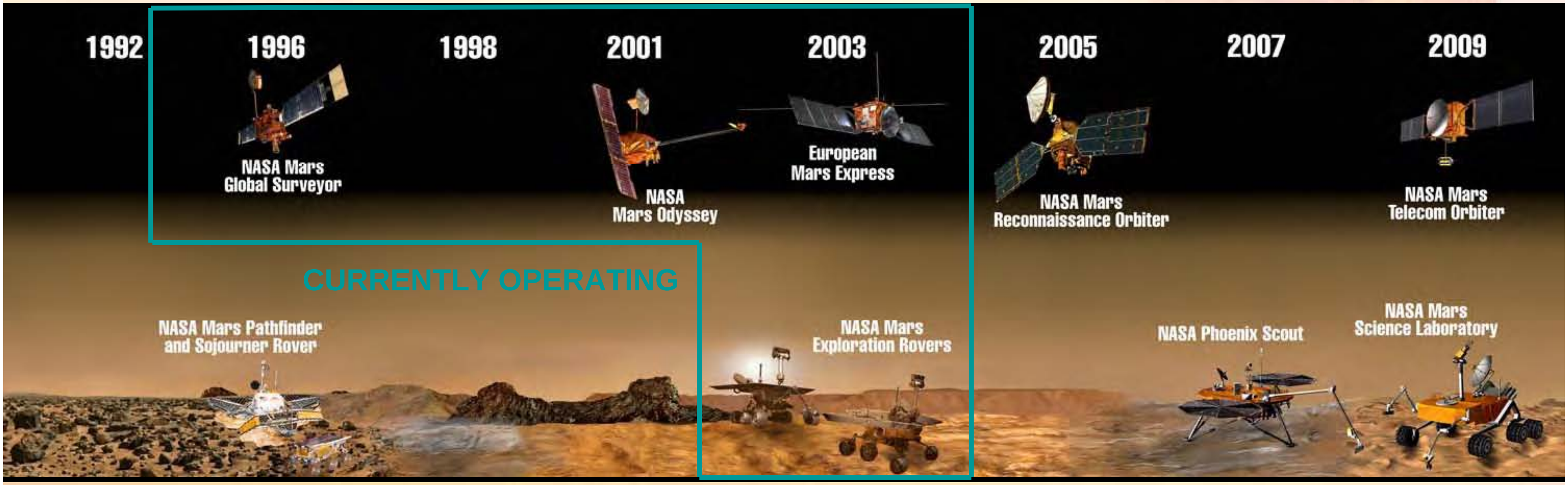
Performance Challenges for Future Robotic Mars Missions

Mark Adler
Jet Propulsion Laboratory
California Institute of Technology

Clearance CL#05-1328

Mars Exploration Program through 2009



- *MRO to join currently operating set this August*
- *Phoenix project confirmed recently, well into development*
- *2009 missions still in flux due to budget uncertainties*

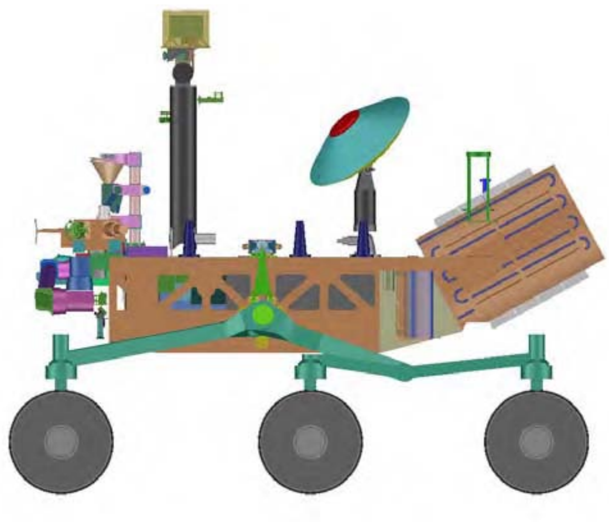
Mars Exploration Program 2011 to 2020

- *Ignore the dates above — the message is the missions*
- *MSR currently no earlier than 2016*
- *AFL / Deep Drill or some other not-yet-conceived missions could precede MSR depending on the science results of current and upcoming missions (Mars Express, MRO, Phoenix, MSL)*
- *Hopefully ESA and Russian missions also in this timeframe*

Big Lander 1: Mars Science Laboratory

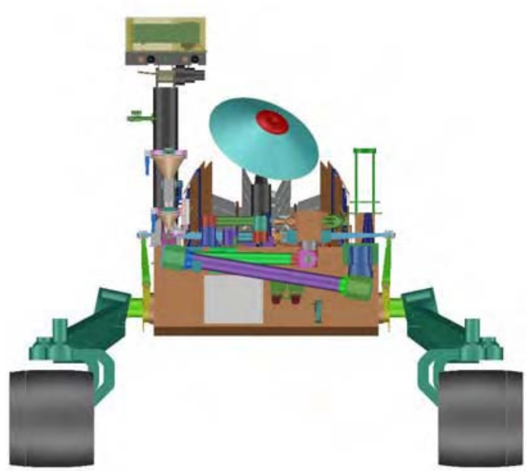
- Objective: perform analytical investigations of Martian material
- Rover carrying ~60 kg of instruments plus sample acquisition and handling equipment
- Landing requirements:
  - Land 700+ kg rover
    - MER rovers are 176 kg each
  - Land as high as 2 km above MOLA reference
    - Previous highest landing was Opportunity at –1.3 km
  - 10 km accuracy landing
    - Previous best MER 40 km
  - Improve landing reliability over Viking and MER
    - Viking vulnerable to large rocks, MER as well to lesser extent, MER subject to wind

Mars Science Laboratory vs. Earth Rover



2009 MSL Rover

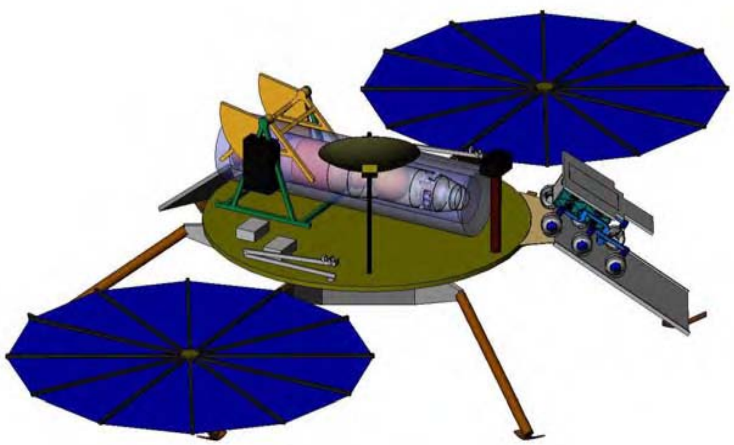
2005 MINI Cooper S

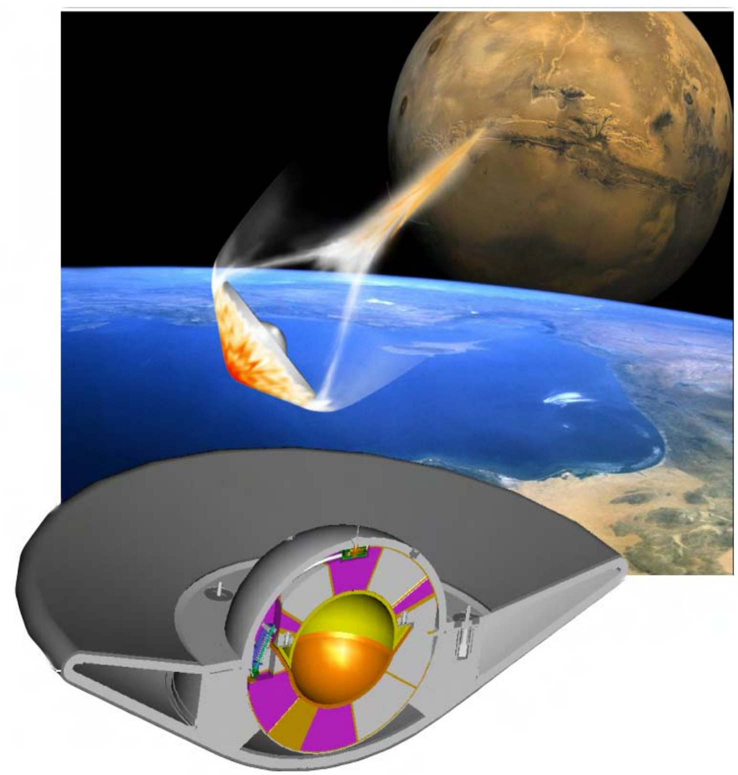


Big Lander 2: Mars Sample Return

- *Objective: return selected samples of Martian rock and soil to Earth*
- *Landed elements: rover to collect samples, rocket to launch them to low Mars orbit*
  - *Another spacecraft in Mars orbit to return them to Earth*
- *Mars landing requirements beyond MSL:*
  - *Land 1000 kg to 1500 kg (separate vs. combined landers)*
  - *Static lander platform for rocket if separate*
  - *1 km landing accuracy for surface rendezvous if separate*
- *Earth landing requirements:*
  - *Extremely high reliability to avoid inadvertent release of Martian material*
  - *Results in passive design—no parachute, crushable material*
  - *Thermal protection system must have high heritage and very large margins*
  - *Protection from micrometeoroids, possibly also detection of damage*
  - *Self-righting on entry*
  - *Flight-testing may be required with boosted Earth entry*

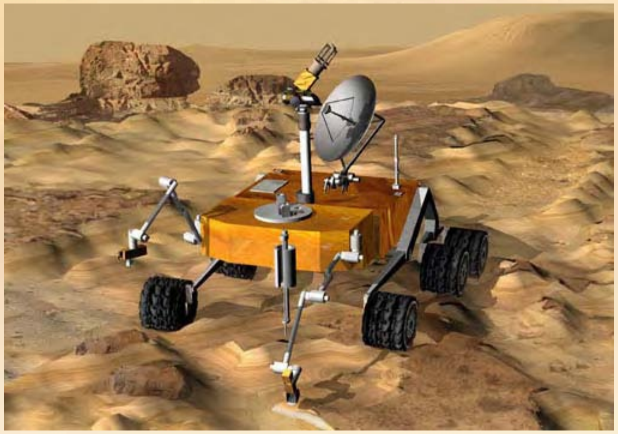
Mars Sample Return Vehicles

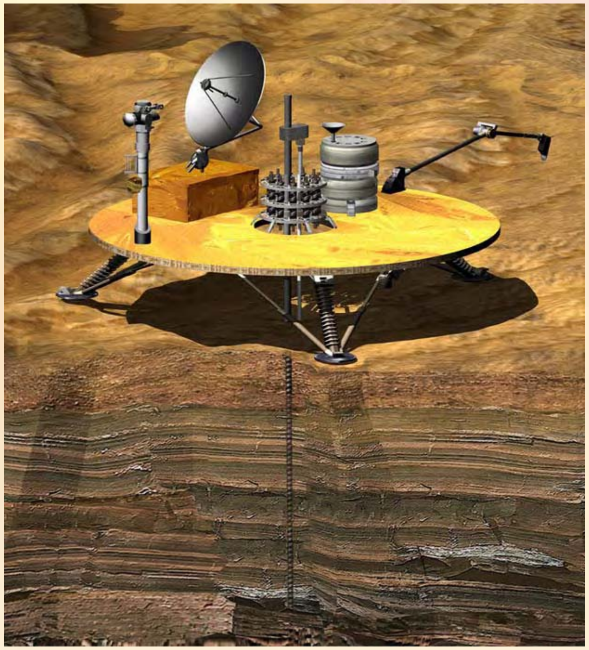




Big Lander 3: AFL / Deep Drill

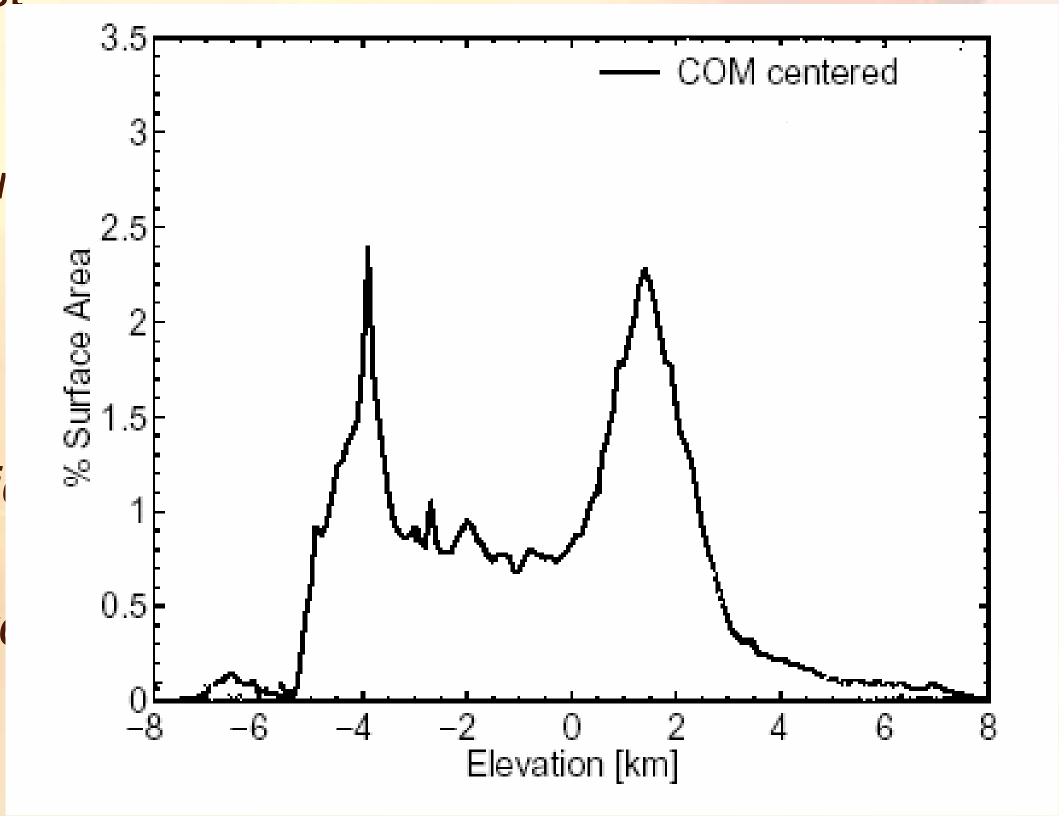
- *Objective: examine Martian material for biogenic and possibly bioactive properties*
  - *Astrobiological Field Laboratory: large rover, ~ 100 kg payload*
  - *Deep Drill: static lander, ~ 100 kg payload plus ~200 kg drill, 10 to 30 meter depth for sample collection*
- *Landing Requirements beyond MSL:*
  - *1000 kg to 1300 kg landed mass*
  - *Static lander platform for Deep Drill*
  - *100 meter landing accuracy for Deep Drill*



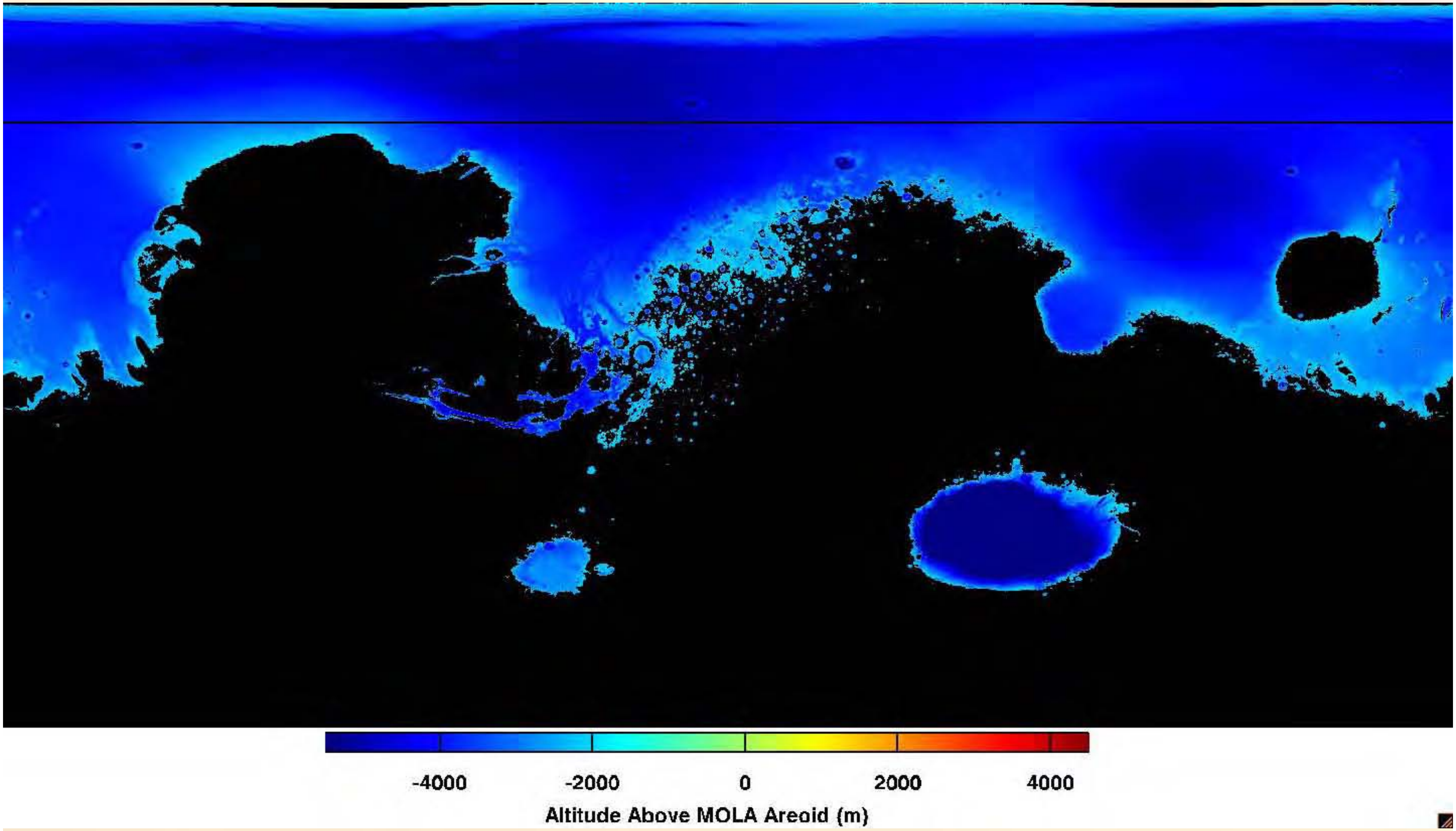


Atmosphere Issues: Altitude

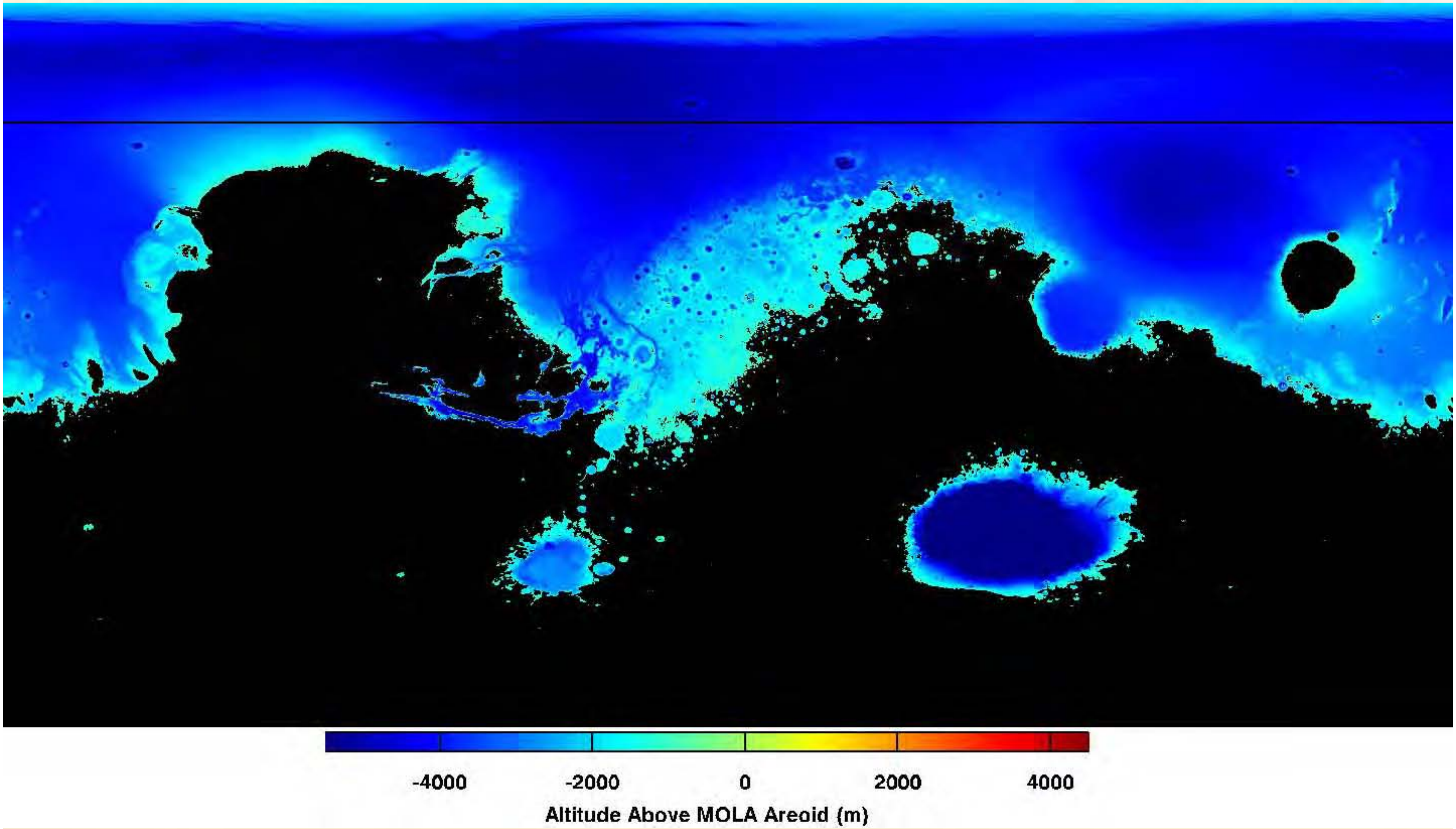
- Requirements for all future Mars missions are to at least +2 km (MOLA reference)
  - Makes it rather more difficult to get parachute ou and lander slowed down before hitting the ground compared to MER –1.3 km requirement
- Why? See Mars hypsometri curve ➡
- Want nearly global access t be able to respond to discovery



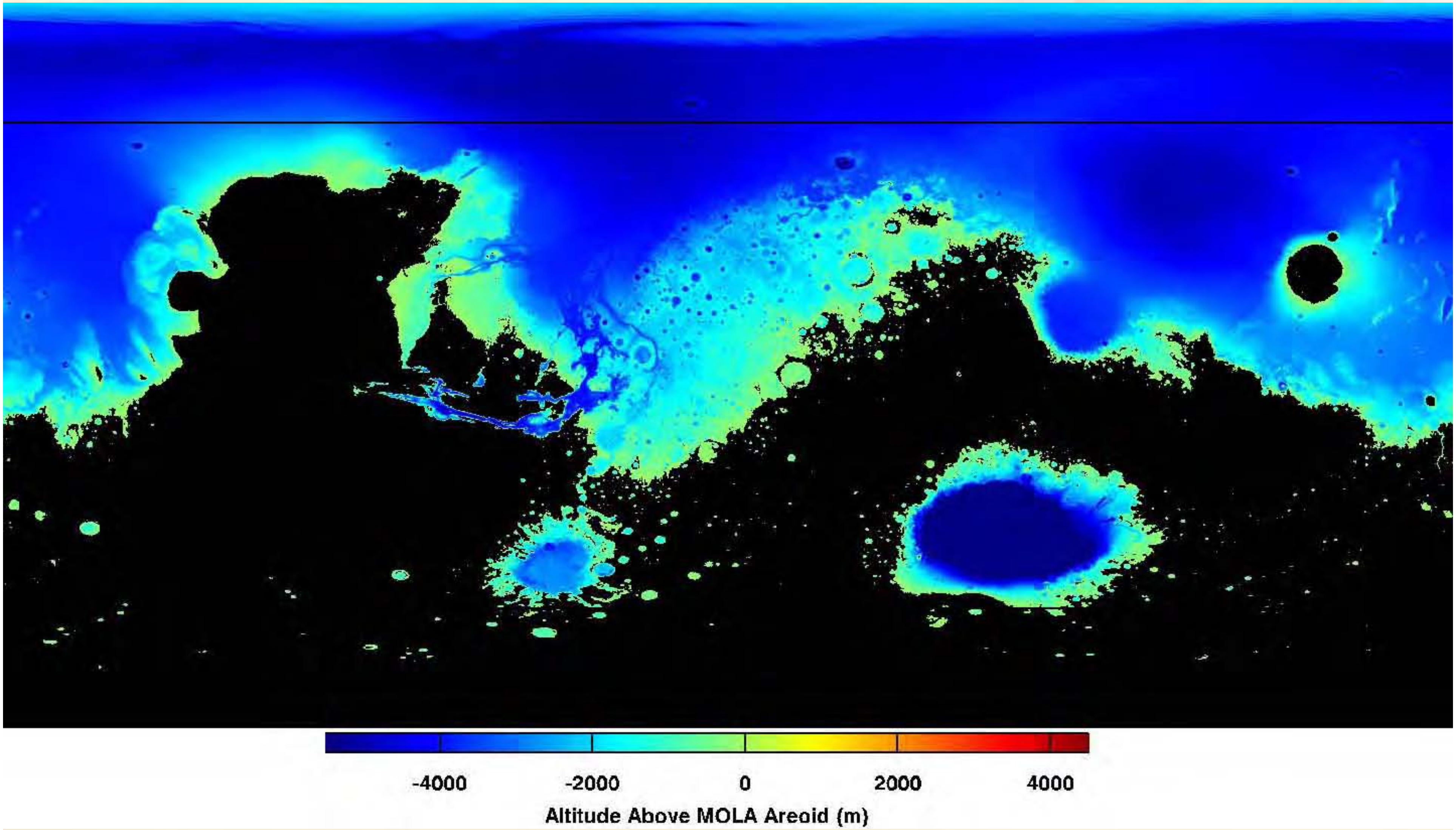
Landing Regions > –2 km Blacked Out



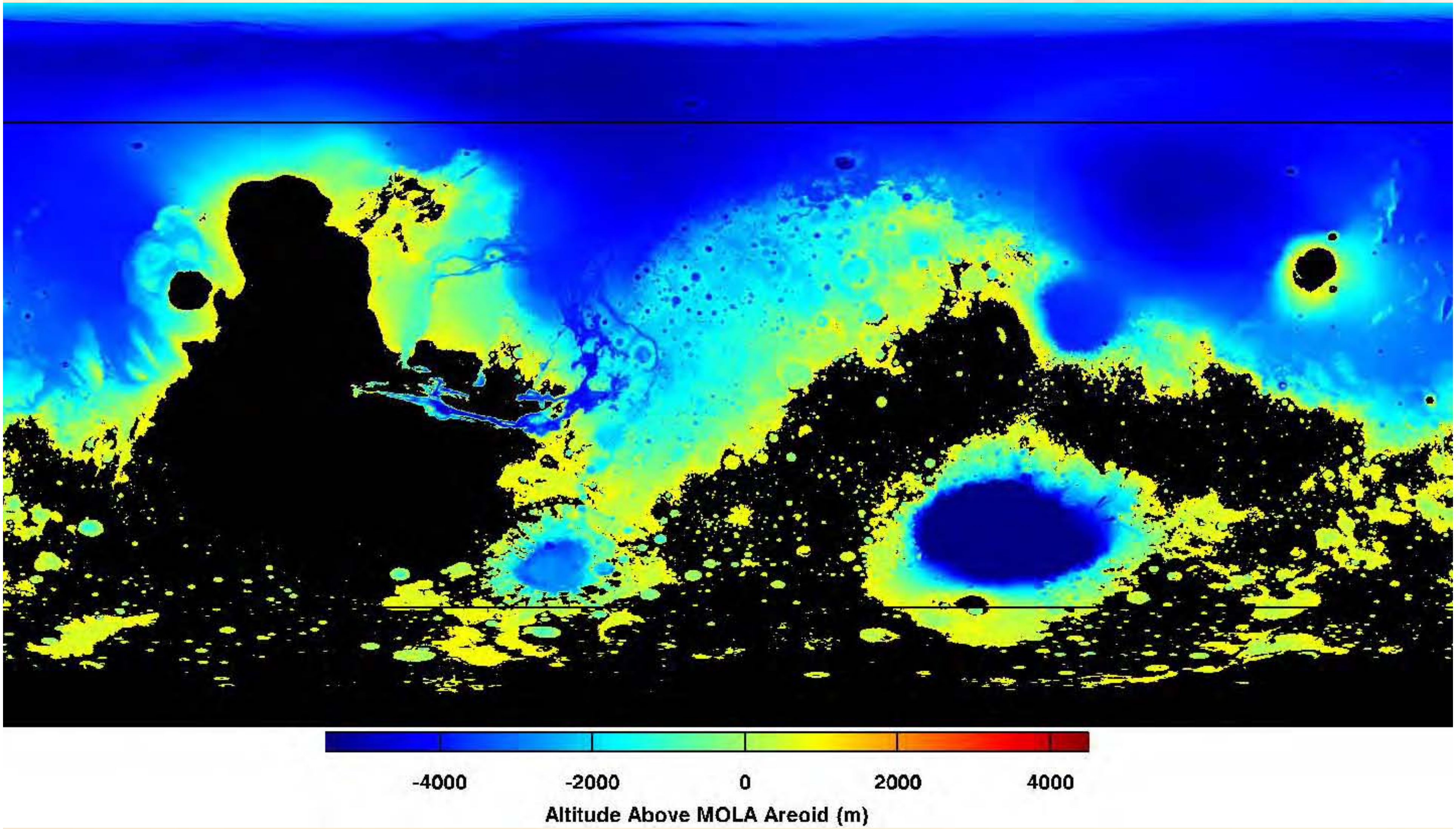
Landing Regions > –1 km Blacked Out



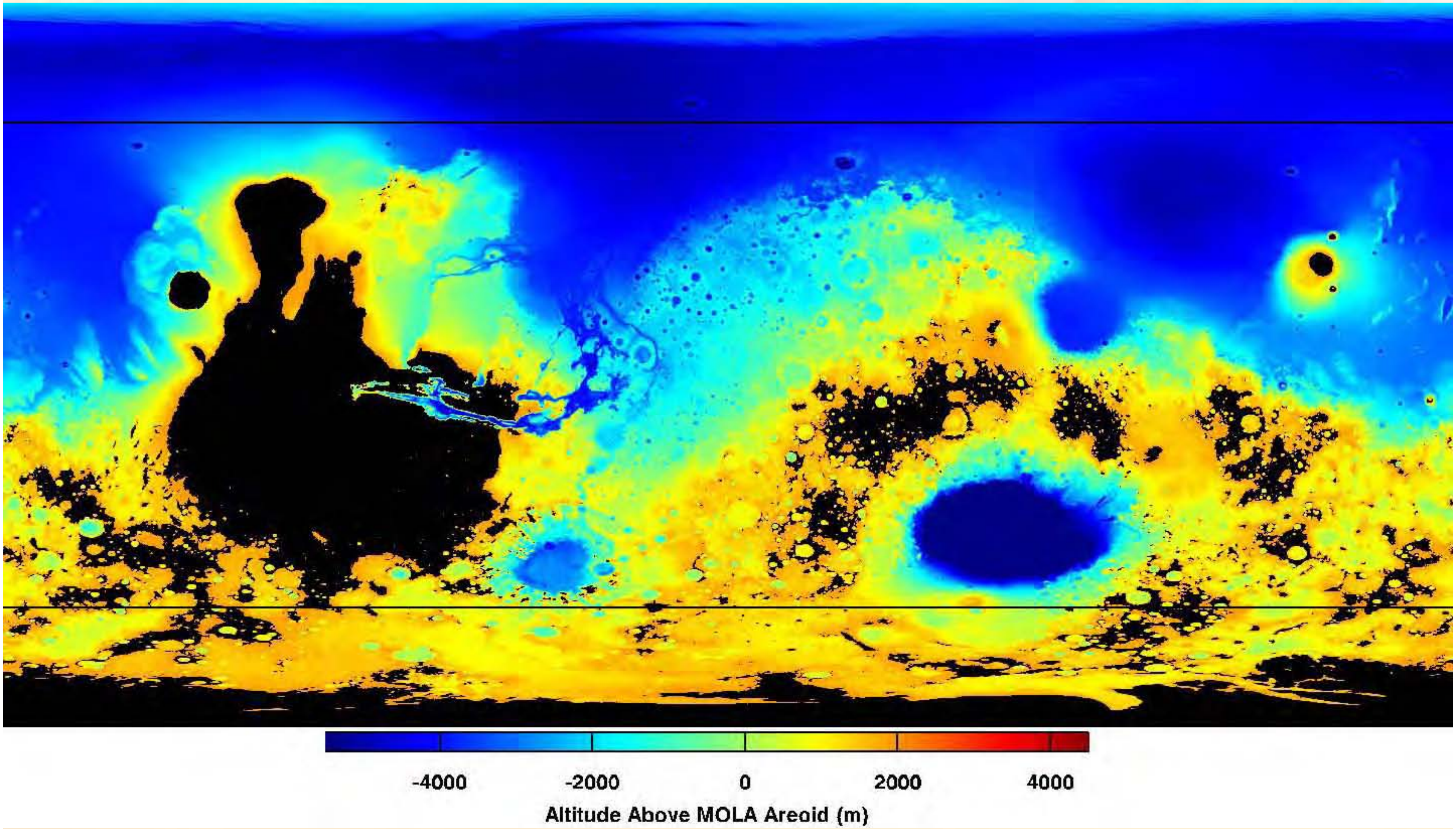
Landing Regions > 0 km Blacked Out



Landing Regions > +1 km Blacked Out

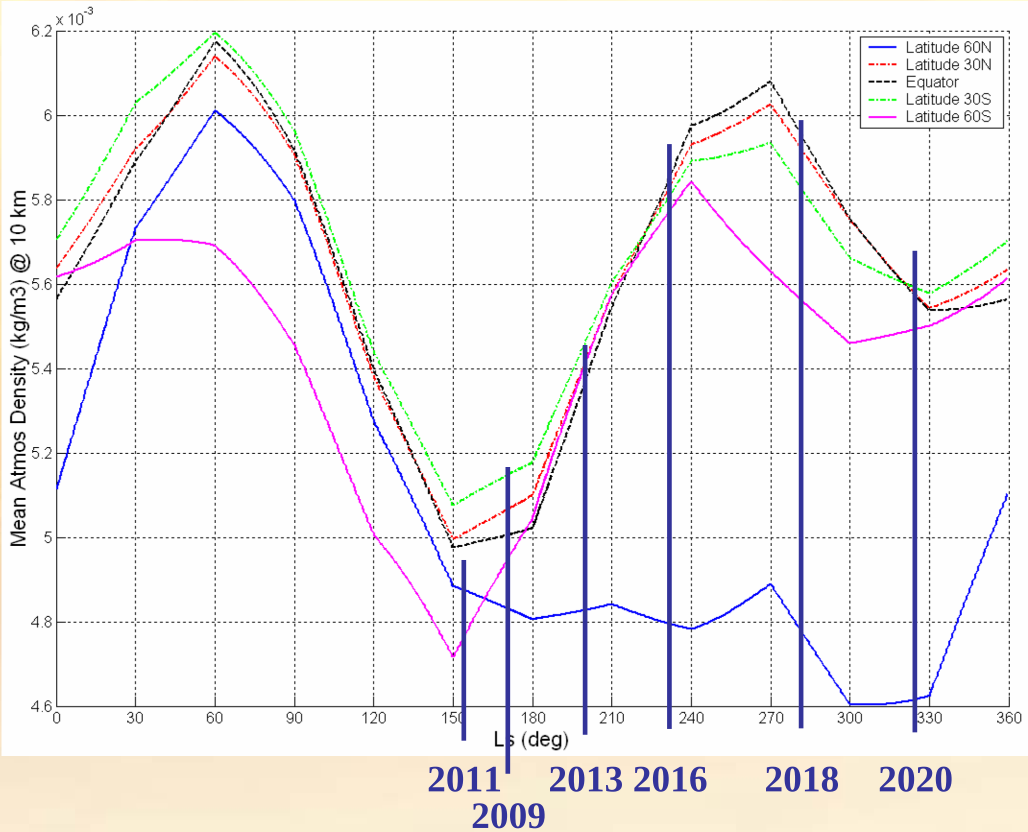


Landing Regions > +2 km Blacked Out



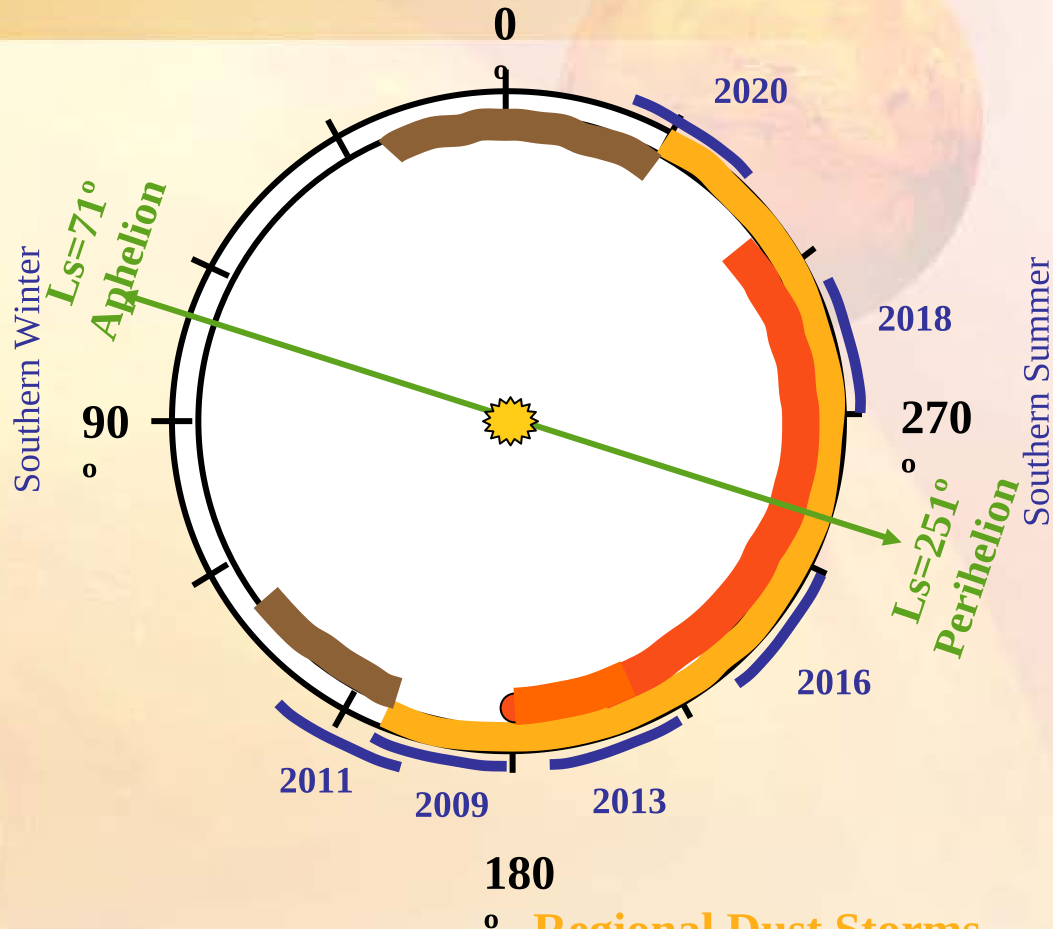
Atmosphere Issues: Seasonal Pressure

- *Mars atmosphere already thin enough to make landing hard …*
- *2009 - 2011 - 2013 opportunities arrive at low atmosphere mass season, high uncertainty in 2013*
- *About a 1 to 2 km altitude loss*



Atmosphere Issues: Seasonal Dust

- *2013 through 2020 opportunities arriving in dust storm season*
- *About a 1 in 3 chance of a global dust storm in any Martian year*
- *A 3 km altitude loss at $\tau = 3$*
  - *$\tau = 3$ is average for months after storm*
- *Much higher τ's have been observed or inferred*

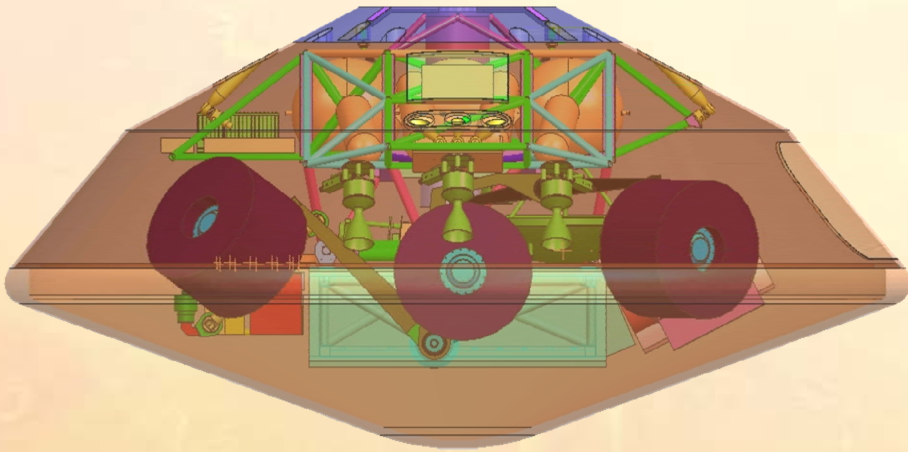


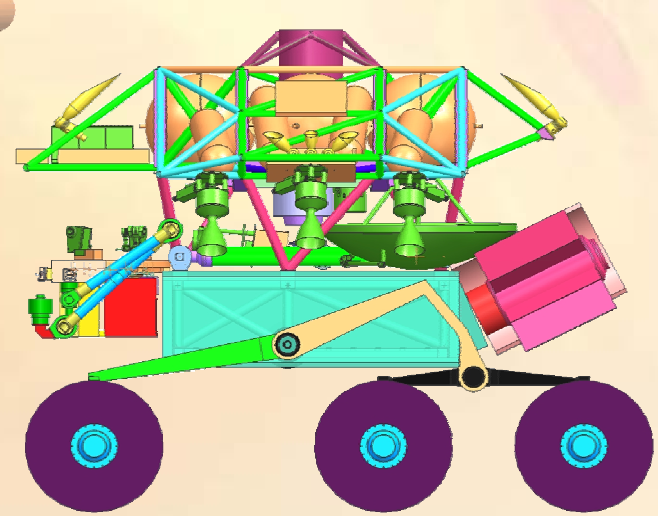
Regional Dust Storms
Planet-encircling Dust Storms
Regional Dust Storms did not occur
Local Dust Storms occur at all seasons

Challenges and Approaches: Entry

- Large, heavy payloads and high density altitude approaches:
  - Large entry vehicle, ~4.7 m diameter, β ~ 100 kg/m^2
    - MER was 2.65 m, β ~ 90 kg/m^2
  - Lifting trajectory
    - L/D as high as 0.22 being considered, buys about 1 km
  - Thermal protection qualified to higher heating rates
    - Transition to turbulence before peak heating
    - ~150 W/cm^2 (including uncertainty) vs. ~100 W/cm^2 for MPF
      - Difficult to calculate effects of turbulence and CO_2 reaction effects
    - May exceed capability of heritage SLA-561V
    - Testing SLA-561V and other candidates to 300 W/cm^2
    - High trim angles of attack of 11° to 16° require attention to backshell
- Precision Landing approaches:
  - Controlled lift by rotation of offset CG (also for lift-up for altitude)
  - Inertial measurement combined with modified Apollo guidance
  - Parachute drift them becomes significant contributor to error

MSL Aeroshell Packaging



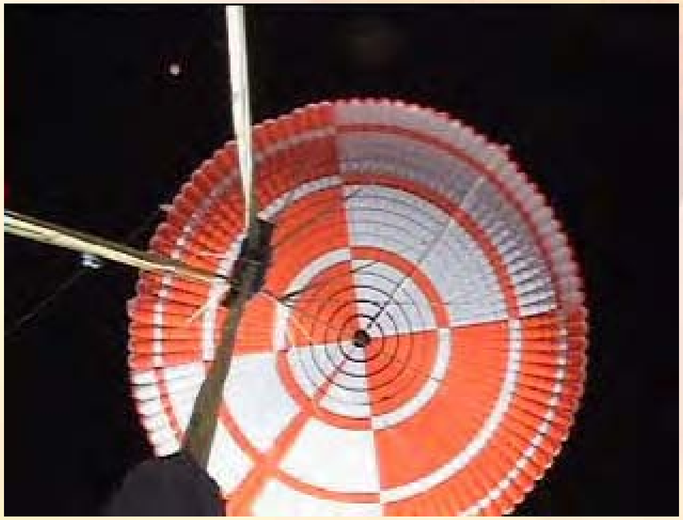


Challenges and Approaches: Descent

- *Large, heavy payloads and high density altitude approaches:*
  - *Larger landed mass requires bigger parachute*
    - *Took us a few months to accept due to high cost of mitigation*
    - *Viking 16.15 m D_0 Mach 2.13 parachute qualified three decades ago*
    - *Been living off of that since (Mars Pathfinder, MPL, MER, Phoenix)*
    - *Have outgrown it, need larger (~30 m) parachute requiring new supersonic qualification (planning for Mach 2.7 qual)*
    - *High-altitude, boosted qualification series is on the order of $100M*
    - *Currently this parachute not in development, under study*
  - *Due to high cost, MSL planning to use stopgap measure:*
    - *Push Viking parachute to 17 m D_0 without supersonic qual*
    - *Deploy 33.5 m D_0 subsonic ringsail parachute at Mach 0.7*
      - *Much cheaper to test using balloon drops, order ~$10-20M*
    - *Barely provides MSL 2 km altitude, won't handle bad dust storm conditions in later opportunites*
    - *Parachute partly through development, looking good so far*

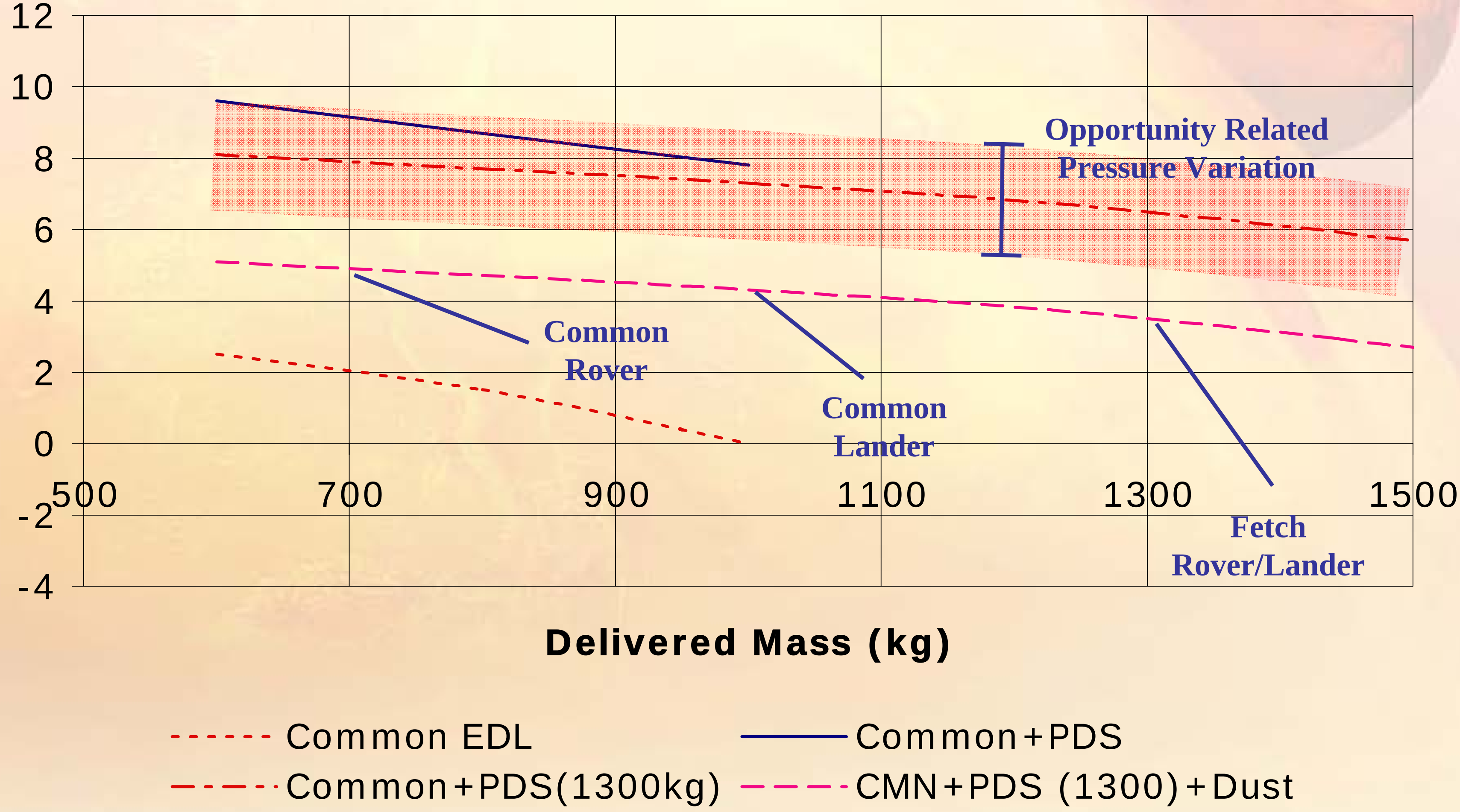
Subsonic Parachute Testing

- ***Something strange was spotted in the Oklahoma sky around 4 p.m. Monday and calls came pouring into our newsroom. Everyone wanting to know what was falling out of the sky.*** *The object landed eight miles east of the Texas border in Roll, Oklahoma. Witnesses could see the object falling from the sky, from at least 20 miles away. If you didn't know any better, you'd guess it was a scene straight out of a Hollywood, sci-fi blockbuster. "We weren't sure what it was," said Darlene York. "We were just coming in with a load of corn," said Darlene's husband Terry.*



QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

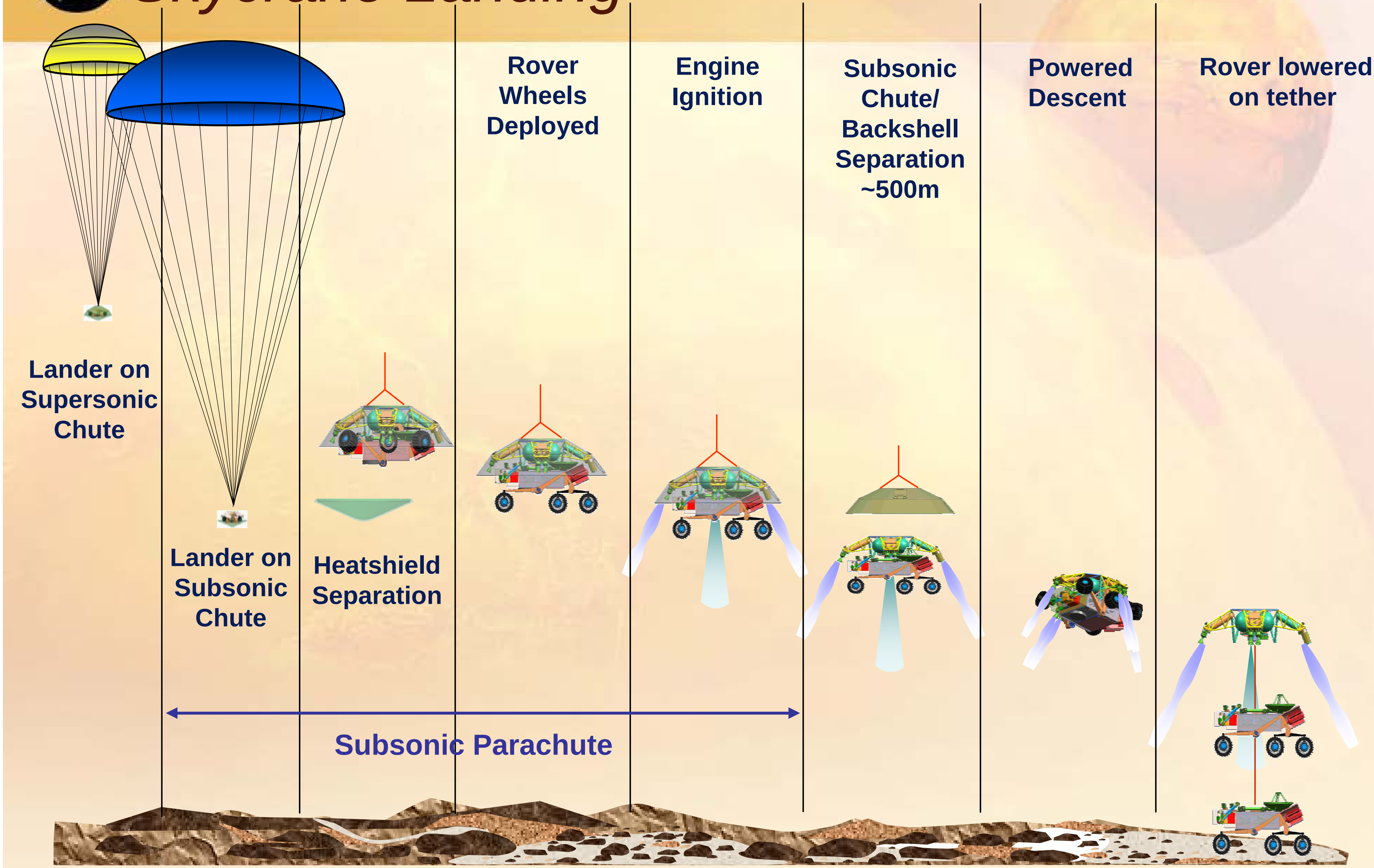
Large Supersonic Parachute Capability



Challenges and Approaches: Landing

- Heritage:
  - Viking: throttled propulsion for legged lander
  - MPF/MER: fixed high thrust propulsion for airbag lander
- Problems:
  - Scaled-up thrusters near surface, a la Viking, creates new hazards on descent and throws rocks and dirt on payload
  - Airbags don't scale up to larger mass payload if impact velocity kept around 20 m/s (MER learned even a little scaling is an issue)
- Solution:
  - Keep propulsion away from ground using cable to descend payload, like MPF/MER
  - Make that propulsion throttled like Viking and use better RADAR to reduce impact velocity
  - Then airbags get smaller — in fact, they disappear completely for <~ 1 m/s impact
  - Rover rocker-bogie mobility system makes great landing gear!
  - No egress (took a week or more on MER)
- Result is called "Skycrane" — MSL baseline landing system

Skycrane Landing



Skycrane Developments

- Throttled Hydrazine engines
  - Based on Viking heritage valve
  - Eight thrusters, 400N - 3000N each
  - Technology development well underway, successful
- RADAR altimeter and velocimeter
  - Helicopter heritage, adapt existing 3-D Doppler RADARs
  - ~0.5 m/s velocity accuracy, ~ 1 m altitude near ground
  - Configuration issues for accommodating RADAR beams
- New test facility to validate terminal guidance algorithms and touchdown dynamics
- Pinpoint landing:
  - Precision entry results in as much as a 10 km miss
  - 1 km to 100 m landing accuracy requires flying it out from there
  - More propellant for Skycrane (few hundred kg)
  - Visual terrain sensor recognizing orbital imagery for guidance

Conclusions

- *Next decade Mars EDL requirements*
  - *Order of one metric ton payloads*
  - *+2 km altitude for global access*
  - *Compounded by annoying atmosphere density issues next decade*
  - *Precision (10 km) and Pinpoint (1 km to 100 m) landing accuracy*
- *Requirements result in several new developments:*
  - *Higher heat-rate TPS*
  - *Guided hypersonic entry using 0.18 to 0.22 L/D from offset CG*
  - *33.5 m subsonic parachute, ~30 m Mach 2.7 parachute*
  - *Throttled hydrazine engines and RADAR altimeter / velocimeter*
  - *Test stand for landing dynamics*
  - *Visual terrain recognition*
- *Mars Sample Return Earth EDL for Assured Containment*
  - *High heritage and margin TPS, self-righting vehicle*
  - *Crushable impact absorption*
  - *Flight testing may be required*