# Aeromaneuvering/Entry, Descent, Landing

- Aeromaneuvering
- Entry, Descent, and Landing
- Case study: Mars EDL
- Case study: Mars Exploration Rovers
- Case study: Mars Science Laboratory

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# Aeromaneuvering

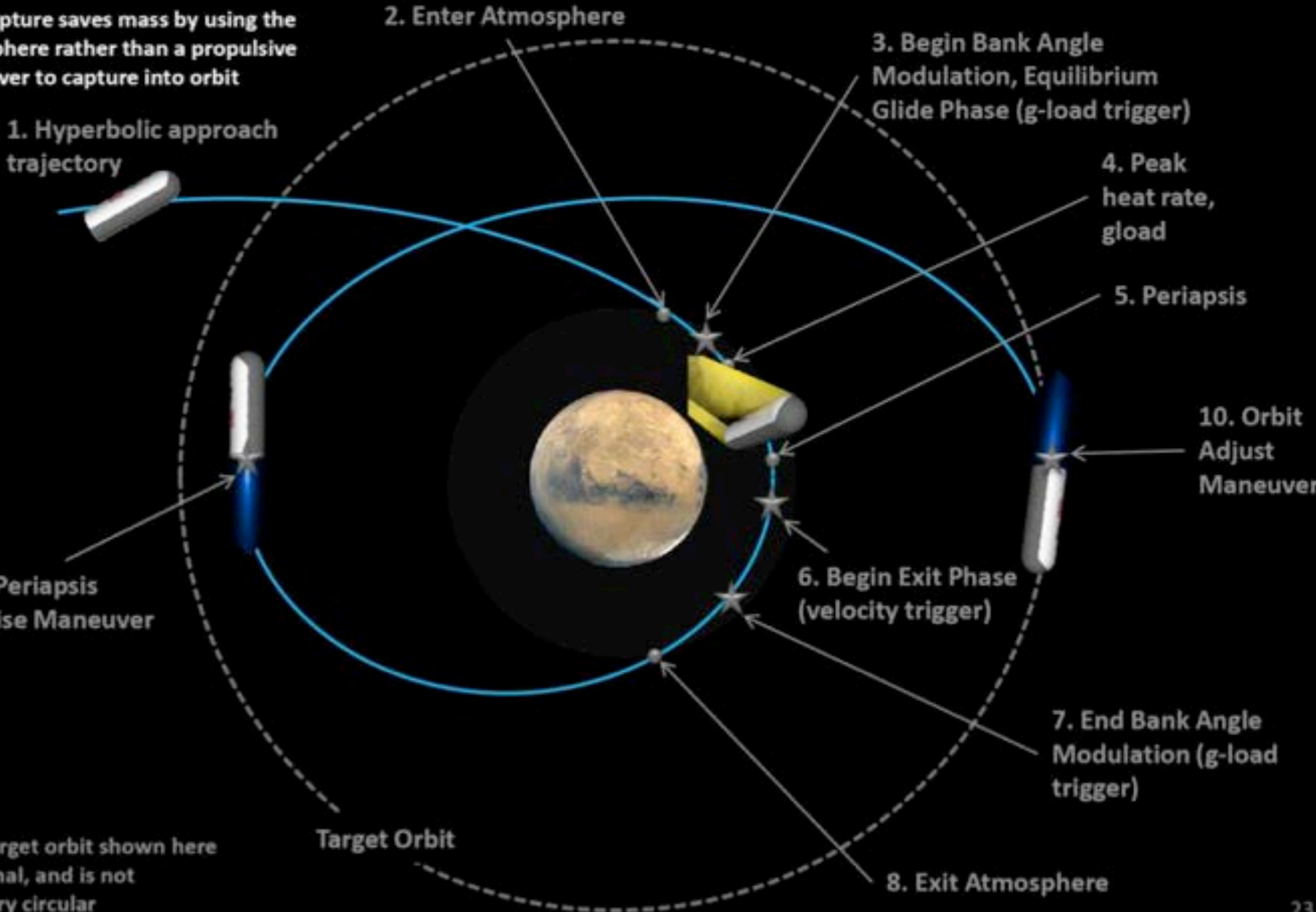
- Using atmospheric flight forces to affect orbit changes while minimizing propellents
- Aerocapture - decelerating into planetary orbit from a single pass
- Aerobraking - lowering apoapsis by atmospheric passes (single or multiple)
- Aeromaneuvering - using aerodynamic forces (e.g., lift) to perform advanced maneuvers such as plane change

# The Challenge of Mars EDL (Entry, Descent, and Landing)

*Ron Sostaric*
*NASA Johnson Space Center*
*AIAA Senior Member*
*April 2010*

# Aerocapture

**Aerocapture saves mass by using the atmosphere rather than a propulsive maneuver to capture into orbit**

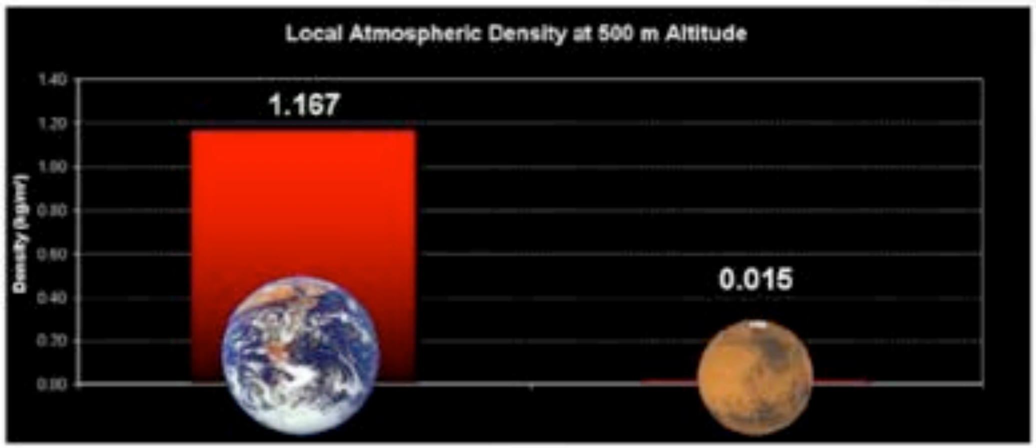


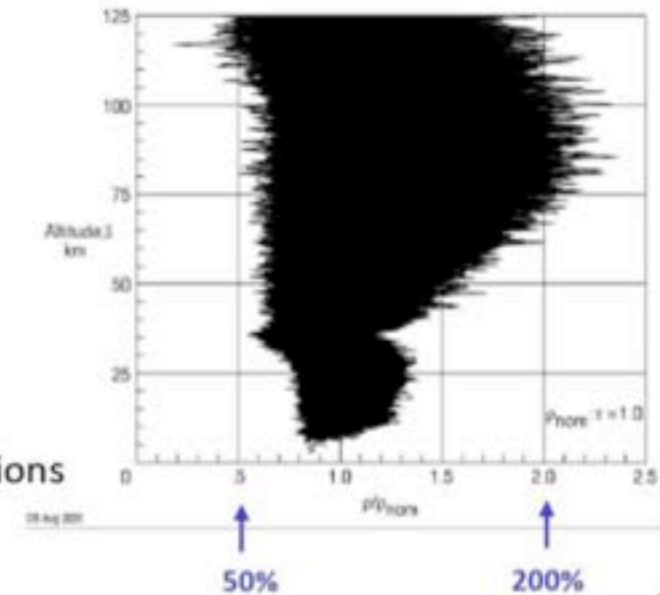

Note: target orbit shown here is notional, and is not necessary circular

# Why is Mars EDL so difficult?

## ATMOSPHERE:

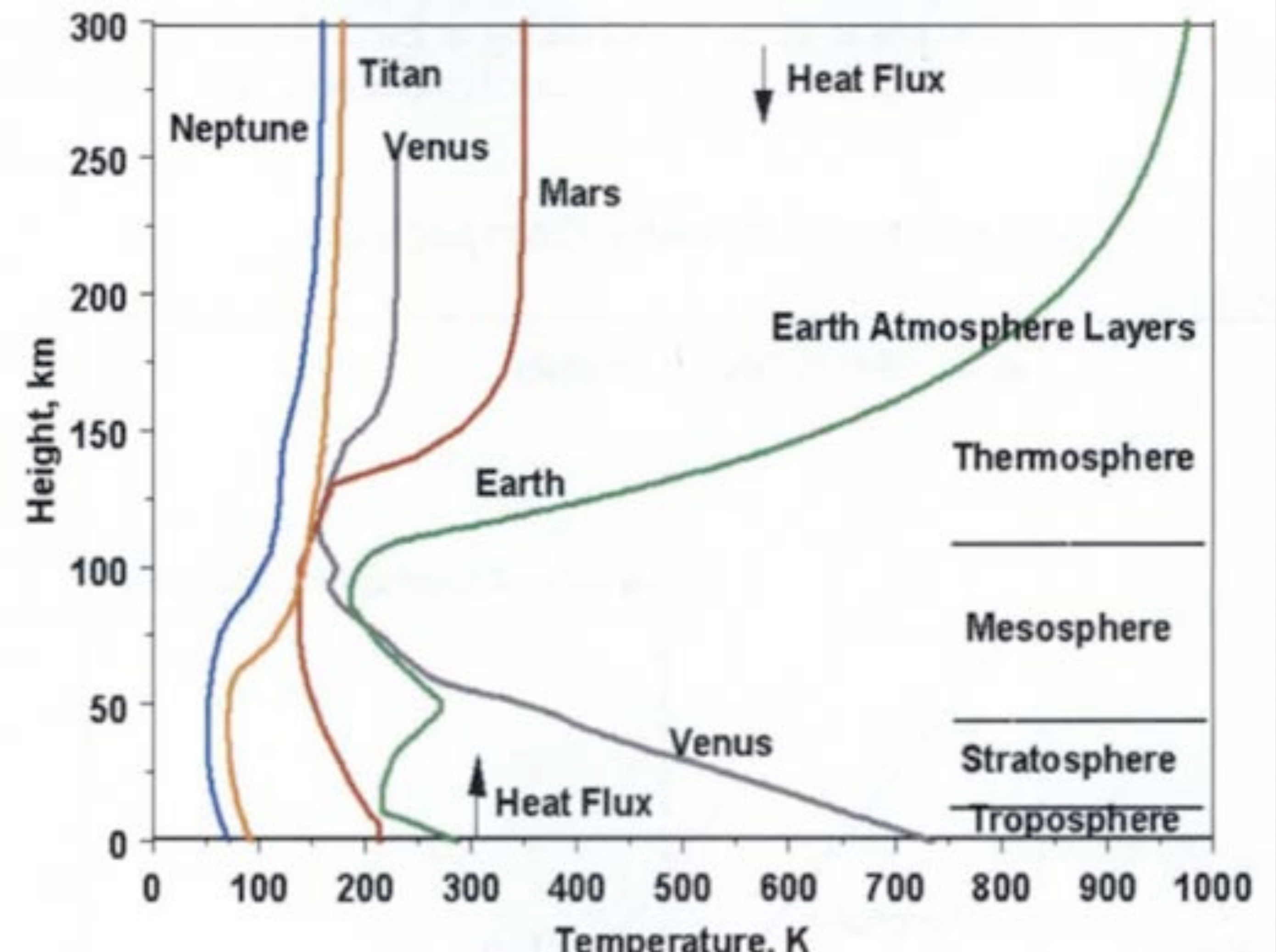
- Thin Martian atmosphere (surface density equivalent to Earth's at 30 km)
- Too little atmosphere to decelerate and land like we do at Earth
- Atmosphere is thick enough to create significant heating during entry



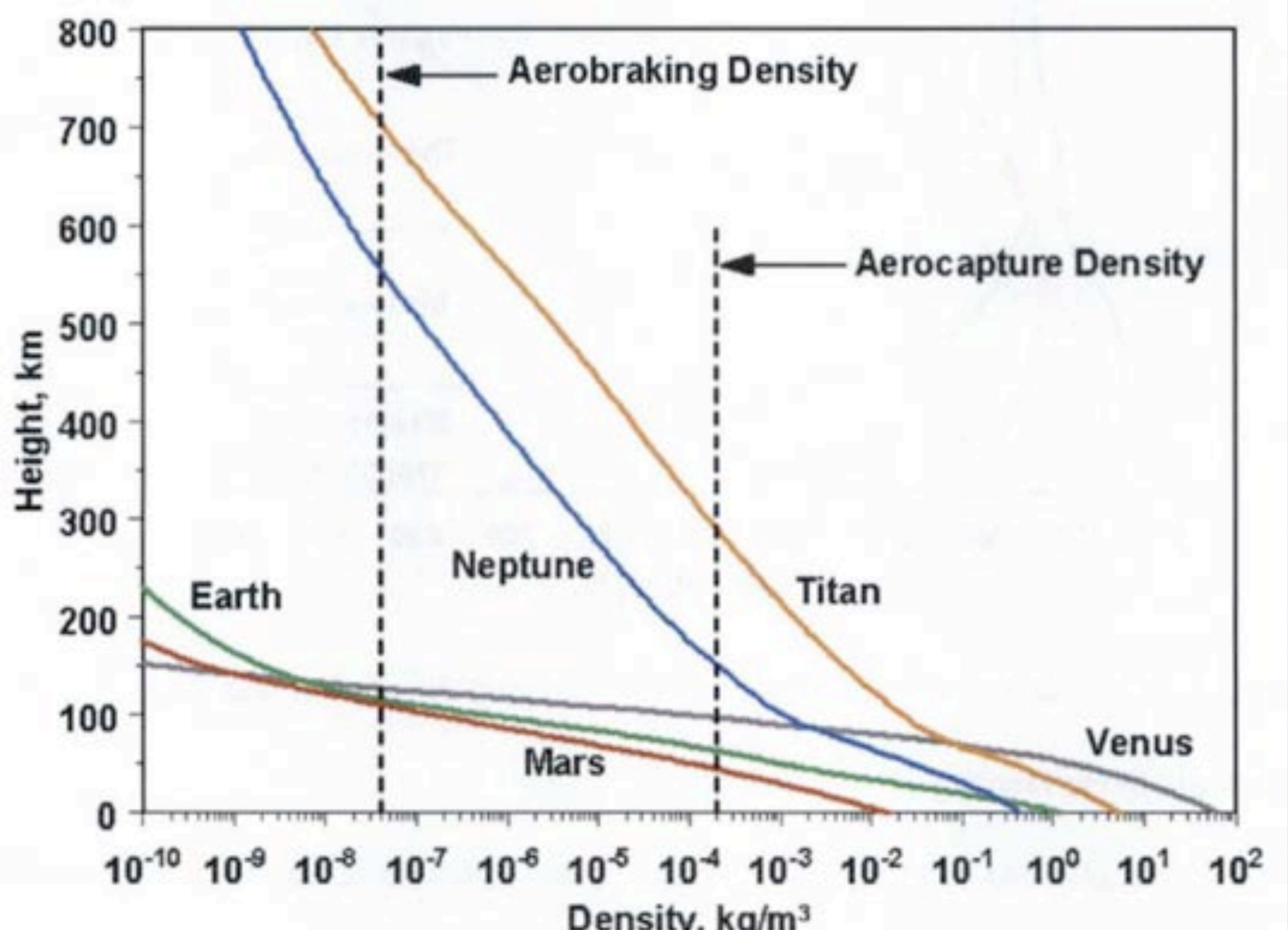

- Lack of understanding of the atmosphere:
  - Aerodynamics, aeroheating, winds, and density variations

# Atmospheric Thermal Profiles




from Justus and Braun, “Atmospheric Environments for Entry, Descent, and Landing”, 5th International Planetary Probes Workshop, August 2006

# Atmospheric Density Profiles




from Justus and Braun, “Atmospheric Environments for Entry, Descent, and Landing”, 5th International Planetary Probes Workshop, August 2006

# Mars EDL History

All six of the successful U.S. Mars EDL systems had:

- Low Landing Site: elevation sites below –1 km MOLA ← that's Mars Sea Level
- Low Mass: Had landed masses of less than 0.6 MT
- UNGUIDED: Had large uncertainty in targeted landing location (300 km for Mars Pathfinder, 80 km for MER)

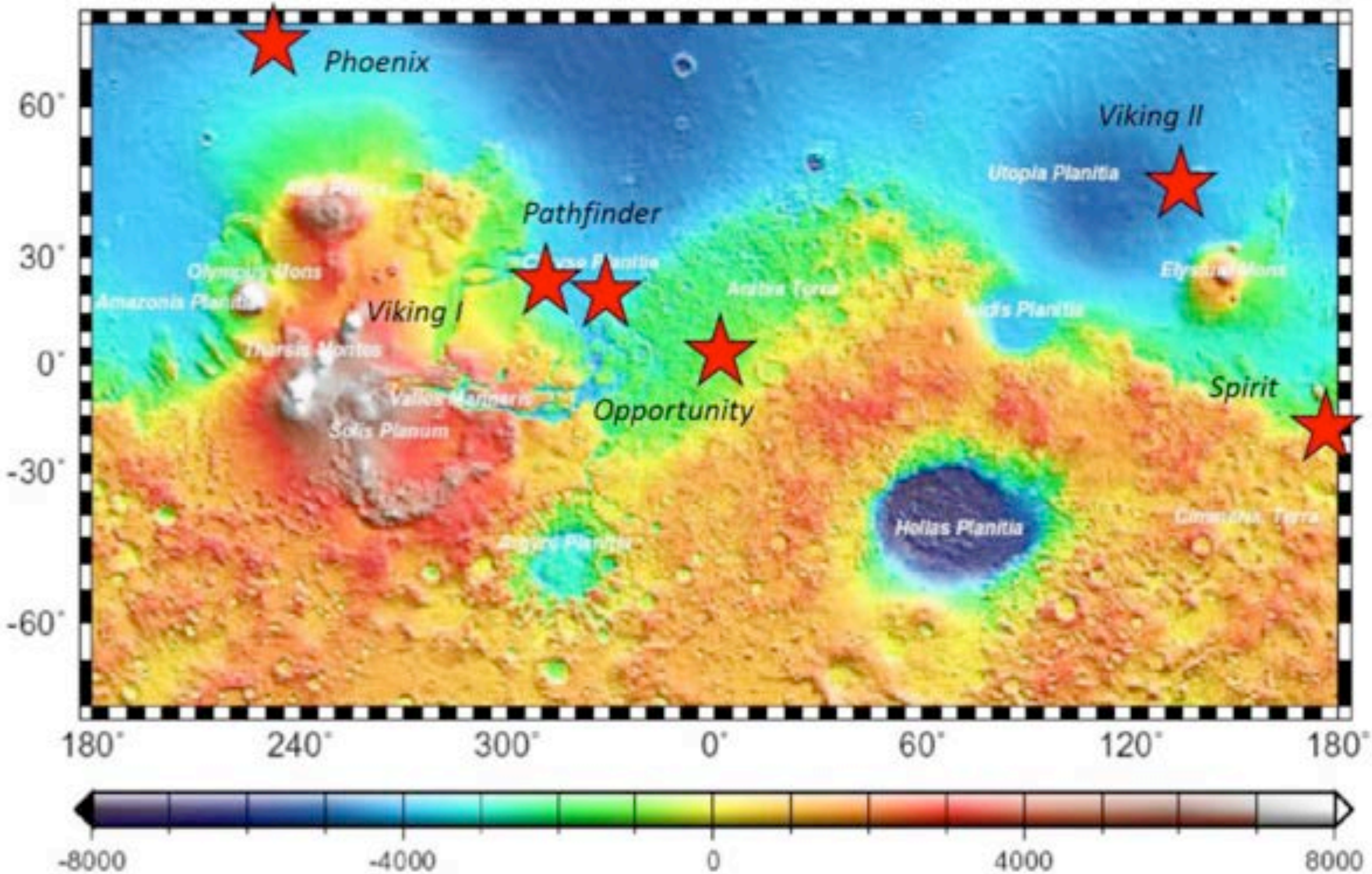
Mars Science Laboratory (MSL) '11 EDL Architecture:

- Low Landing Site: Landed elevation requirement for sites below 0 km MOLA
- Low Mass: Has landed mass of 0.9 MT
- GUIDED: Has uncertainty in targeted landing location of 10km

HUMANS need more capability:

- All of the current Mars missions have relied on large technology investments made in the late 1960s and early 1970's as part of the Viking Program (heatshield shape, thermal protection material, and parachute)
- Large Mass (Entry Mass of ~100 – 150 MT)
- Higher elevations – interesting science
- Precision Landing

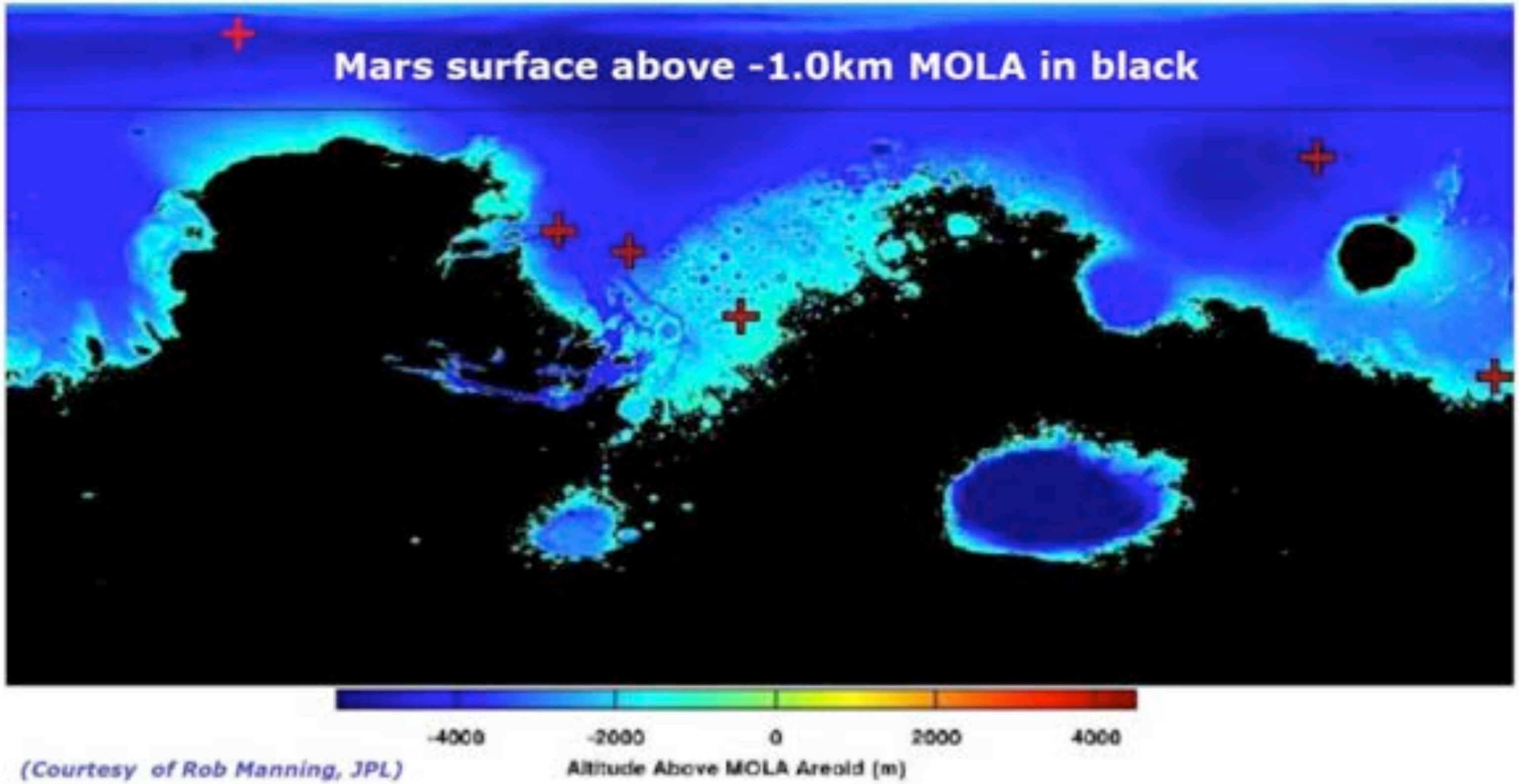
# 6 U.S. Mars Entry, Descent, and Landing Successes



# Current Mars Accessibility

Previous Viking derived EDL systems and the thin Martian atmosphere and small scale height have limited accessible landing sites to those below -1.0km MOLA

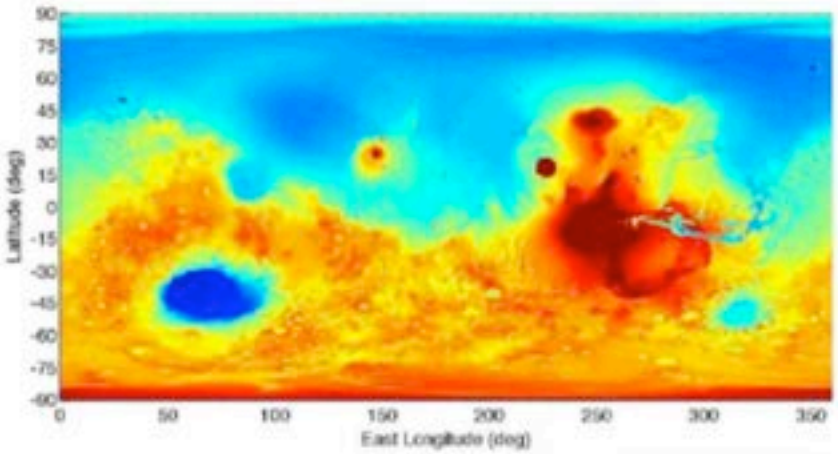
To date the southern hemisphere has been largely out of reach (approximately 50% of the planet surface remains inaccessible with current EDL technologies)



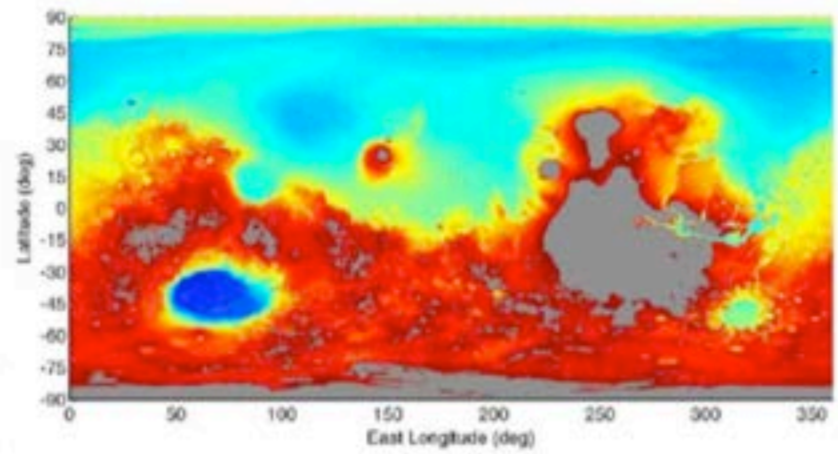

*(Courtesy of Rob Manning, JPL)*

# Landing Site Elevation / Accessibility

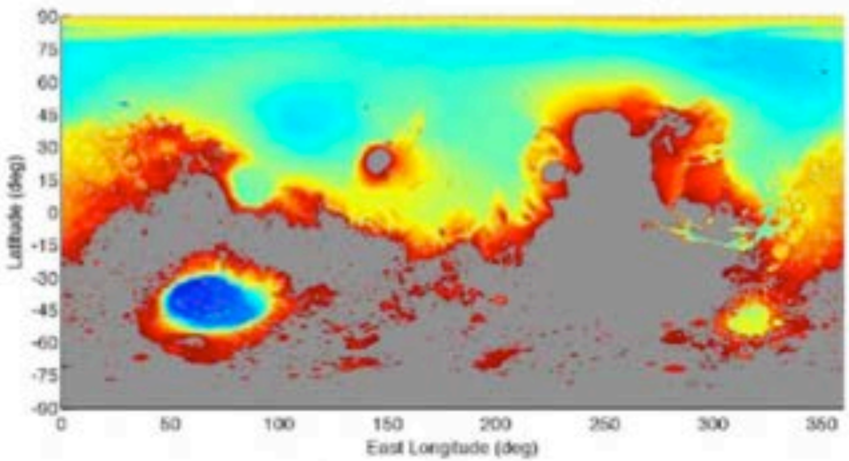
MOLA 1/4° Topographic Data



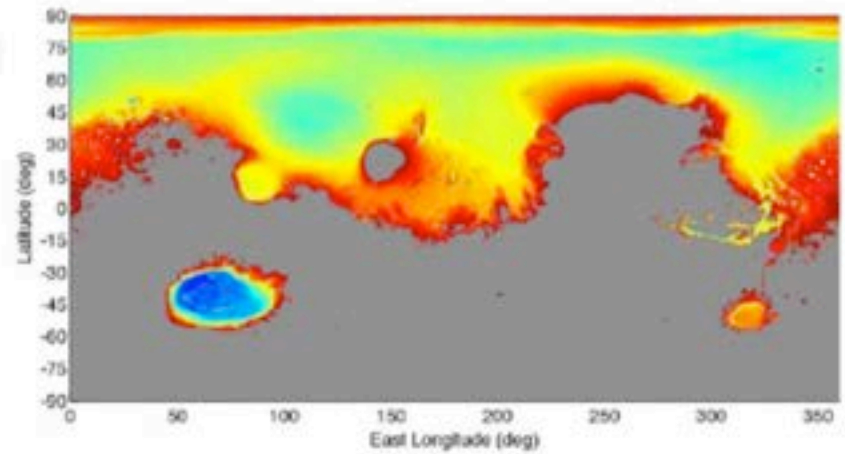

< 2.5 km (90% of Surface)




< 1.0 km (65% of Surface)

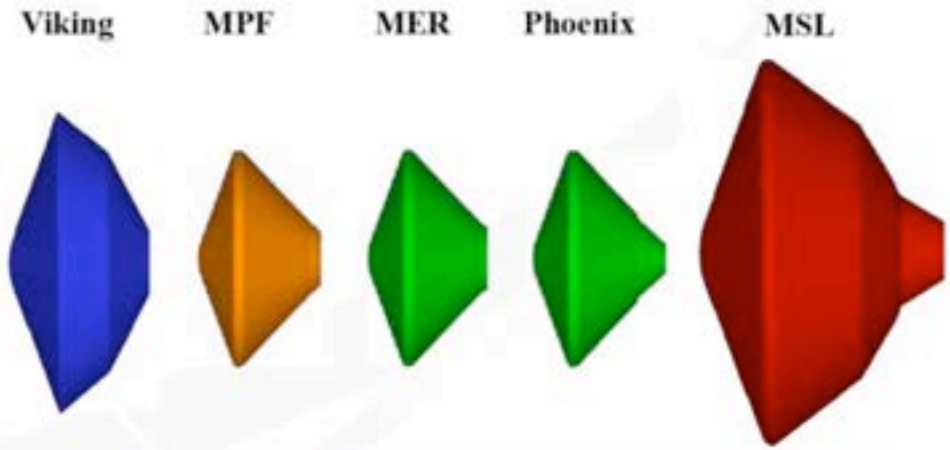



< -1.0 km (45% of Surface)



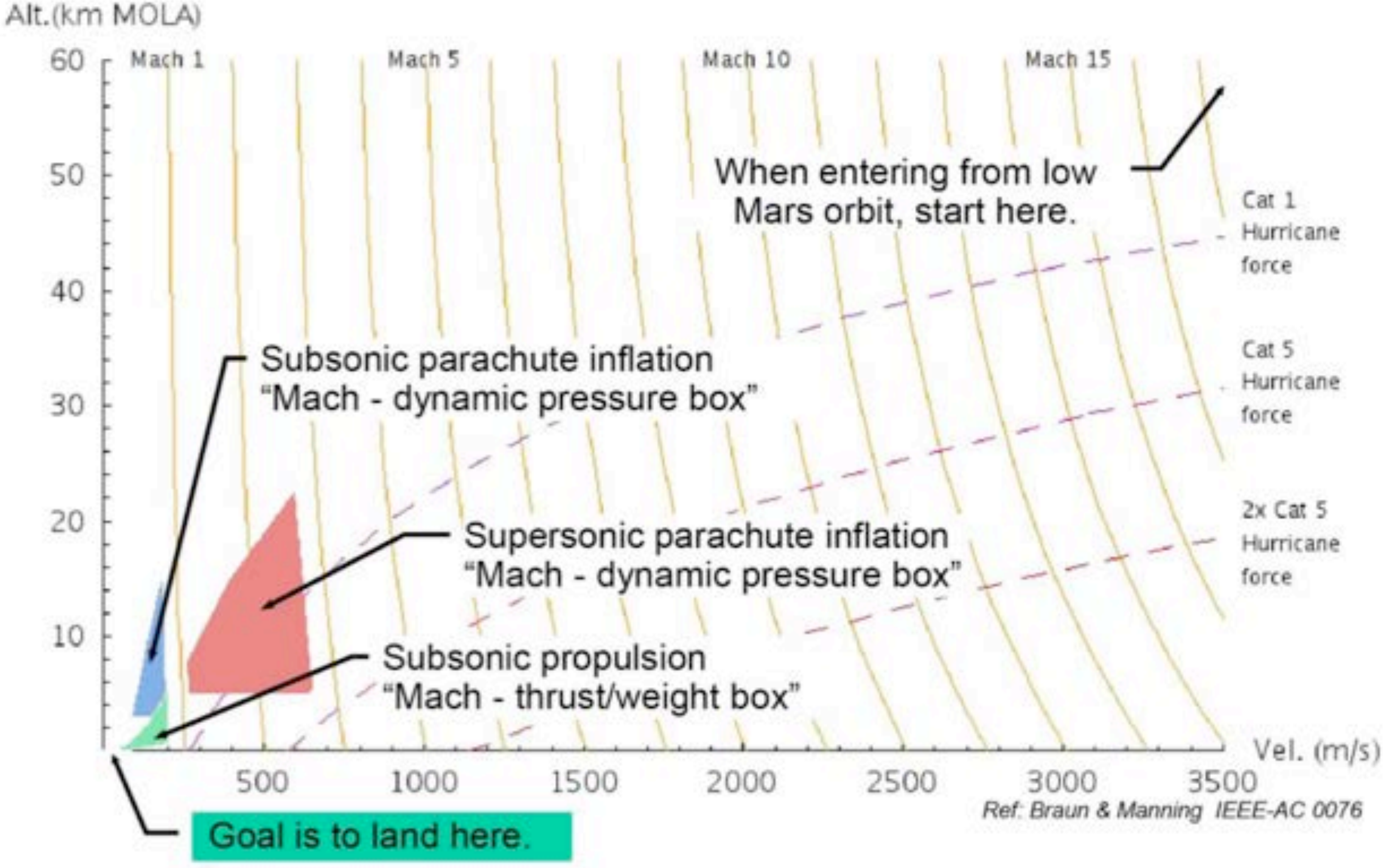
# Mars Heritage Aeroshell - Mission Comparisons

Core Viking Technologies:
70° sphere-cone aeroshell

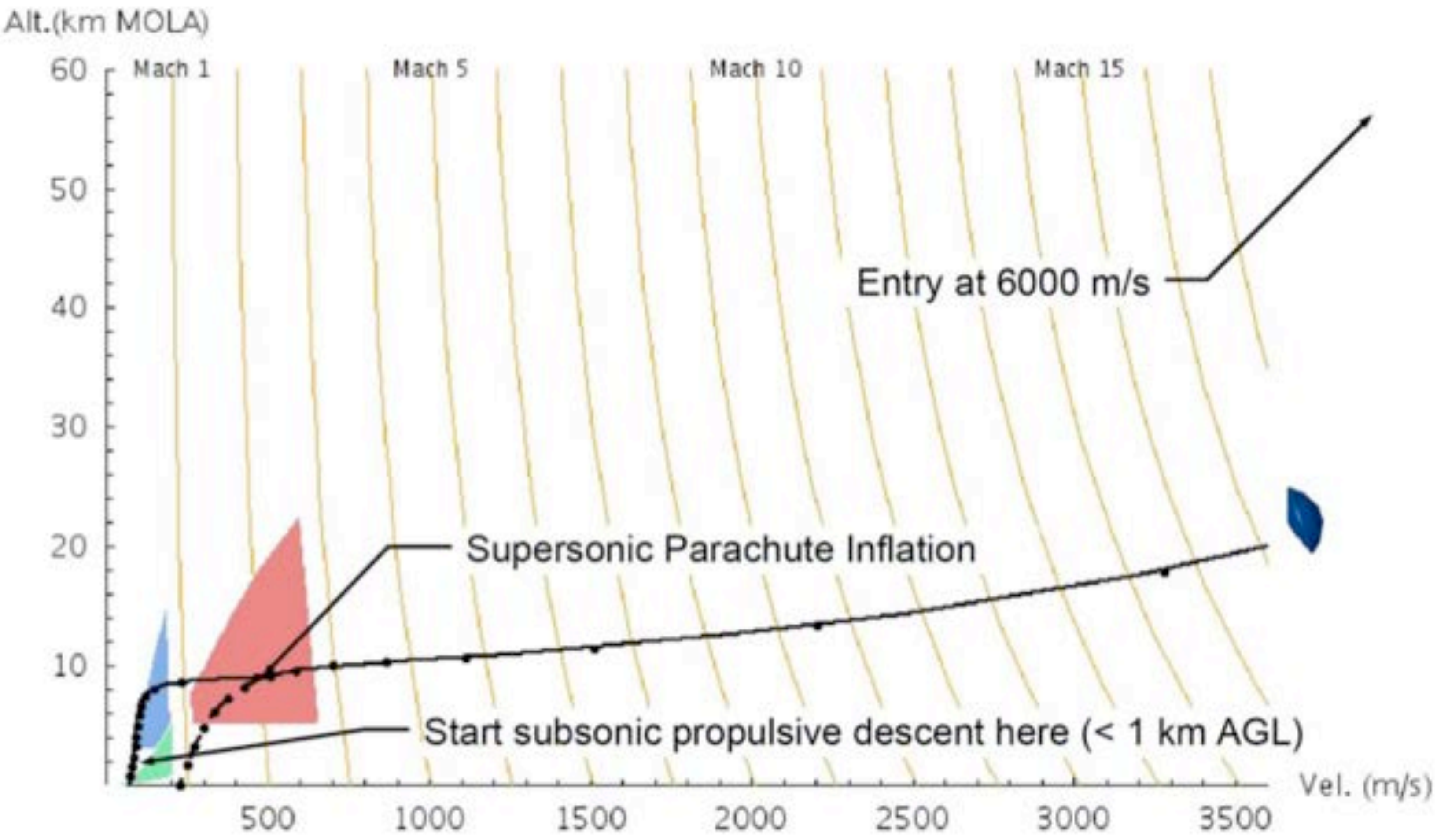



| Parameter | Viking | MPF | MER | Phoenix | MSL |
|---|---|---|---|---|---|
| Entry Mass (kg) / Ballistic Coeff. (kg/m²) | 980 / 66 | 585 / 63 | 836 / 90 | 603 / 65 | 3257 / 140 |
| Lander/Rover Mass (kg) | 612 | 11 | 173 | 64 | 850 |
| Aeroshell Diameter (m) | 3.5 | 2.65 | 2.65 | 2.65 | 4.5 |
| Angle-of-Attack (deg) / L/D | 11.1° / 0.18 | 0° / 0.0 | 0° / 0.0 | 0° / 0.0 | -15.5° / 0.24 |
| Peak Heatrate (W/cm²) | 21 | 106 | 44 | 59 | <210 |
| Parachute Diameter (m) | 16.15 | 12.4 | 14.1 | 11.5 | 19.7 |
| Landing Site Elevation (km) | -3.5 | -1.5 | -1.3 | -3.5 | 0.0 |

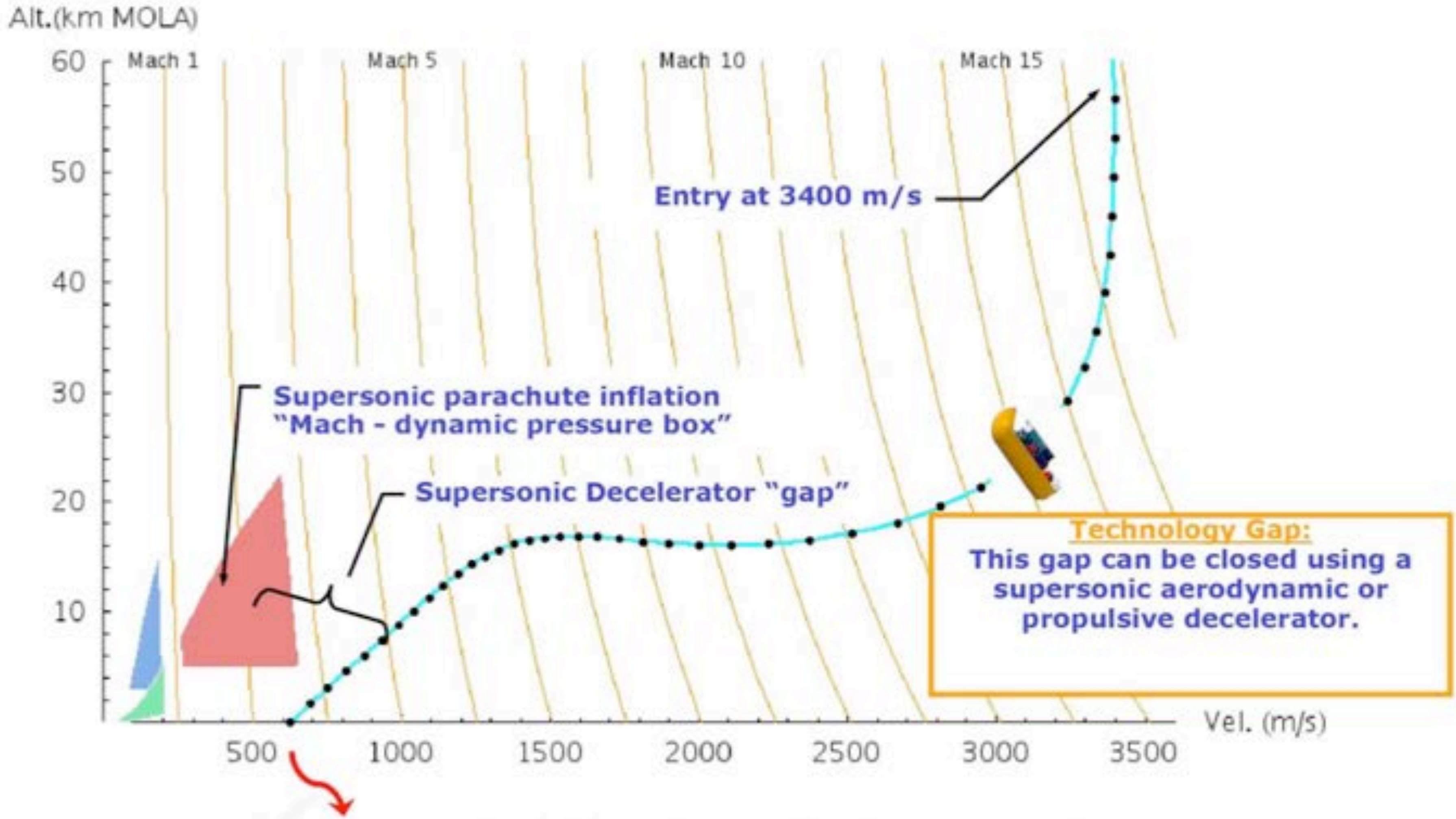
# EDL Phase Plot – A Handy Way to Visualize EDL



# Robotic program: No gap so far ....



# How would Humans Land?

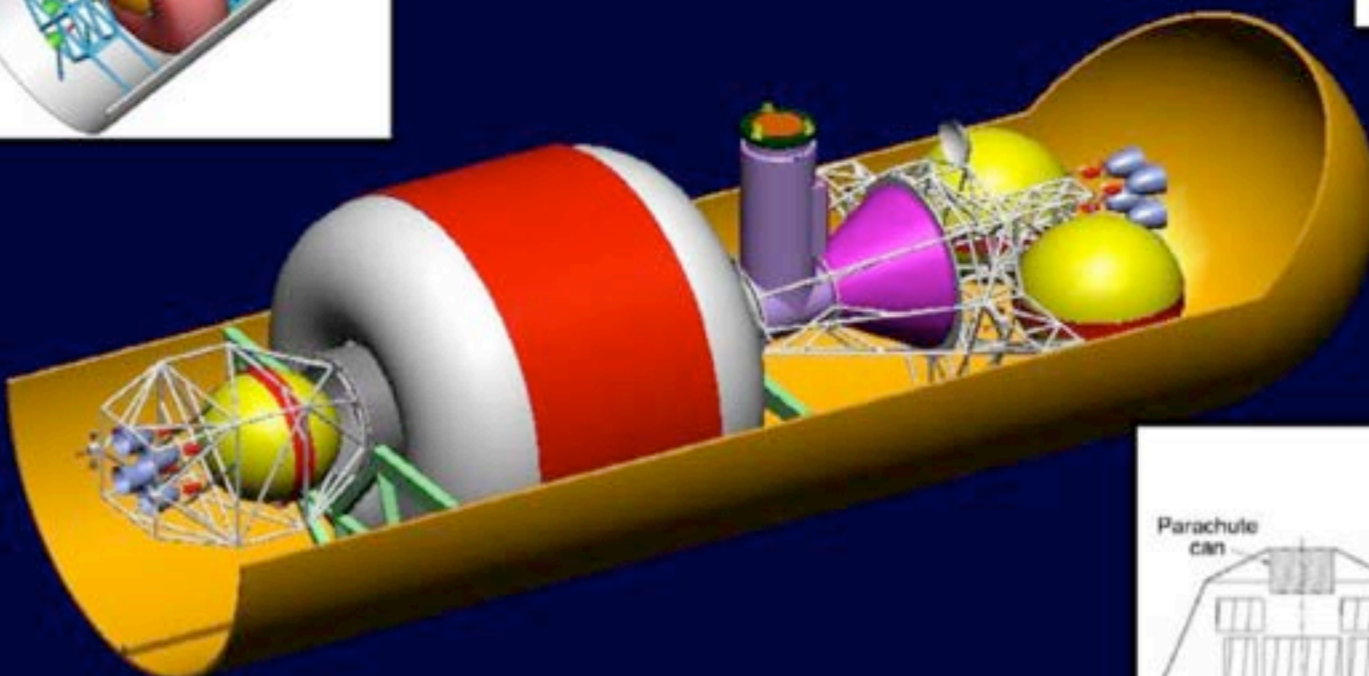


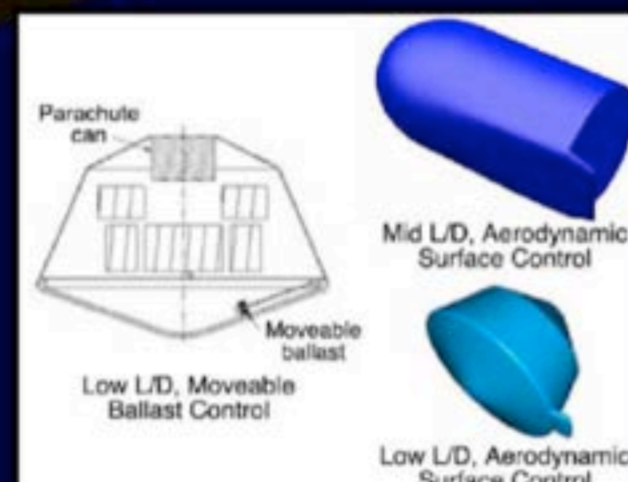

Without new technologies we have surface impact at Mach 2.5

# EDL Technology Development

- **Technologies that can help close the "gap"**
  - Rigid Aeroshell
  - Inflatable Aerodynamic Decelerator (IAD)
  - Supersonic Retro-Propulsion
- **Other technologies of interest**
  - Aerocapture
  - Precision Landing
  - Hazard Detection and Avoidance

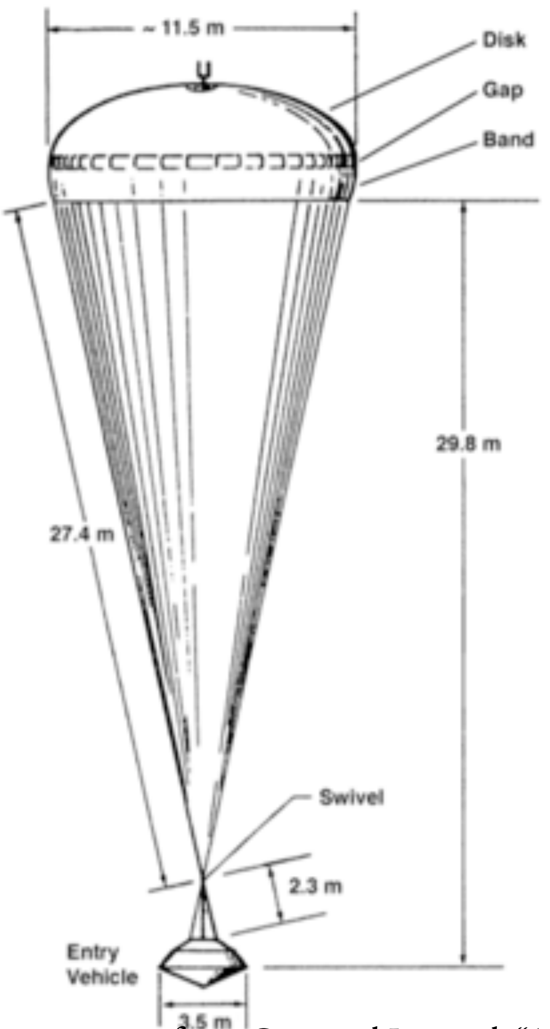
# Rigid Aeroshells





# Inflatable Aerodynamic Decelerators

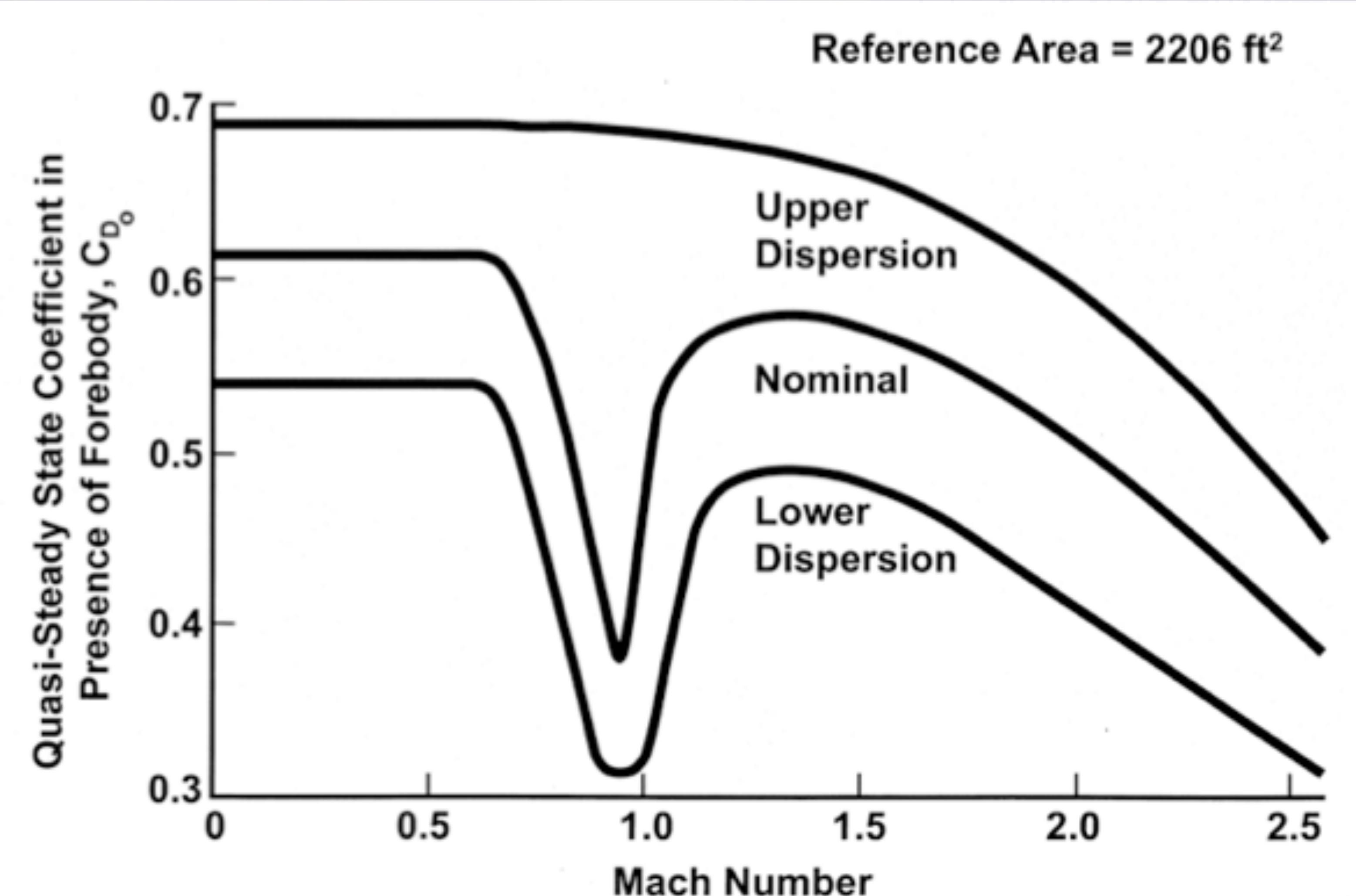
# Viking Parachute Configuration




- "Disk-Gap-Band" (DGB) or "bandgap" parachute
- Deployed at Mach 2
- Had to have sufficient deceleration to allow jettison of heat shield and dropping of lander from aeroshell

from Cruz and Lingard, "Aerodynamic Decelerators for Planetary Exploration: Past, Present, and Future", AIAA 2006-6792, AIAA Guidance, Navigation, and Control Conference, August 2006

# Viking Chute Drag Coefficient Model




from Cruz and Lingard, "Aerodynamic Decelerators for Planetary Exploration: Past, Present, and Future", AIAA 2006-6792, AIAA Guidance, Navigation, and Control Conference, August 2006

# Terminal Velocity

Full form of ODE -

$$\frac{d\left(v^2\right)}{d\rho} - \frac{h_s}{\beta \sin\gamma} v^2 = \frac{2gh_s}{\rho}$$

At terminal velocity, $v = \text{constant} \equiv v_T$

$$-\frac{h_s}{\beta \sin\gamma} v_T^2 = \frac{2gh_s}{\rho}$$

$$v_T = \sqrt{-\frac{2g\beta \sin\gamma}{\rho}}$$

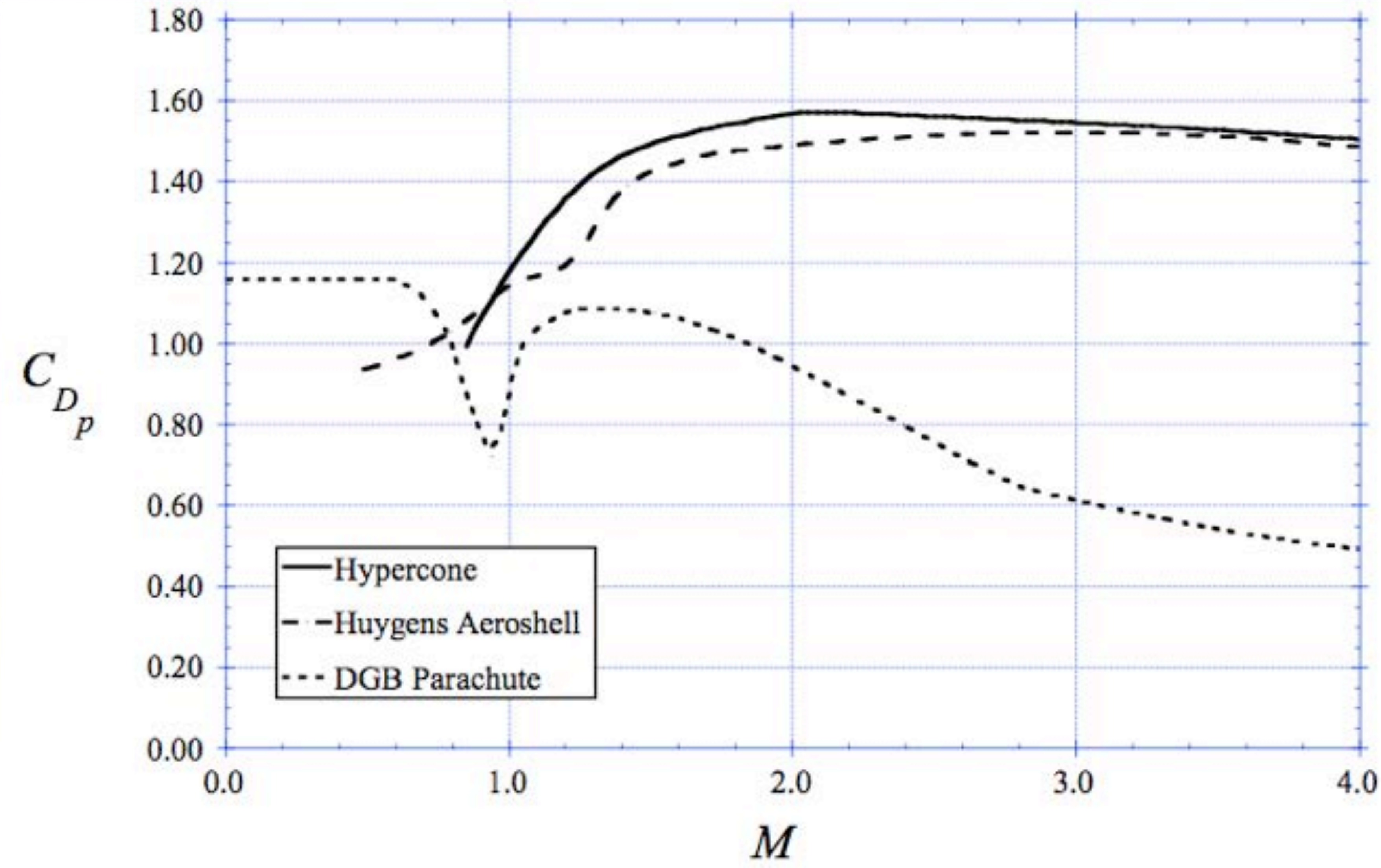
# Viking Terminal Velocity Under Chute

$$\beta = \frac{m}{c_D A} = \frac{930\ kg}{0.62\left(\frac{\pi}{4}\right)(16.15\ m)^2} = 7.322\ \frac{kg}{m^2}$$

$$v_T = \sqrt{-\frac{2g\beta \sin\gamma}{\rho}} = \sqrt{-\frac{2(3.711\ m/s^2)(7.322\ kg/m^2)\sin(-30^o)}{0.02\ kg/m^3}} = 36.9\ \frac{m}{sec}$$

$$\beta_{crit} = -\frac{\rho_o h_s}{\sin\gamma} = -\frac{0.02\ kg/m^3(10,800\ m)}{\sin(-30^o)} = 432\ \frac{kg}{m^2}$$

# Rigid and Inflatable Aeroshell vs. Chute



# Low Ballistic Coefficient Hypersonic Decelerator Development Challenges

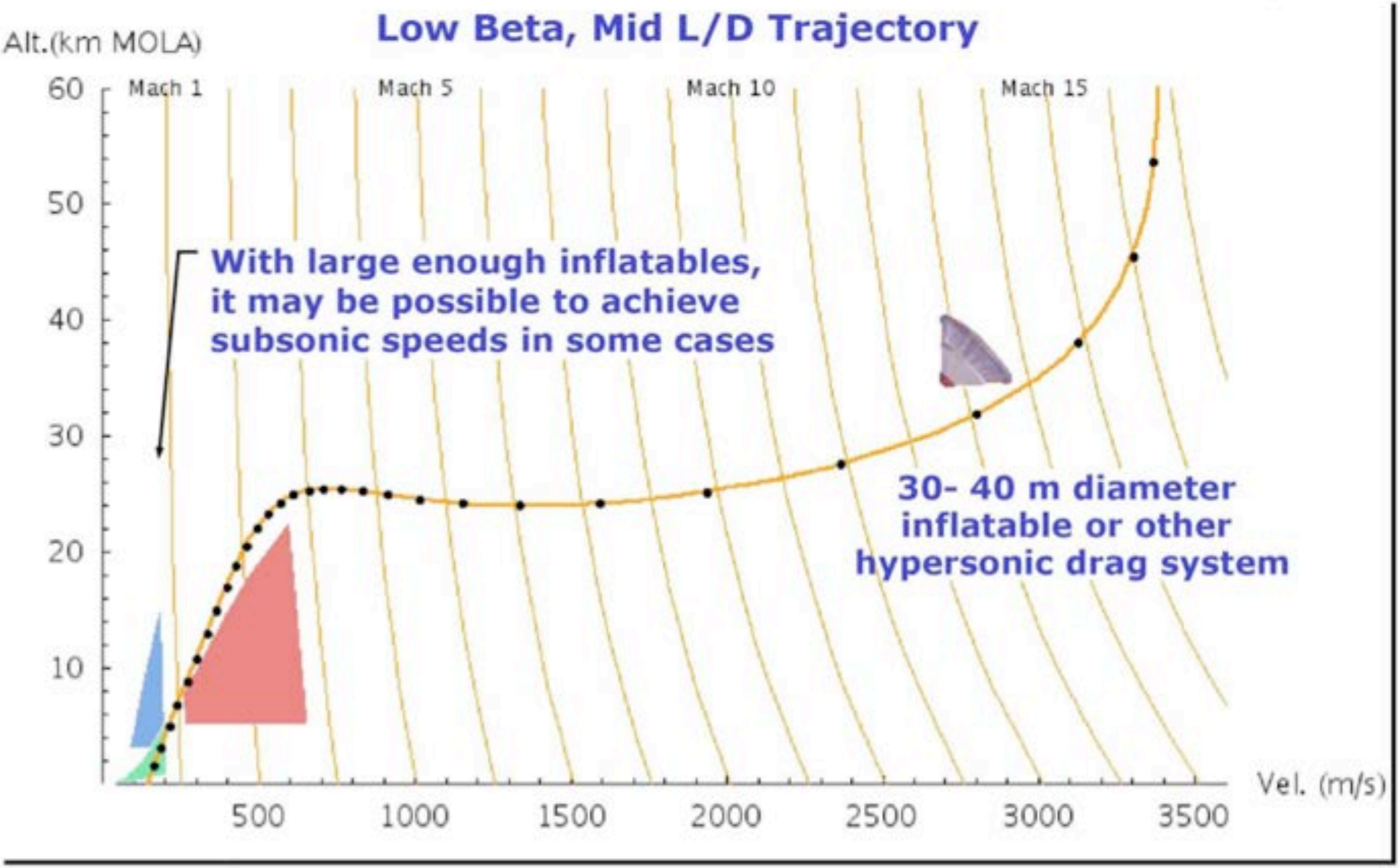
- **For 50-100 MT entry masses we need a 20-40 m diameter aeroshell.**
- **Large uncertainties (unknown-unknowns):**
  - Lift control (how to modulate drag) with large density uncertainties
  - Dynamic stability issues at supersonic and transonic conditions
  - Subsonic position correction
  - Subsonic separation mechanism

  Specifically for an Inflatable Hypersonic Decelerator:
  - Lift control
  - RCS
  - Fluid structures interactions
  - Light weight flexible TPS with large radiative heating

  Specifically for a Rigid On-orbit-deployed Hypersonic Decelerator:
  - Mass fraction of Aeroshell & deployment device

- **Again, there are NO Earth analog for these systems.**
  - NASA, Russia and ESA have tested very small scale inflatable Earth entry systems (IRVE, IRDT)

# What about Large Inflatable Entry Vehicles?
# (ballistic coefficient = 50 $kg/m^2$ & L/D = 0.3)



# Supersonic Retro-Propulsion

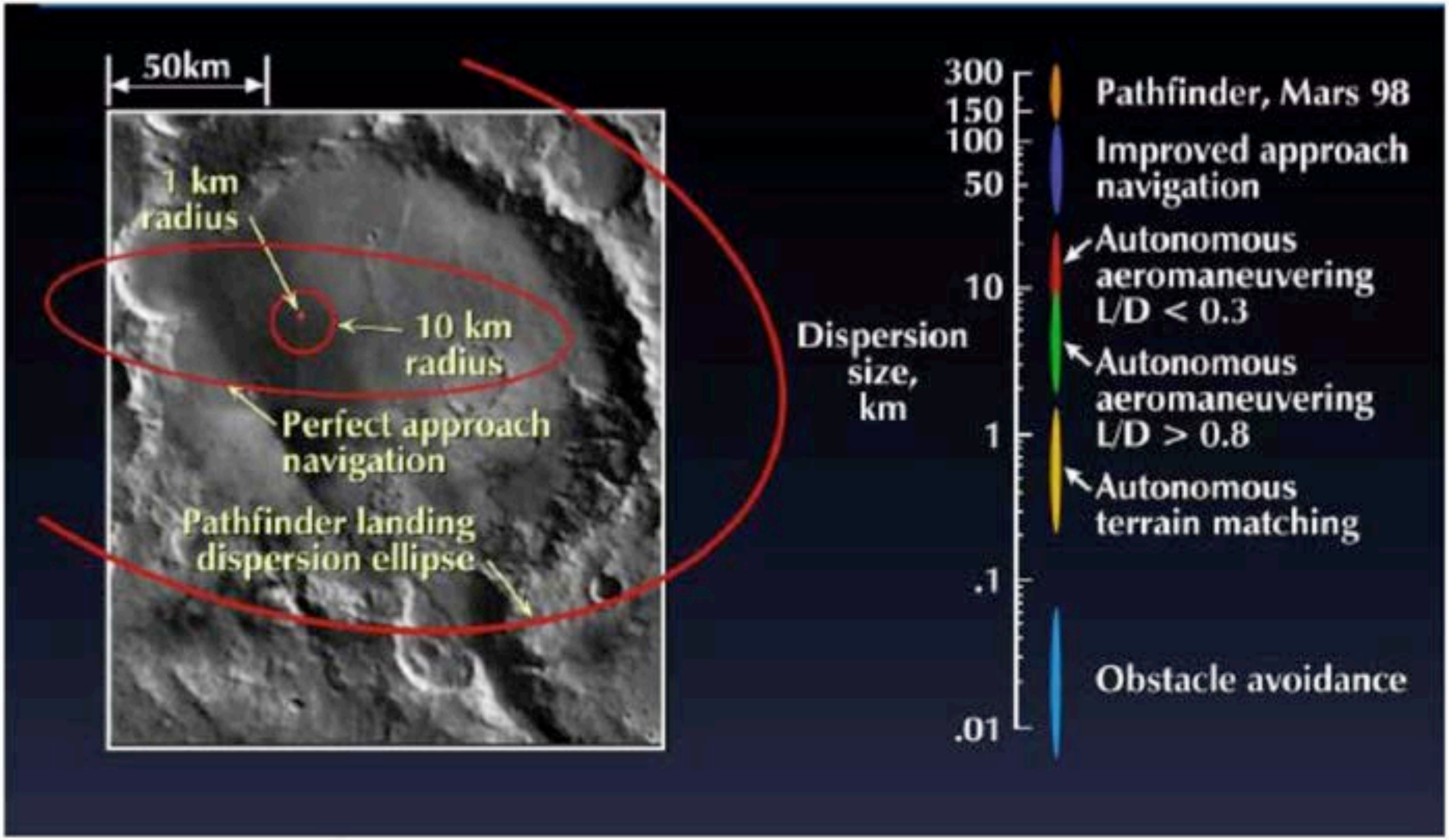
- **Advantages:**
  - More precise landing – aerodynamics / winds now secondary effect
  - Control authority and altitude from Mach > 3 to the ground
  - Fewer complex systems (e.g.parachutes, deployable systems)

- **Disadvantages:**
  - Large propellant mass fractions
  - Aerodynamic stability of the vehicle plume and flow impingements
  - RCS / flow interactions
    - Aerodynamic / propulsion flow interactions
    - Plume / flow aeroheating
  - Surface contamination issues

# Potential Exploration Architectures

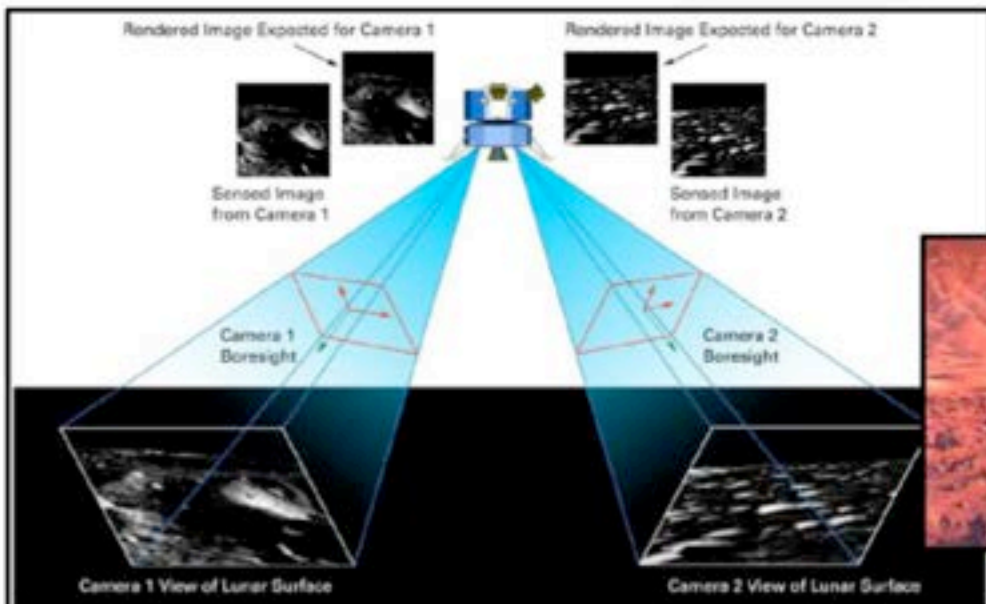
*Some possible combinations…*

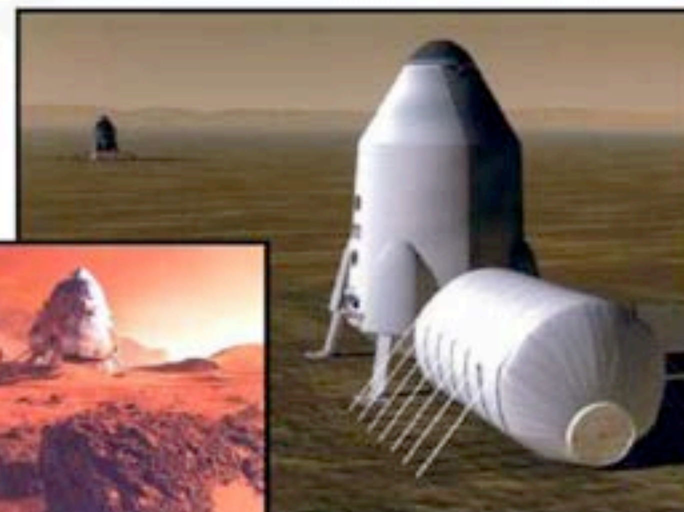
# The Case for Precision Landing, Hazard Avoidance, and Pinpoint Landing



# Precision Landing

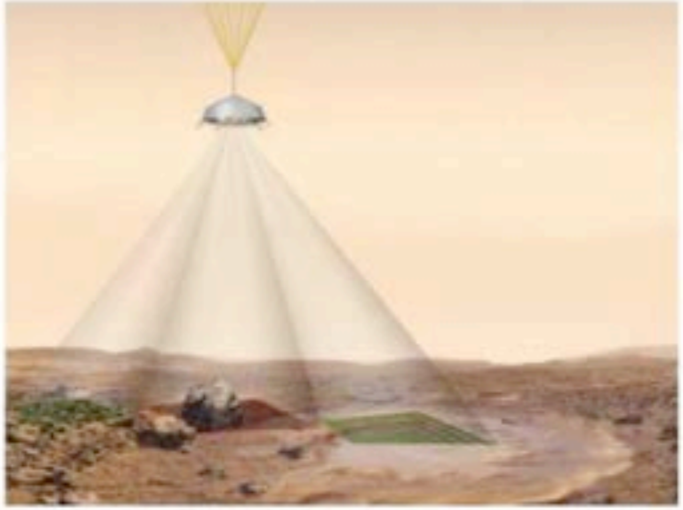
- Precision landing is the capability to land very accurately
- Requires very good knowledge of the vehicle state (navigation) at the right time, in addition to the ability to correct for state errors (guidance and control)
- A combination of sensors including star tracker, inertial measurement unit (IMU), altimeter, and velocimeter are used for state estimation
- Terrain Relative Navigation is a technology being developed for the Moon and Mars which may enable a precision landing level of performance

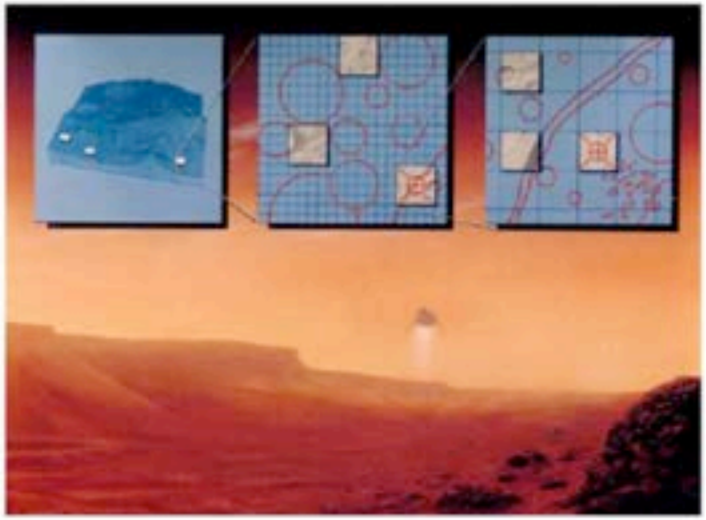


# Hazard Detection and Avoidance (HDA)

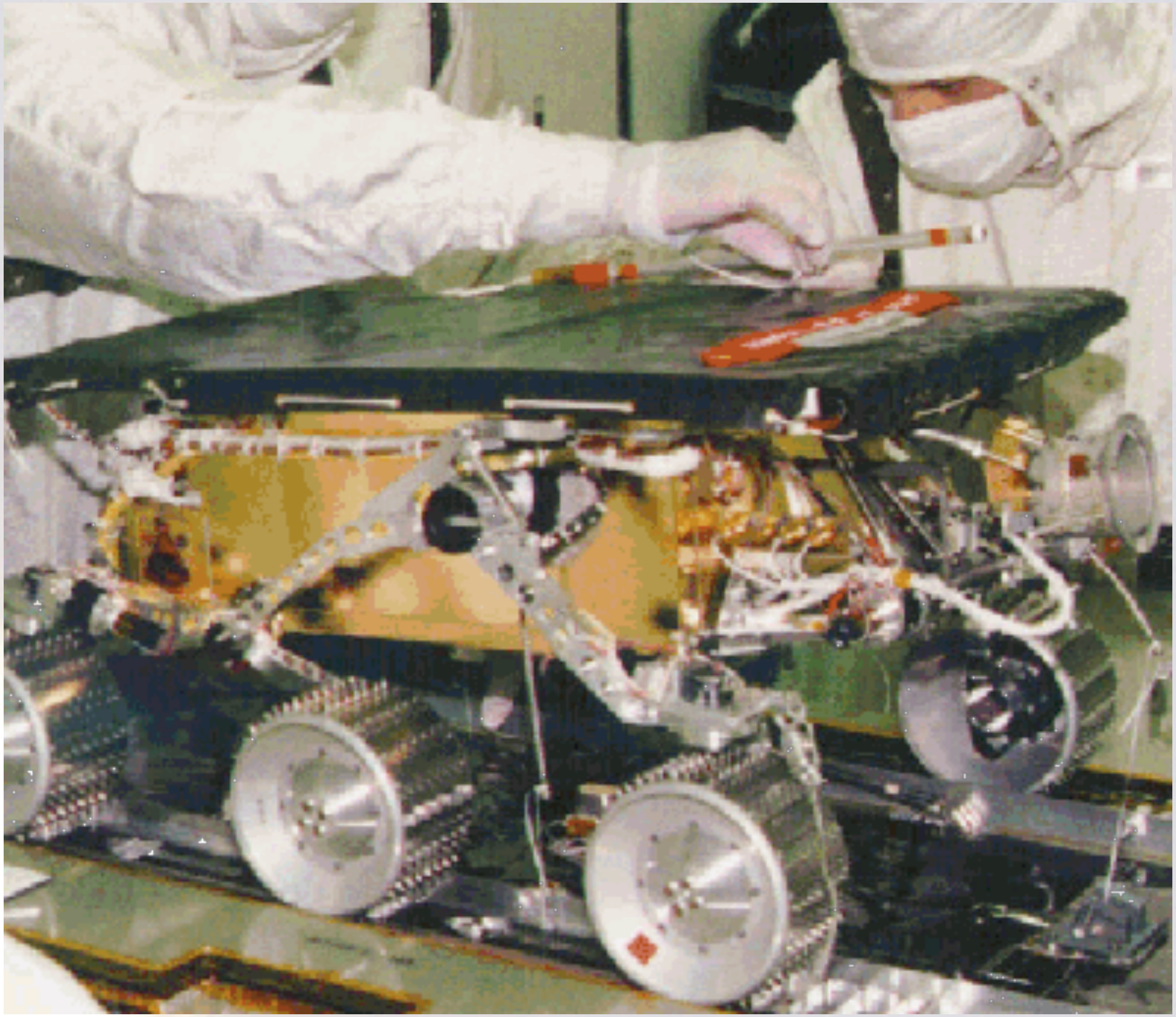
- HDA is the capability to detect and avoid hazards during the landing
- An onboard hazard map is developed real time during the descent using flash LIDAR
- The flash LIDAR returns a 3-D image of the landing area which contains higher resolution information of the landing area than currently possible using orbit reconnaissance
- An updated landing point is then selected (either automatically or via crew intervention) and the vehicle re-targets to the new landing point



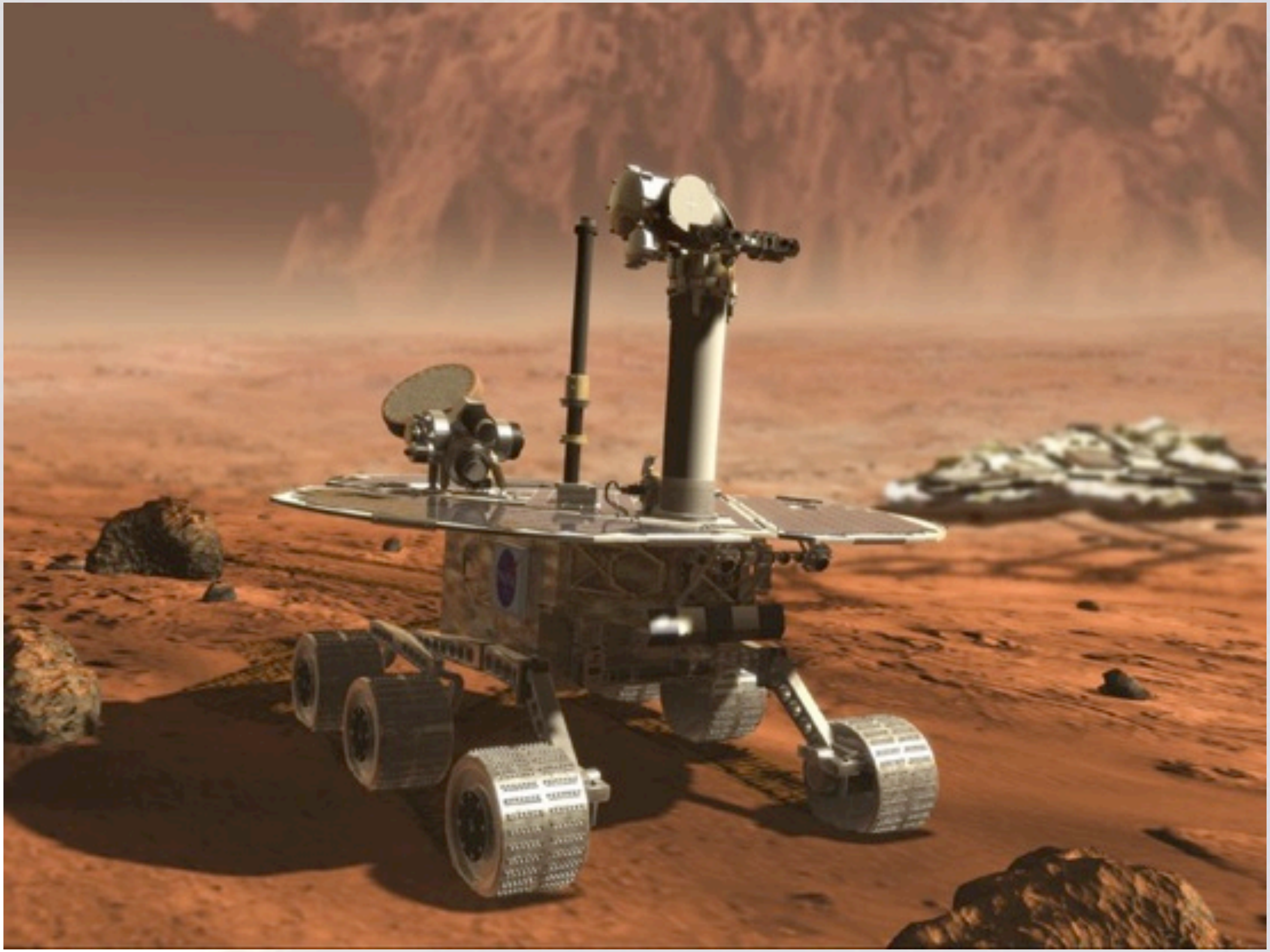


# Viking Panoramas (1976)

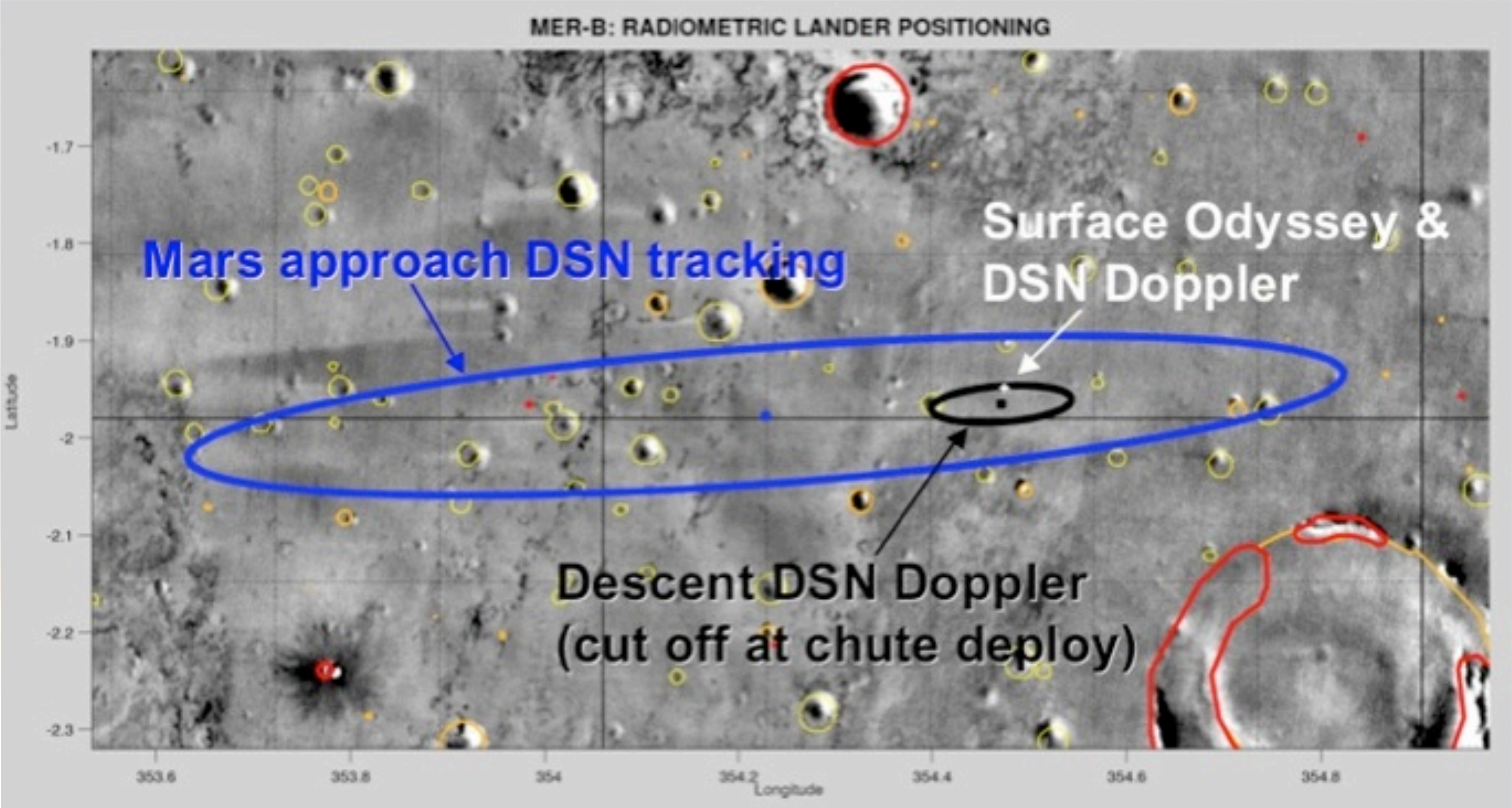
# Mars Pathfinder Rover ("Sojourner")



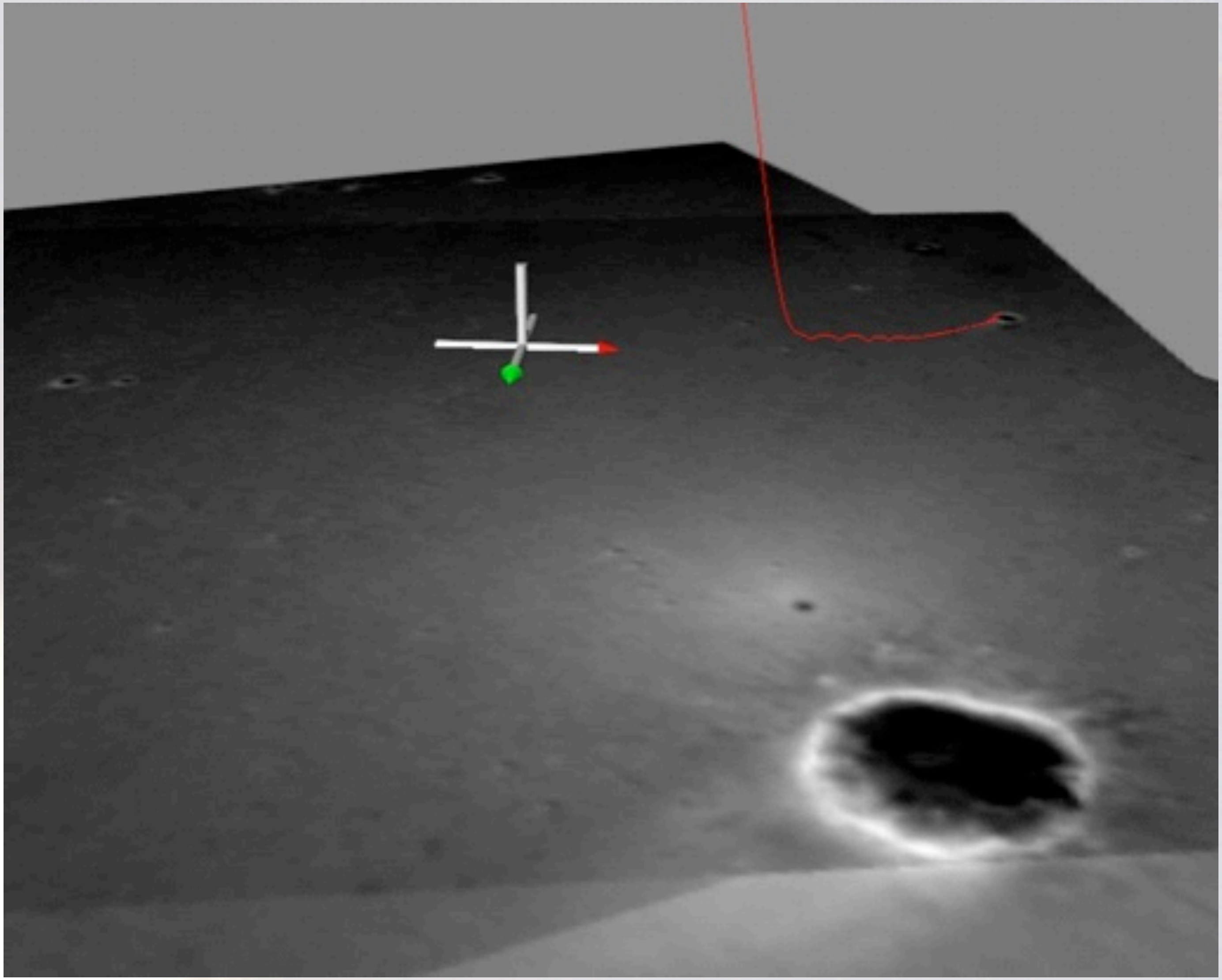
# Mars Exploration Rover



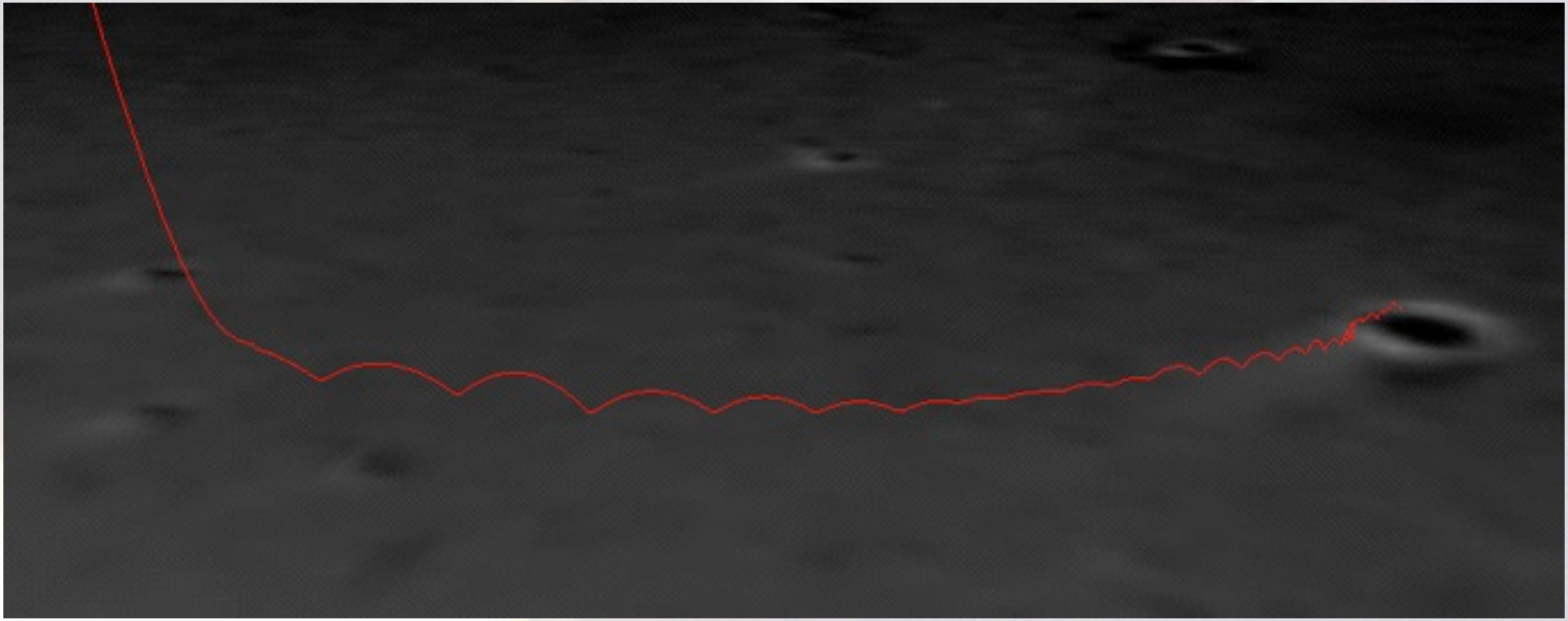
# Opportunity Landing Targeting



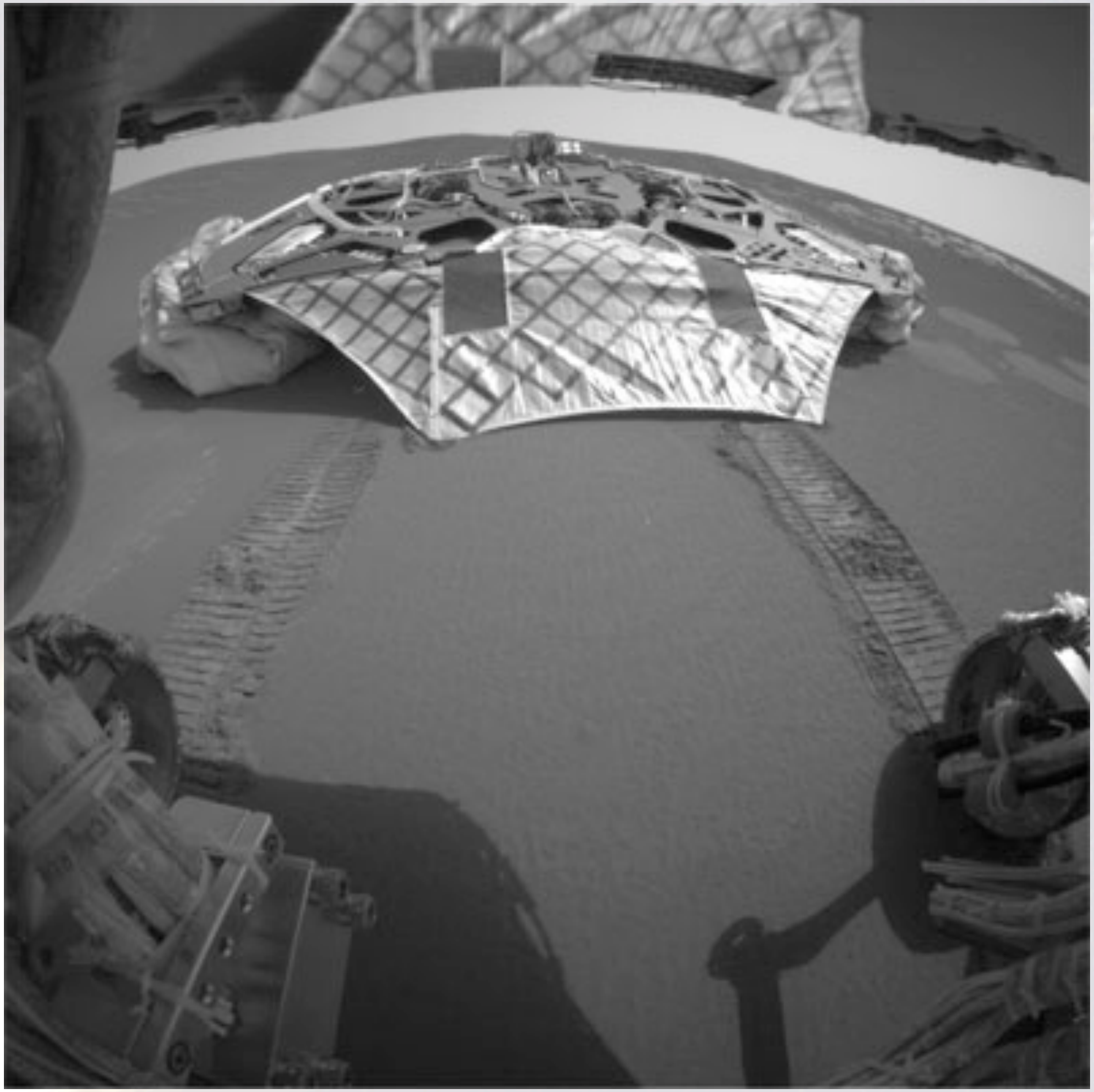
# Sometimes the Bounces Go Your Way...



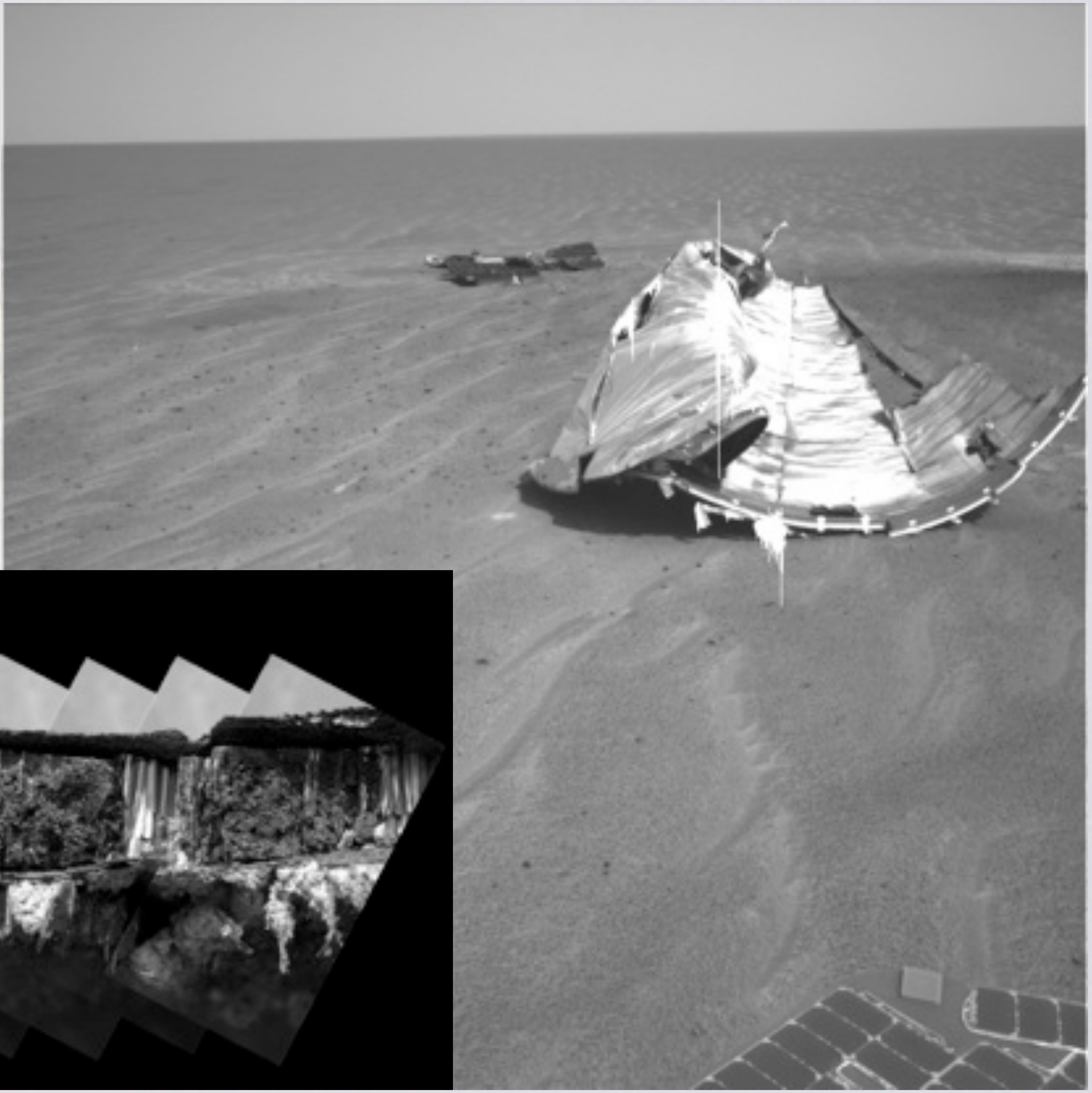
# ...Opportunity Scores a Hole in One

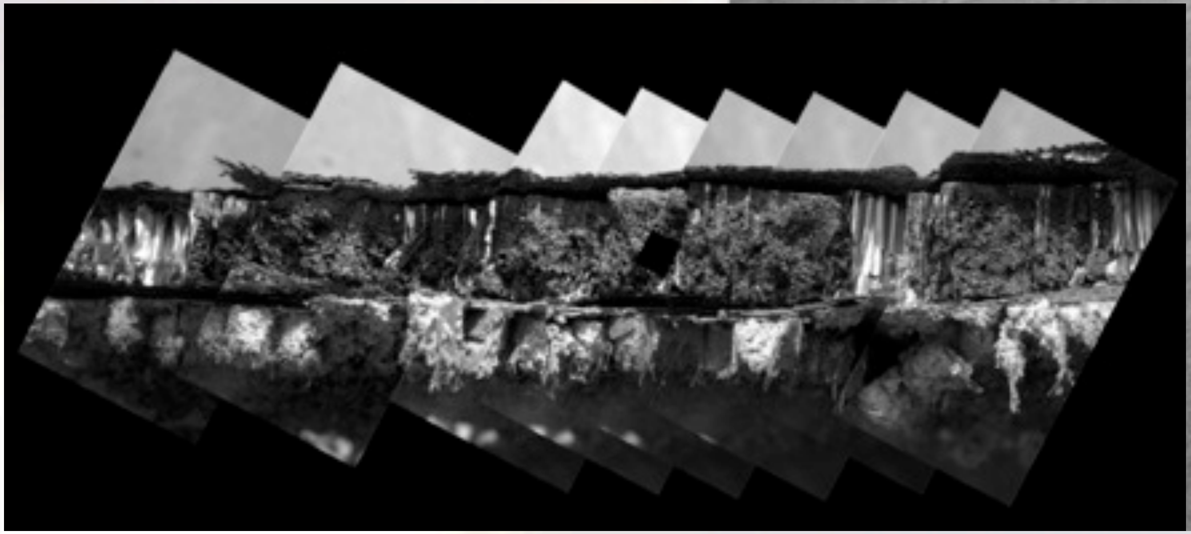


# Spirit Lands in Gusev Crater



# Odyssey Finds its Heat Shield...





# Mars Phoenix Lander Touchdown