Mission Implementation Constraints on Planetary Muon Radiography

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Mars Exploration Rover Opportunity at the Santa Maria crater, viewed from the Mars Reconnaissance Orbiter (NASA/JPL-Caltech/U. Arizona)

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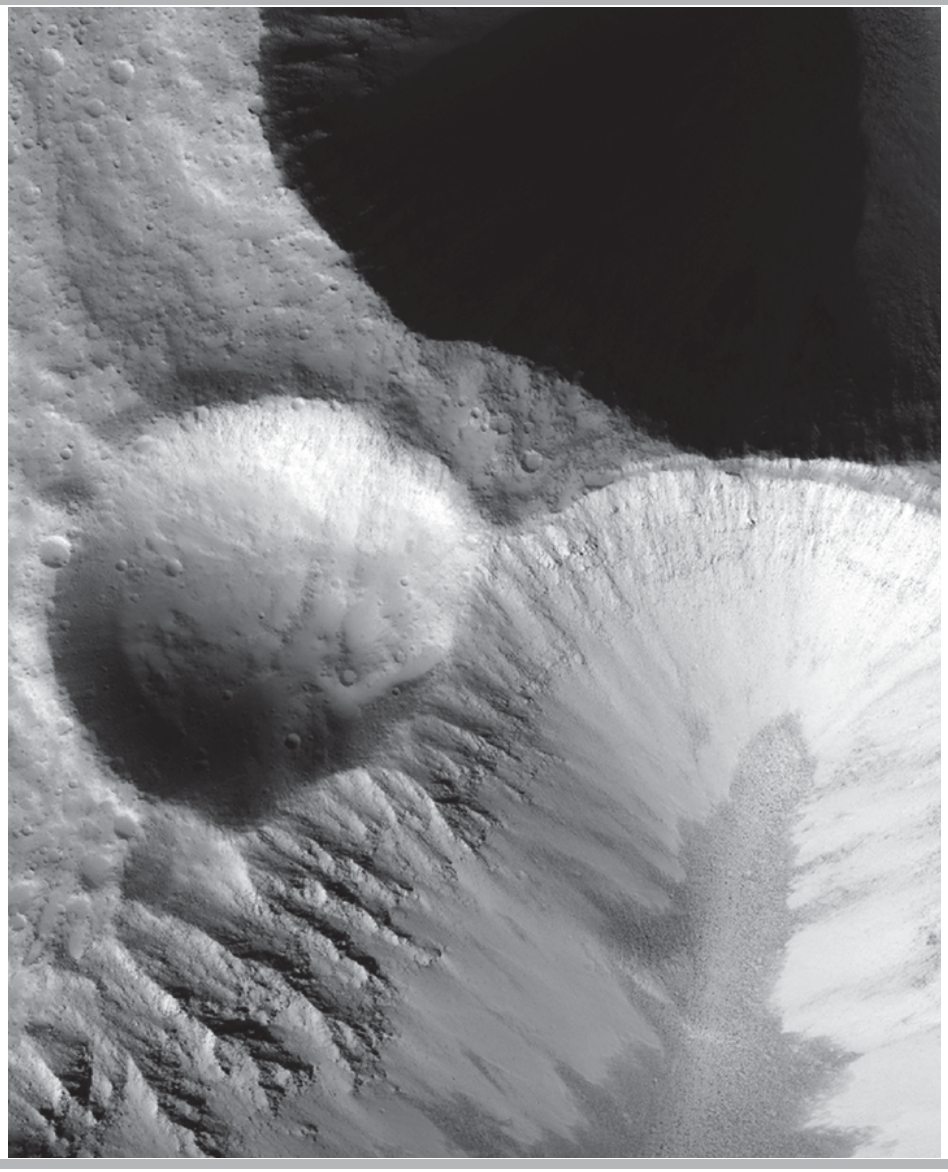


Artynia Catena, Alba Patera, imaged by HiRISE, MRO (NASA/JPL-Caltech/U. Arizona)

NASA Solar System & Mars Exploration Mission Classes

Cost Class for Mission:

1. **Flagship Mission (> $750M)**

   Major mission addressing highest priority goals of the NASA planetary science program. Highest funding levels but with longer development time and lowest allowed risk posture.

2. **New Frontiers ($500M – $750M)**

   Intermediate cost missions with high quality, focused science goals.

3. **Discovery (< $500M)**

   More frequent focused mission with lower cost, shorter delivery schedule, and higher allowed risk posture.

Risk Class for Payloads:

1. **Class A**

   All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used.

2. **Class B**

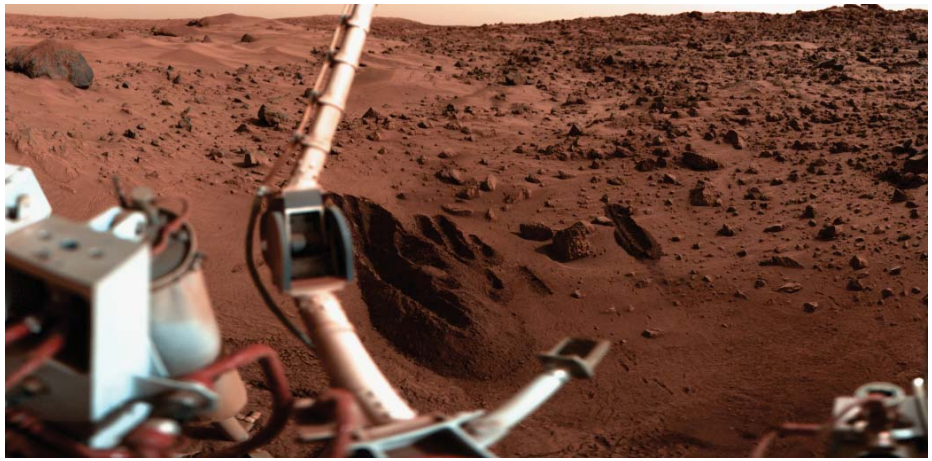
   Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success.

3. **Class C**

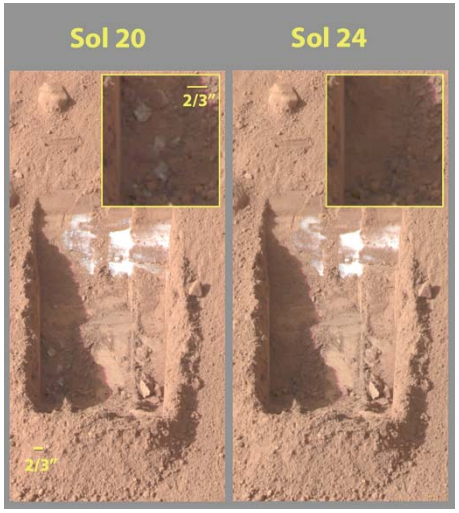
   Medium risk of not achieving mission success may be acceptable. Reduced assurance standards are permitted.

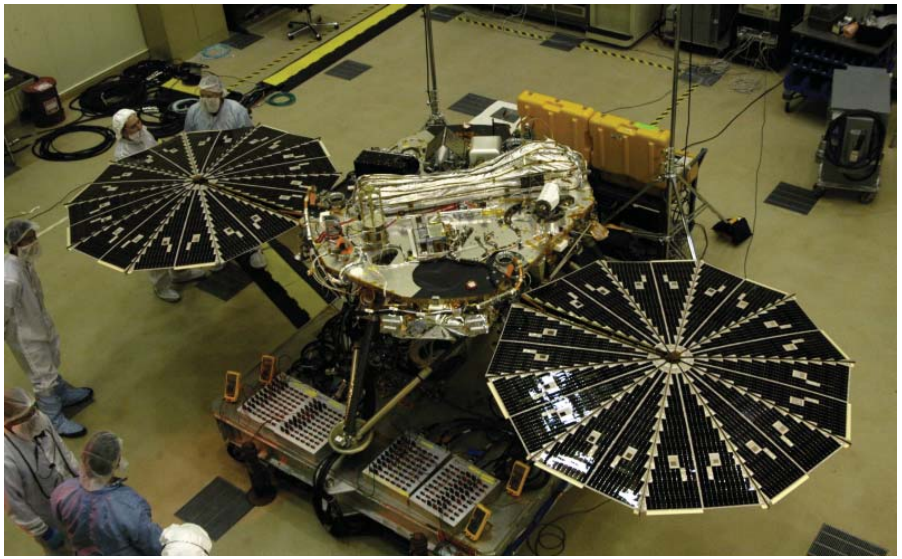
NASA Mars Landed Missions – Stationary Landers

Viking 1/2
1975 – 1982
Flagship-class



Phoenix
2007-2008
Discovery-class



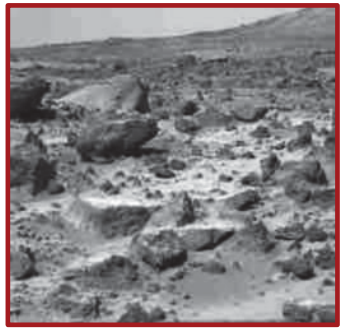


NASA Mars Landed Missions – The Rovers

Goal for Mars Exploration Program: Potential Sample Return, then Human Exploration

Mars Exploration Rovers, Spirit and Opportunity, 2003 – present (New Frontier)

Mars Science Laboratory, Curiosity Rover, to launch in Dec. 2011 (Flagship)

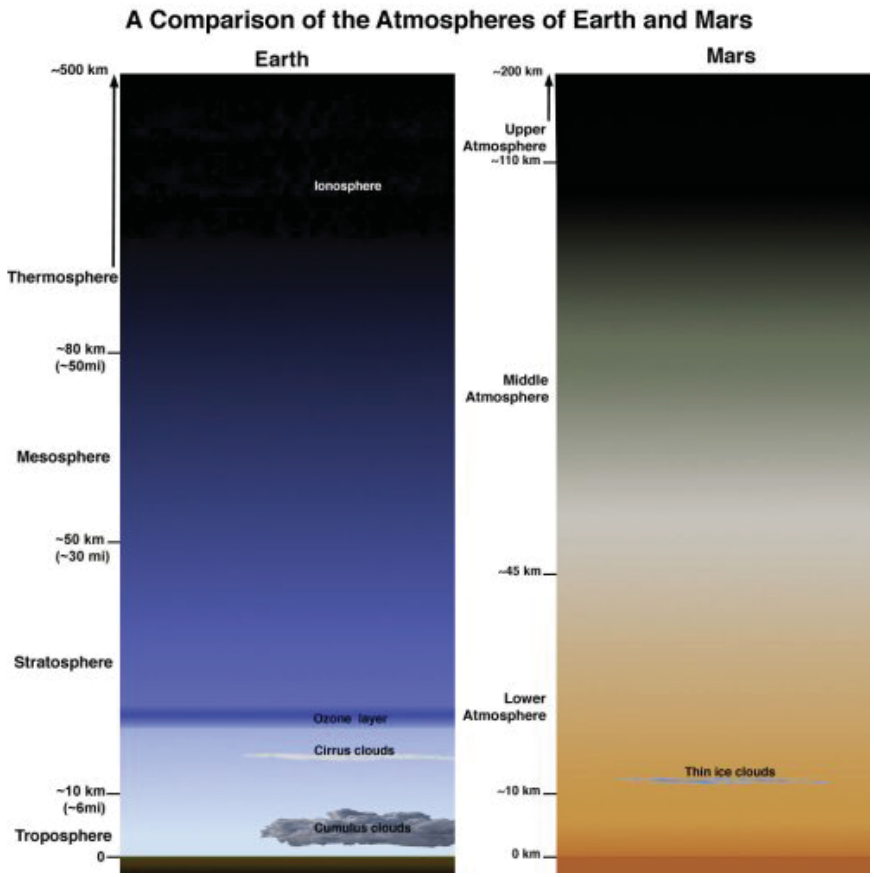


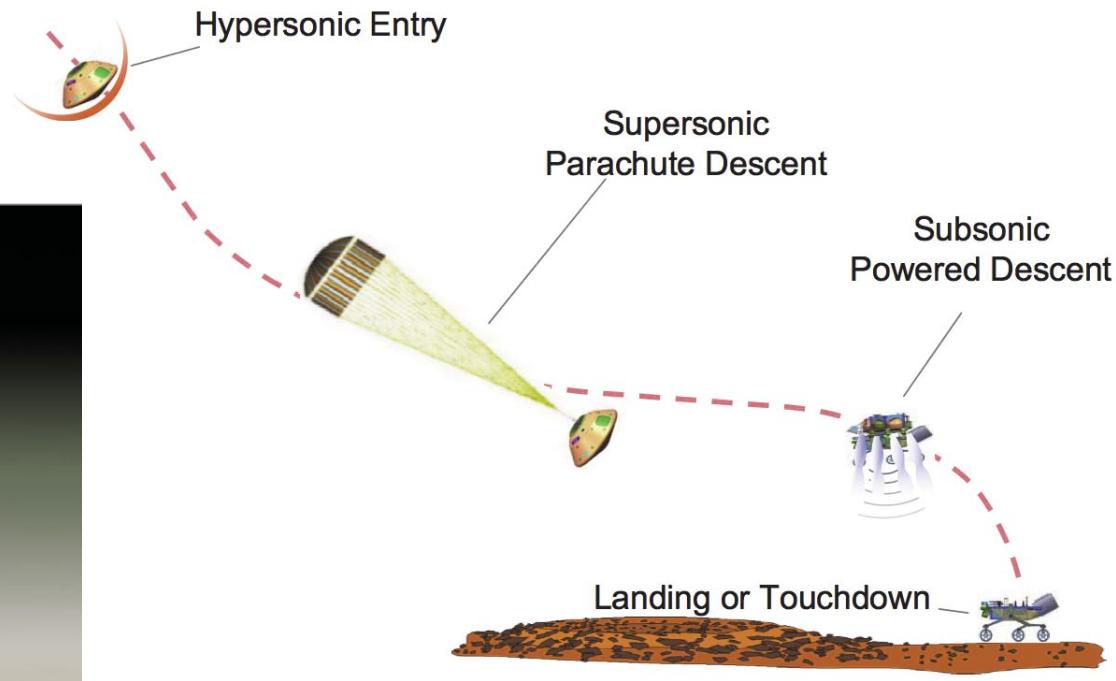
Mars Pathfinder, Sojourner Rover, 1996 – 1997 (Discovery)

Proposed: Mars 2018, launch in 2018 or later

Critical Mission Stage: Entry, Descent and Landing (EDL)

Descent from upper atmosphere on a parachute…





Shock during pyro-firing events is the most significant vibration/acceleration. There are 90 pyro events in the MSL cruise and descent stages.

~6 mbar pressure at Mars surface

The Final Descent Stage

… following by surface landing using …

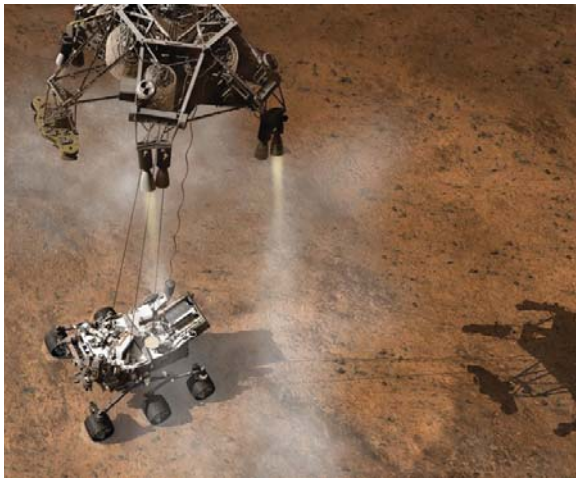
Airbag

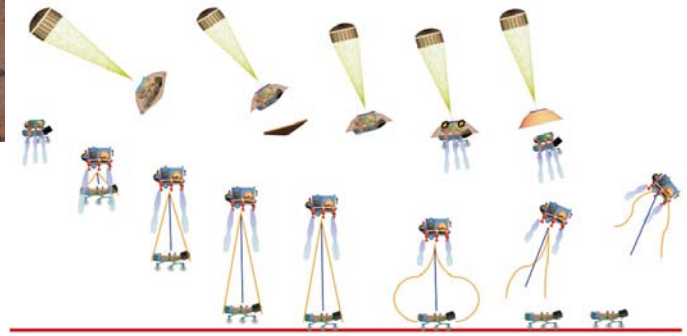
Example: Mars Pathfinder, Mars Exploration Rovers (MER)

Rockets

Example: Phoenix

Rockets plus Sky Crane



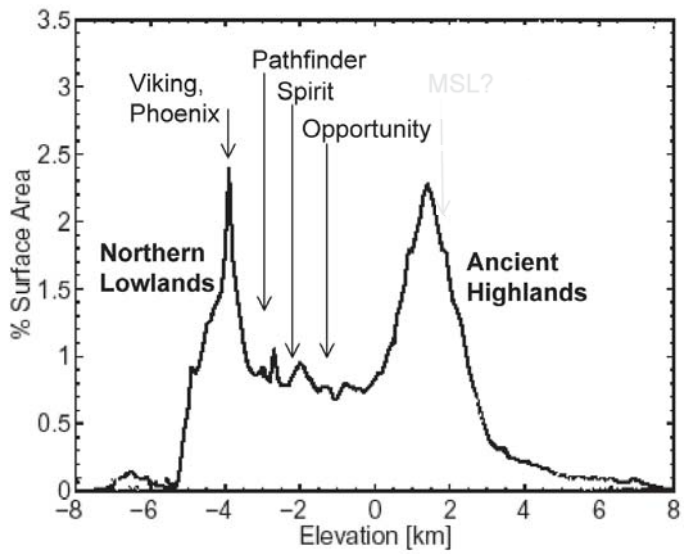


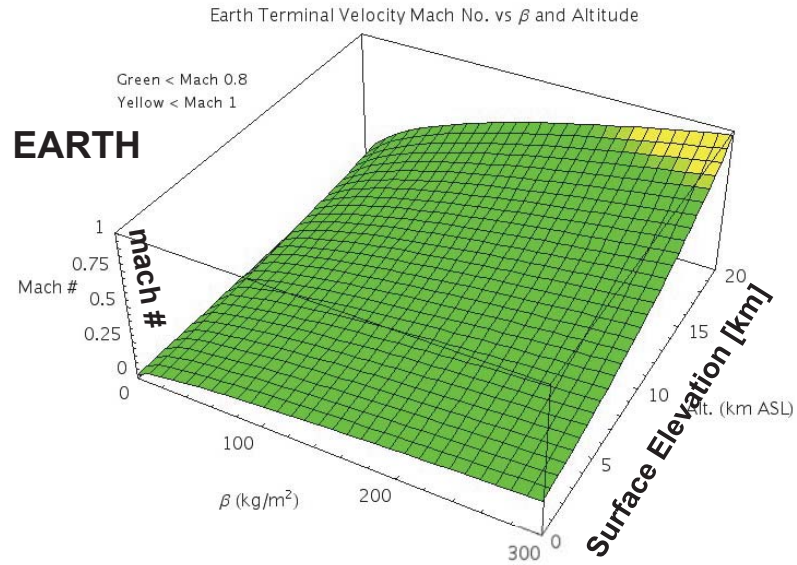
Example: Mars Science Laboratory (MSL)

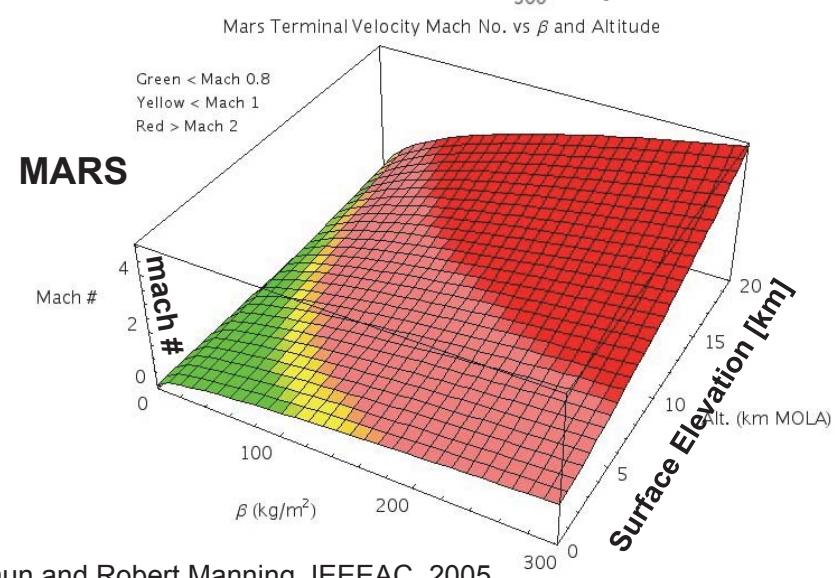
Importance of Landing Site Location

Terminal Descent Velocity vs. Surface Elevation

Because the Mars atmosphere is so thin, entry vehicles decelerate at lower altitudes and reach the subsonic terminal descent velocity much later in descent than they would on Earth. The entry time and atmospheric pressure limits the practically accessible landing sites on Mars.



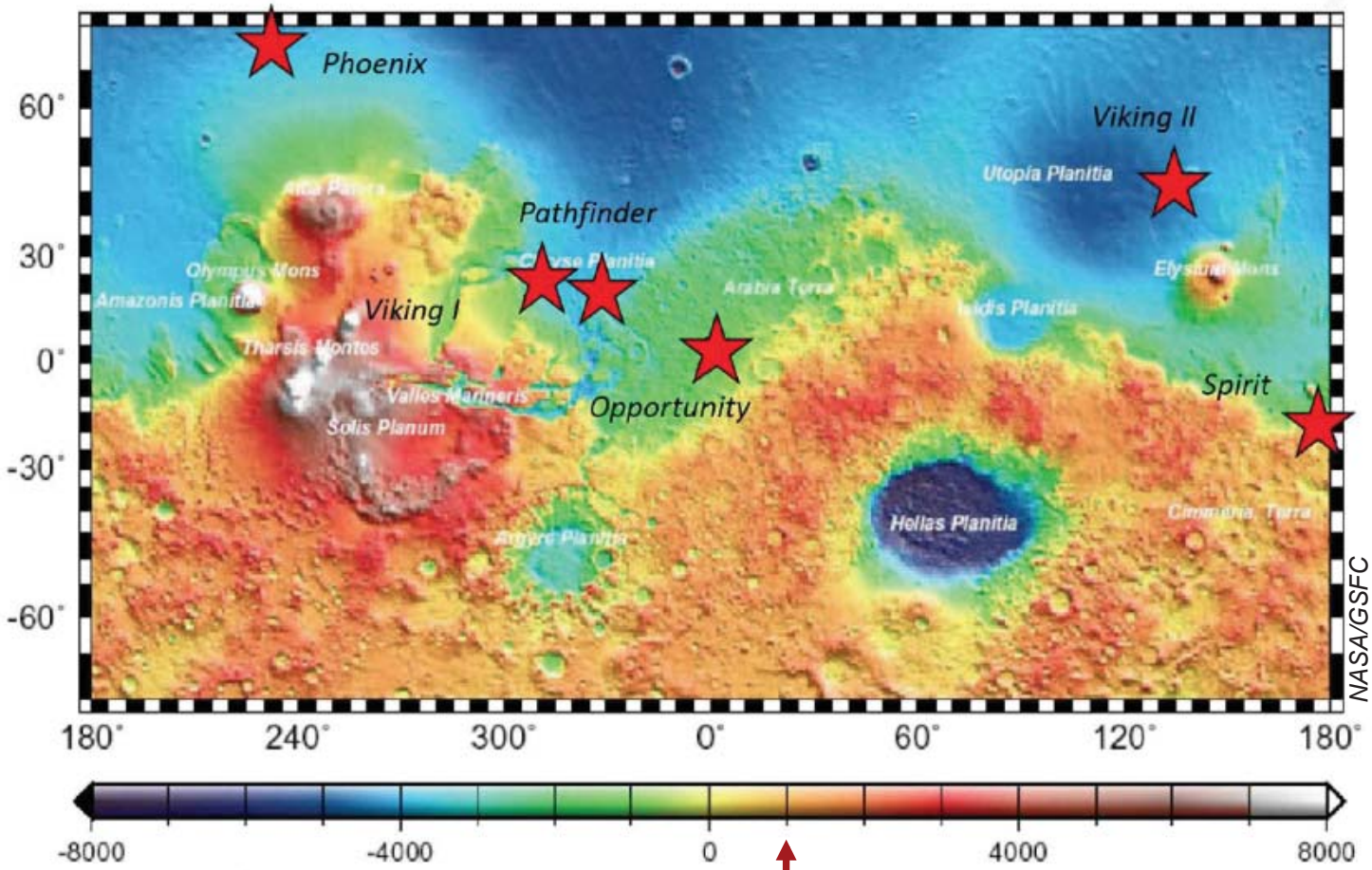




From *Mars Exploration Entry, Descent and Landing Challenges*, Robert Braun and Robert Manning, IEEEAC, 2005.

MOLA Surface Elevation

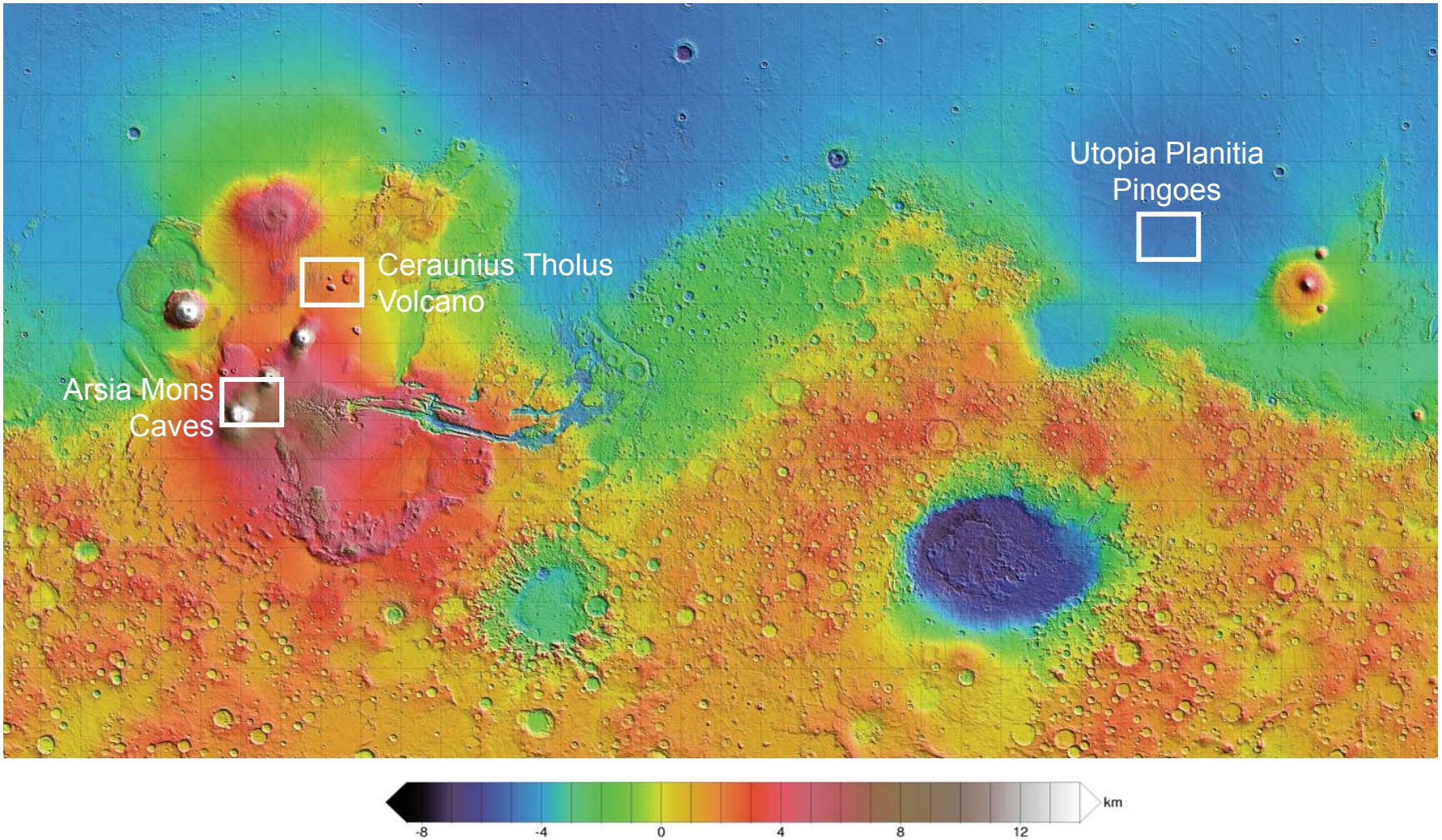
Mars Orbiter Laser Altimeter (MOLA) Surface Topography Map



Surface Elevation, meters

MSL maximum elevation for sky crane landing = 1 km

Study Site Location

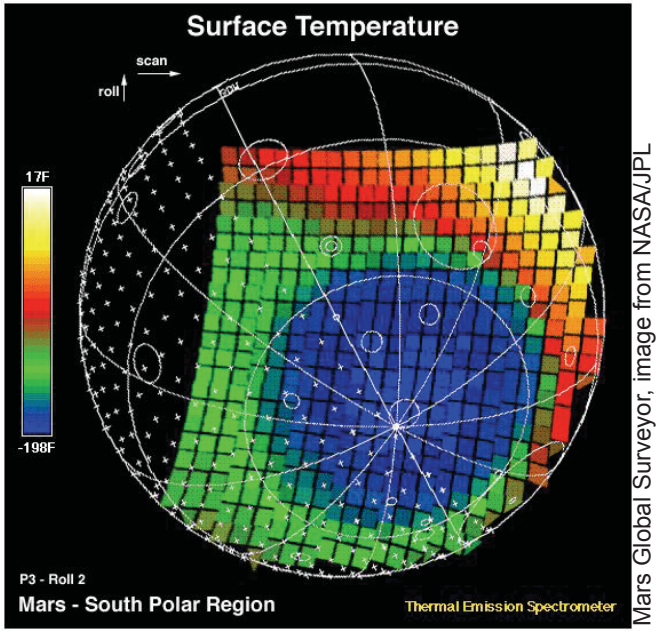


Mars Surface Conditions

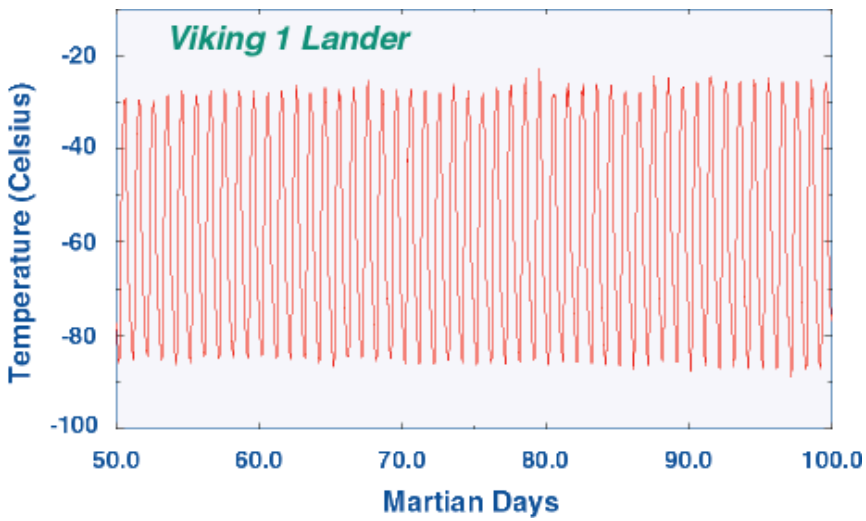
Mars atmosphere: 95.3% CO_2, 2.7% N_2, 1.6% Ar, 0.13% O_2

Surface Pressure: 6.36 mbar at mean radius; variable from 4.0 to 8.7 mbar seasonally; also varies with surface elevation

Surface Temperature: -63° C average (typical diurnal variation from -90° C to -30° C)

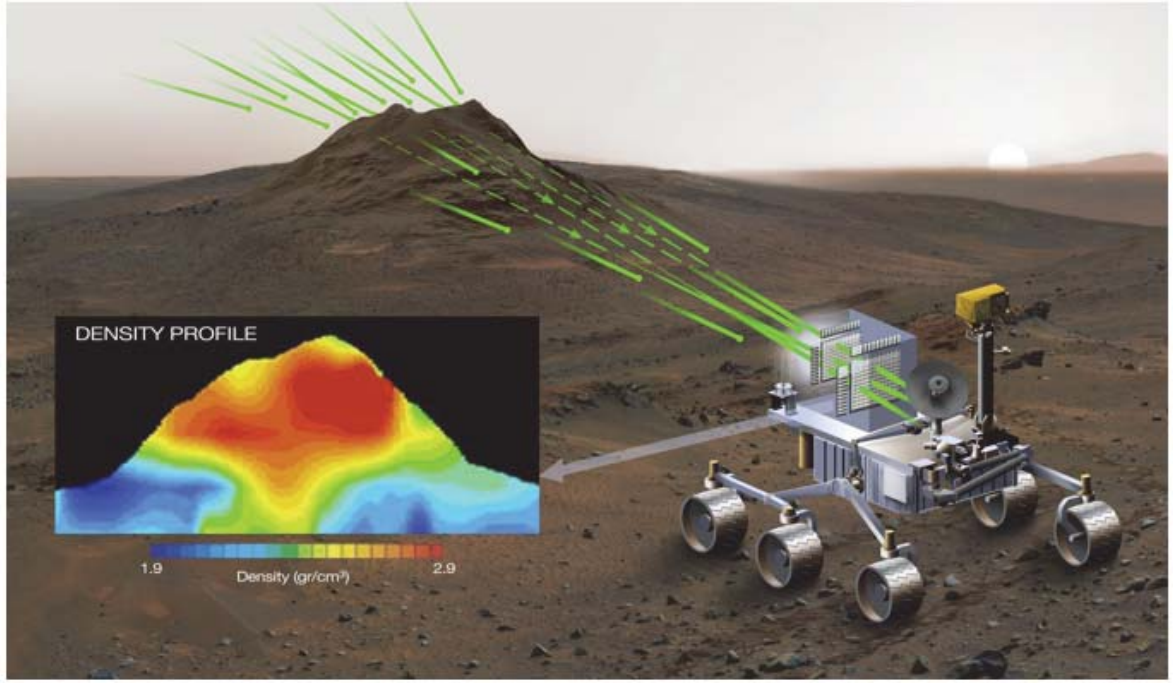


Mars Global Surveyor, image from NASA/JPL



(1) Consider the calibrated operation temperature range of the instrument. Will have to either turn off the instrument outside that range (loss of integration time) or use heaters and blankets (more power and mass) to stay within that range.
(2) As much as possible, place electronics on lander deck to take advantage of waste heat from other instruments.

Instrument Size/Volume



Instrument concept: A possible observational scenario for muon radiography is to use it to image the interior of edifices on planetary surfaces and determine the structure and density distribution for interpretation of their geological origin and composition. Muons generated by interactions of primary cosmic rays in the planet's atmosphere (green spheres) pass through a geologic object of interest, such as a volcano or pingo, and are partially absorbed by the object. A passive muon detector composed of parallel scintillating plates on a lander or rover records the tracks of the muons. The recorded tracks are analyzed to determine the direction from which they entered the detector and the amount of energy absorbed by the target. These observations are processed to yield a density image of the geological target, much like an X-ray radiograph would, except using muons as a passive source of radiation. The density profile (inset) is a result from a terrestrial Showa-Shinzan lava dome in Japan [*Tanaka*, 2007]. In this concept image, the detector is one of several instruments mounted on a rover. The suite of instruments can be used to identify and characterize the 3D structure of targets of interest for in-situ exploration.

- A muon detector with two x-y planes of size 1 m x 1 m, separated by 1 m is reasonable for a planetary instrument.
- The planes might have to fold to fit within the spacecraft volume during the cruise stage from Earth to Mars, then unfold after landing on the planet.
- Planetary mission instrument designers have experience with these issues, so innovative solutions can be found.

The Critical Factor: Instrument Mass

Mars Rover Comparison, payload vs. rover mass for the different NASA Mars missions:

Requirement	*MSL*	*MER*	*Sojourner*
Driving Distance	20 km	0.6 km	N/A
Mission Lifetime	687 Sols	90 Sols	7-30 Sols
Number of Instruments	10	8	1
Payload Mass	80 kg	5 kg	1 kg
Rover Mass	930 kg	175 kg	10.5 kg
Power Generation	115 W (Nuclear)	140 W (Solar)	13 W (Solar)

- Available mass for payload instruments is small in comparison to terrestrial instrument mass.
  - Consider detector technologies that are lighter than scintillators, such as silicon strip detectors.
  - Mass budget includes everything associated with the instrument, such as mounting, heaters, thermal blankets, etc.
- Available mass for payload instruments is generally larger on a stationary lander than on a rover because of the added rover weight.
- Instrument power requirements are probably not an issue for a reasonable design.
- The higher the elevation of the landing site, the more mass must go into the frame of the lander and/or the final descent stage to withstand the higher terminal velocity at landing.

Technology Motivation for Mars Muon Radiography

THINKING OUTSIDE THE BOX

STRATEGY: Combine science motivation with technology motivation to gain wider support for including a Mars muon radiography instrument on a Mars mission.

1. **The missions currently outlined within NASA's Mars Exploration Program focus on potential sample return, in preparation for human exploration of Mars as a very long term goal.**
2. **Human exploration missions will require robust surface instrumentation to support surface exploration.**
3. **A muon radiography instrument is a low power option for determining the location of caves or voids and could be included as support equipment for human exploration missions.**
4. **Prior demonstration of the technology is very valuable in this context.**
5. **The combination of science motivation with support of future Mars Program technological goals would increase overall community support for including Mars muon radiography in a near-term mission.**

Summary
CONSTRAINTS

Cost: Use heritage hardware, especially use a tested landing system to reduce cost (Phoenix or MSL EDL stage). The sky crane technology delivers higher mass to the surface and enables reaching targets at higher elevation, but at a higher mission cost.

Rover vs. Stationary Lander: Rover-mounted instrument enables tomography, but the increased weight of the rover reduces the allowable payload weight.

Mass is the critical design constraint for an instrument for a planetary mission.

Many factors that are minor factors or do not enter into design considerations for terrestrial operation are important for a planetary application. (Landing site, diurnal temperature variation, instrument portability, shock/vibration)