National Aeronautics and
Space Administration

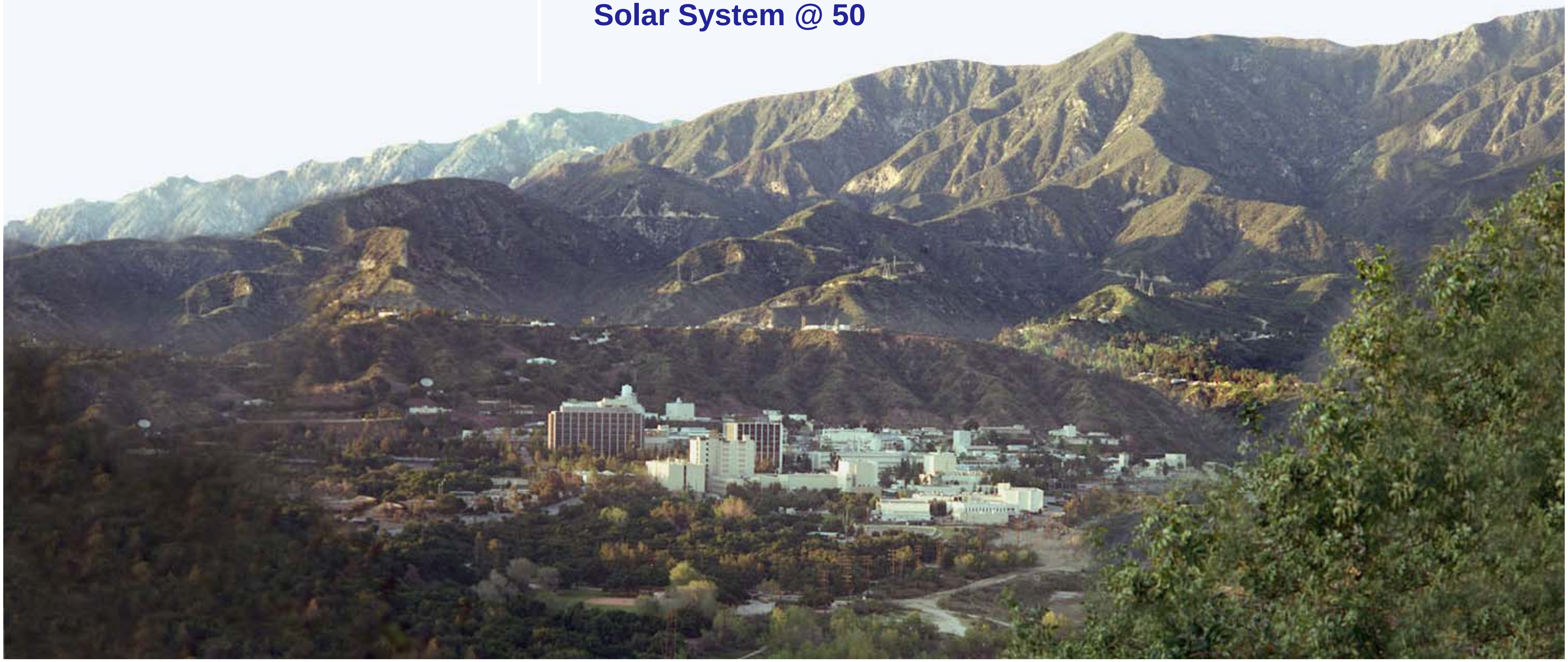
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

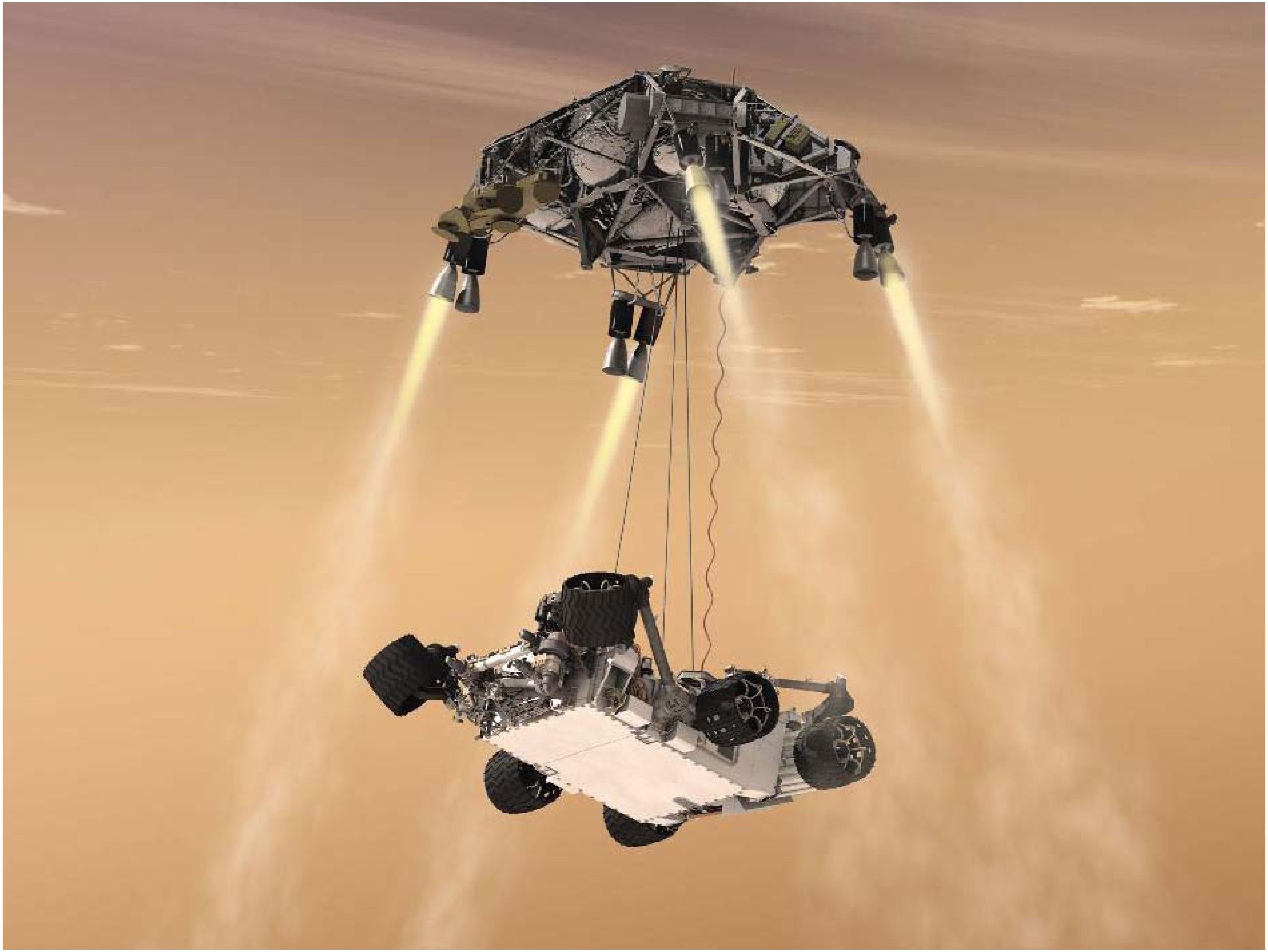
Dreaming of Mars Sample Return

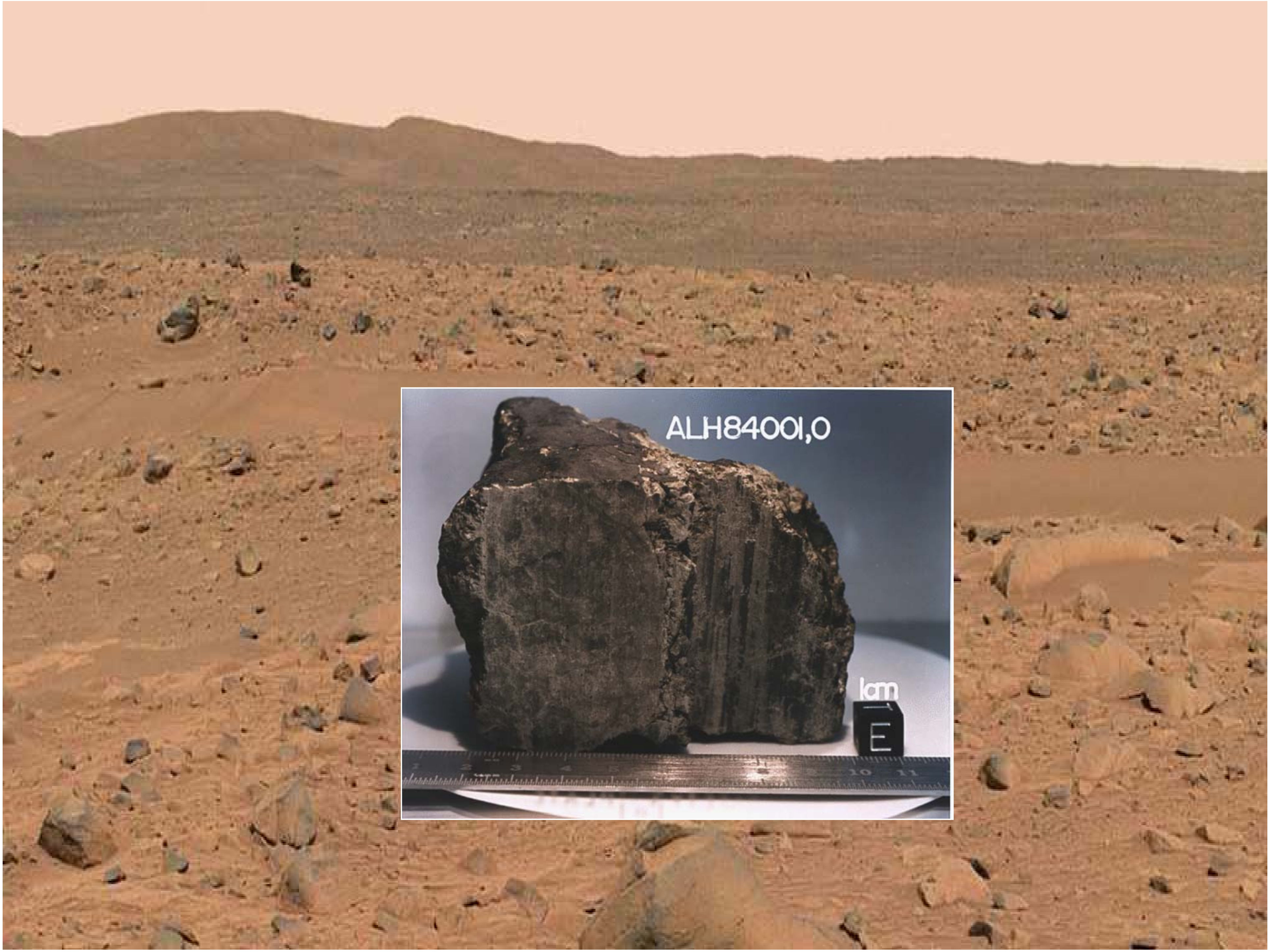
Erik M. Conway

October 2012

Solar System @ 50



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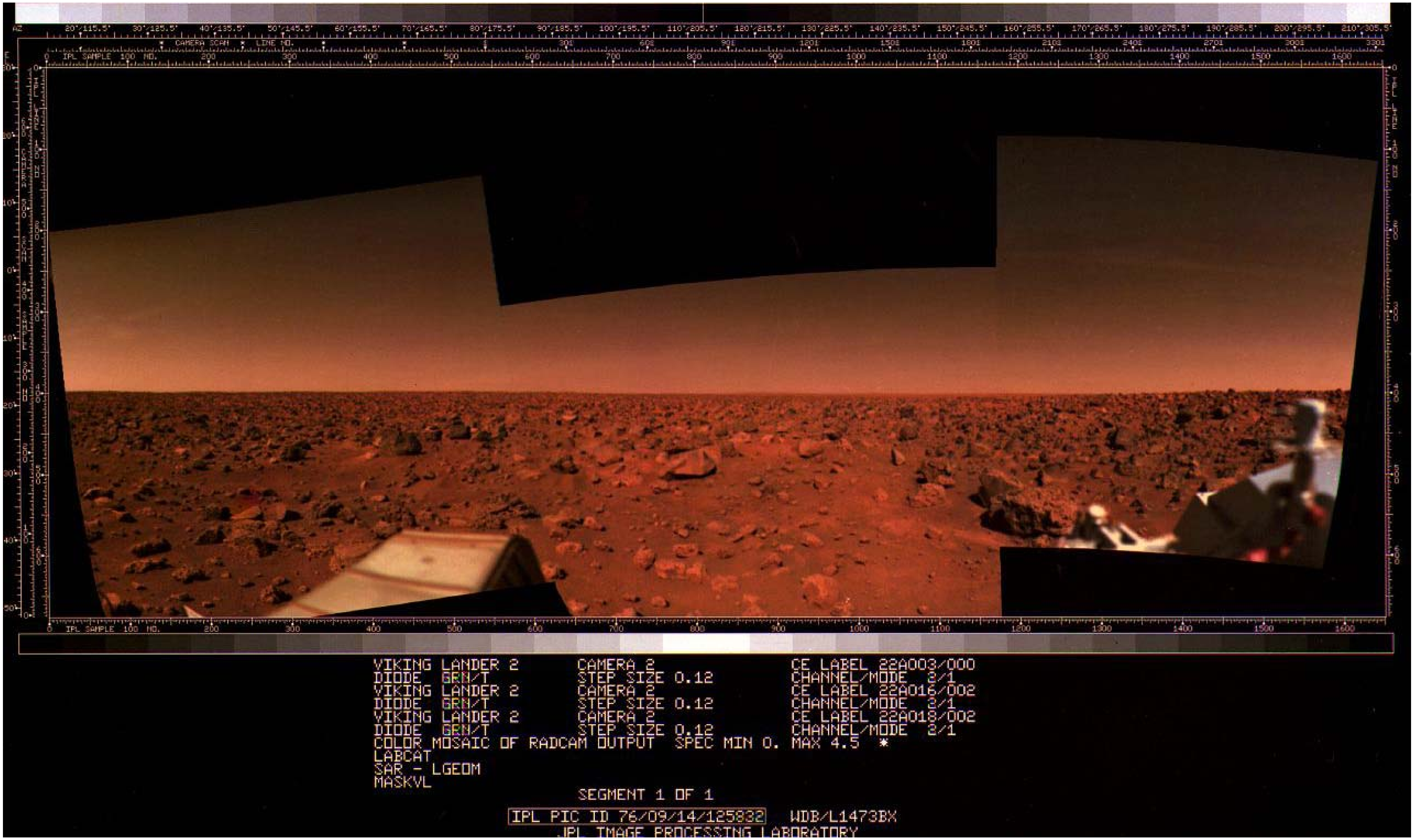
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Strategy for Exploration of the Inner Planets: 1977–1987

The National Research Council

Committee on Planetary and Lunar Exploration

Space Science Board

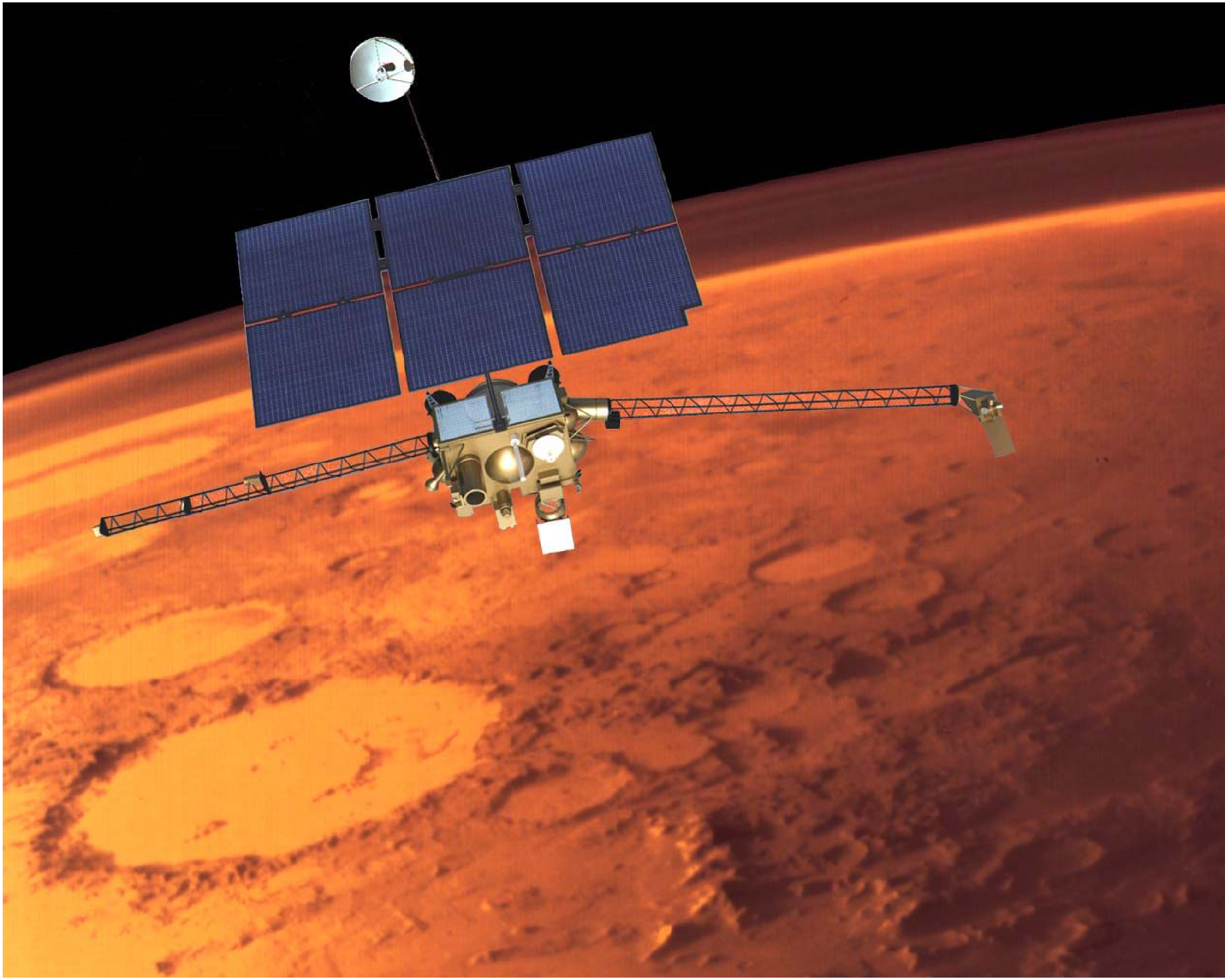
nbly of Mathematical and Physical Sciences

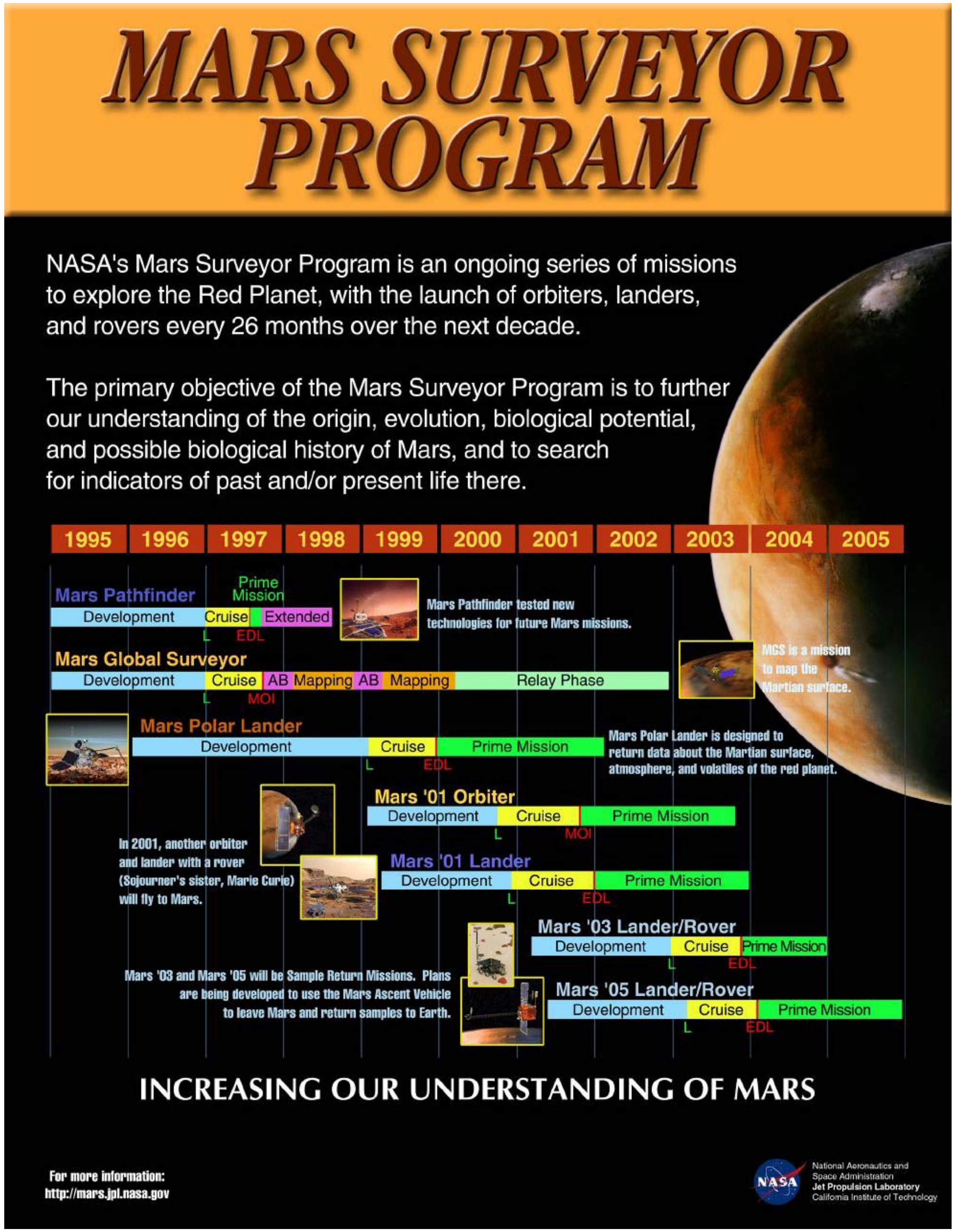
Threads of this Story

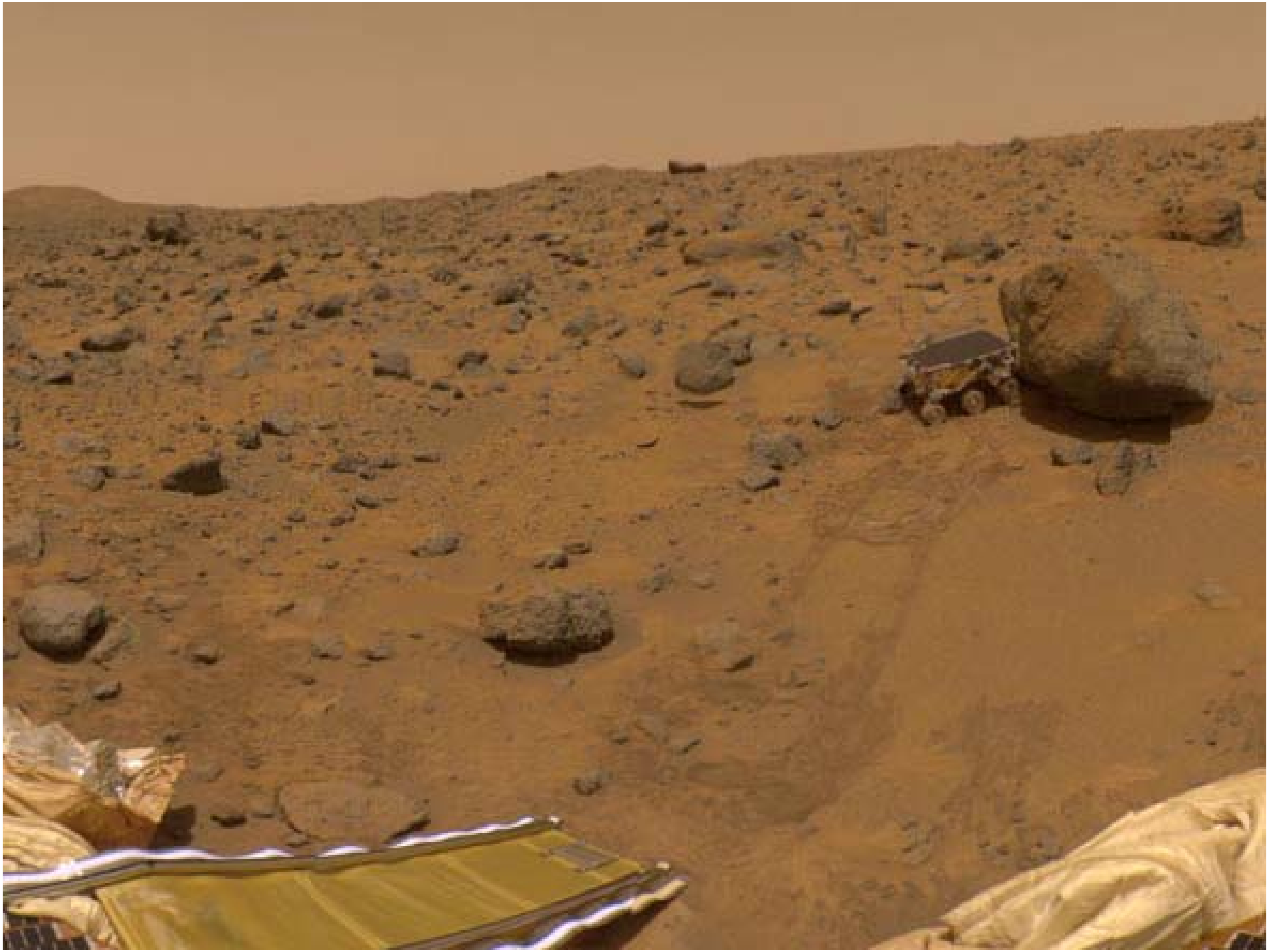
- Design and Engineering in support of science
- Competition for funds within NASA
- NASA's dual self-image as
  - A scientific agency
  - The enabler of human expansion into the solar system

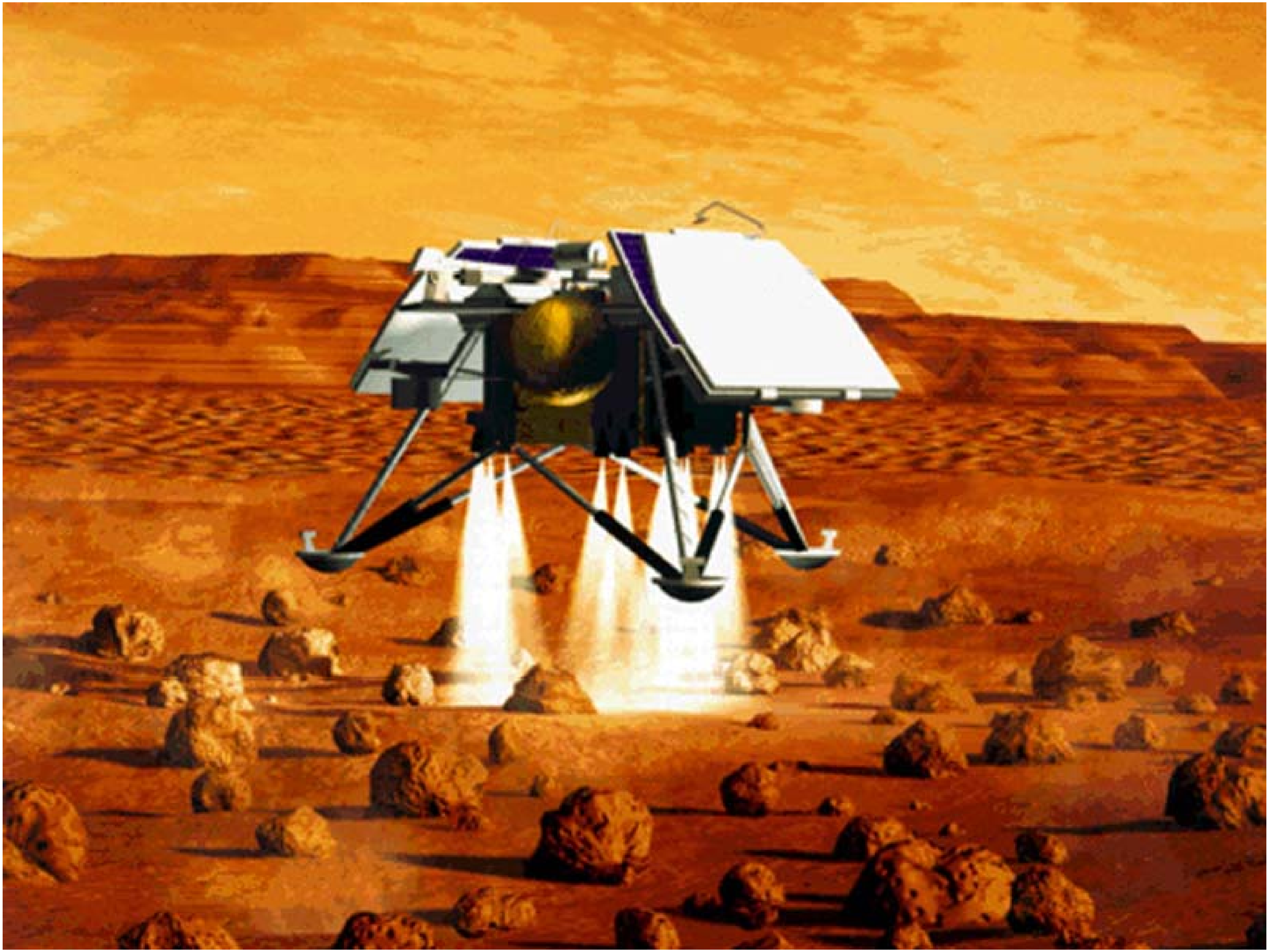
Act I: Scientists and Sample Return, 1977-1989

Act II: Sample Return in the Faster, Better, Cheaper Era

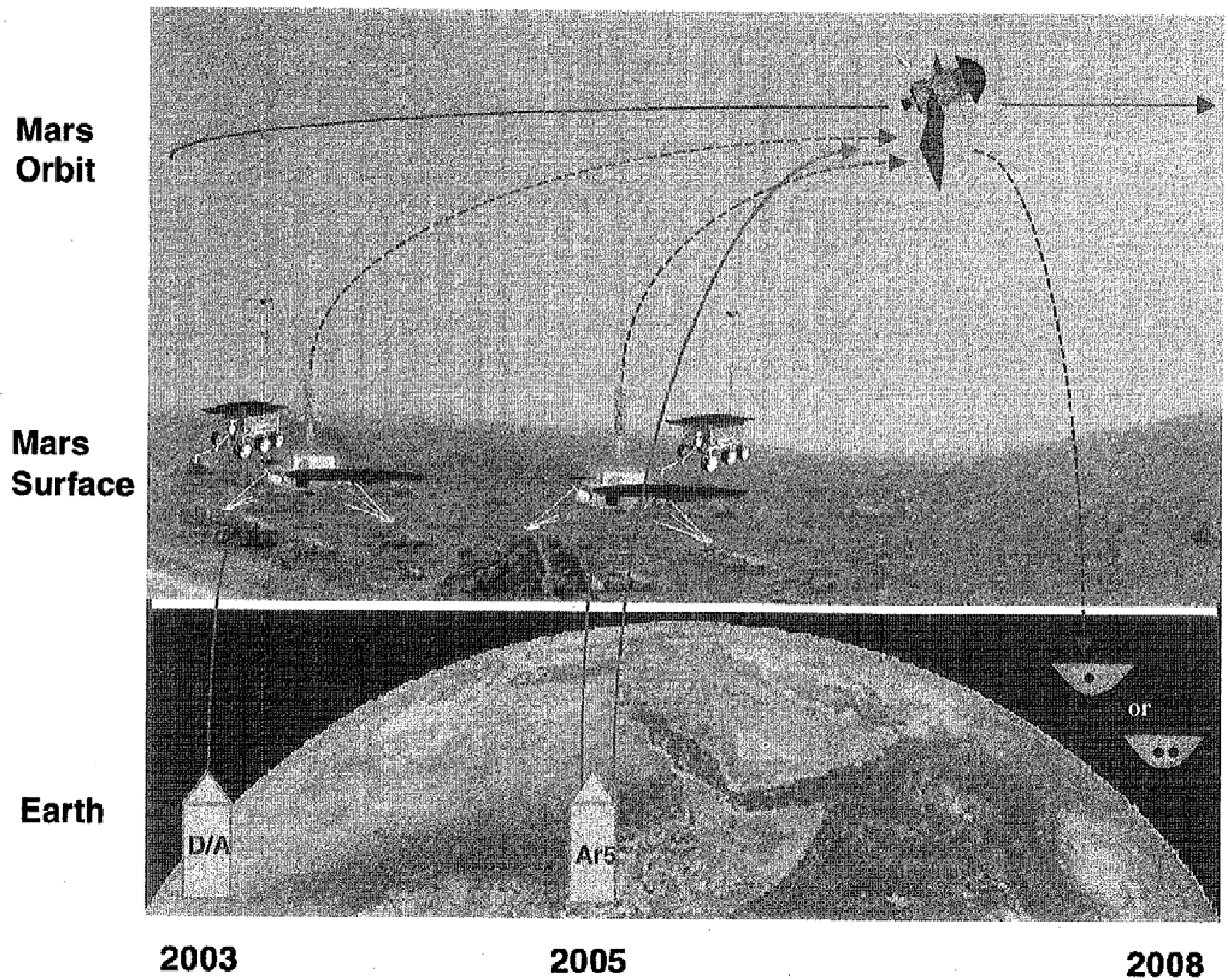



MARS SURVEYOR PROGRAM
NASA's Mars Surveyor Program is an ongoing series of missions to explore the Red Planet, with the launch of orbiters, landers, and rovers every 26 months over the next decade.
The primary objective of the Mars Surveyor Program is to further our understanding of the origin, evolution, biological potential, and possible biological history of Mars, and to search for indicators of past and/or present life there.
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
Mars Pathfinder
Prime Mission
Development
Cruise
Extended
L
EDL
Mars Pathfinder tested new technologies for future Mars missions.
Mars Global Surveyor
Development
Cruise
AB
Mapping
AB
Mapping
Relay Phase
L
MOI
MGS is a mission to map the Martian surface.
Mars Polar Lander
Development
Cruise
Prime Mission
L
EDL
Mars Polar Lander is designed to return data about the Martian surface, atmosphere, and volatiles of the red planet.
Mars '01 Orbiter
Development
Cruise
Prime Mission
L
MOI
In 2001, another orbiter and lander with a rover (Sojourner's sister, Marie Curie) will fly to Mars.
Mars '01 Lander
Development
Cruise
Prime Mission
L
EDL
Mars '03 Lander/Rover
Development
Cruise
Prime Mission
L
EDL
Mars '03 and Mars '05 will be Sample Return Missions. Plans are being developed to use the Mars Ascent Vehicle to leave Mars and return samples to Earth.
Mars '05 Lander/Rover
Development
Cruise
Prime Mission
L
EDL
INCREASING OUR UNDERSTANDING OF MARS
For more information:
http://mars.jpl.nasa.gov
NASA
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

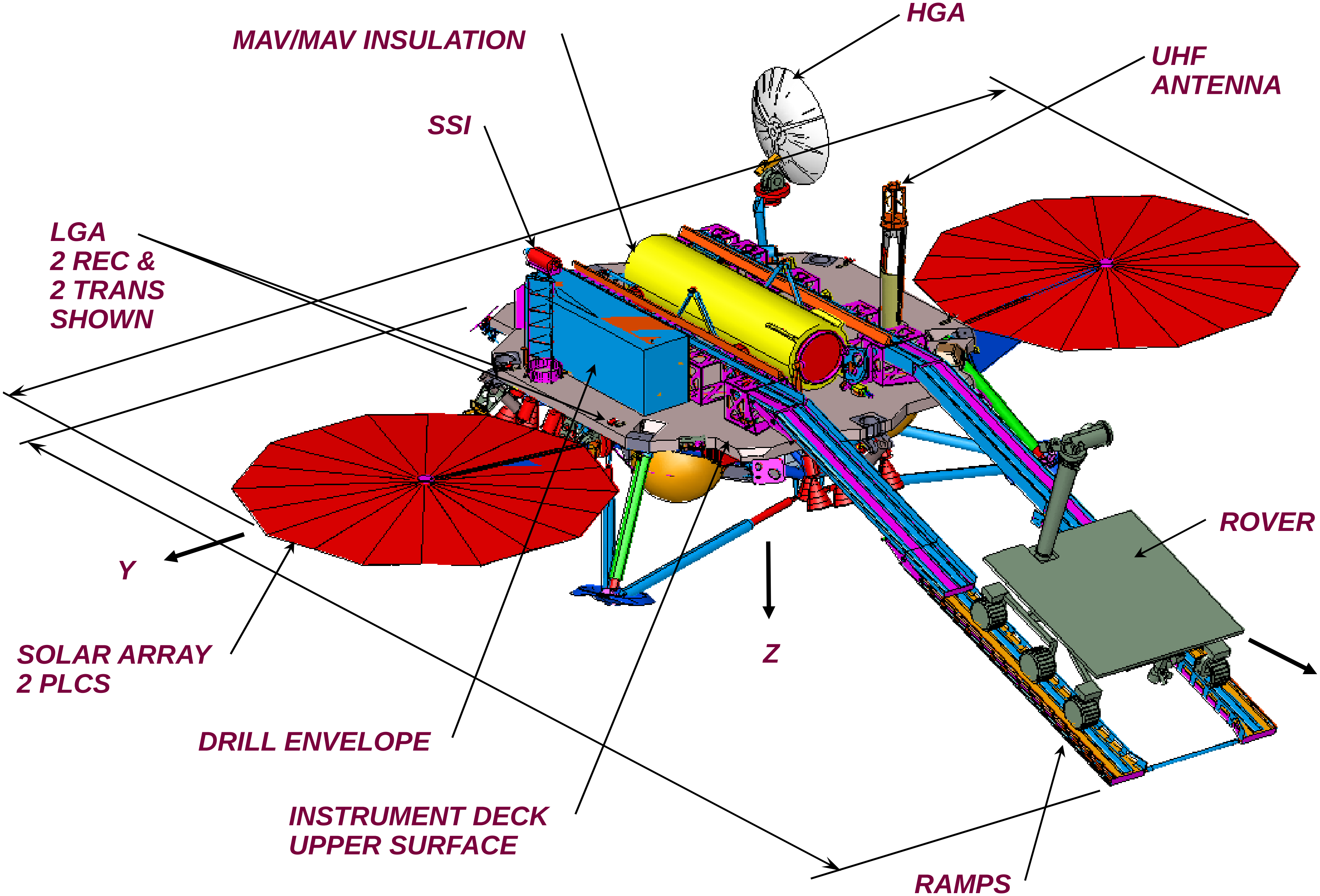




Mars Sample Return Missions: 2003, 2005 Opportunities



LANDED CONFIGURATION



Report on the Loss of the Mars Polar Lander and Deep Space 2 Missions

JPL Special Review Board

22 March 2000

Jet Propulsion Laboratory
California Institute of Technology

JPL D-18709

Act III
The Bubble Team and Large Lander Studies

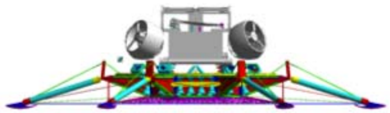
Evolution from MSR Large Lander to Mars Smart Lander (circa early 2000)

Mars 98 & MSR

•The failure of the M98 lander mission during MSR's phase A, led to a change in risk posture on landing robustness.

•Several review boards and tiger teams were assembled to redirect MSR's landing/EDL architecture.

•Robust rover egress for MSR was never addressed.

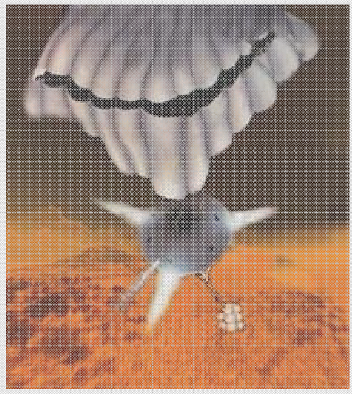


Mars Smart Lander

•Extensive evaluation of many different EDL and Landing architectures suitable for MSR were studied.

•Pallet style landing system with a large rover was selected based on expectation of a 2005 launch.

•Pallet greatly improved egress and landing safety.

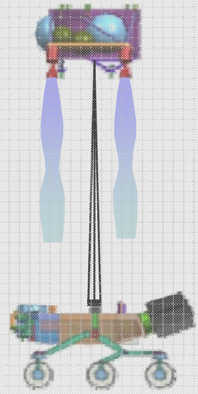


Mars Expl. Rover

•MSL mission was delayed to 2007 and then 2009, resulting in more time to develop technologies.

•MER made a large investment in developing multi-body control dynamics.

•MER discovered the hidden challenges and costs of egressing a rover.



Mars Science Lab.

•EDL architecture given one last "fresh" look, focused on:

Cost Reduction

Performance Increase

EDL Feed Forward

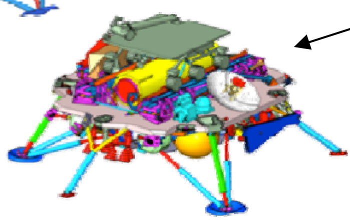
•Desire to incorporate best lessons and technologies from MER; multi-body control, DRL…

•Further advancement of sensor technologies & HDA

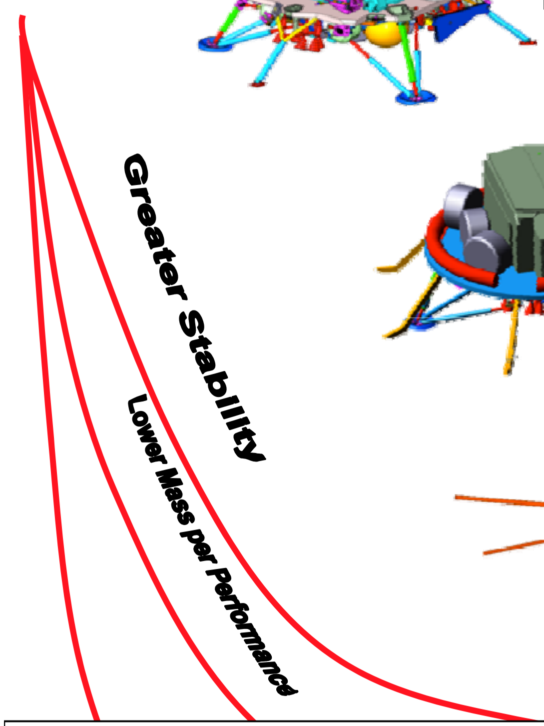
• Sky Crane invented

Design Evolution From Tripod to Pallet

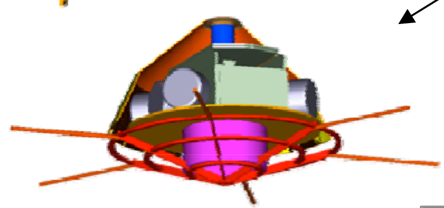
Starting Point:
- Tripod lander based on Viking heritage.
- Deployable ramps required for rover egress.



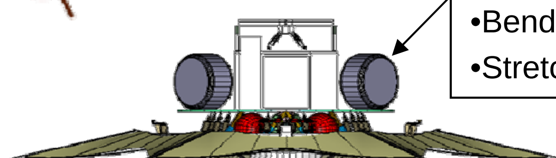
Modified Tripod 1:
- Viking tripod with stability enhancing outriggers added.
- Deployable ramps required for rover egress.



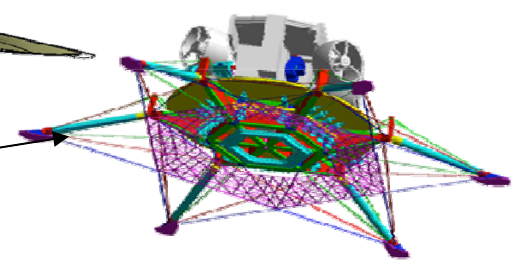
Modified Tripod 2:
- Viking tripod with stability enhancing outriggers added.
- Belly ruggedization for direct rock strikes.
- Inflatable ramps for rover egress.



Pallet Concept 1:
- Crushable belly with low CG & stability outriggers.
- Stretched fabric for rover egress.



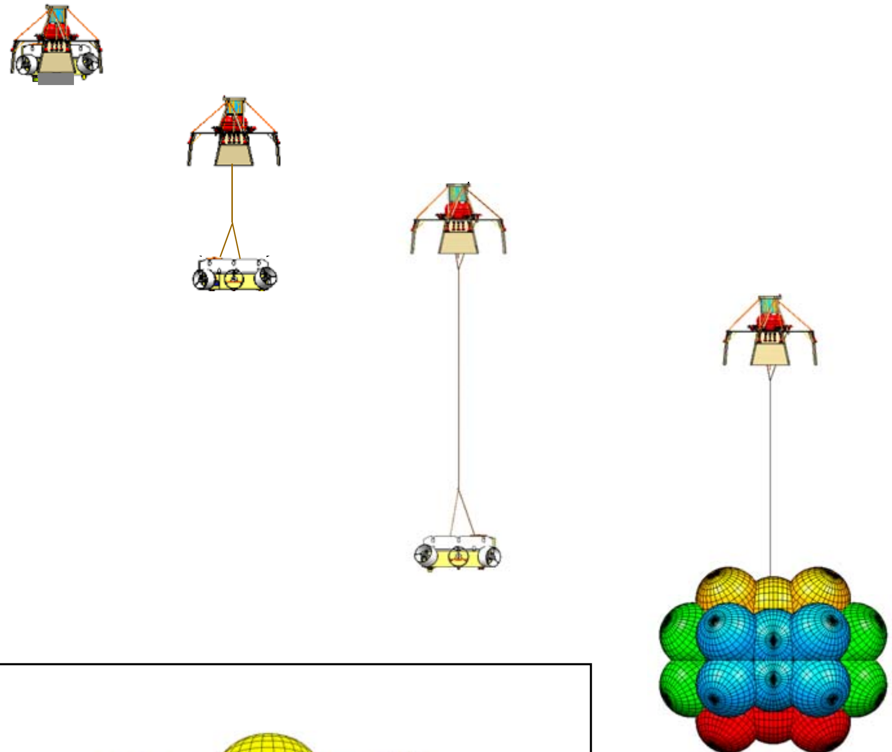
Pallet Concept 2:
- Crash-worthy belly with KE absorbing struts, very low CG and stability outriggers.
- Bending members with discrete energy absorption
- Stretched fabric for rover egress.



Pallet Concept 3:
- Crash-worthy belly with KE absorbing struts, low CG & stability outriggers.
- Cable stayed Tension-Compression outriggers.
- Stretched fabric for rover egress.

Airbag System Landing Concept

The “Rocket-on-a-Rope” approach



System Advantages:

-Descent stage never requires engine shut off

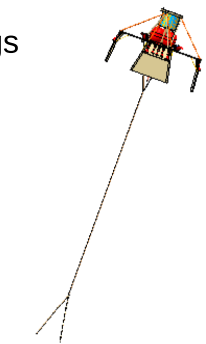
-Propulsion hardware does not require impact protection

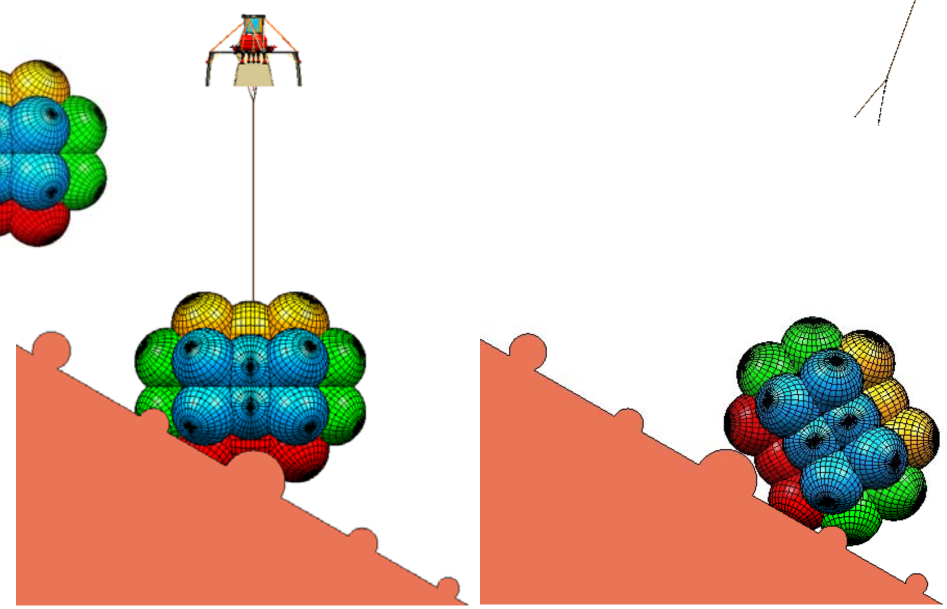
-Improved velocity control (vs Pathfinder & MER missions)

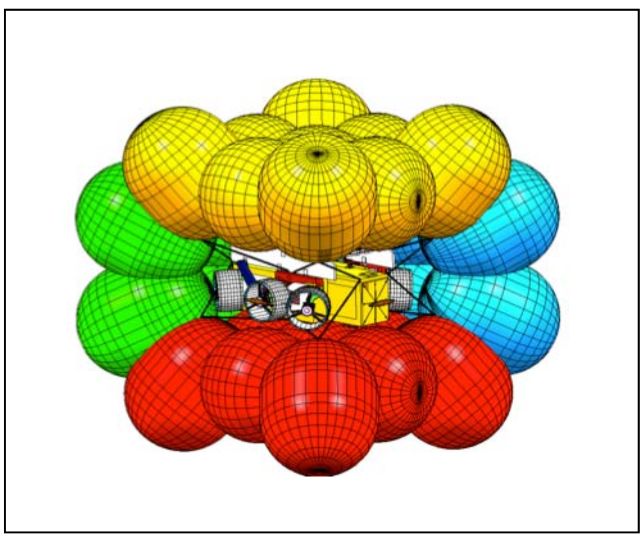
System Disadvantages

-Interface complexity between rover and airbags

-System self-righting and extraction/egress







Sky Crane System Architecture

Two-Body Architecture
Decouples descent stage control from touchdown event and allows persistent touchdown signature

Prop and GNC Away from Surface
Closed loop during the touchdown event

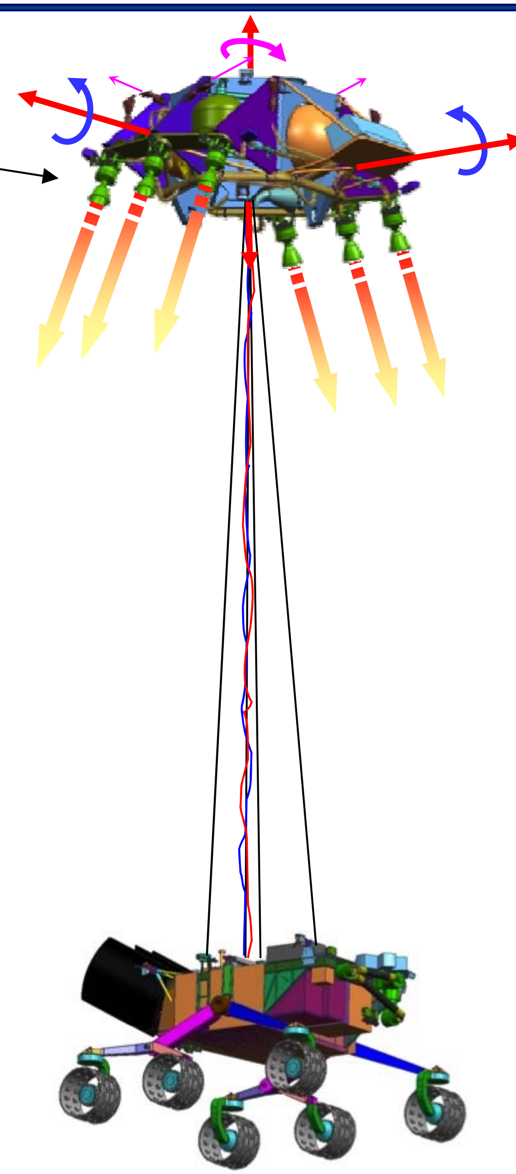
High Bandwidth Vertical Velocity Control
results in low and near constant D/S velocity

Higher Stability
Persistence of tethering during touchdown improves landing stability on rough terrain

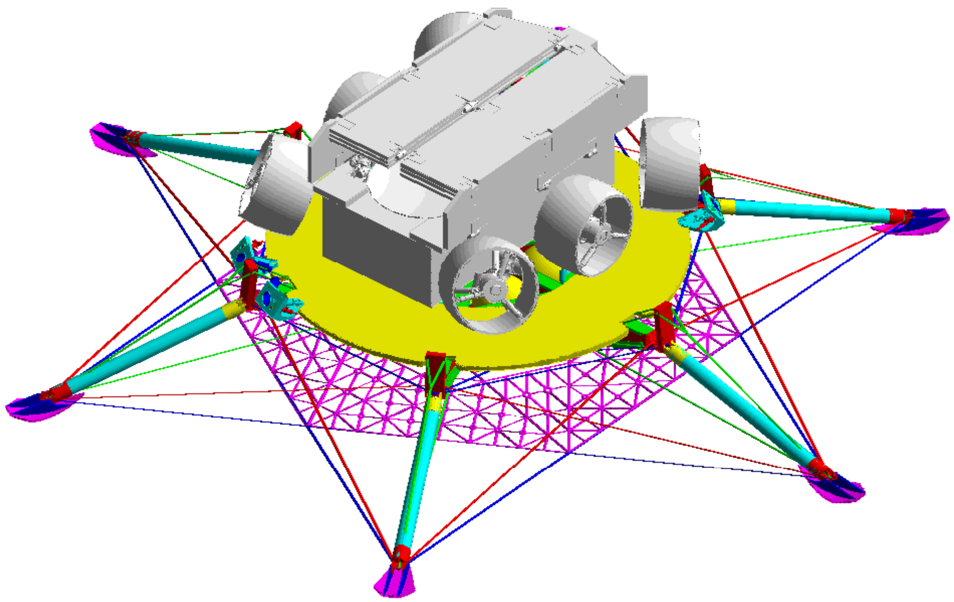
Lower Loads
Low velocities
allows rover landing loads to be similar to the rovers driving loads

System Design
High stability and low landing loads mean:
- Separate TD system not required
- Egress system not required

Rover Becomes the Touchdown System
Rover provides ground clearance, static stability, and terrain adaptation

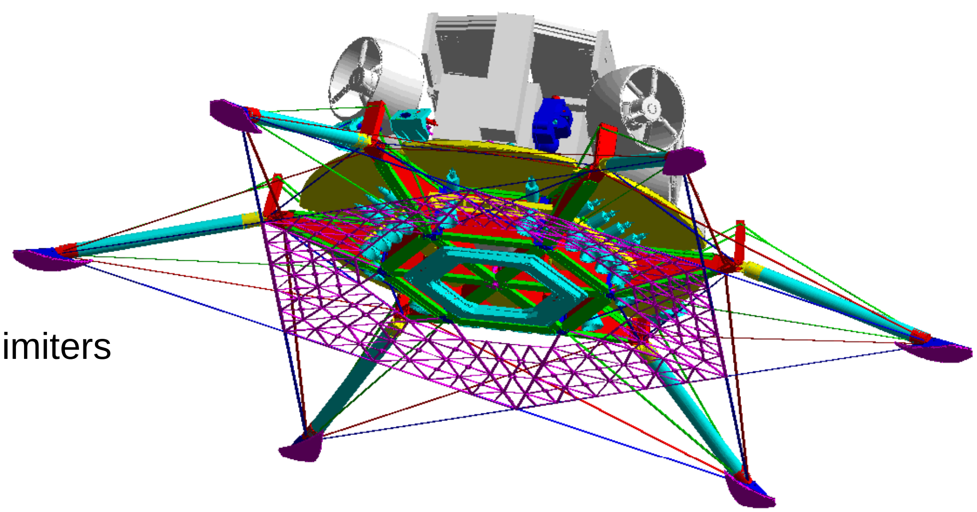


Design for 2005 Pallet Lander with Long-distance Range Rover



Bottom View

–Rock nets protect lander propulsion and avionics during touchdown



Top View

–Cable-stayed outriggers utilizing load limiters on the cables to control loads and stability envelope

Act IV: Planning a New Mars Program

Mars Mobile Pathfinder '03
Mark Adler
Joy Crisp
Howard Eisen
Rob Manning
Jake Matijevic
May 3, 2000

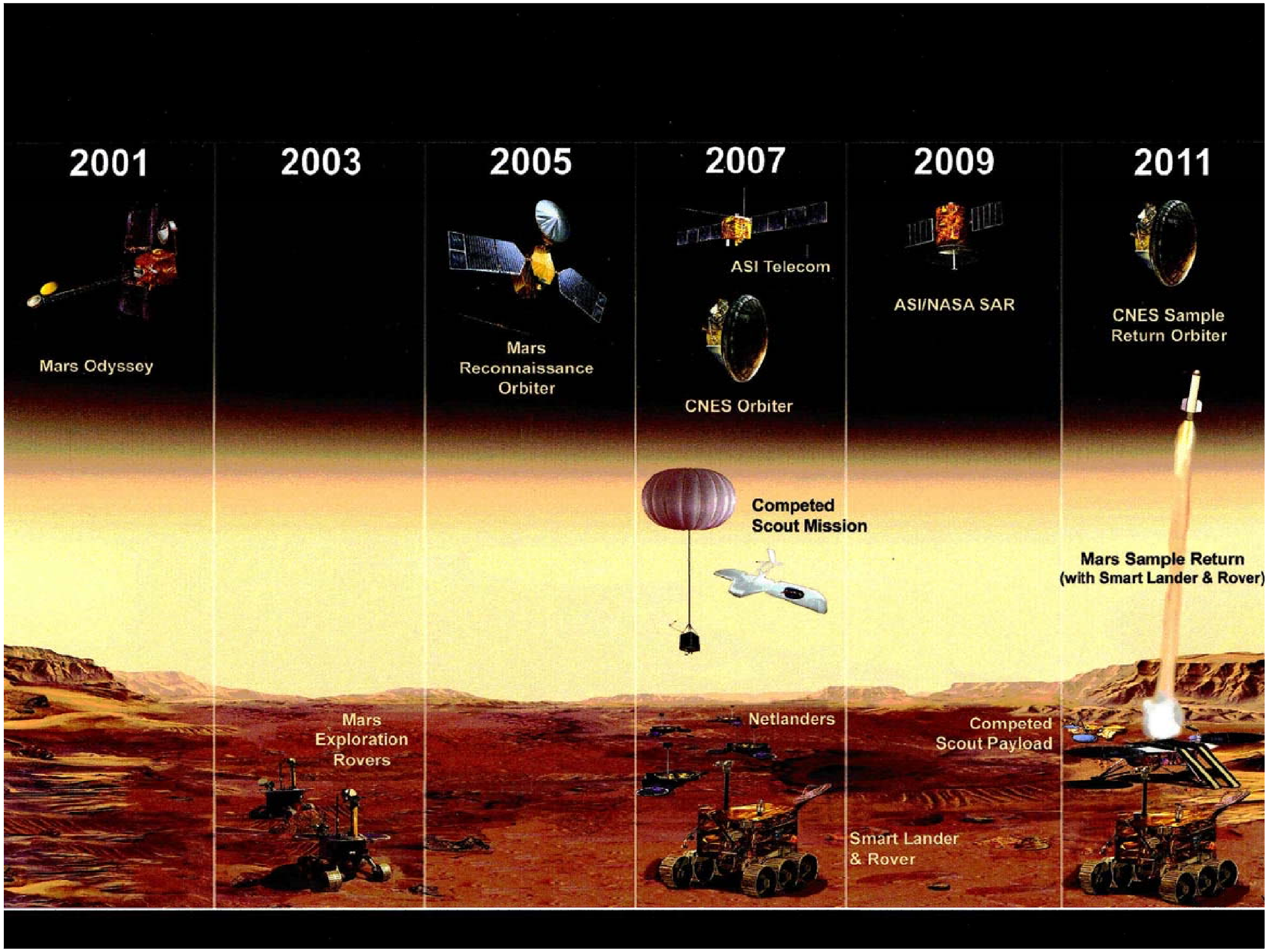
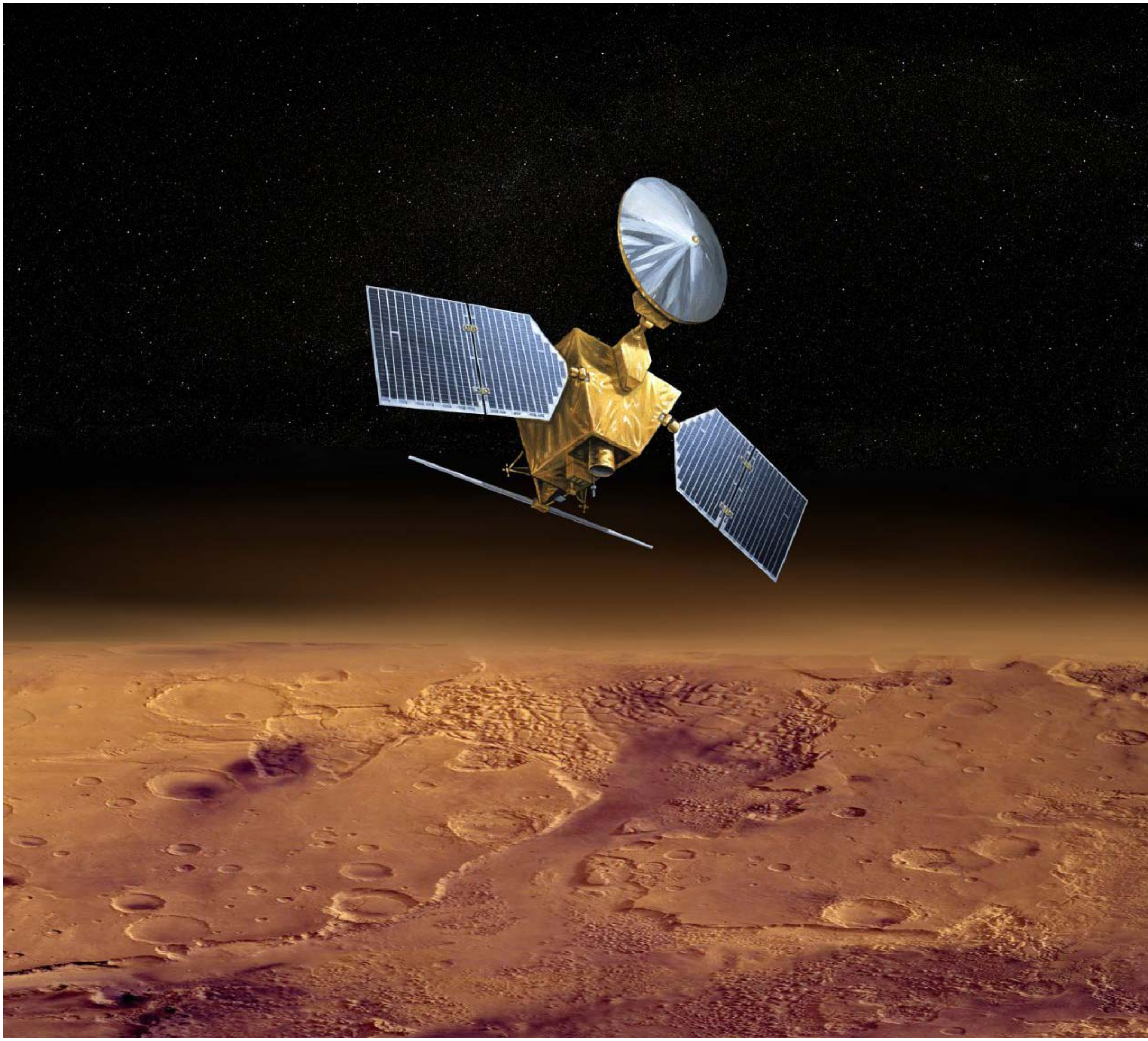
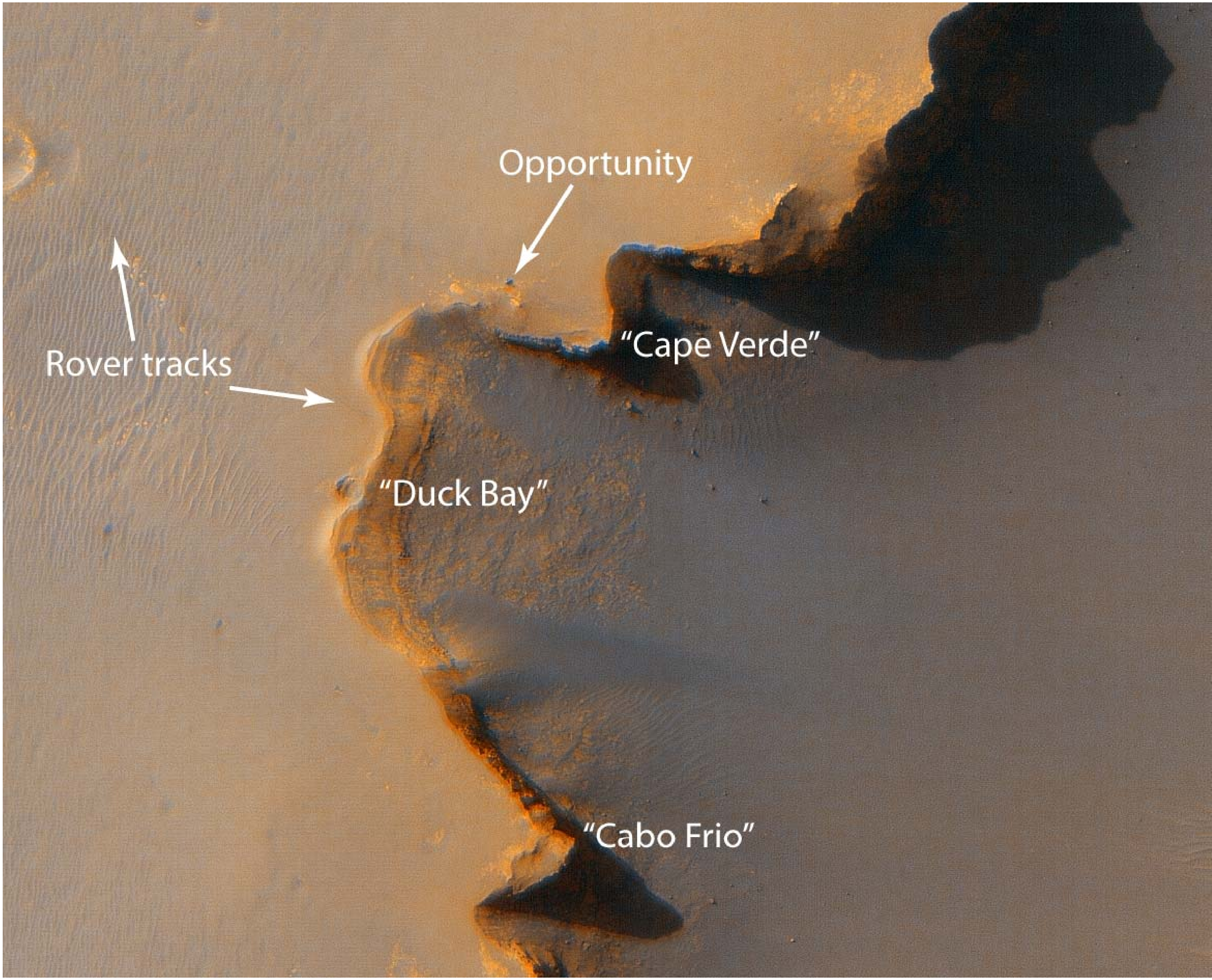
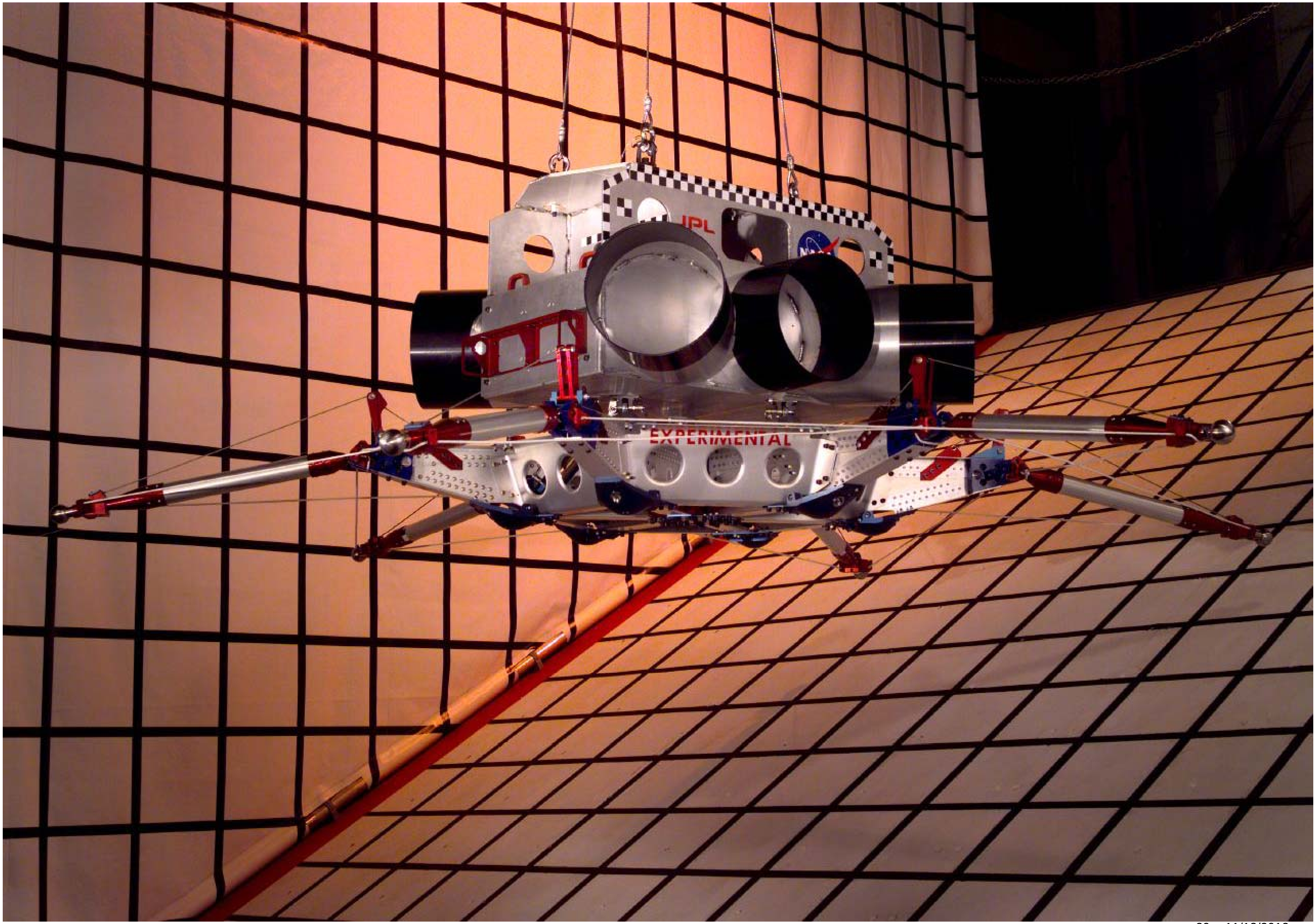


FIG. 3. Chronological view of the missions that constitute the "core program" of NASA's MEP, starting with Mars Odyssey (launched 2001) and continuing up until the first of several MSR missions.

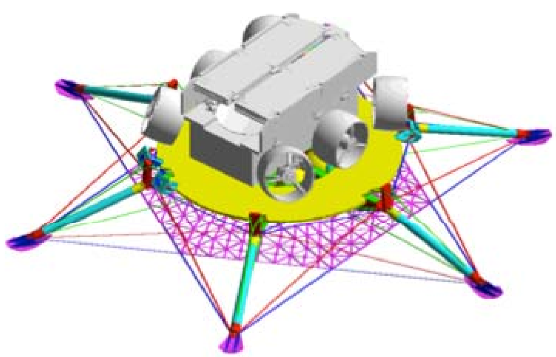



Opportunity
Rover tracks
"Cape Verde"
"Duck Bay"
"Cabo Frio"

Act V: Whither (or Wither?) The Smart Lander


JPL
EXPERIMENTAL

"The SDT looked at this opportunity to define the Smart Lander Mission as the capstone mission for this decade by making groundbreaking scientific discoveries and paving the way for the sample return mission."



of latitudes for surface operations will be limited to approximately 30 degrees about the equator. The mission lifetime and operational activities will also be highly modulated by seasonal controls on amount of sunlight. On the other hand, use of RPS power systems would allow access to all locations on the planet below the altitude cutoff, with an extended period of operations. A primary mission duration of 180 sols is assumed for solar-powered missions and 360 sols for RPS-powered systems. It is noted that RPS systems could easily provide steady power for up to 720 sols, but that the total cost of the mission would need to increase significantly to accommodate flight systems designed to operate over such a long period of time.

These main characteristics of the Smart Lander Mission were the background for the SDT deliberations. The job of the SDT was to make recommendations focused on science to be accomplished during this landed opportunity and the payloads needed to [illegible]plish the science, and to comment on topics specifically requested in the SDT [illegible]endix 1). The Smart Lander precision landing, coupled with delivery of a large pa[illegible] the surface, offers an opportunity to conduct science on an unprecedented scale o[illegible]rs. The SDT looked at this opportunity to define the Smart Lander Mission as the capstone mission for this decade by making groundbreaking scientific discoveries and paving the way for the sample return mission.

3.0 Science Objectives and Measurements Matched to Mission Capabilities

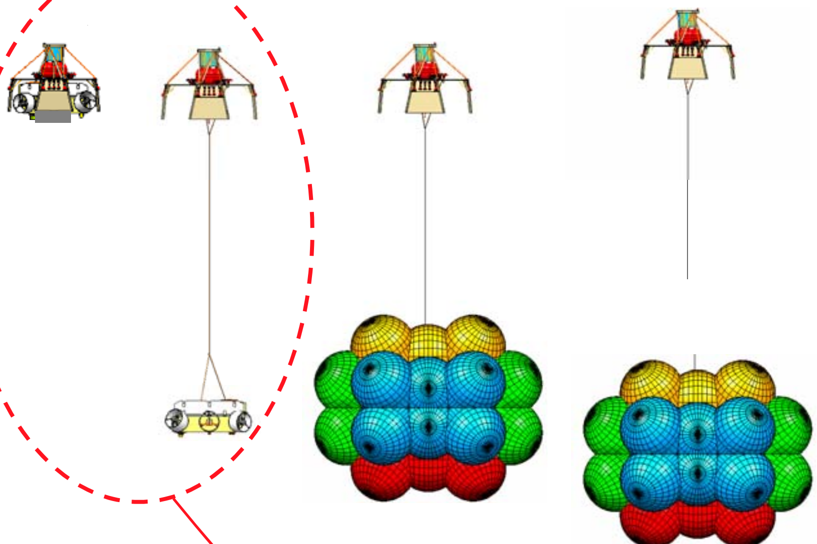
The Mars Exploration Payload Analysis Group (MEPAG) has developed a comprehensive strategic plan for exploration of Mars that is focused on the overarching goals of understanding whether or not life got started and evolved, the causes and timing of current and past climates, and the nature and extent of resources available at and beneath the surface [Greeley, 2000]. The role and availability of water is a central theme. Further, a full understanding of life, climate, and resources requires detailed study of the evolution of the interior, surface, and atmosphere, along with the interplay of various cycles (e.g., climatic and tectonic) that may have dominated Mars during past epochs. All of these results impact our understanding of the extent to which surface and near-surface materials can be used to support human expeditions and the extent to which humans need to cope with hazards during their missions.

The MEPAG document was the starting point for SDT deliberations. That is, the goals, objectives, investigations, and measurements defined by MEPAG were scrutinized for applicability to the Smart Lander Mission, refined and updated as needed, and used to form the backbone of the science to be accomplished during the 2007 landed opportunity. What follows in this section is a discussion of the science objectives that can be addressed for each of the Mars Exploration Program's main themes, which are: development and evolution of life, current and past climates, evolution of the surface and interior, and preparation for human expeditions.

MER Lessons Learned

- Multi-bodies tethered system dynamics
  - The JPL GNC and systems team gained a tremendous amount of knowledge on dynamics and control of the MER multi-body system.
- Descent Rate Limiter
  - New robust DRL device was developed for MER which increased the teams confidence in using such a device in a critical application.
- Egress Challenge
  - Extensive development of the MER egress hardware and operational procedures highlighted the hidden challenges and risks associated with the seemingly simple act of driving off the lander.

Can We Have the Best of Both Worlds?



Airbag w/ Descent Stage System Advantages:

-Descent stage never requires engine shut off continuous GNC

-Propulsion hardware does not require impact protection

~~-Airbags are a robust, understood means of landing.~~

Sky Crane Landing System Advantages

-Descent stage never requires engine shut off

-Propulsion hardware does not require impact protection

-Low CG provides stability for large slope landings

-Highly decoupled and simple I/Fs between rover and pallet

-Low CG provides stability for large slope landings

-Rover standup on a known engineered surface → no standup

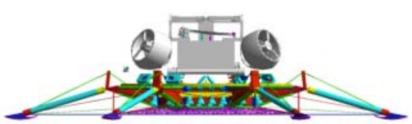
-Lower risk egress easier to design and test → no egress

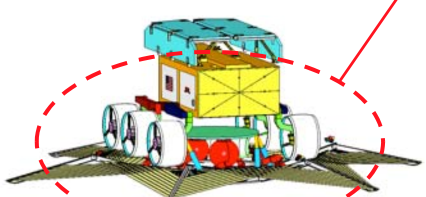
Disadvantages:

-Requires bridle deployment mechanism

-Requires fly-away maneuver

-Requires single nozzle thruster development





Pallet Landing System Advantages:

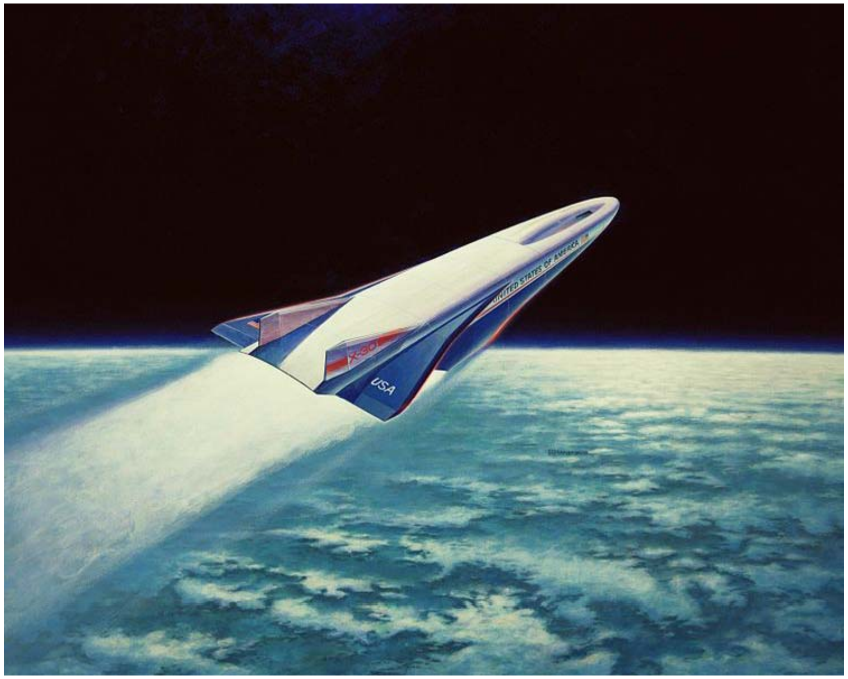
-Highly decoupled and simple interfaces between rover and pallet

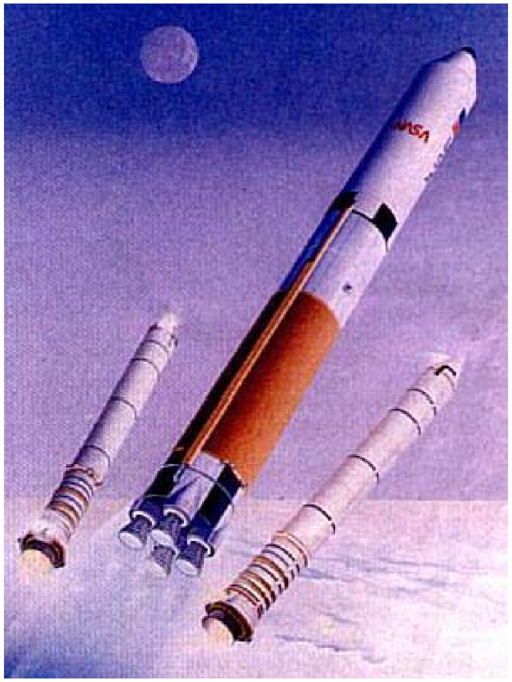
-Low CG provides stability for large slope landings

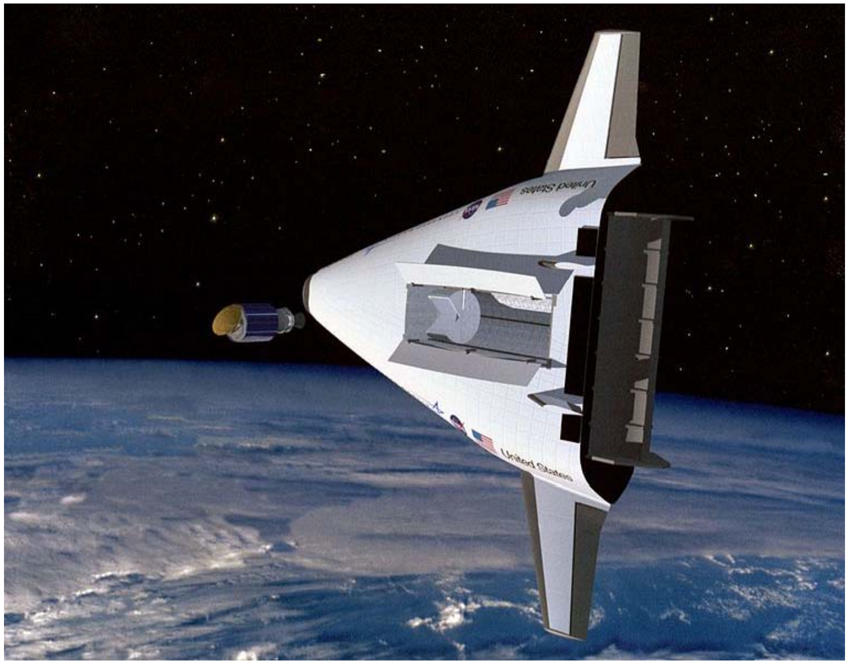
-Rover stand-up on a known engineered surface

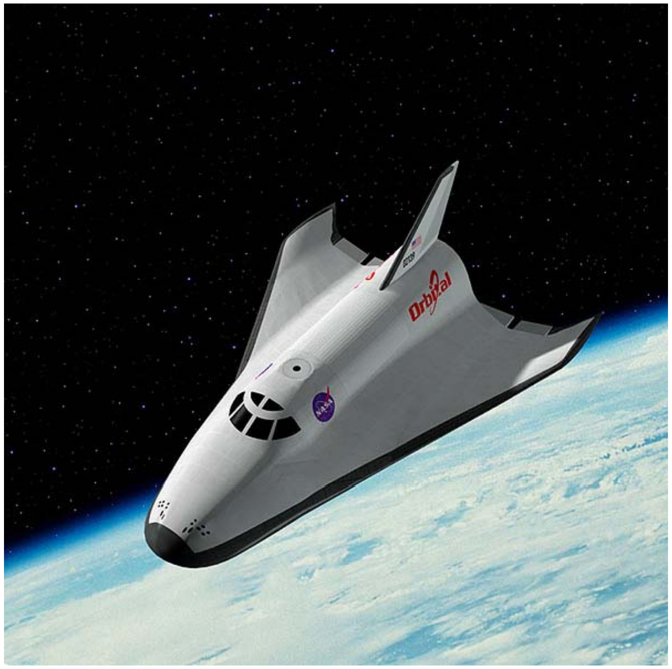
-Lower risk egress easier to design and test

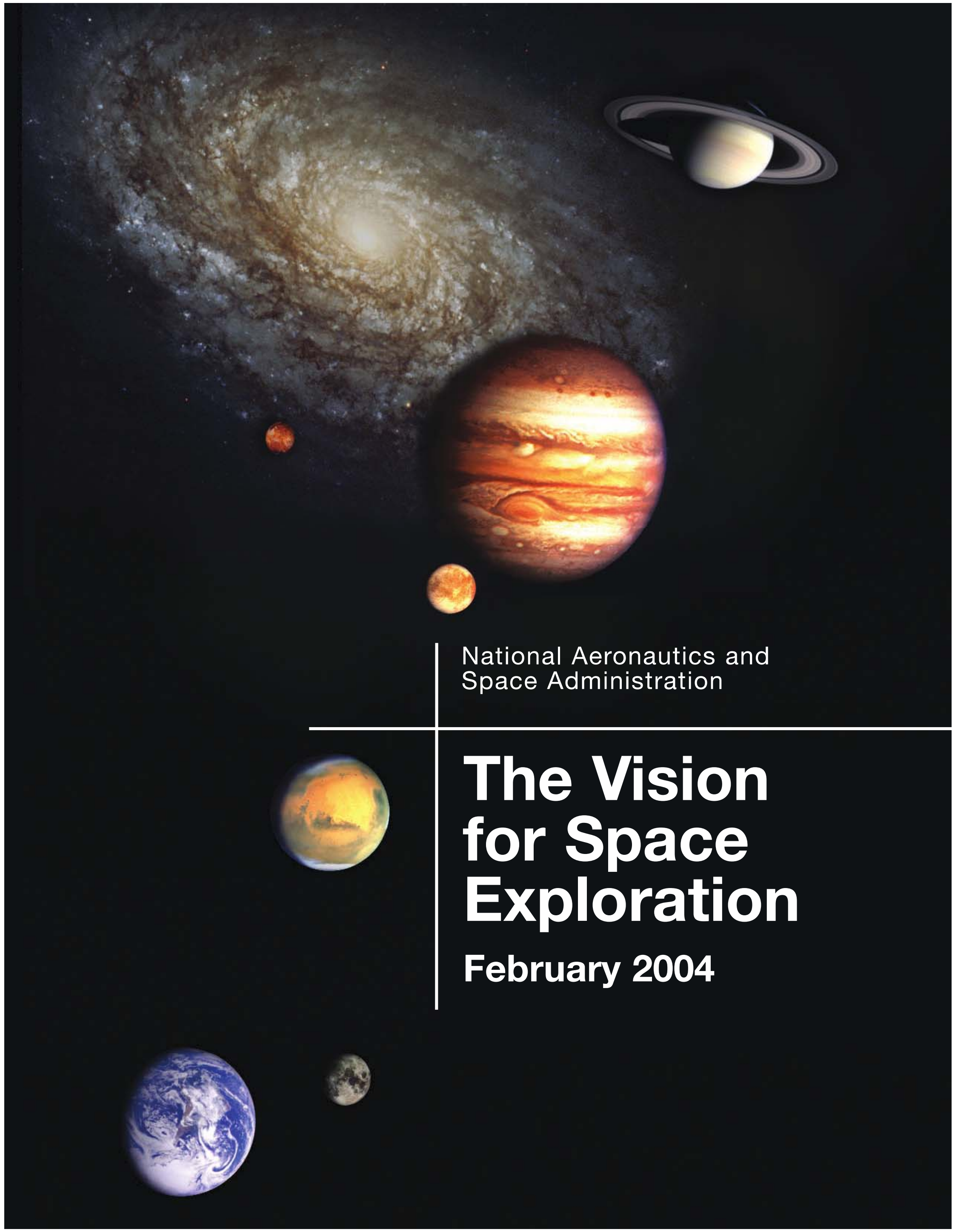
Act VI: The Demise of Sample Return, Redux


USA


NASA


United States
United States


Orbital

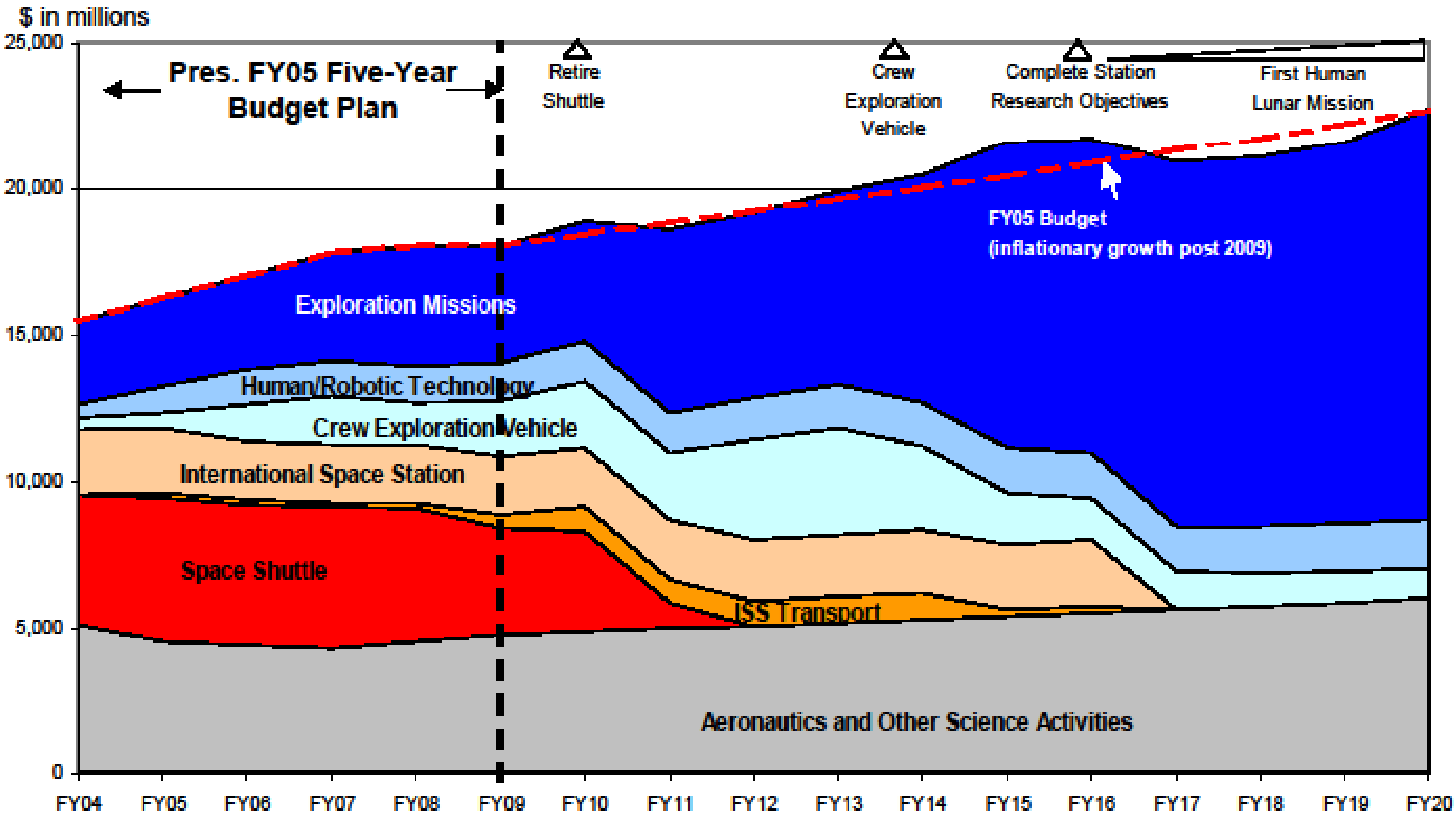


National Aeronautics and
Space Administration

The Vision for Space Exploration

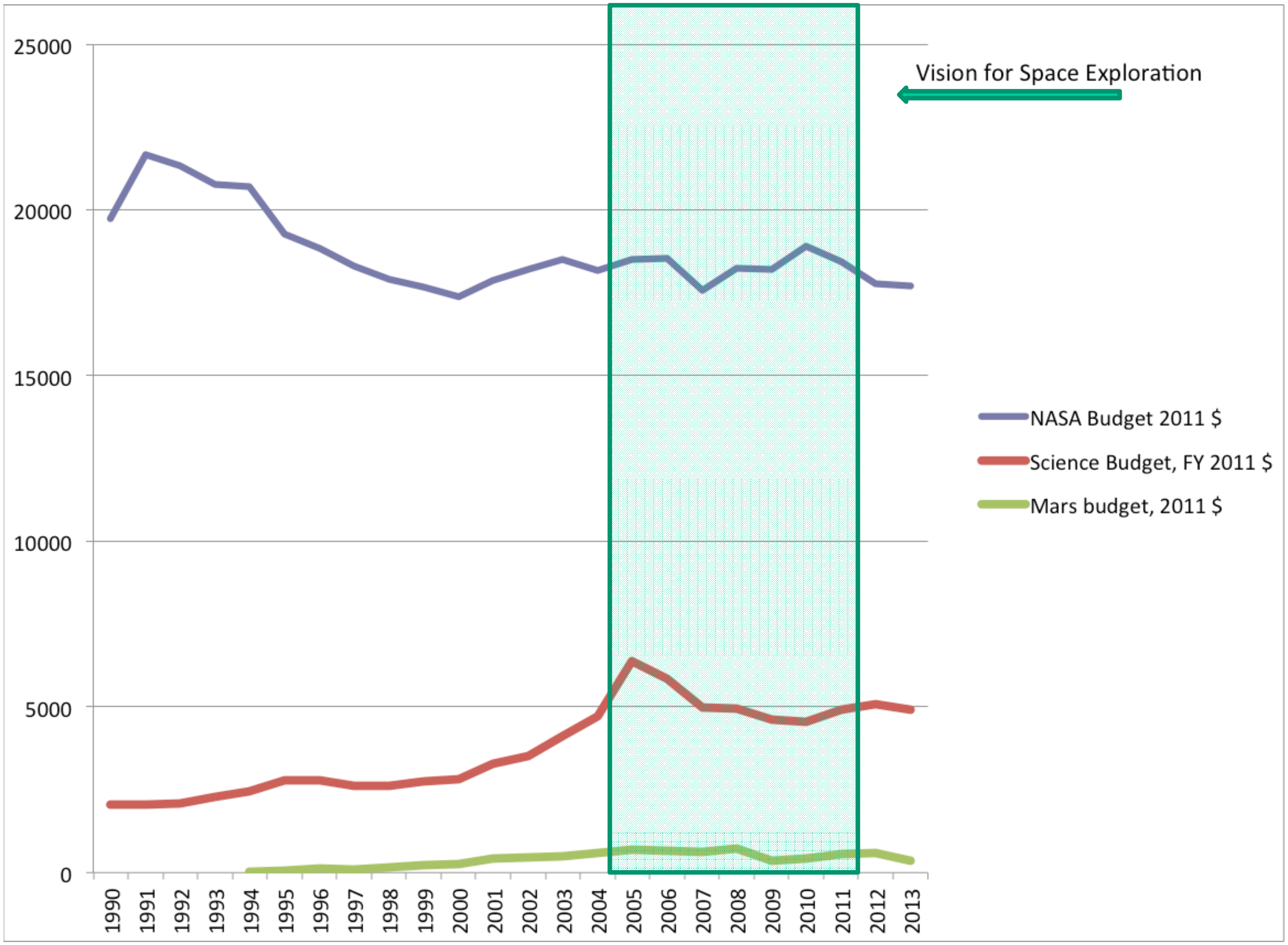
February 2004

Strategy Based on Long-Term Affordability

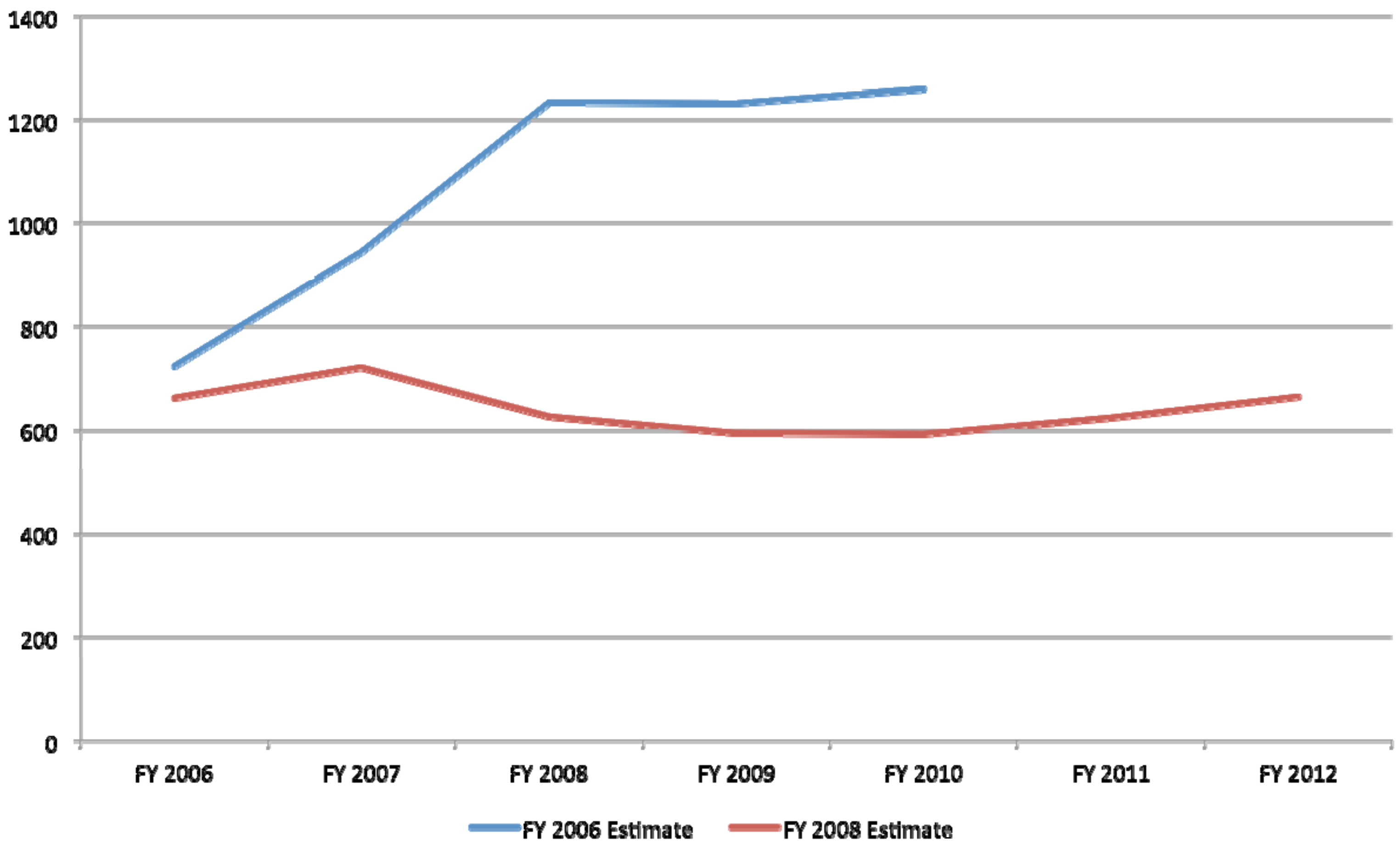


NOTE: Exploration missions – Robotic and eventual human missions to Moon, Mars, and beyond
Human/Robotic Technology – Technologies to enable development of exploration space systems
Crew Exploration Vehicle – Transportation vehicle for human explorers
ISS Transport – US and foreign launch systems to support Space Station needs especially after Shuttle retirement

Mars Program in Context



Evolution of Mars Budget



Conclusions and Ruminations


Review of U.S.
HUMAN SPACEFLIGHT
Plans Committee
SEEKING A
HUMAN SPACEFLIGHT PROGRAM
WORTHY OF A GREAT NATION

"The highest-priority flagship mission for the decade 2013-2022 is the Mars Astrobiology Explorer-Cacher (MAX-C), which will begin a three-mission NASA-ESA Mars Sample Return campaign extending into the decade beyond 2022."

TABLE ES.1 Medium-Class Missions—New Frontiers 4 (in alphabetical order)

Mission Recommendation	Science Objectives	Key Challenges	Chapter
Comet Surface Sample Return	• Acquire and return to Earth for laboratory analysis a macroscopic ($\geq$500 cm^3) comet nucleus surface sample • Characterize the surface region sampled • Preserve sample complex organics	• Sample acquisition • Mission design • System mass	4
Lunar South Pole-Aitken Basin Sample Return	Same as 2003 decadal survey[a]	Not evaluated by decadal survey	5
Saturn Probe	• Determine noble gas abundances and isotopic ratios of hydrogen, carbon, nitrogen, and oxygen in Saturn's atmosphere • Determine the atmospheric structure at the probe descent location	• Entry probe • Payload requirements growth	7
Trojan Tour and Rendezvous	Visit, observe, and characterize multiple Trojan asteroids	• System power • System mass	4
Venus In Situ Explorer	Same as 2003 decadal survey[a] (and amended by 2008 NRC report *Opening New Frontiers*[b])	Not evaluated by decadal survey	5

NOTE: On May 25, 2011, following the completion of this report, NASA selected the OSIRIS-REx asteroid sample-return spacecraft as the third New Frontiers mission. Launch is scheduled for 2016.

[a] National Research Council, *New Frontiers in the Solar System: An Integrated Exploration Strategy*, The National Academies Press, Washington, D.C., 2003.

[b] National Research Council, *Opening New Frontiers in Space: Choices for the Next New Frontiers Announcement of Opportunity*, The National Academies Press, Washington, D.C., 2008.

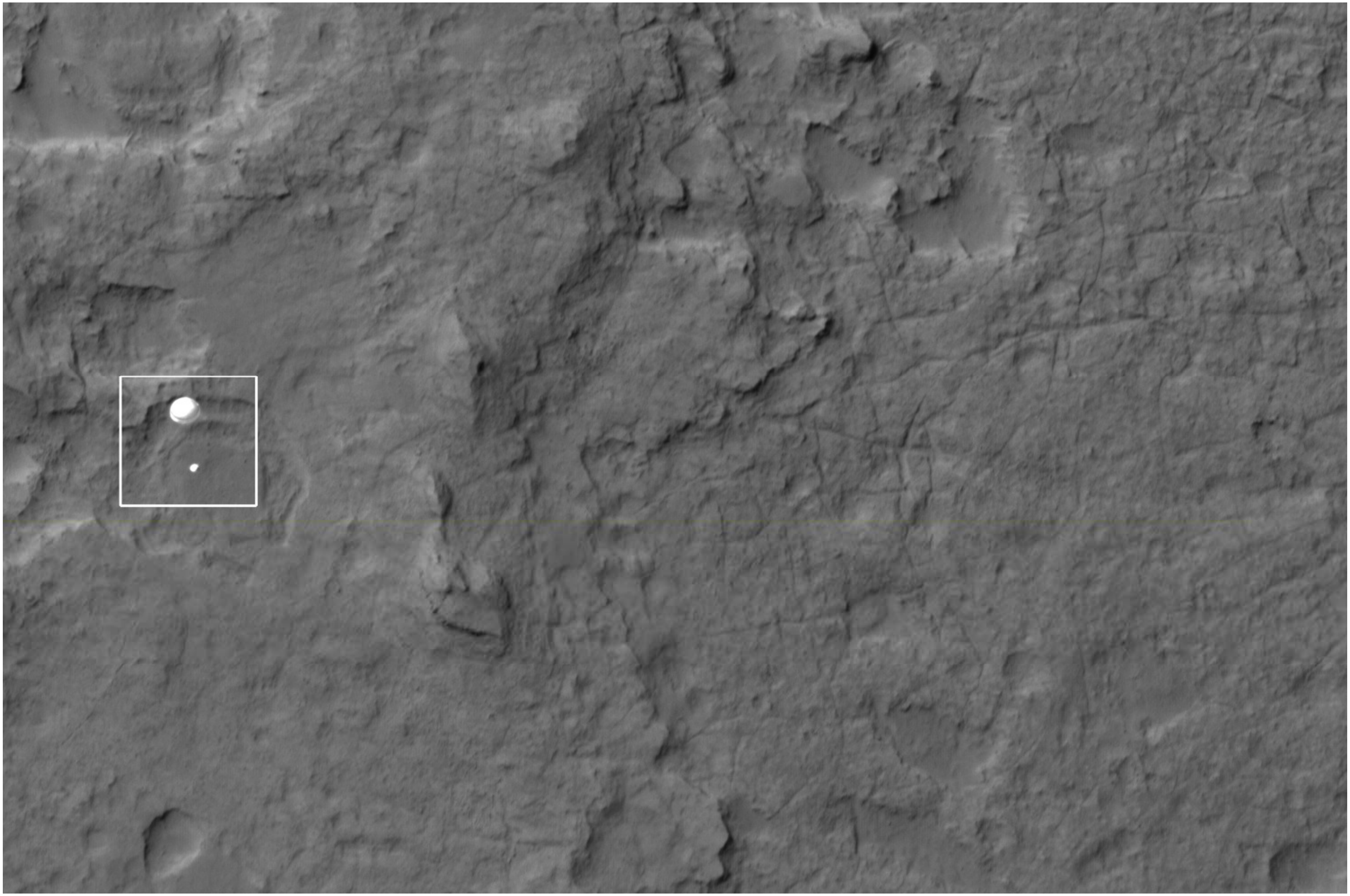
LARGE MISSIONS

The highest-priority flagship mission for the decade 2013-2022 is the Mars Astrobiology Explorer-Cacher (MAX-C), which will begin a three-mission NASA-ESA Mars Sample Return campaign extending into the decade beyond 2022. At an estimated cost of $3.5 billion as currently designed, however, MAX-C would take up a disproportionate share of NASA's planetary budget. This high cost results in large part from the goal to deliver two large and capable rovers—a NASA sample-caching rover and the ESA's ExoMars rover—using a single entry, descent, and landing (EDL) system derived from the Mars Science Laboratory (MSL) EDL system. Accommodation of two such large rovers would require major redesign of the MSL EDL system, with substantial associated cost growth.

The committee recommends that NASA fly MAX-C in the decade 2013-2022, but only if the mission can be conducted for a cost to NASA of no more than approximately $2.5 billion FY2015. If a cost of no more than about $2.5 billion FY2015 cannot be verified, the mission (and the subsequent elements of Mars Sample Return) should be deferred until a subsequent decade or canceled.

It is likely that a significant reduction in mission scope will be needed to keep the cost of MAX-C below $2.5 billion. To be of benefit to NASA, the Mars exploration partnership with ESA must involve ESA participation in other missions of the Mars Sample Return campaign. The best way to maintain the partnership will be an equitable reduction in scope of both the NASA and the ESA objectives for the joint MAX-C/ExoMars mission, so that both parties still benefit from it.

The second-highest-priority flagship mission for the decade 2013-2022 is the Jupiter Europa Orbiter (JEO). However, its cost as JEO is currently designed is so high that both a decrease in mission scope and an increase in NASA's planetary budget are necessary to make it affordable. The projected cost of the mission as currently



- **My story has several threads**
  - **Scientific and engineering ambitions**
  - **Robotic vs human spaceflight**
  - **Conflicting visions of launch vehicle development**
  - **Learning across projects**
- **Long-term drive for sample return has produced:**
  - **Innovation**
  - **Scientific results in related areas**
- **NASA’s duality, it’s schizophrenia, leaves it perpetually torn between scientific mission and what I call it’s colonization mission**