribu tion of Life in the Universe: what generated the conditions for life on Earth? Was the re ever life elsewhere in the solar system? IS there life elsewhere in the universe?

Sun-Earth-Heliosphere Connection: What is responsible for the variability of the Sun, a typical star, on all time scales'? How (lo the magnetic field regions and uppermost atmospheres of the planets, especially Earth, respond to variations in solar radiation and solar wind? What drives the solar wind and the dynamic interplanetary environment? What govern s the origin and acceleration of solar and galactic cosmic rays? What governs their propagation through the solar system?

The Galaxy and the Universe: now did structure evolve from chaos? How (lid galaxies evolve, and what triggers the formation of stars? How are stars born, how do they die, and what are the consequences of their deaths? Are the fundamental laws of physics invariant throughout 'the universe?

QUESTS

To more rapidly identify the key scientific questions, and to stimulate the development of techniques to achieve answers, the Road Map team developed a Set of three basic "quests" for knowledge. The quests indicate where the Road Map activities lead in the long run, and why. Each of the quests includes basic underlying questions about the universe and our place in il.

Quest #1: To Explain the Formation and Evolution of the Solar System and the Earth

- Understand the origin of the solar nebula and the forces that formed Earth and other Planets
- Determine the evolutionary processes that led to the diversity of solar system bodies and the uniqueness of planet Earth
- Use the exotic worlds of our solar system as natural science laboratories

Quest #2: '1'0 Chart our Destiny in the Solar System

- Understand the solar system forces and processes that affect the future habitability of Earth
- Find extraterrestrial resources of human interest
- Assess space frontiers suitable for future human exploration

Quest #3: To Seek the Origin of Life and its Existence Beyond the Earth

- Understand the sources and reservoirs of water and organics -- the building, blocks of life
- Determine the planetary conditions required for the emergence of life
- Search for evidence of past and present life elsewhere in our solar system

CAMPAIGNS

The order in which the basic issues are tackled are driven by a variety Of factors including cost, launch opportunities, difficulty, and technical capabilities. By combining scientific questions with challenging technology, the Road Map missions were organized into five campaigns -- -sets of focused scientific investigations by which wc, will achieve the goals of the quests using innovative tools and techniques. The five campaigns in Solar System Exploration which combine scientific and technical challenges, arc:

Campaign #/1: Building Blocks and Our Chemical Origins

The purpose of this campaign is to reveal the properties of the material from which the solar system formed, and determine how the present solar system evolved from the solar nebula to the early plaints. By evaluating the sources and reservoirs of water and organics, we may begin to understand the conditions required for the emergence of life. Records of the composition and physical processes at the time of planet formation are preserved in comets, asteroids, meteoroids, outer planet atmospheres, and tile Sun. The campaign wiii inventory the basic physical, chemical, and isotopic properties of the diverse materials from which planets formed, by exploring representative bodies from widely separated regions of the solar nebula with different physical conditions. The campaign should result in a completed survey of the solar system, key information on the early solar system and potential sources of organics and volatiles, and an inventory of resources for potential human exploration and hazards assessment.

>o.ential missions under consideration for .his campaign would ne ude:
- Pluto/Kuiper Express
- Multi-Body Visitors
- a Large Asteroid Orbiter
- a Small Body Sample Return
- Giant Planet Deep Probes.

Campaign #2: Pre-biotic Chemis.ry n the Outer Solar System

This campaign seeks to identify and map the distribution of organic compounds, assay and understand the details of organic chemical processes, and search for evidence of pre-biological or proto-biological activity on satellites of the gas giants. Satellites such as Europa and Titan might provide clues to understand how planetary evolution lead to life.

Europa is a Moon-sized body whose surface is covered by a smooth, relatively young layer of water ice. Liquid water oceans may exist under this ice crust, and liquid water appears to be the critical ingredient for the development and sustenance of life. Internal heating of Europa may produce hydrothermal vents; similar vents on Earth are known to harbor non-photosynthetic forms of life. Thus, detection and characterization of any Europa oceans is an integral part of our search for evidence of life in the solar system.

Titan has a thick atmosphere and a prodigious organic chemistry powered by sunlight. While the Cassini/Huygens mission will provide a snapshot of the nature of the surface and how the surface and atmosphere interact chemically, the next step in understanding the organic chemistry and possible pre-biotic evolution of Titan requires missions which better characterize the chemical composition of Titan's atmosphere and surface. This may provides clues to the conditions on early Earth that led to the emergence of life.

Potential missions under consideration for ıis campaign would inc ude:
- Europa Ocean Explorer
- Europa Landers
- Titan Biologic Explorer.

Campaign #3: Formation and Dynam cs o Earth-Like Planets

Many aspects of the formation and evolution of the Earth are best illuminated by he study of our planetary neighbors. This campaign seeks a better understanding Earth's history as a planet and how its evolution differed from other planets. While the earliest history of the Earth is no longer preserved, the surfaces of he Moon and Mercury have been little modified over much of the age of the solar system; they present excellent models for understanding the history of the early Earth, and how its evolution differed from other planets. Mercury, Venus, Mars, and Io span a range of sizes and levels of current activity, and so provide several different points of comparison to Earth. Missions to these bodies to search for and characterize such activity will allow inter-comparisons of the internal dynamics of diverse worlds.

Potential missions under consideration for his campaign would nclude:

- Lunar Giant Basin Sample Return
- Mars Surface Network
- Venus Surface Mission (Landers and Aerobots)
- Io Volcanic Observer
- Mercury Orbiter.

Campa gn #4 Evo u ion of Earth- ke Environments

Earth and its closest neighbors, Mars and Venus, share many similarities, yet each has had a dramatically different history. Of the planets in our solar system beyond Earth, Mars holds the greatest chance for having developed life. The crucial ingredient for life is liquid water. Thus, a key element of this campaign is the history of liquid water on Mars, including its abundance, distribution and cycling in the crust, and its role in sculpting the Martian landscape and modifying the long-term climate. For Venus, the question of the early climatic history of the planet, nature of the run-away greenhouse, and the possibility that water once existed on the Venusian surface provide addit onal fundamental focuses in this campaign.

This campaign focuses upon the early climatic conditions of Mars and Venus. It seeks evidence of past or present life on Mars, and an understanding of the resources available on Mars to assist in future exploration of the planet. For Venus, the question of the early climatic history of the planet, the nature of the run-away greenhouse, and the possibility that water once existed on the Venusian surface also provide fundamental focuses for this campaign.

Po ential missions under consideration for h s campaign would include:

- Mars Water and Mineralogical Mapper
- Mars Mobile Science Laboratory
- First Mars Sample Return
- Advanced Mars Sample Collection and Return
- Mars Geoscience Aerobot
- Venus Geoscience Aerobot

Campa gn #5: Astrophysical Analogs in the Solar System

The solar system provides a number of analogs to phenomena occurring in the early solar system. The comas and tails of active comets tell us about the interaction between sunlight, gas, plasma and dust grains which took place in the solar nebula and still occur in a wide range of astrophysical settings. The structure and dynamics of diverse planetary magnetospheres reveal how flowing plasmas interact with a with magnetic fields under a variety of conditions: this helps us better understand phenomena such as geomagnetic activity, pulsars, x-ray bursters, and radio galaxies.

This campaign has two major aims: to study astrophysical phenomena for a better understanding of the fundamental processes that led to solar system formation, and o find common pi nciples connecting physical systems of radically different size.

Potential missions under consideration for his campaign would nclude:

- Outer Planets Multiprobes
- Jupiter Polar Orbiter
- Neptune Orbiter with Triton Flybys
- Saturn Ring Observer
- Mercury Magnetospheric Multi-Sa e i es

PORTRAIT MISSIONS

A set of eighteen "Portrait" missions have been identified through this Road Map process. For each of the five Campaigns, a set of specific science objectives have been developed, and representative missions that could achieve these objectives and embody the critical campaign technology challenges have been identified. Actual missions will be selected periodically, as part of the ongoing strategic and program planning process.

Bu ding Blocks and Our Chemica Origins

- Pluto/Kuiper Express
- Primitive Body Explorers (Mult -Flyby Visitors, a arge Asteroid Orbiter)
- Small Body Sample Return
- Giant Planet Deep Probes

Pre-Biotic Chemistry in the Outer Solar System

- Europa Ocean Explorer
- Titan Biologic Explorer

Fo mation and Dynamics of Earth-Like anets

- Lunar Giant Basin Sample Return
- Mars Surface Network
- Io Volcanic Observer
- Mercury Orbiter.

Evo ution of Earth-like Environments

- Mars Water and Mineralogical Mapper
- Mars Mobile Science Laboratory
- Mars Sample Returns
- Mars Geoscience Aerobot
- Venus Geoscience Aerobot

Astrophysical Analogs in the So ar Sys em

- Jupiter Polar Orbiter
- Neptune Orbiter
- Saturn Ring Observer

CONCLUSION

An exciting and scientifically rewarding Road Map, Mission to the Solar System, is nearing completion. The Road Map reflects inputs from a broad community of scientists, engineers, technologists, and educators.

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