Successes and Failures of Recent Mars Exploration

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Aims of this talk

- Describe the past decade of Mars exploration
- Describe how half of attempted missions failed
- Describe how NASA responded to failures in short and long term
- Discuss lessons learned

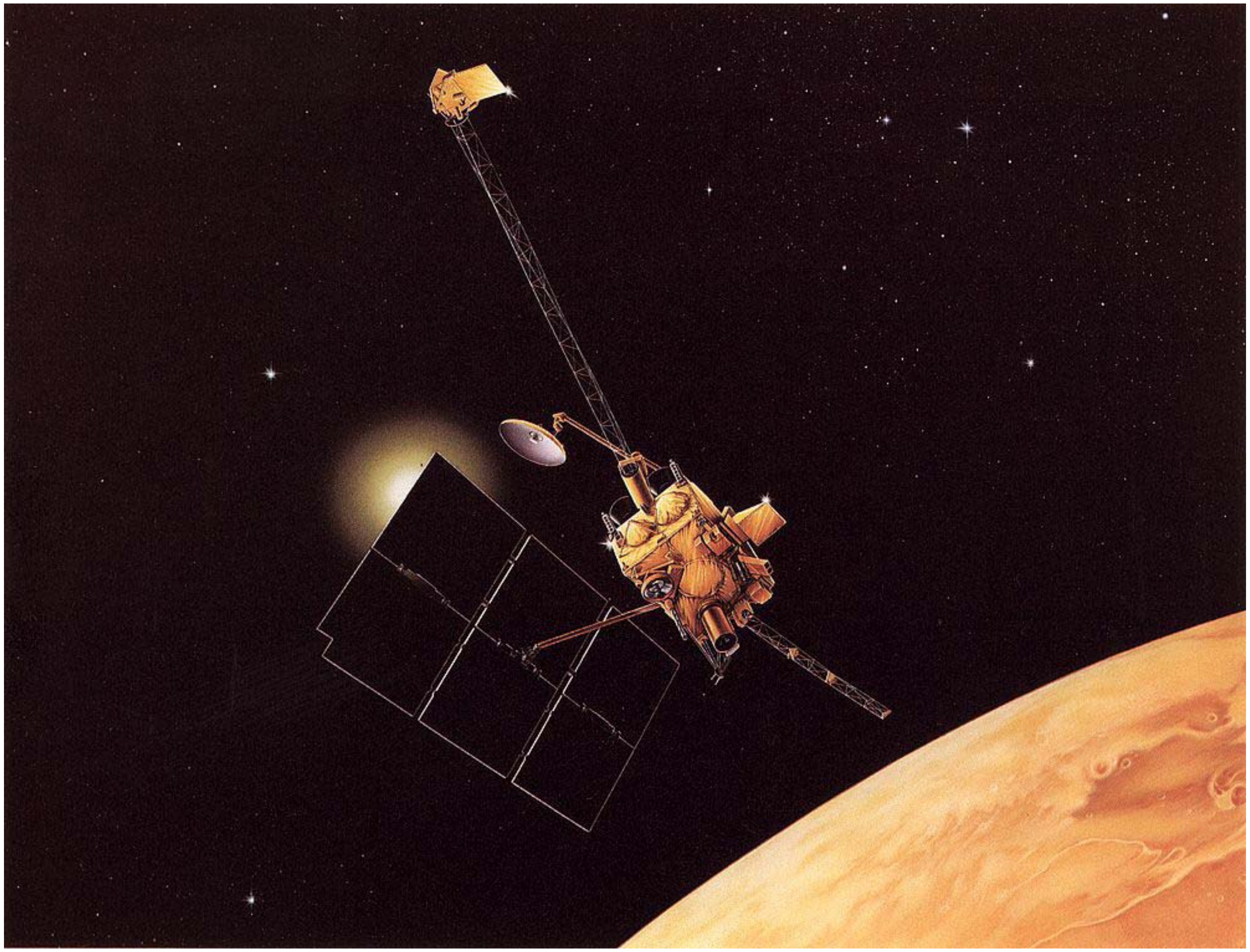
- Not an overview of Mars science

Sequence of Missions

• Mars Observer	(1992)		failure
• Mars 96	(1996)	[Russia]	failure
• Mars Pathfinder	(1996)		success
• Mars Global Surveyor	(1996)		success
• Nozomi	(1998)	[Japan]	failure
• Mars Climate Orbiter	(1998)		failure
• Mars Polar Lander	(1999)		failure
• Deep Space 2	(1999)	(2 small probes)	failure (x2)
• 2001 Mars Odyssey	(2001)		success
• Mars Express	(2003)	[ESA]	success (?)
• Beagle 2	(2003)	[ESA/UK]	failure

- Mars Exploration Rovers Spirit and Opportunity (2003) success (x2) (?)
- **12 years, 14 spacecraft, 8 failures, 3 successes, 3 probable successes**

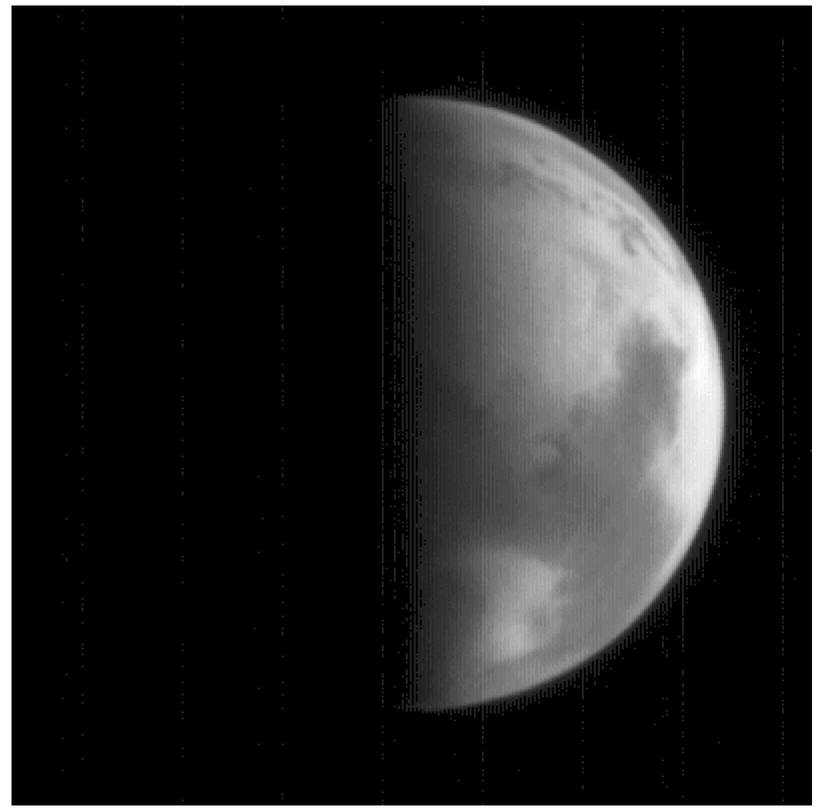
Mars Observer (1992)



Scientific Aims of Mars Observer

- Global topo and gravity map
- Measure magnetic field
- Elemental makeup of surface
- 2m-pixel images of surface
- Mineralogical map of surface
- Study atmospheric circulation

- $980 mission, first US mission to Mars since Viking in 1976.



Failure of Mars Observer

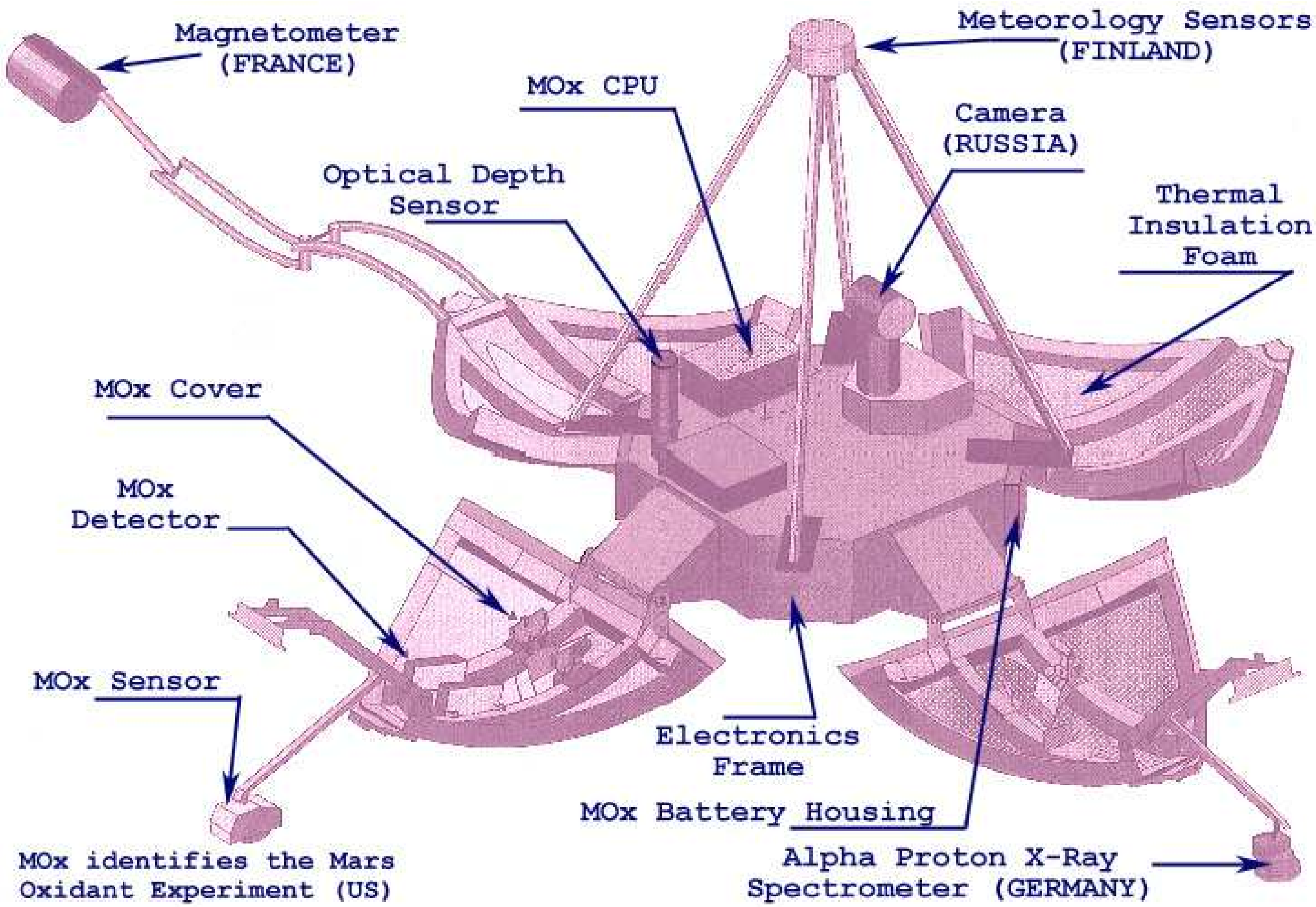
- Plan: Pressurize fuel tank a few days before Mars Orbit Insertion
- Plan: Turn transmitter off during pressurization to protect its components from shock, turn on again after pressurization complete
- Reality: No further transmissions received after start of pressurization, complete loss of mission.
- Failure Analysis: A fuel line ruptured during pressurization and the corrosive fuel disabled the spacecraft. Some parts were designed assuming pressurization after launch, not many months after launch.

Subsequent Recommendations

- Stephenson report (JPL, internal), Coffey report (independent)
- http://klabs.org/reports.htm
- Poor risk assessment
- Poor documentation
- Need telemetry during all mission-critical events
- Too much trust placed in heritage from Earth-orbiting spacecraft
- Fixed-price contract failed due to the significant development beyond a “production-line” spacecraft that was required

Mars 96 (1996) [Russia]

Mars 96 Small Station



Scientific Aims of Mars 96

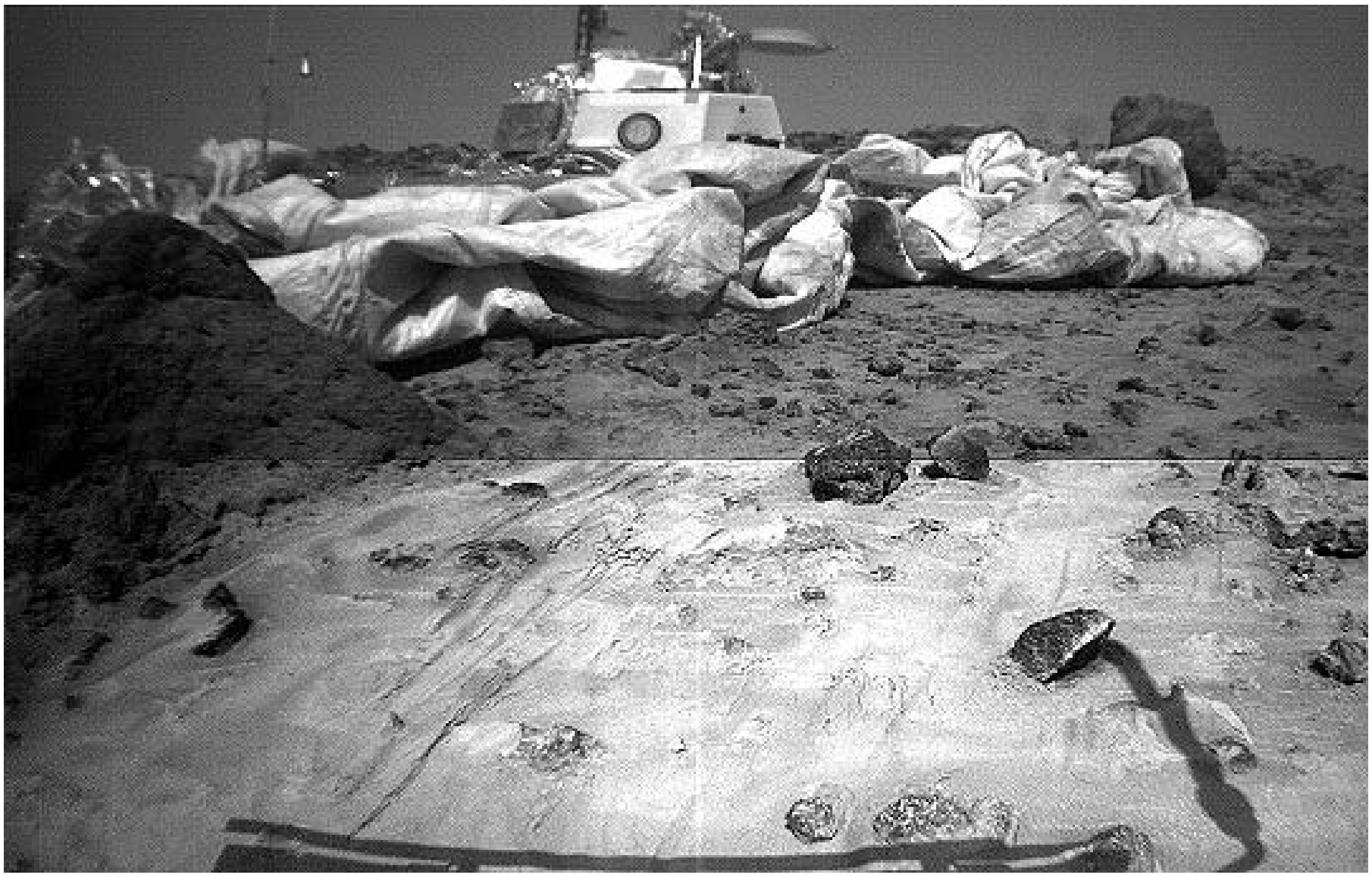
- One orbiter, 2 soft-landing large landers, 2 hard-landing small penetrators
- Russian-led, with several European and American instruments
- Immense payload on orbiter, cameras, IR and UV spectrometers, gamma and neutron spectrometers, radar, plasma instruments
- Small station had camera, weather station, descent science, APXS, seismometer, 1 year lifetime
- Penetrators had camera, weather station, seismometer, 1 year lifetime
- 3 times heavier than Mars Observer – the Russians build cheap, powerful rockets
- Last Russian-led planetary exploration spacecraft

Failure of Mars 96

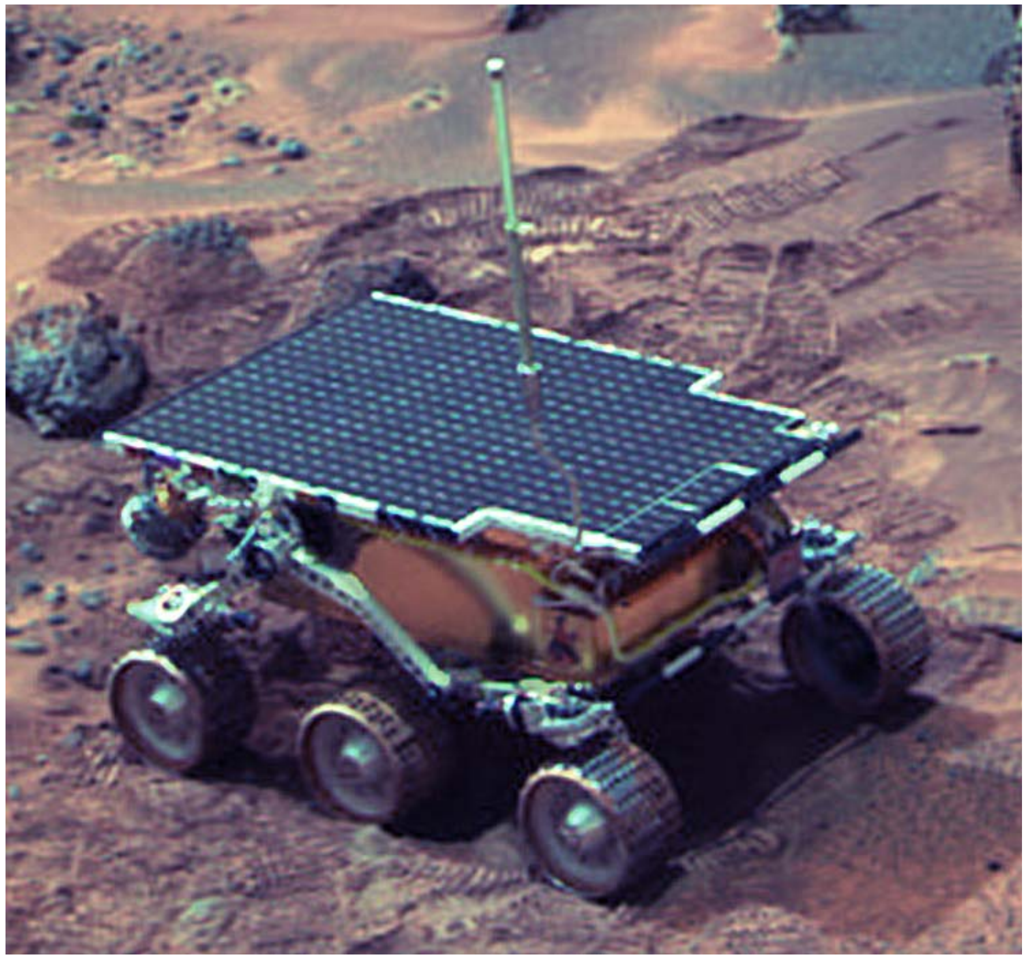
- Crashed in Chile after 2 orbits of Earth
- Failure occurred as rocket was firing to accelerate Mars 96 from Earth orbit to interplanetary cruise – out of range of Russian tracking stations, so no telemetry was available.
- Dispersed 200g plutonium over Chilean desert.

- This failure ended Russian planetary exploration

Mars Pathfinder (1996)



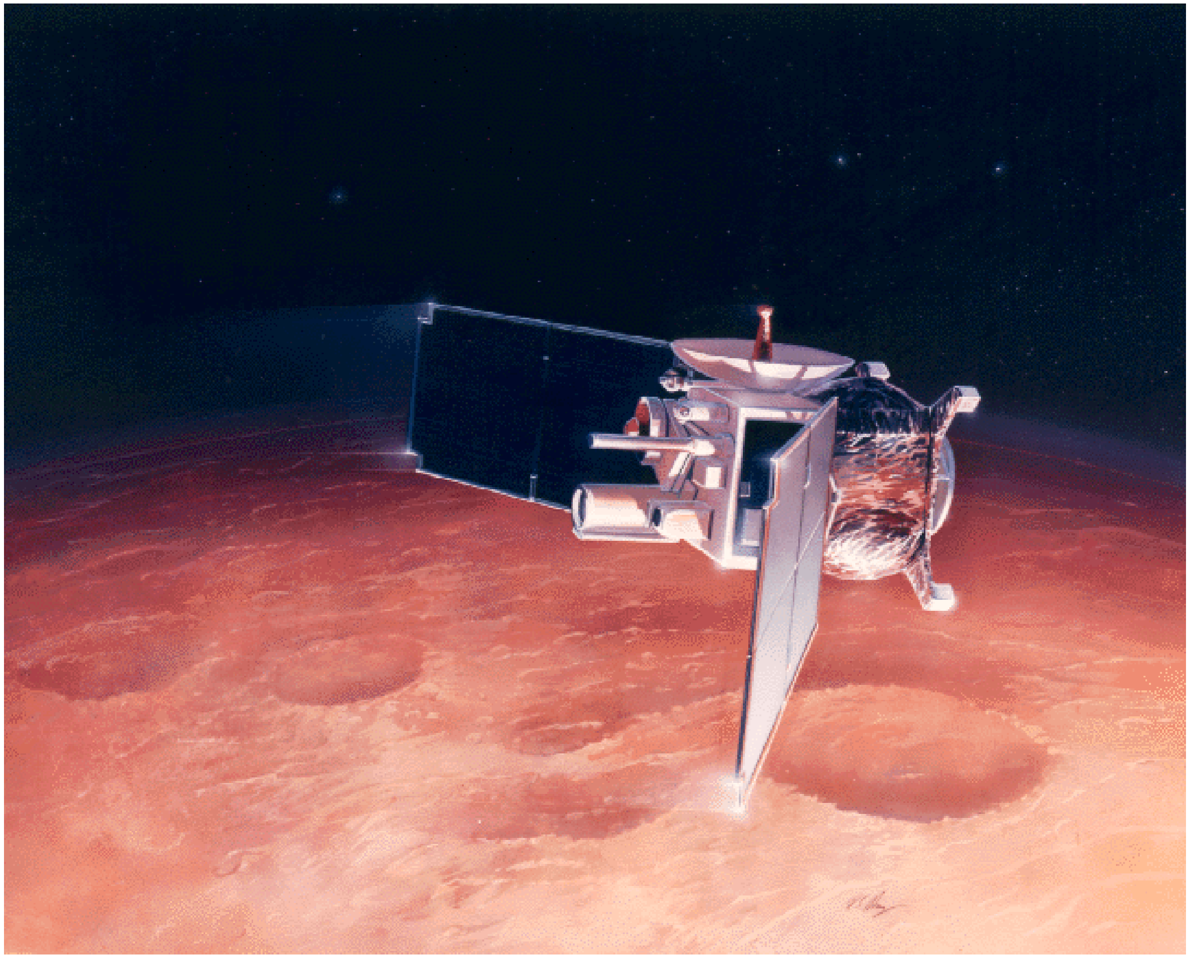
Sojourner, Pathfinder’s Rover



Scientific Aims of Mars Pathfinder

- Demonstrate feasibility of low-cost landings on Mars
- Demonstrate roving capability on Mars
- Any science is a bonus! Pathfinder's scientific results did not revolutionize our understanding of Mars due to its fairly basic instrumentation.
- Entry science, surface images, incomplete elemental analysis
- An early "Faster, Better, Cheaper" mission in the competed Discovery program
- $265M cost, first successful landing on Mars since Viking 20 years before

Mars Global Surveyor (1996)



Scientific Aims of Mars Global Surveyor

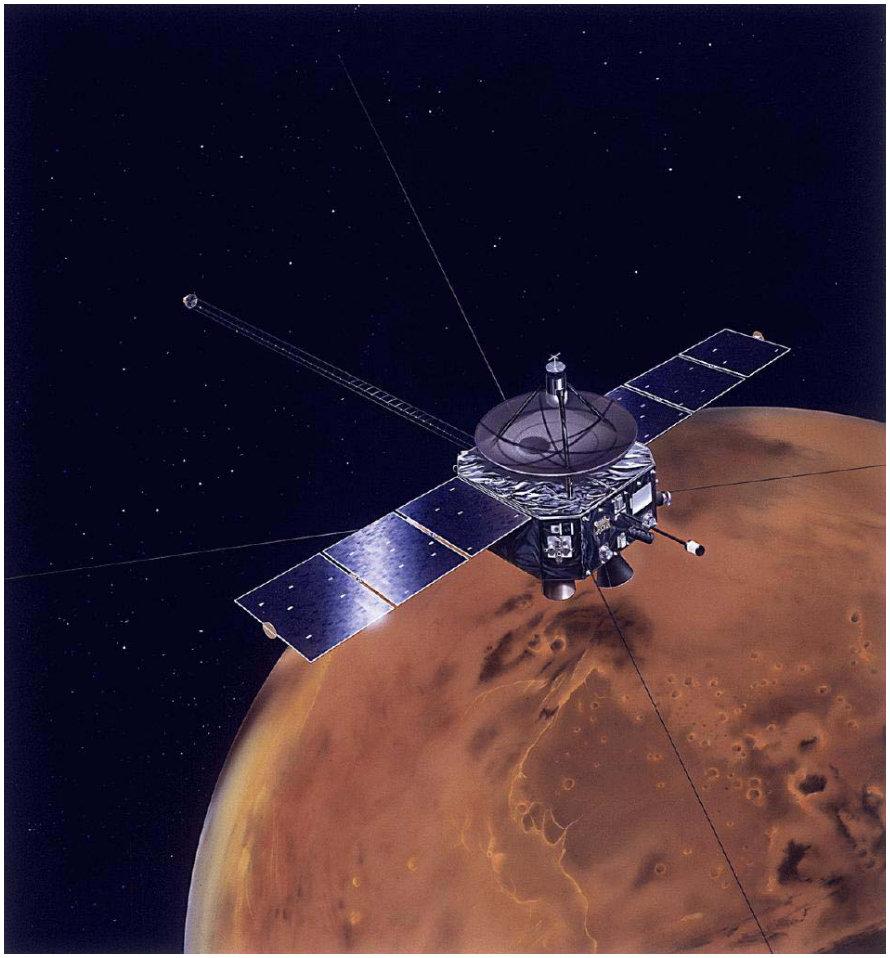
- Partially recover science lost with Mars Observer by flying the lightest 5 of Mars Observer's 7 instruments
- Demonstrate orbit insertion using aerobraking
- Made global topographic and gravity map
- Discovered evidence of water-related minerals (Opportunity)
- Discovered weak, inhomogeneous magnetic field
- Discovered active gullies and pervasive layering
- Cost $250M
- Launched on a $50M Delta, not a $300M Titan
- Problem with solar panels discovered during cruise…

Aerobraking with a broken wing

- Plan: Spend few months aerobraking into desired orbit
- Problem: Solar panels would snap at weak spot if implemented
- Solution: Aerobrake very, very tentatively for over a year
- Implications: Much better upper atmospheric observations
- Implications: Improved magnetometer observations as well
- Implications: Delayed start of primary mission

- After 6.5 years at Mars, MGS is still functioning well with only one instrument failed. Designed for 2 year lifetime, likely to survive for several more years until consumables consumed. Played major role in Spirit and Opportunity landings.

Nozomi (1998) [Japan]



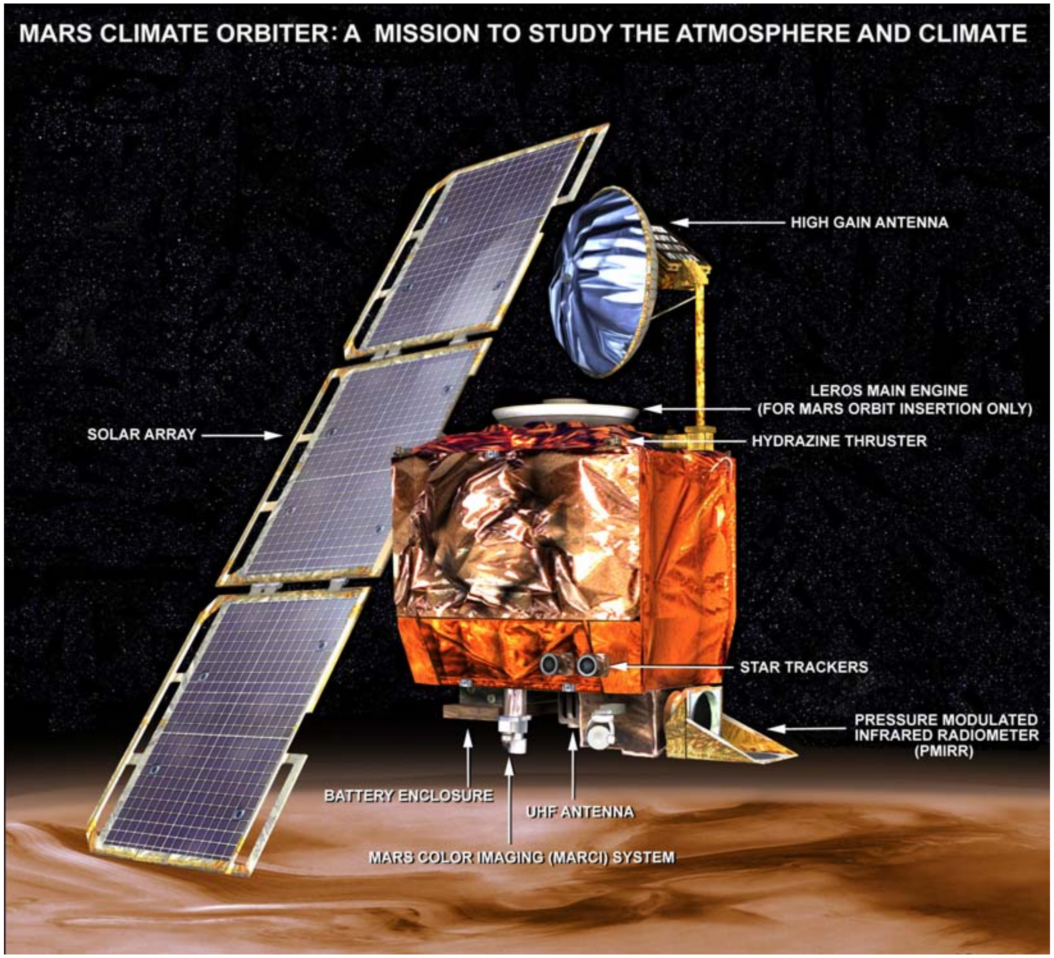
Scientific Aims of Nozomi

- Study upper atmosphere, escape of water, magnetosphere, plasma of Mars
- Plan: launch July 1998, wait in Earth orbit for a few months, leave Earth orbit Dec 1998, arrive Mars Oct 1999, orbit Mars.
- Japanese launch site interferes with fishing fleet, so launchs are only possible at certain times of the year…
- Insufficient fuel supplied during rocket burn to leave Earth orbit, due to valve malfunction, so Nozomi was not on direct path to Mars
- Then corrective burns used too much fuel…
- Recovery plan: Use several Earth flybys to change trajectory, arrive at Mars Dec 2003.

The lingering death of Nozomi

- Solar flare damages electronics before next Earth flyby
- Fuel freezes as a result
- Fuel eventually thaws and Dec 2002 and Jun 2003 Earth flybys are successful
- Attitude control problems make Mars orbit insertion burn impossible and Nozomi flies past Mars helplessly
- There were probably other problems that prevented any flyby science, but Japan hasn't publicized them much
- Initial failure after botched burn probably doomed the mission, despite lengthy efforts to resurrect it.

Mars Climate Orbiter (1998)



Scientific Aims of Mars Climate Orbiter

- Climate monitoring (atmospheric temperatures, water vapour, dust, ozone)
- Surface images
- Relay for future landers
- Recover another one of the lost Mars Observer instruments
- Aerobrake like Mars Global Surveyor into orbit around Mars
- Cost (together with Mars Polar Lander) $200M, which is very, very cheap.

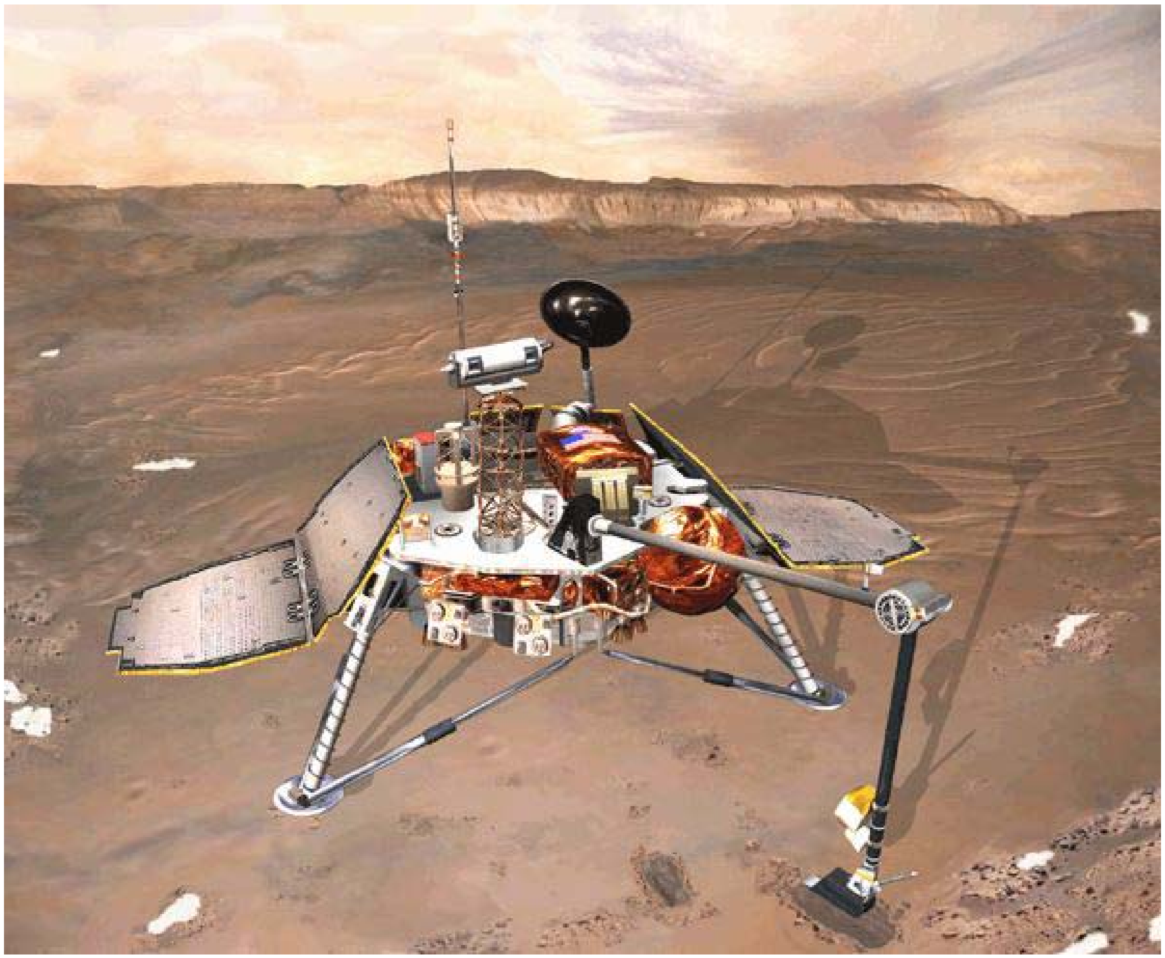
Failure of Mars Climate Orbiter

- Closest approach to Mars was 57 km, not the targeted 150 km
- Aerocapture, instead of aerobraking, and MCO turned into a meteor
- Cause: Lockheed Martin had supplied data on force of trajectory control thrusters in the wrong units. Numerical values were factor of 4-5 away from values in expected units.
- Bad as that problem is, the systemic failure to detect it is much, much worse.
- JPL Navigation team's predictions of trajectory became steadily worse and worse as MCO approached Mars and they puzzled over the reason

Like Watching a Trainwreck…

- After last trajectory correction manoeuvre, navigators watch MCO drift further and further away from its intended course and lower into the atmosphere.
- A further trajectory correction was discussed which would raise the altitude of closest approach, but rejected because it had not been proven that the existing trajectory was unsafe. The existing trajectory had not been proven to be safe, because no-one really knew what it was with any confidence.
- When the actual trajectory was finally known accurately, it was too late and as the world watched a JPL control room monitor the closest approach, most of the engineers there expected catastrophic failure. They were right.

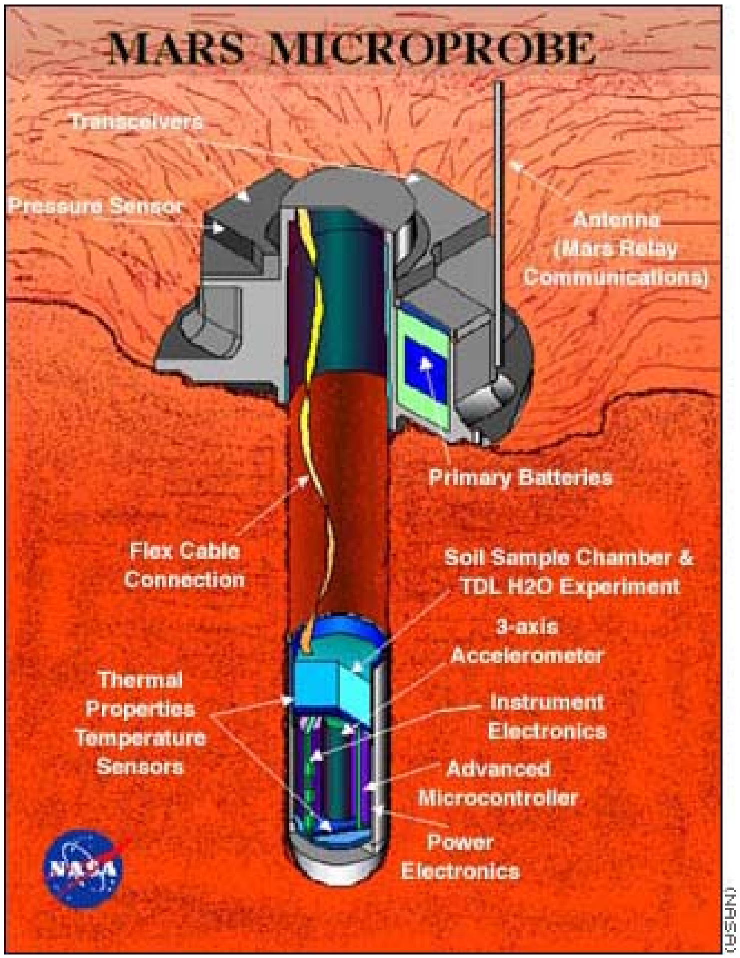
Mars Polar Lander (1999)

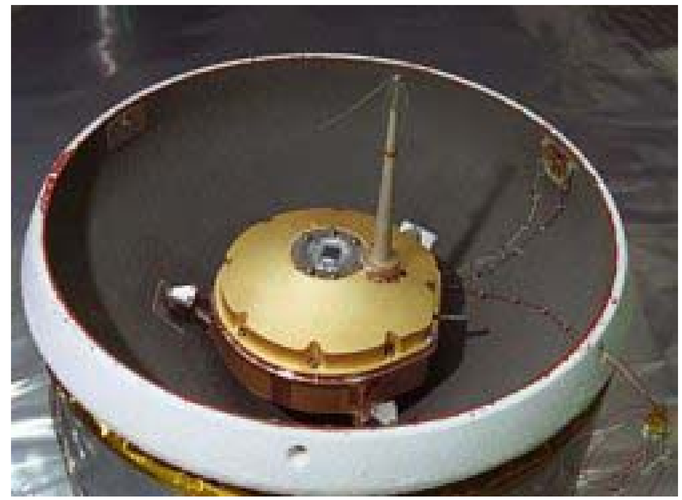


Mars Polar Lander

- Land near South Pole, study meteorology, soil properties, analyze water and carbon dioxide in atmosphere and soil, photograph surroundings
- First landing outside tropics of northern hemisphere
- Communications shut off as planned at start of atmospheric entry and nothing more was ever heard from the lander.
- Most likely failure mode was that control system for retrorockets would interpret shaking as lander legs deployed as contact with ground and shut down retrorockets too early, splat from 40m altitude.
- End-to-end test of landing system was deleted from schedule due to time pressure, problem was simple to detect and fix.

Deep Space 2 (1999)





I won a NASA competition to
name them Scott and Amundsen

Aftermath of 4 Failures in 3 Months

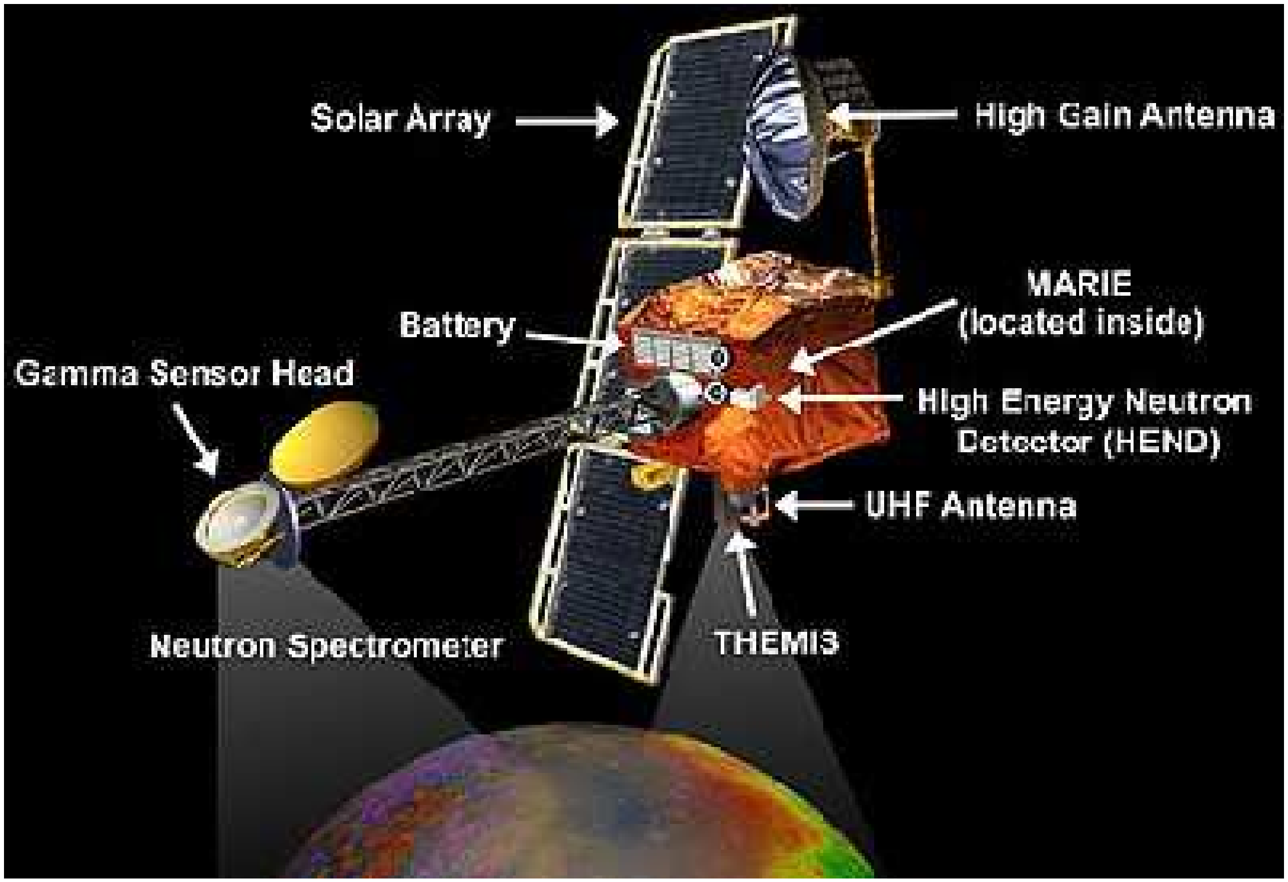
- Young Report, revaluation of NASA's Mars Exploration Program and "Faster, Better, Cheaper"

- Poor systems testing (MPL), lack of critical event telemetry (MPL)
- Deep Space 2 was "not ready for launch", insufficient testing and inflight monitoring.
- Lack of aggressive and adversarial progress reviews
- Cancel 2001 lander, delay plans for sample return from Mars in 2005-2010

More Aftermath

- "Faster, Better, Cheaper" was being used as a management mantra without proper definition
- Lockheed Martin quoted an unrealistically low cost to win the contract, 30% lower than was realistic
- Fixed low cost, fixed schedule, overchallenging goals led to risk increases being accepted without question.
- Dysfunctional communications existed between NASA HQ (define mission goals and resources), JPL (manage construction, testing, and operations), and Lockheed (design and build spacecraft)

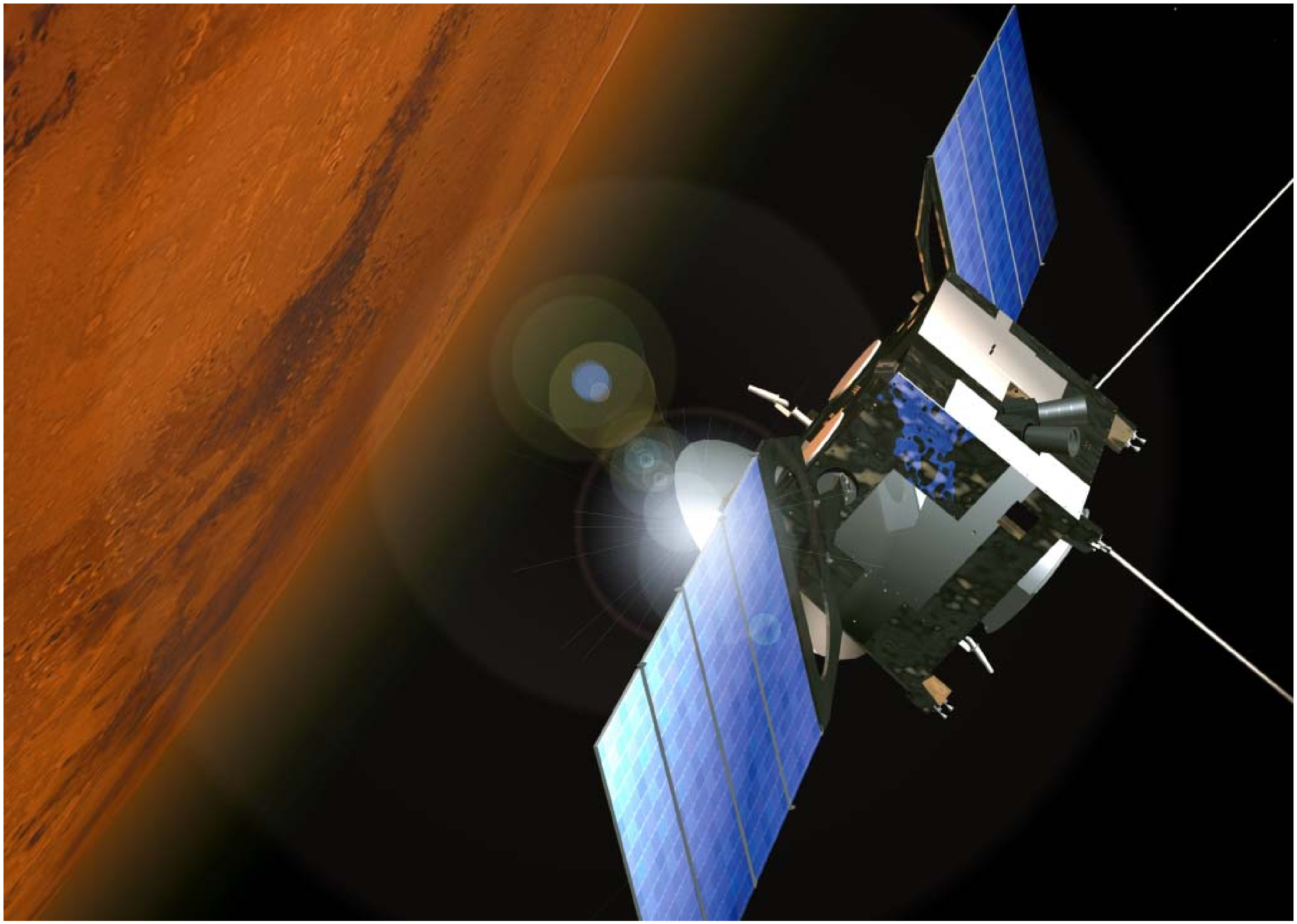
2001 Mars Odyssey (2001)



Mars Odyssey

- Refly one of the lost Mars Observer instruments, which just leaves the atmospheric instrument that was lost on MO <u>and</u> on MCO to fly again in 2005.
- Measure elemental composition of surface, near-surface water, mineralogical composition of surface, take yet more images
- Aerobraked successfully as designed
- Serving as a relay for Spirit and Opportunity
- No major problems and a long life seems likely
- Cost $300M

Mars Express (2003) [ESA]



Scientific Aims of Mars Express

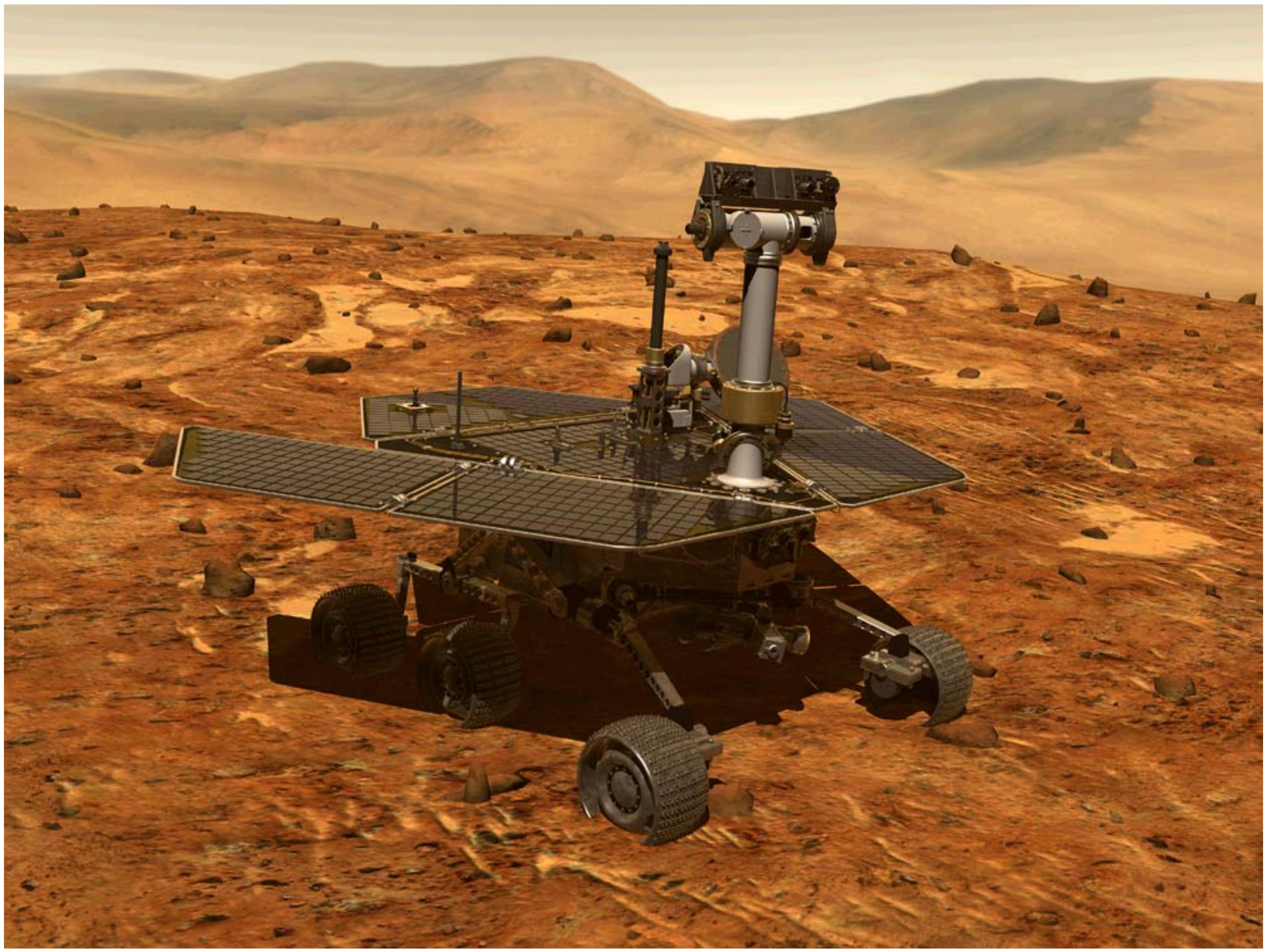
- Subsurface radar
- 10m resolution stereo surface images
- Atmospheric escape processes
- Surface mineralogy
- Water, ozone, and weather monitoring
- Did not use aerobraking
- Arrived safely at Mars in December 2003, first results starting to be released
- Everything seems to be working well
- Cost $150M

Beagle 2 (2003) [ESA/UK]

Failure of Beagle 2

- Released from Mars Express 3 days before entering martian atmosphere
- No communication possible between release and landing
- No communications received since release, total failure of mission
- Always a high-risk, low-cost ($60M?) mission
- Probably the landing speed was too great for the airbags to support
- Failure report should be interesting reading…

Mars Exploration Rovers
Spirit and Opportunity



Scientific Aims of Spirit and Opp.

- Demonstrate 1km range
- Investigate a site believed to show evidence of past water
- Imaging, mineralogy, measure iron content of rocks, microscopic imaging
- Landed in Jan 2004, potentially serious software glitch fixed and ~six month lifetime anticipated
- Huge PR success for NASA
- Failure not an option, $800M cost

Lessons Learned

- Do not deviate from sound engineering practices
- Test, test, and test again
- If you can’t verify that something is safe, then it isn’t
- Telemetry is essential for understanding failures
- Always know how your career plans will adapt if your current main project blows up or is cancelled tomorrow – never keep all your eggs in one basket
- Make a fuss. If you’re not convinced something is right, then get the attention of your boss and your boss’s boss.
- NASA doesn’t seem to have a webpage on “Reports on our Failures”, but http://klabs.org/reports.htm has a good archive.
- http://nssdc.gsfc.nasa.gov/planetary/ provides information on many missions