IAF-98-Q.3.01

THE NASA MARS EXPLORATION PROGRAM

Norman R. Haynes

Director for Mars Exploration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA USA

49th International Astronautical Congress
Sept 28-Oct 2, 1998/Melbourne, Australia

IAF-98-Q.3.01

THE NASA MARS EXPLORATION PROGRAM

by

Norman R. Haynes
Director for Mars Exploration
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California USA 91109-8099
818-354-0564

INTRODUCTION

In 1994, shortly after the unfortunate failure of the Mars Observer mission, NASA proposed and received approval for a new program of missions to Mars, called the "Mars Surveyor Program" (MSP). The program would consist of 2 launches at each Mars opportunity which occur about every 25 months. The two launches were to consist of an orbiter and Lander and were to use a new MED-lite Launch vehicle, the Delta 7425, The goals of the MSP shown in Figure 1 were to (1) understand the potential for life on Mars, (2) understand the relationship between Mars and Earth climate change processes, and (3) understand the solid planet, how it evolved and its resources for future exploration. A cross-cutting, common thread that ran through all three goals was the study of water and its history on the planet.

In August of 1996, a multi-disciplinary group of scientists was brought together by NASA to develop a strategy to seek the answer to the question -- did life ever exist on Mars? The group recommended that "in-situ studies conducted on the surface of Mars are essential to our learning more about Martian environments and for selecting the best samples for collection. However, for the next 10 years or more, the essential analyses of selected samples must be done in laboratories on Earth.[1] As a consequence, sample return missions rather than in-situ analysis became the focus of the Mars Surveyor program.

In FY98, the Mars Surveyor program was augmented to allow sample return missions to be included. Studies indicated that the earliest time for return of the first samples from Mars was in 2008.

The prime objective of the program became returning multiple samples to the earth, the first in 2008, and within the augmented budget.

THE MARS SURVEYOR PROGRAM

By this time, FY98, the Mars Surveyor program had been underway for several years. Mars Pathfinder was launched toward Mars in December 1996 and made a successful landing on July 4, 1997. Pathfinder carried stereo imaging, and meteorological instruments on the Lander and deployed a small Rover, Sojourner, carrying cameras and an Alpha Proton x-ray experiment for measuring the elemental composition of rocks. Pathfinder was part of the Discovery program, not the Mars Surveyor Program, but nonetheless, made an important contribution to understanding Mars.

Mars Global Surveyor (MGS), was launched in November 1996. MGS is an Orbiter carrying 5 of the 7 experiments originally carried by Mars Observer. MGS also carries a radio link capable of relaying data from future Landers to the Earth. MGS was inserted into orbit in September 1997 and began aerobraking into its final orbit. Aerobraking is scheduled to be complete and detailed mapping of the surface will begin in March, 1999.

Beginning December 10, 1998, the launch period opens for the launch of the first Mars Surveyor 98 Mission, the Mars Climate Orbiter (MCO). MCO carries the 6th Mars Observer experiment, the Pressure Modulated Infrared Radiometer, an imaging system and a radio relay link for the Mars 98 and subsequent Landers.

The Mars Surveyor 98 Lander, the Mars Polar Lander, MPL, launch period opens on January 3, 1999. MPL will land near the Martian South Pole at about 80 degrees south latitude, and carries a suite of experiments including descent imaging, stereo surface imaging, a robotic arm and camera capable of digging up to a meter in the Martian soil and transporting soil samples to a Thermal Evolved Gas Analyzer. The Lander also has a meteorological station and an instrument to measure the sounds of Mars.

In 2001, the Mars Surveyor 2001 Missions will be launched. The Orbiter will carry the last of the Mars Observer instruments, a Gamma Ray Spectrometer, along with an imaging infrared spectrometer and a radiation detector. The radiation detector is part of a collaboration between the Mars Surveyor Program and the NASA Office of Human Exploration and Development of Space (HEDS). The Lander will carry a stereo image, a thermal emission spectrometer, and a Mossbauer spectrometer along with three HEDS' experiments, a soil and dust experiment, a surface radiation detector and an in-situ propellant making experiment along with the MPL robotic arm and camera. It may carry a Rover similar to the Mars Pathfinder Sojourner.

Figure 2 shows the Mars Surveyor Program just described. Figure 3 shows the annual funding available to the MSP. The on-going missions, MGS, MPL , MCO, Mars 2001 and the Mars Surveyor Operations Project are included as "Firm Commitments." The remainder of the funding is in the "Available for Program Budget Wedge", which must cover all of the missions after MSP '01.

MARS SAMPLE RETURN MISSION

The Sample Return Missions are expected to take virtually all of the funding shown as "Available for Program Budget Wedge". As a consequence, the MSP called together an international group of experts into two workshops to address the best, most cost effective way of accomplishing the sample return missions. Figure 4 shows the recommendations by the workshop participants for eight critical trade-offs. The group recommended that, at least initially, the MSP use a nearly unguided, spinning solid rocket vehicle for ascent from the Martian surface with the samples to low Mars orbit, that Mars orbit rendezvous (MOR) be used as the mission mode, that Rovers be used to collect the samples, that rocket capture at Mars with aerobraking be used by the Orbiter, rather than aerocapture, and that direct entry of the sample carrying Earth Entry Capsule be used at the earth. They also suggested that sample transfer from the Rover to the Mars Ascent Vehicle to the Earth Entry Capsule would be a difficult problem and that the MSP should get started immediately on possible solutions.

MARS SURVEYOR PROGRAM ARCHITECTURE

Following the Sample Return Workshops, another set of workshops involving international experts was convened to address the issue of the MSP architecture after the MSP '01 Mission. The workshops were given a set of commitments, constraints and assumptions. The key commitment is to plan a family of sample returns with the first sample returned to earth by 2008. The key constraints are that the MSP must conduct the sample returns within the budget defined. Budgets for the infusion of HEDS technologies are yet to be determined and, therefore, the timing of the infusion of HEDS technology is also to be determined. The Rovers that collect the samples are to carry a payload of instruments called Athena, which was originally selected for the MSP 2001 mission. Among the critical assumptions is that several potential international collaborations will be consummated . They include an agreement with the French space agency, CNES, within which CNES would supply an Ariane 5 launcher in 2005, Orbiters capable of returning two samples back to earth beginning in the 2005 Mars opportunity, and Netlanders to be carried on the 2005 mission.

NASA is assumed to provide the Landers, Rovers, Mars Ascent Vehicles and Earth Entry Capsules, beginning in 2003, the launcher for all missions beginning in 2003 except the 2005 launch.

Together, NASA and CNES will develop the capability to deliver small (<200 kg) micro spacecraft from earth orbit to Mars. CNES will provide the Ariane 5 launch to Geosynchronous Transfer Orbit on which the micro spacecraft will "piggy-back." The micro spacecraft will then use propulsion and lunar swing-bys to inject itself and its; payload to Mars. CNES is assumed to supply the launch, NASA the development of the micro spacecraft bus.

Another assumed collaboration is with the Italian Space Agency, ASI. In this case, ASI will provide drills and other robotic elements for the Landers beginning in 2003. ASI will also provide radio relay equipment to the European Space Agency, Mars Express Mission in 2003, to be used for data transfer from subsequent Landers to earth.

The European Space Agency, ESA, will fly an Orbiter mission in 2003, called Mars Express. NASA and ASI have agreed to supply a Sounding Radar to the Mars Express.

All of these potential International collaborations are shown in Figures 5 and 6.

The workshops participants, after two, multi-day meetings, agreed with a proposed architecture.

The architecture through 2008 is shown schematically in Figure 7. In 2003 a single launch by a Delta 3 class launcher will inject a Lander carrying a sample-collecting Rover, a Mars ascent vehicle (MAV), a drill and robotic arm, and if funding is available, a series of HEDS experiments, to the surface of Mars. The Rover will collect a sample over several months, return it to the Lander and transfer the sample to the MAV. The MAV will then inject the sample into a low Mars orbit where it will await pick-up by the 2005 mission.

In 2005, a single Ariane 5, containing a duplicate of the 2003 Lander, Rover, MAV and a CNES provided Orbiter will launch to Mars. The Lander, with Rover and MAV, will land at a different site than 2003, collect a sample by Rover, and launch the sample to orbit using the MAV. The Orbiter will be inserted into a highly elliptic Mars orbit, aerobrake to low orbit, rendezvous and dock with the 2003 sample, and then rendezvous and dock with the 2005 sample. After 11 months in orbit the Orbiter will fire it's rocket engines to inject itself and the two Earth Entry Capsules (EEC) each containing a sample, on an earth return trajectory. The Orbiter will target the two EEC's onto impact trajectories, deploy the EEC's and then deflect its' trajectory so the Orbiter misses the earth.

Figure 8 shows the architecture through the 2013 opportunity. It allows the opportunity, if all goes well, to return a maximum of 6 samples from 6 separate sites on Mars. In the 2007 opportunity, another single launch, using a U.S. Delta 3 class launch vehicle, of a Lander, Rover, MAV combination will take place. The samples collected will be cached on orbit to await pick-up by the 2009 Orbiter. In 2009, two launches, using Delta 3 class launch vehicles will occur. The first will launch an Orbiter, the second a Lander, Rover, MAV combination. The Orbiter will collect the samples from both the '07 and '09 Landers to return to earth.

The same scenario repeats itself in the 2011, 2013 opportunities.

Several micro spacecraft missions are also possible during this time frame, including possibly one in 2003, and two in 2005, 2007 and 2009.

At the bottom of Figure 8, the infusion of HEDS related technology is shown. The time at which the infusion takes place is dependent on the pace of the HEDS' budget.

HEDS technology demonstrations include in-situ propellant production from the Mars environment for the return trip to earth, the transition to mid-L/D entry vehicles and the use of aerocapture for insertion into Mars orbit.

Another interaction with the HEDS involves the emplacement of a significant telecommunication infrastructure at Mars that would eventually enable nearly real time video from Mars to Earth.

All of these technologies will eventually be needed when humans go to Mars. The MSP mission can serve as necessary precursors for human missions and can be used to reduce the cost and risk of the eventual human missions.

Figure 9 illustrates how the architecture fits within the budget available through the 2009 missions.

SUMMARY

The architecture developed for the MSP will provide the following:

- Acquisition and return of the first sample from Mars by 2008.
- Acquisition and return of three sets of samples by 2012.
- A continuous flow of scientific information about Mars present and past.
- Injection of technology and new science investigations every two years.
- Strong international participation.
- Public engagement in the evolving Mars exploration story.

It should also provide the opportunity to:

- Return two samples from two different sites by 2008 as a means to enhance the likelihood of getting at least one sample.
- Acquire carefully selected surface samples and samples from a few meters below the surface.
- Conduct a number of scientific investigations from Landers and micro spacecraft missions.
- Demonstrate key technologies for future human exploration.

And, with a modest new initiative will allow the establishment of a long term telecommunications infrastructure capable of ~1 Mbps communication rates between Mars and Earth.

ACKNOWLEDGMENT

The work described in this paper was performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

REFERENCE

1. The Search for Evidence of Life on Mars, the Mars Expeditions Strategy Group, 26 September 1996.

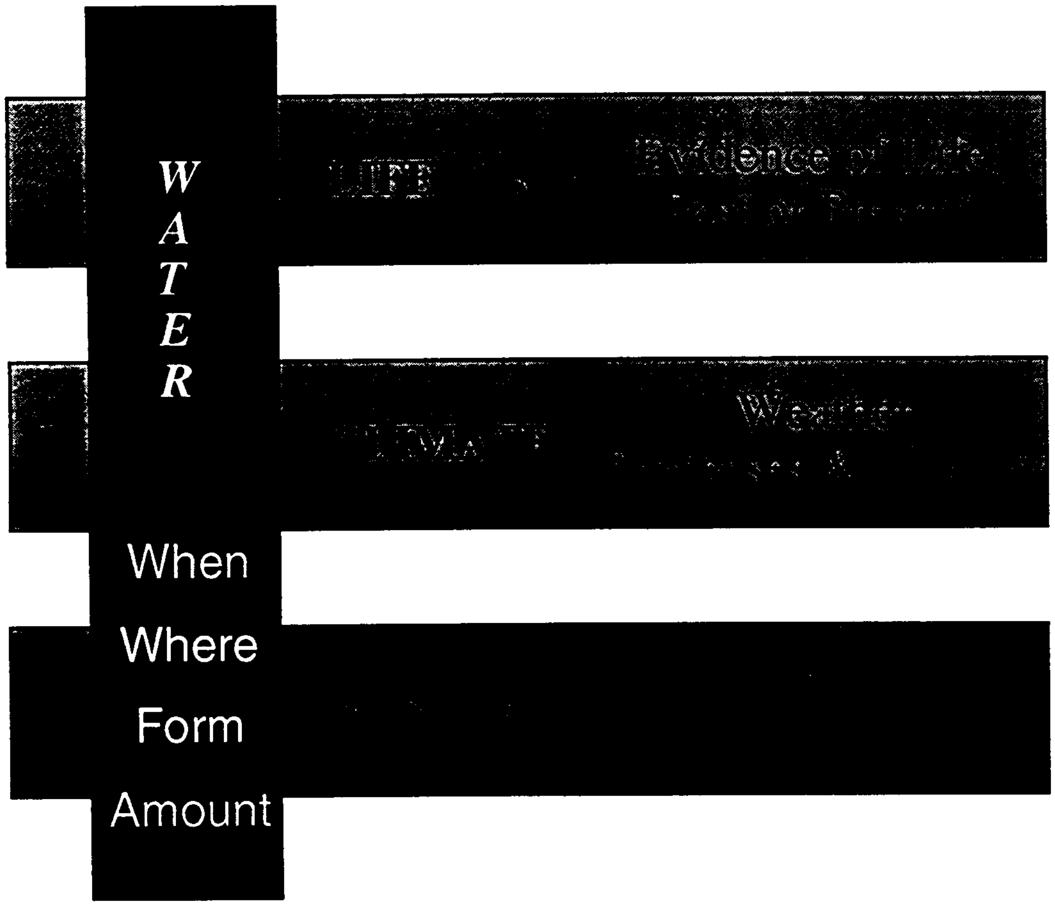
Figure 1

MARS EXPLORATION

The Common Thread

Primary Goals

Resulting Knowledge



Understand the Potential for Life Elsewhere in the Universe

Understand the Relationship to Earth's Climate Change Processes

Understand the Solid Planet: How It Evolved and Its Resources for Future Exploration

Figure 2

MARS EXPLORATION PROGRAM (1996-2001)

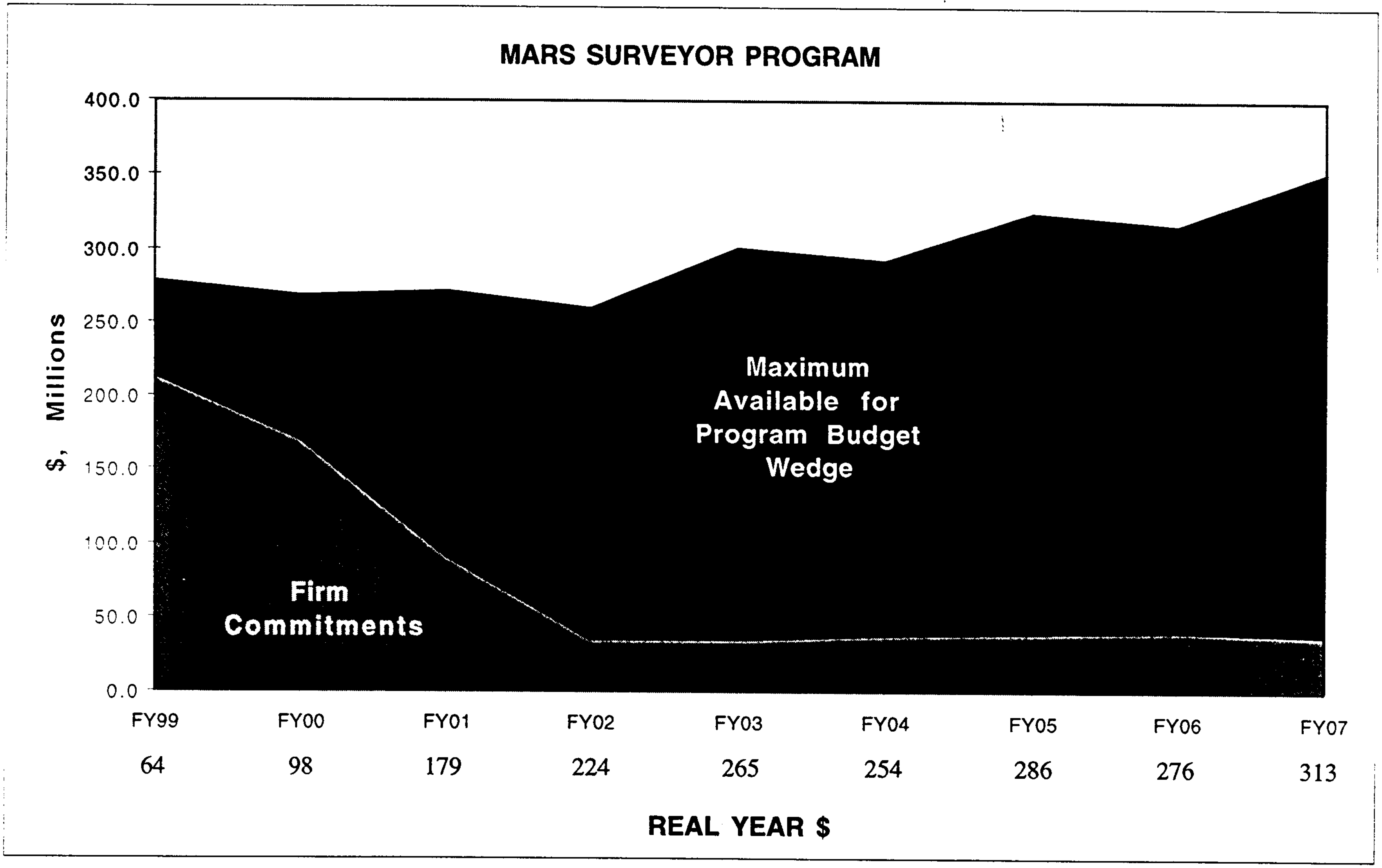
Launch Dates:

1996	1998	2001	2003	2005	2007	2009
Geology & Geophysics	*Water, Volatiles & Climate*	*Elemental Composition & Global Mineralogy*	*Geology & Mineralogy*			
			Mars Express (ESA/ASI)			
Lander Technologies; Microrover	*Analyze Subsurface Ice*	*Survey Conditions for Human Exploration*		TBD		
Mars Pathfinder	DS-2 Microprobes					
	Interaction with Solar Environment					
	Nozomi (Japan)					

= NASA Mars Surveyor Program = NASA Discovery Program = NASA New Millennium Program = International Missions

9/15/98

Figure 3



MARS SURVEYOR PROGRAM
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
$, Millions
Maximum Available for Program Budget Wedge
Firm Commitments
FY99
FY00
FY01
FY02
FY03
FY04
FY05
FY06
FY07
64
98
179
224
265
254
286
276
313
REAL YEAR $

Figure 4

TRADE Recommendations from Sample Return Workshops

- ISPP vs. BYOP
- Liquid guided vs. Solid unguided
- Direct return vs. Rendezvous with orbiter
- Rover vs. Other mobility
- Direct Earth entry vs. Other
- Surface rendezvous
- Aerocapture vs. Rocket capture
- Sample transfer

- Start with BYOP
- Solid unguided
- Rendezvous with orbiter
- Rover
- Direct Earth entry
- No
- Rocket capture
- Tough problem

Figure 5

Potential International Contributions

(for multiple opportunities, unless otherwise noted)

- **NASA Provides**:
  - Lander, Rover, Mars Accent Vehicle, Rendezvous and Docking Equipment, Earth Entry Capsule, beginning 2003
  - Delta 3/4 Class Launch Vehicles beginning in 2003
  - Micromission Bus, beginning in 2003
- **CNES Provides**:
  - Orbiter, capable of bringing two samples back to earth, beginning 2005
  - Ariane 5 Launch Vehicle in 2005 only
  - Ariane Piggyback Launches to GTO, beginning in 2003
  - NetLanders in 2005

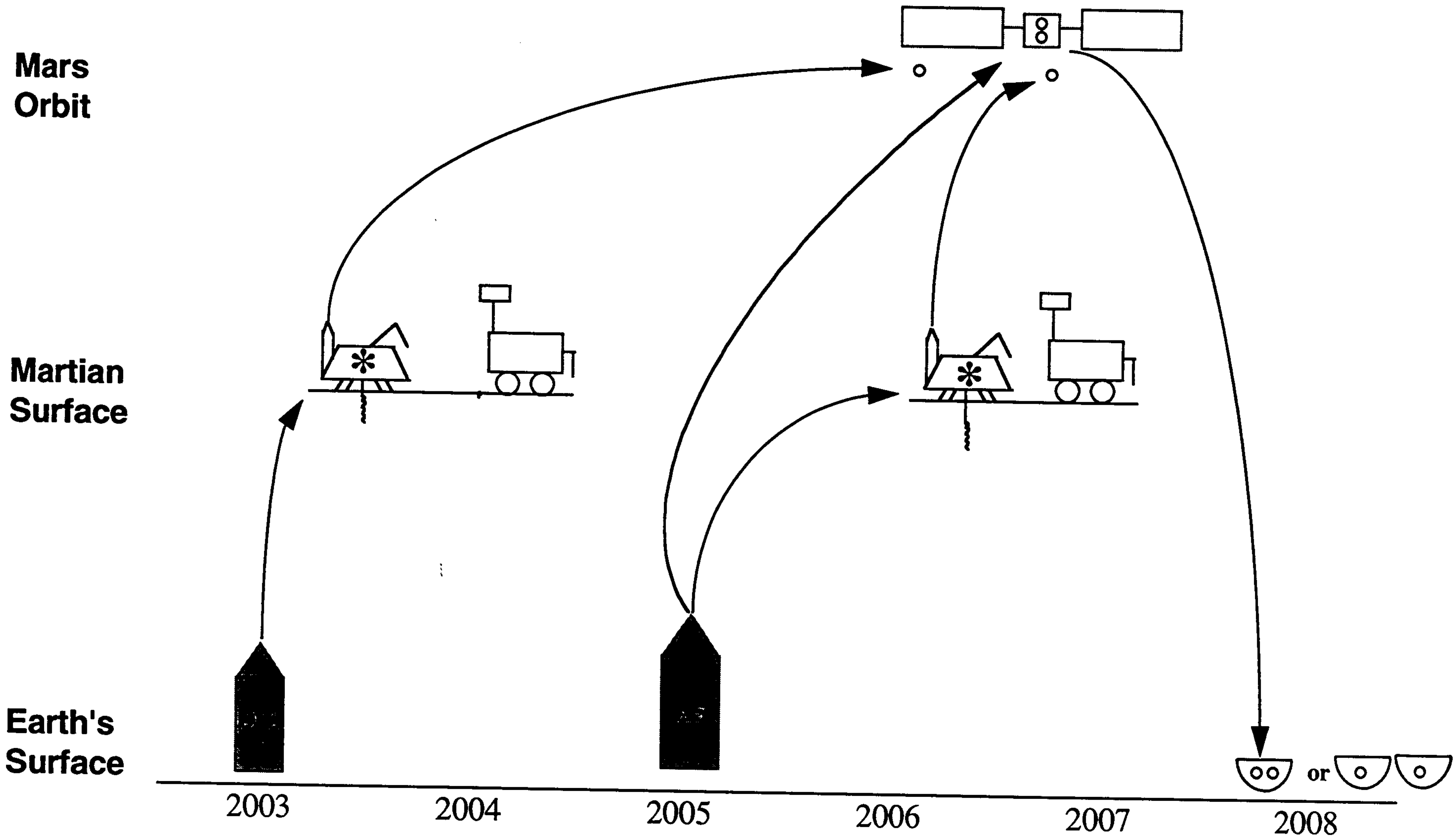
SOLAR SYSTEM EXPLORATION

Potential International Contributions (cont'd.)

- **ASI provides:**
  - Drill and other robotic elements for Landers, beginning 2003
  - Relay telecom on Mars Express
- **ESA provides:**
  - Mars Express Orbiter in 2003
  - Sample canister sighting and orbit determination in 2004 (using DLR high resolution stereo camera)

Figure 7

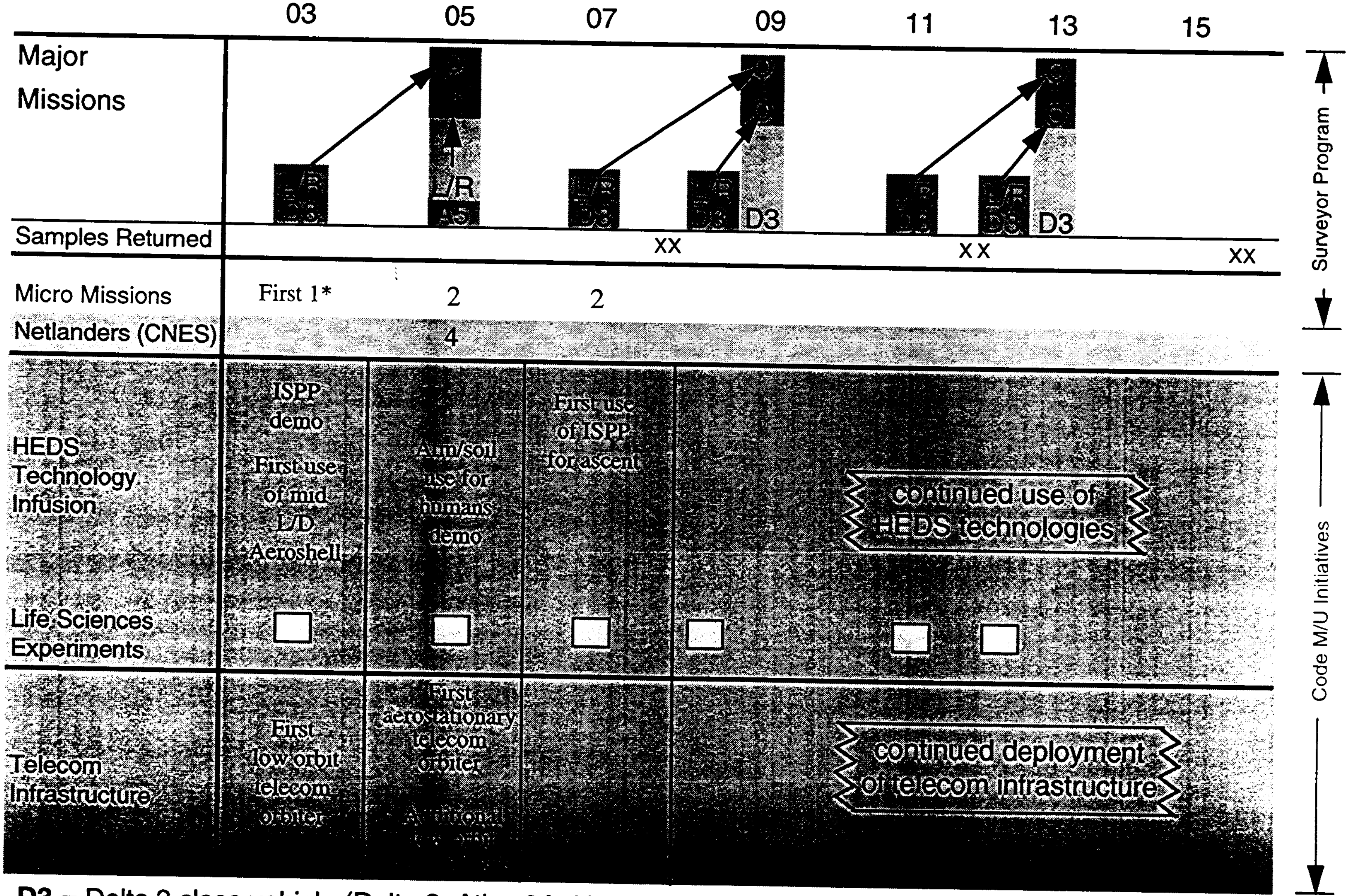
Mars Surveyor Proposed Architecture 2003, 2005 Opportunities



DIII = Delta 3 class vehicle (Delta 3, Atlas 3A, H2, etc.)
*** = Includes 100 kg mass for drill, arm and experiments in addition to rover and mini MAV**

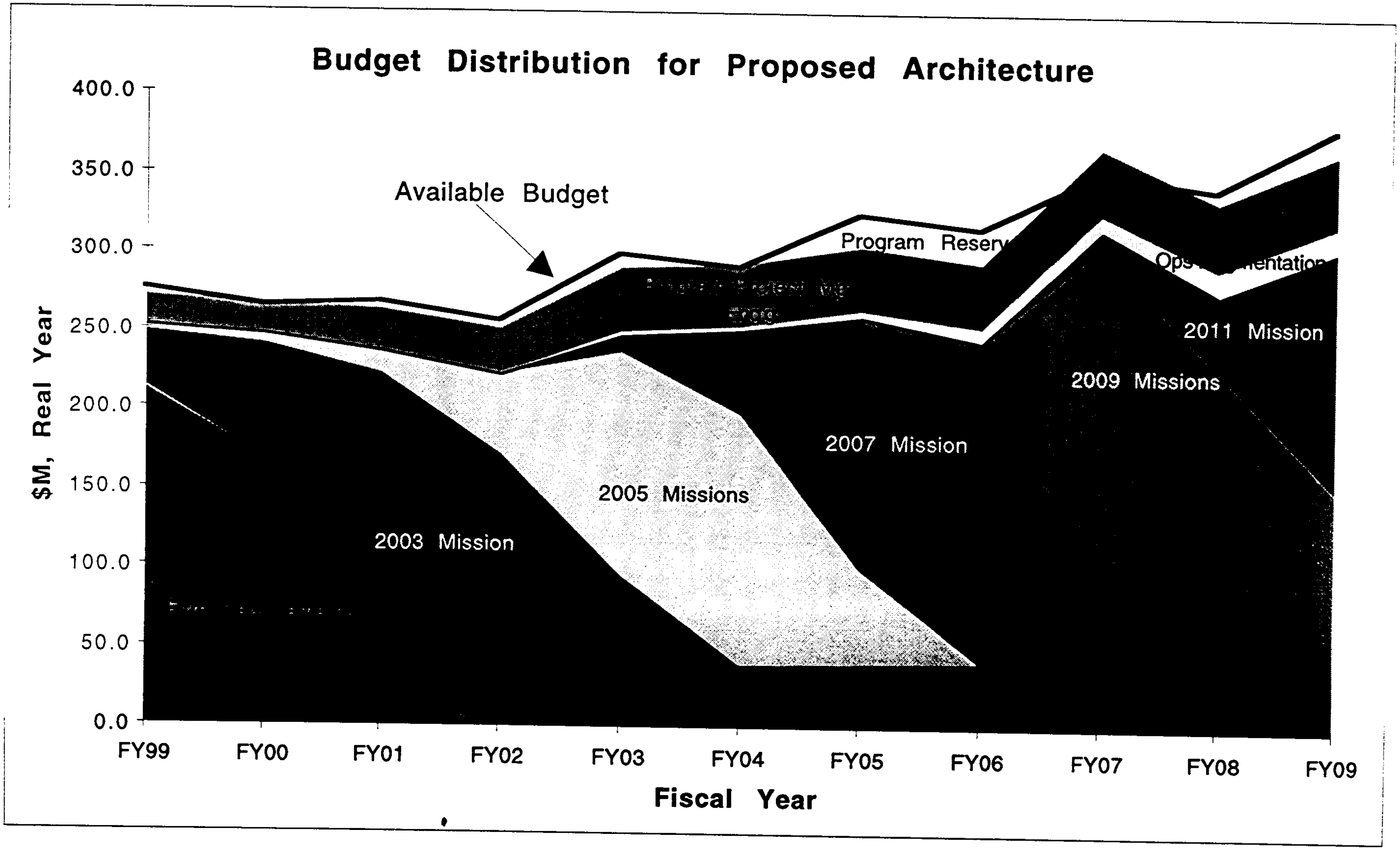
Figure 8

Proposed Integrated Architecture



D3 = Delta 3 class vehicle (Delta 3, Atlas 3A, H2, etc.) * = currently not fully within budget profile

Figure 9


Budget Distribution for Proposed Architecture
Available Budget
2003 Mission
2005 Missions
2007 Mission
2009 Missions
2011 Mission
$M, Real Year
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
FY99
FY00
FY01
FY02
FY03
FY04
FY05
FY06
FY07
FY08
FY09
Fiscal Year