Mars Entry and Descent

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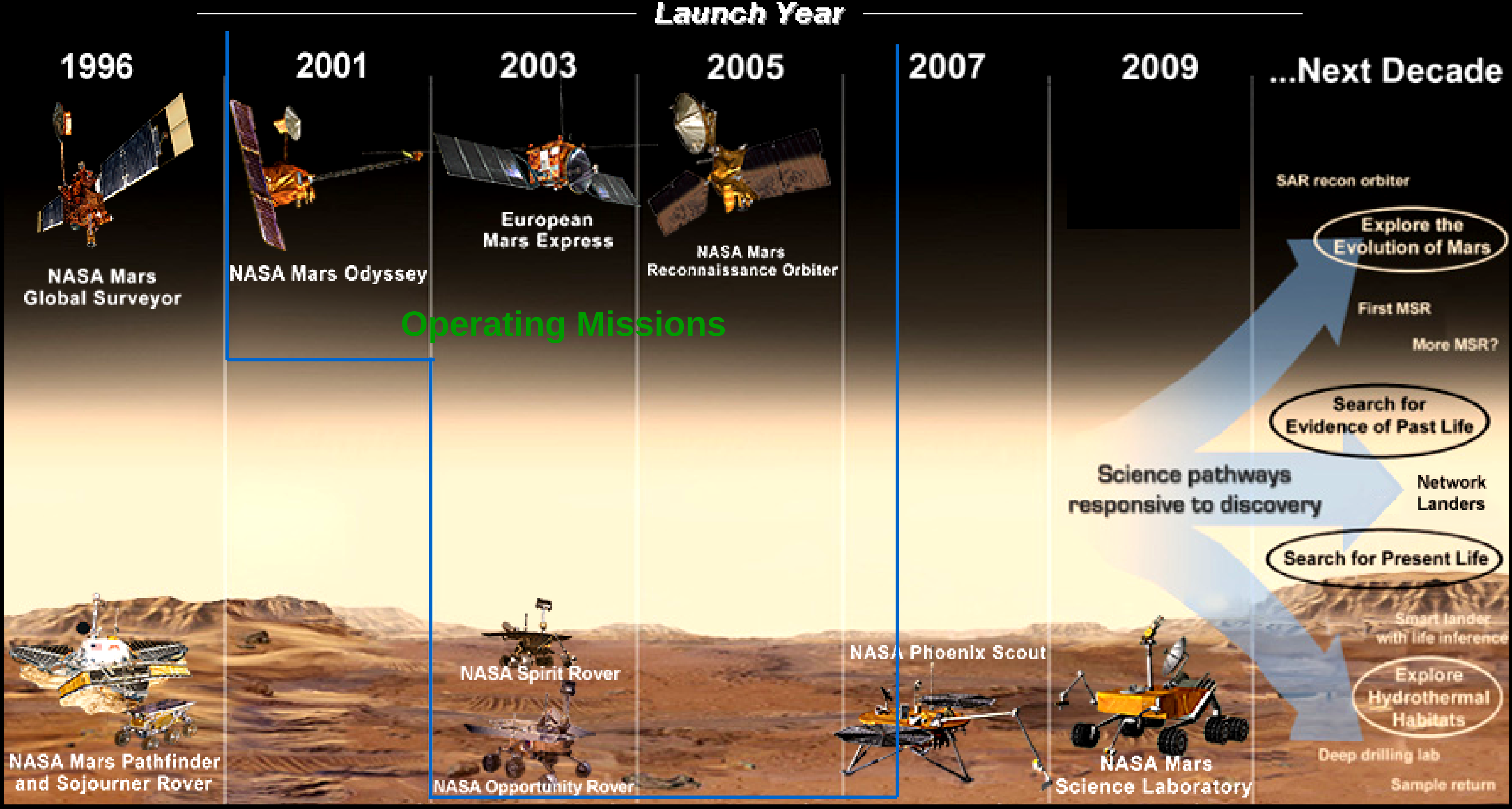
Robotic Mars Exploration



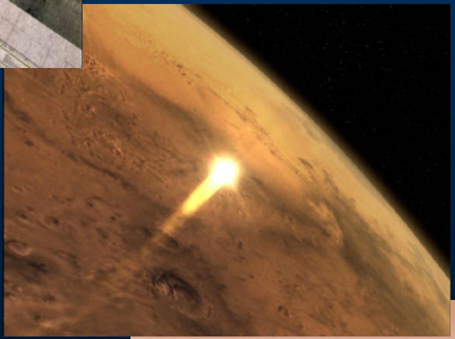
Why Mars?

Life and Water

The Mission

Launch/Cruise

Entry

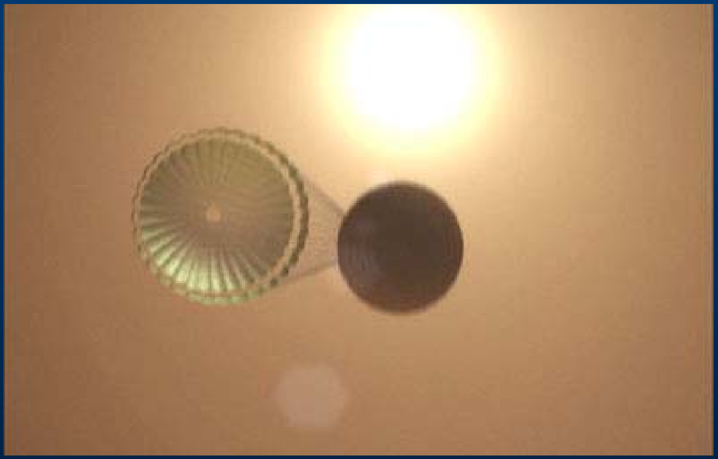


Descent/Landing

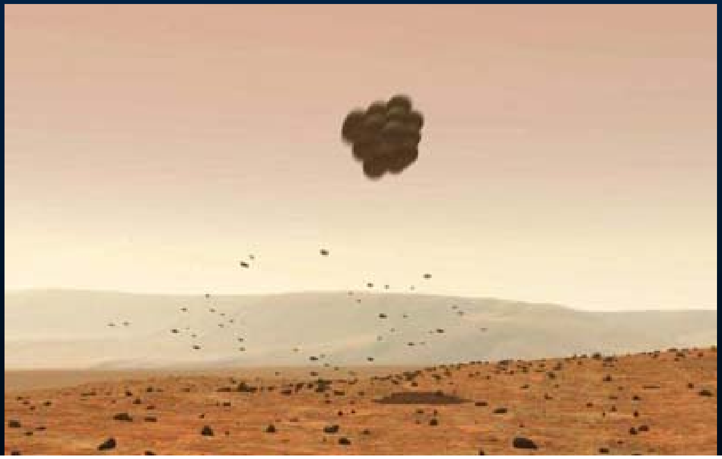
Exploring the Red Planet

QuickTime™ and a
Sorenson Video 3 decompressor
are needed to see this picture.

Entry



Descent



Landing

Current Usage of Clusters

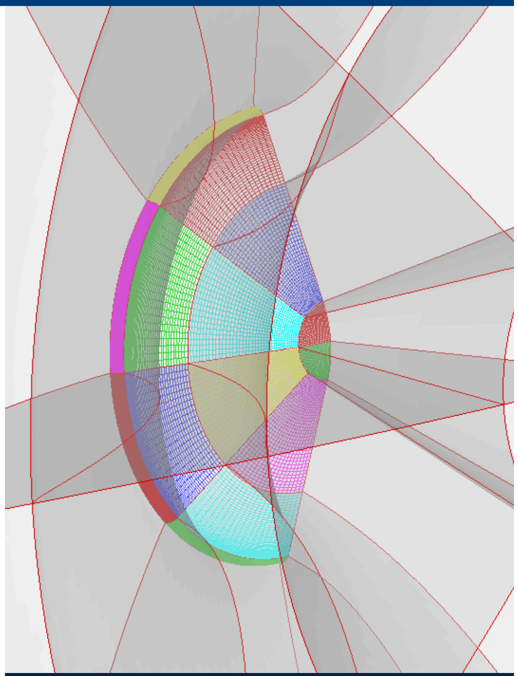
- Significant portion of analysis of aerothermodynamics of planetary vehicles is done with CFD
  - Codes: LAURA, OVERFLOW, FUN3D
    - MPI codes with wide range of physical gas and surface models
    - Structured, unstructured and overset capability
  - Aerodynamics and aerothermodynamics process:
    - MPI problem setup
    - MPI problem convergence
    - Quality checks (residual, grid alignment convergence, heatrate convergence, force-moment convergence)
    - Post-process and output surface environments, forces and moments

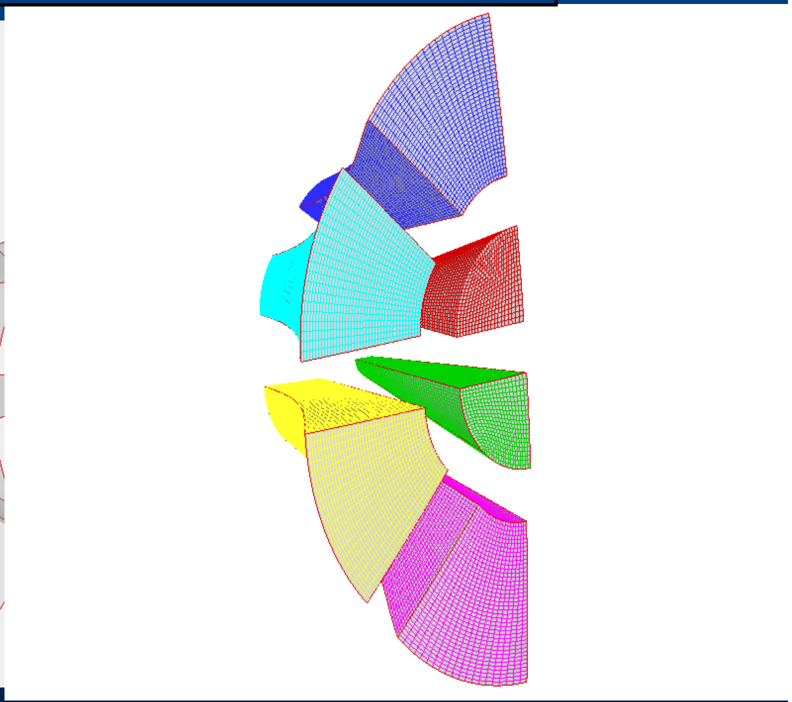
- Trajectory Simulation and Analyses using Monte Carlo method
  - Code: POST2
    - Multi-vehicle capable trajectory simulation and optimization software
  - Used in design, development, testing, and operations of entry systems & trajectory

Solution Process

Capsule Shape

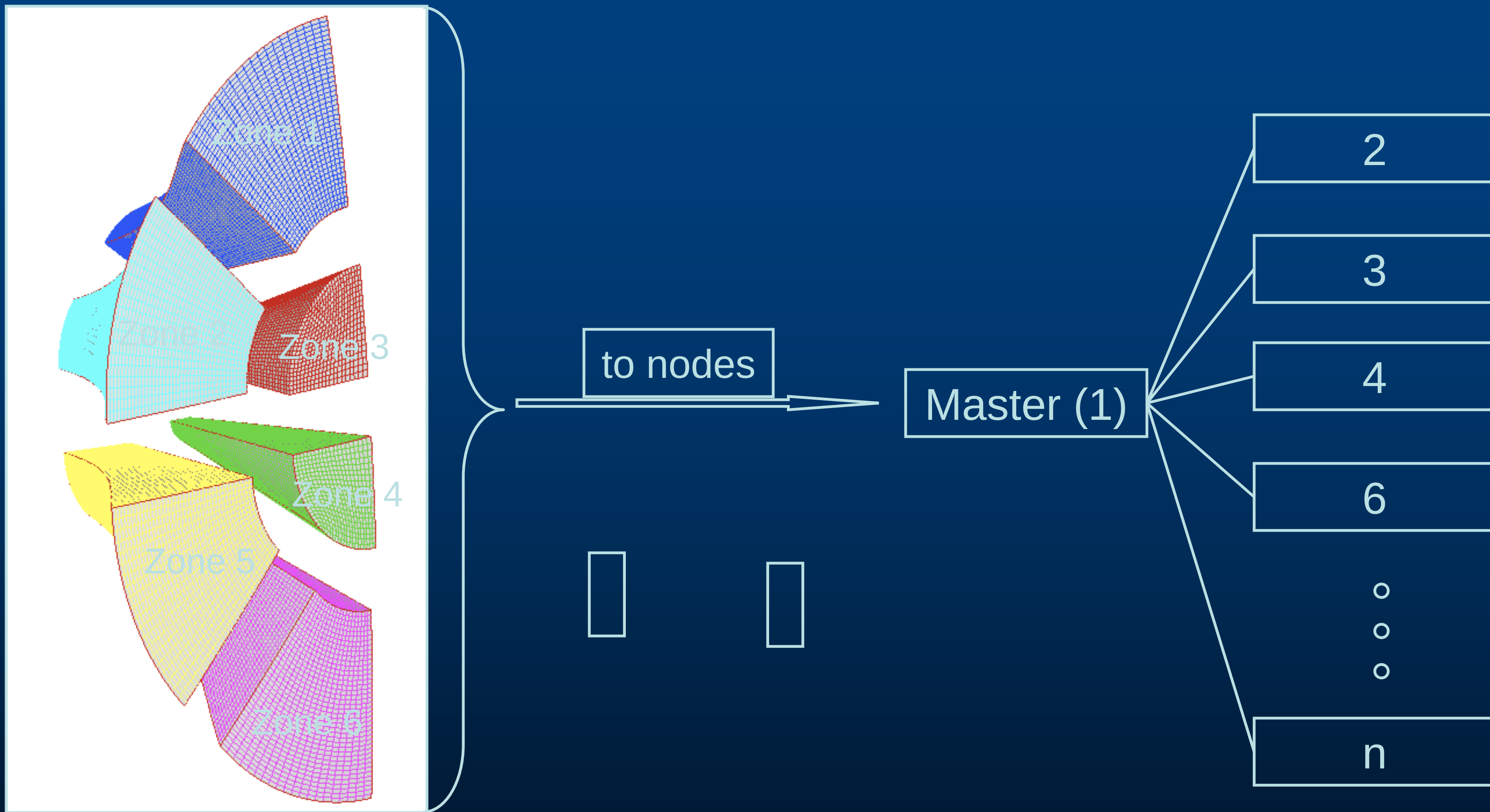
Grid and Partitioning of Surrounding Volume





- Grid of surrounding volume
- Governing equations are solved on that grid
  - free-stream, surface and interface conditions are applied
- Partition problem among multiple CPUs

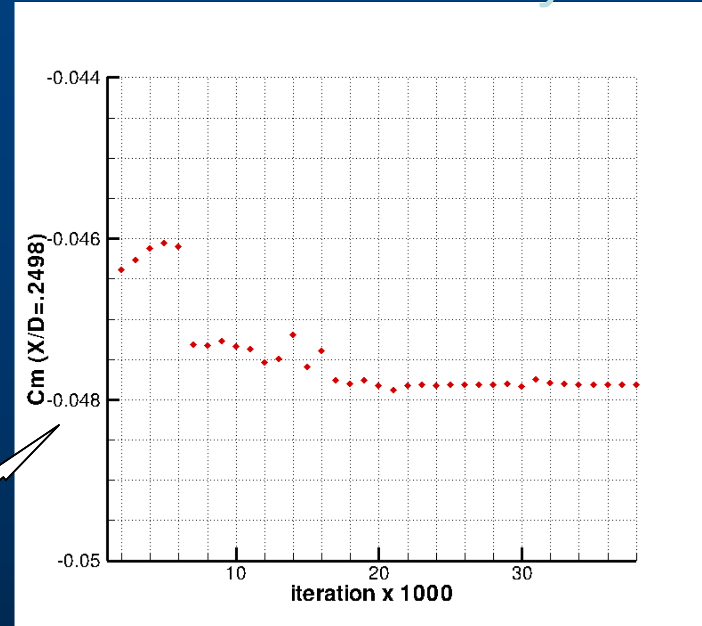
Flow of Solution



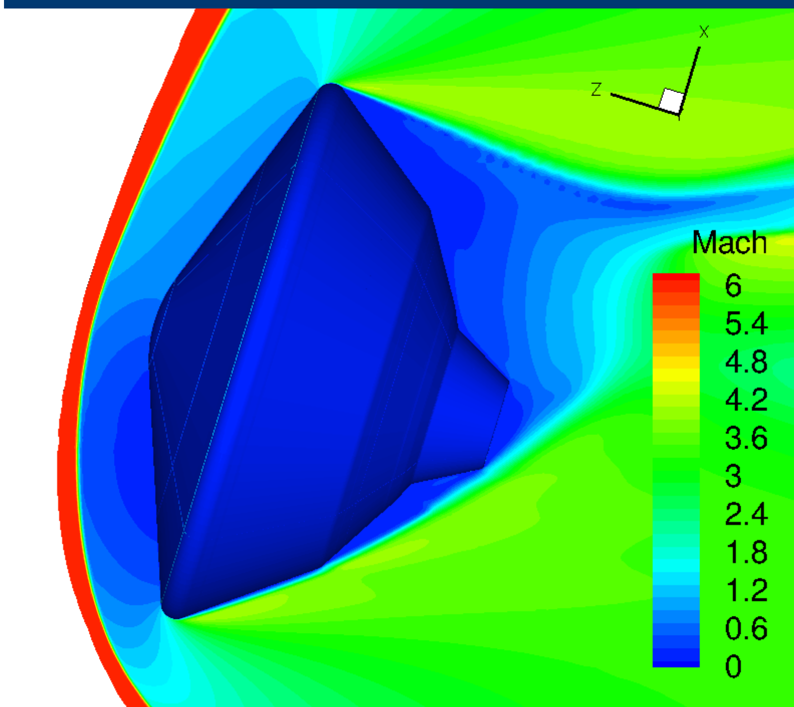
- 1 zone per CPU (unless a large problem requires to double up)
- Block interfaces are passed through Master CPU

Results

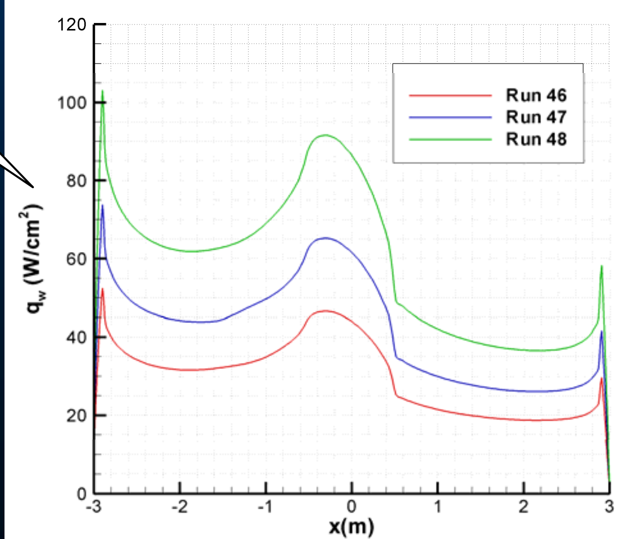
Results of analysis



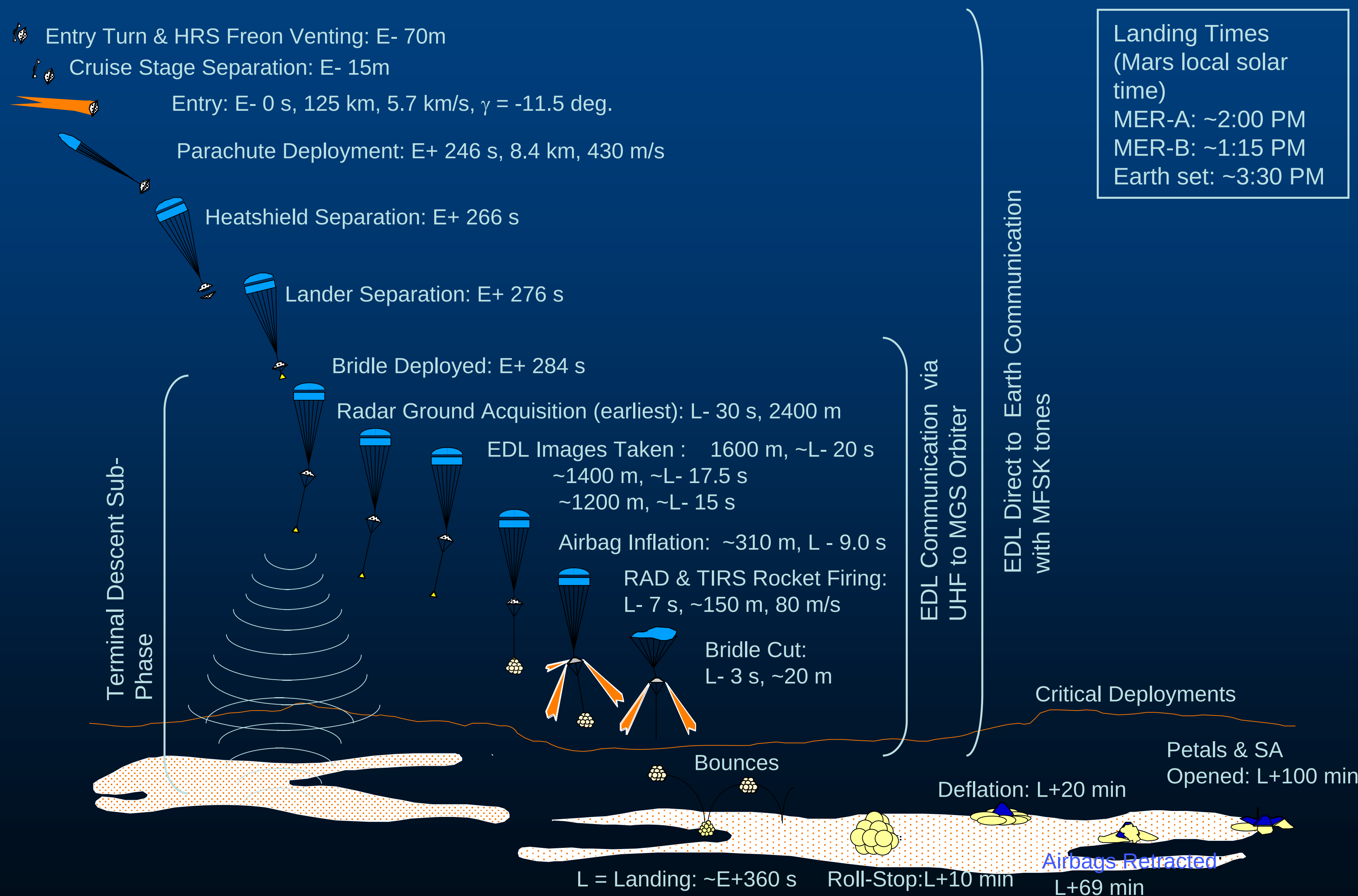
Result of Computation



quality checks

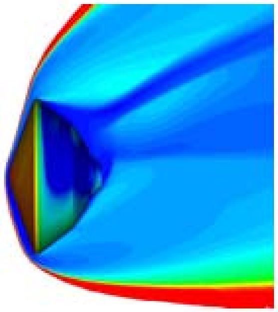


MER Entry, Descent, and Landing (EDL) Sequence



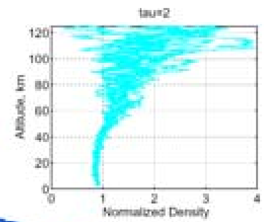
MSL POST2 Trajectory Simulation

Aerodynamics &
Aerothermodynamics

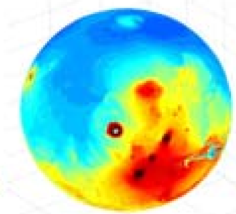


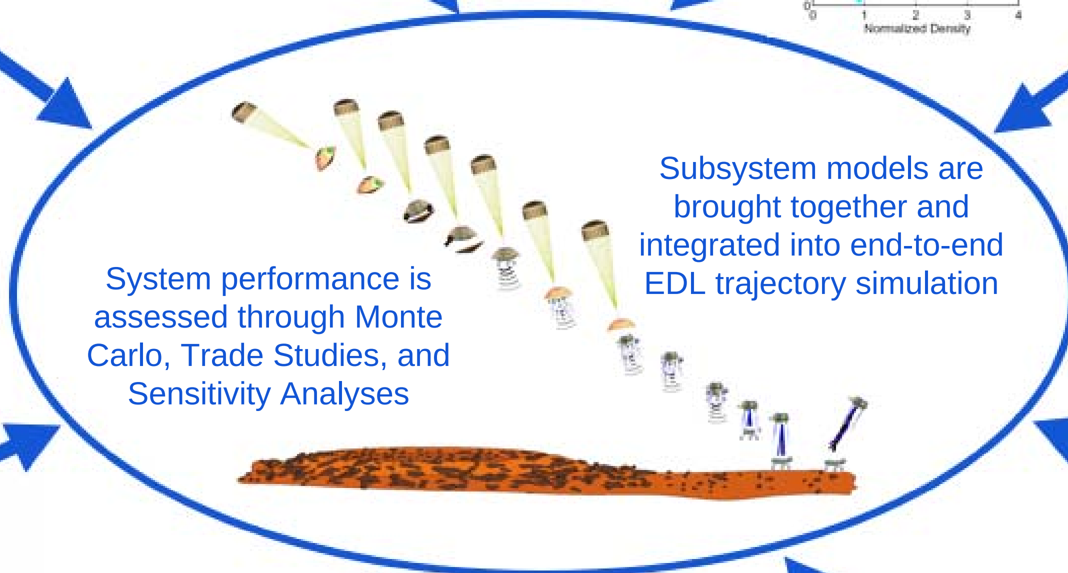
Mass Properties

Atmosphere Model

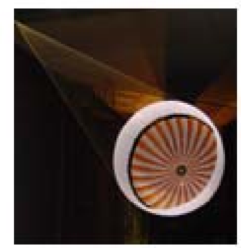


Planet Model
(MGS/MOLA)

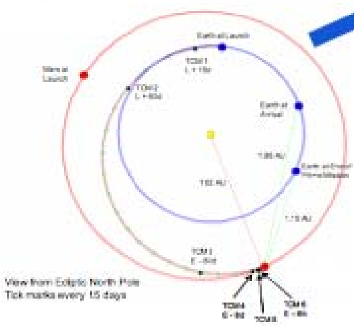




Parachute Model



Initial Entry Conditions &
Approach Navigation



Propulsion

Guidance, Navigation, & Control

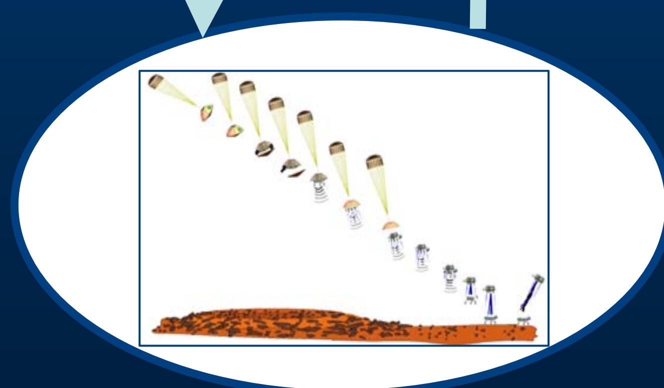
Monte Carlo Performance Analysis

Inputs:
•Initial states
•Attitude initialization
•Atmospheric uncertainties
•Aerodynamic uncertainties
•Mass property dispersions
•IMU biases and misalignments
•Propulsion uncertainties
•Etc.

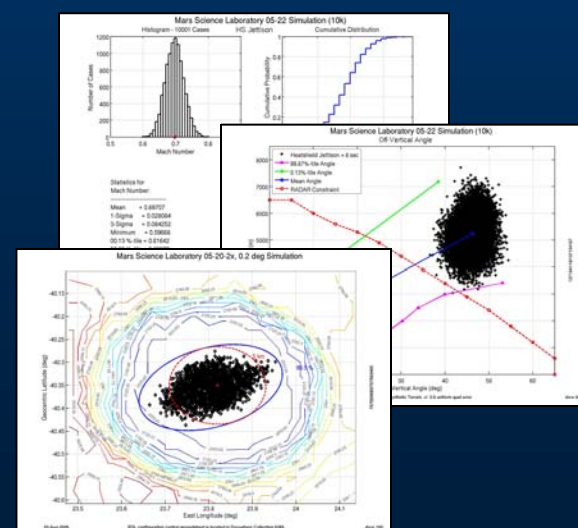
400 Node Linux Cluster (Bldg 1268)

Products:
- Statistics/Histograms
- Landing Ellipse/Footprints
- Scatter plots
- Detailed examination of Outliers
- Animations
- Scorecards
- Etc.

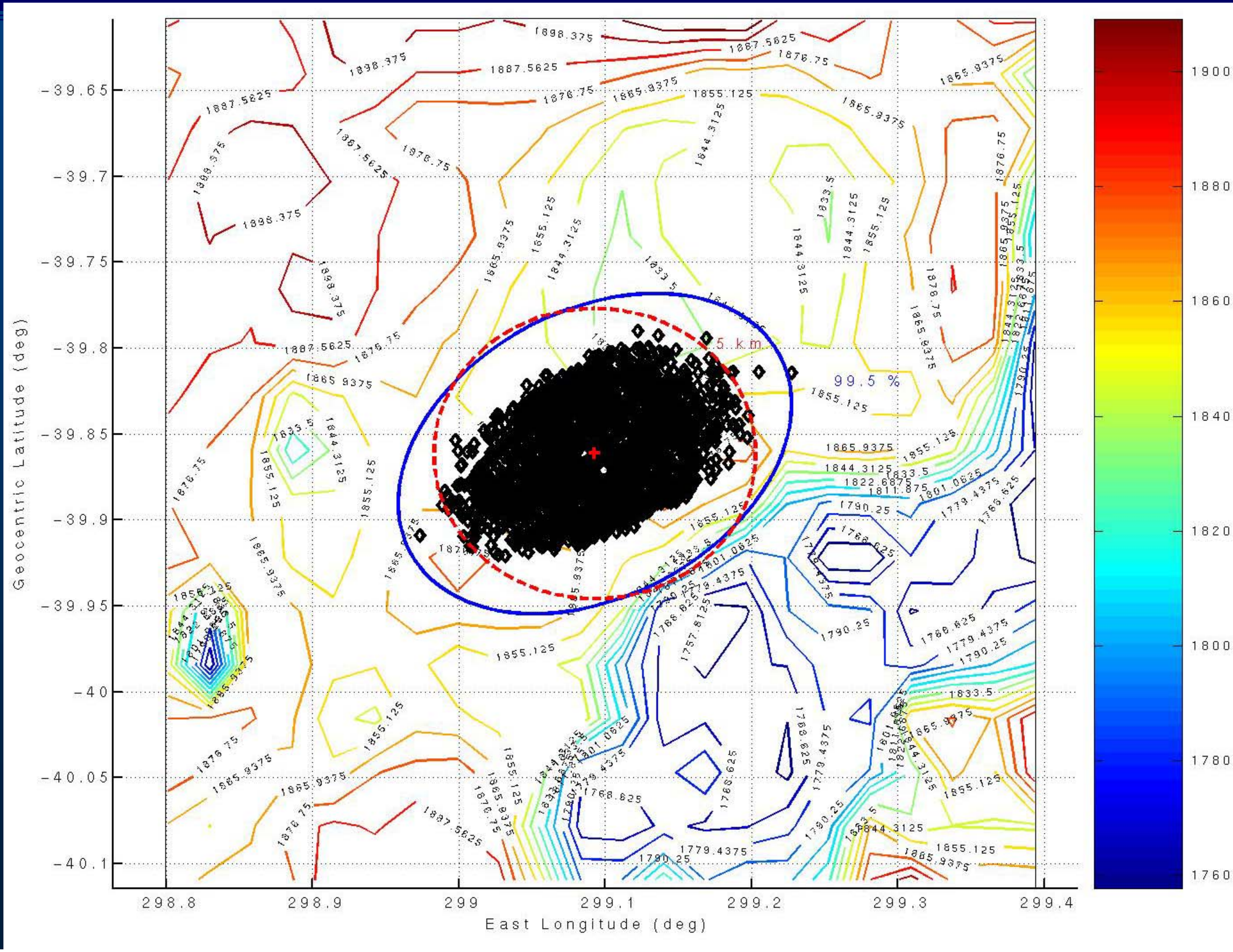
2000 to 100,000 Dispersed Cases



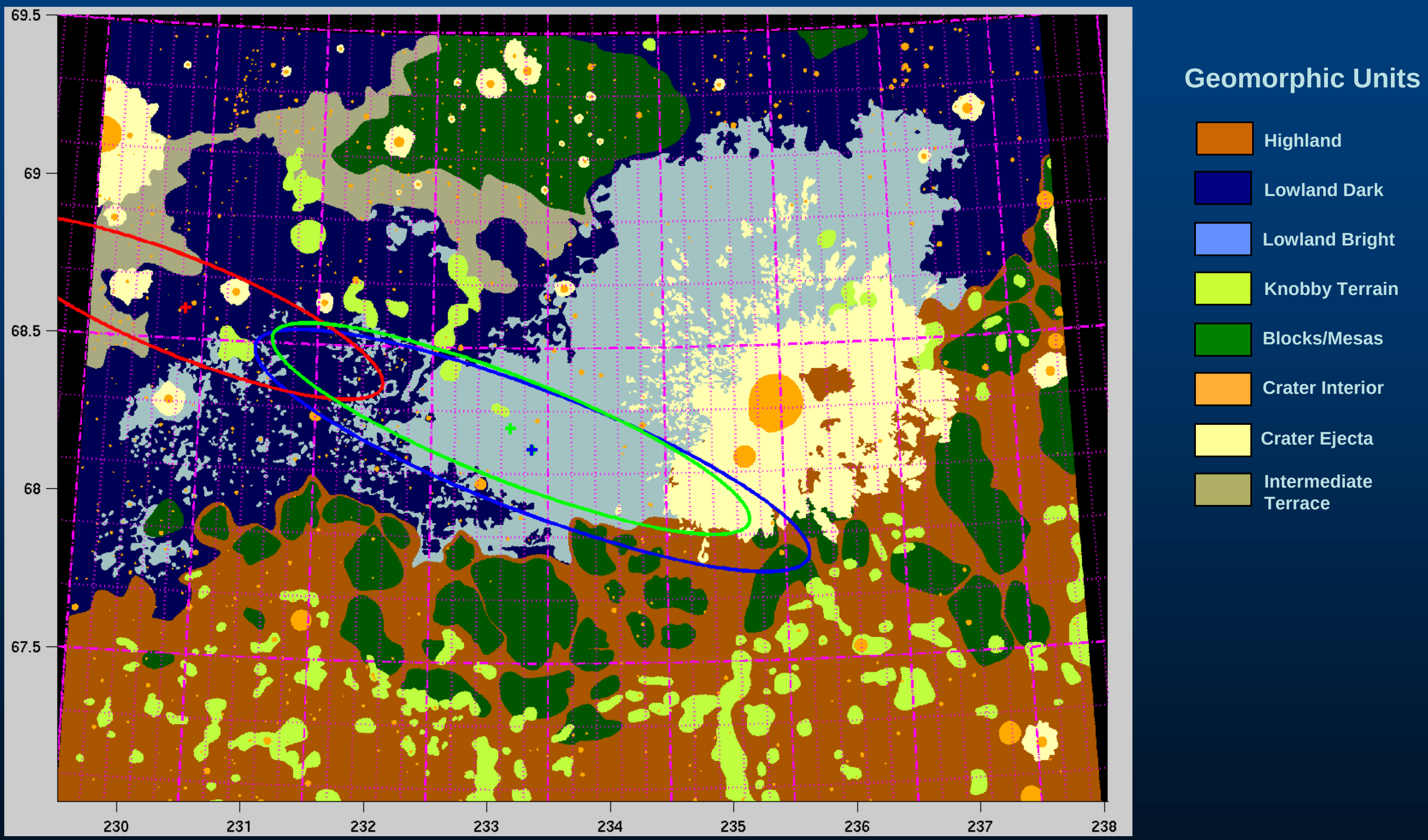
Each dispersed EDL case is simulated from end-to-end in POST2



Touchdown Footprint



Phoenix Landing Site



Multi-Body Parachute Simulation Analysis

- **Capability resident to allow modeling of all entry, descent, and landing phases of mission (i.e., end-to-end simulation from cruise-stage separation to landing)**

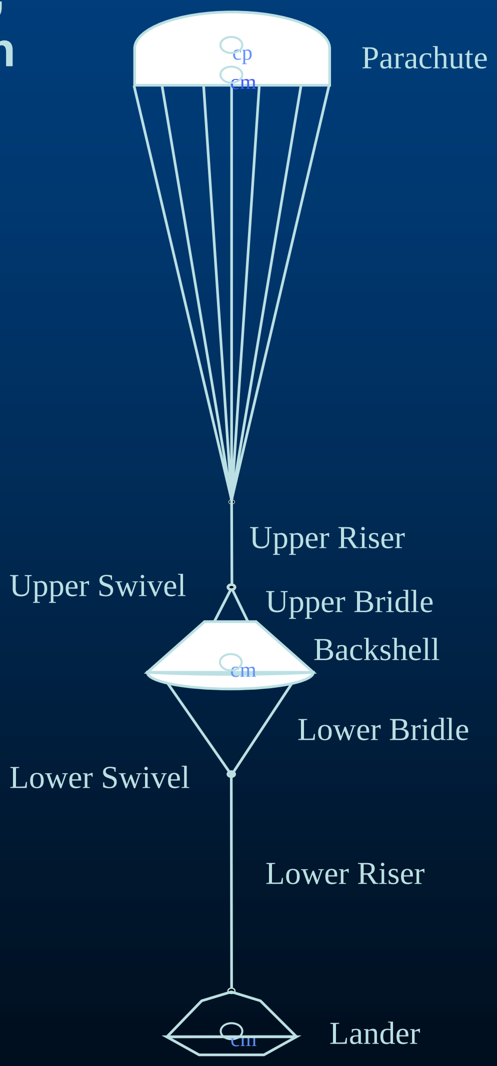
- **Flight software incorporated simulation**
  - Parachute deploy algorithm
  - TIRS/RAD firing algorithm
  - IMU model
  - Radar model
  - Digital Terrain Map
  - Etc.

- **Extensive simulation validation completed**

- **This end-to-end simulation was critical for final landing site selection for Project**
  - •Did not have time or money to perform end-to-end hardware test
  - •Hence, had to rely on simulation for complex dynamics
  - •JPL Cluster was critical to understand this system for parameter selection of fight software

- **Capability will feed forward to future missions**

MER Terminal Descent Configuration
(5 Bodies)



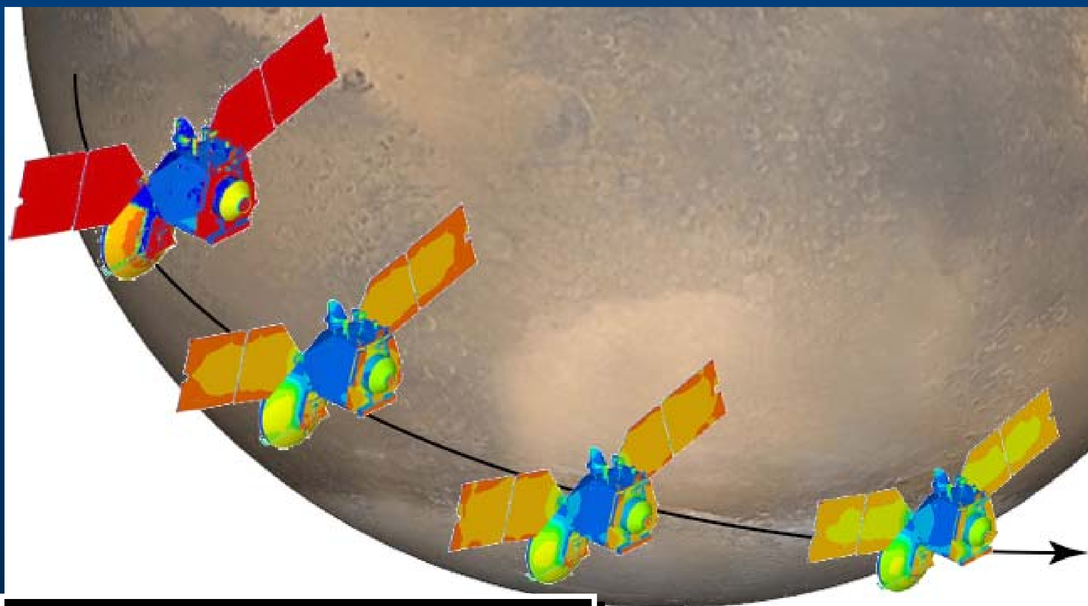
MER Preflight Simulation

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

MRO Aerobraking Animation

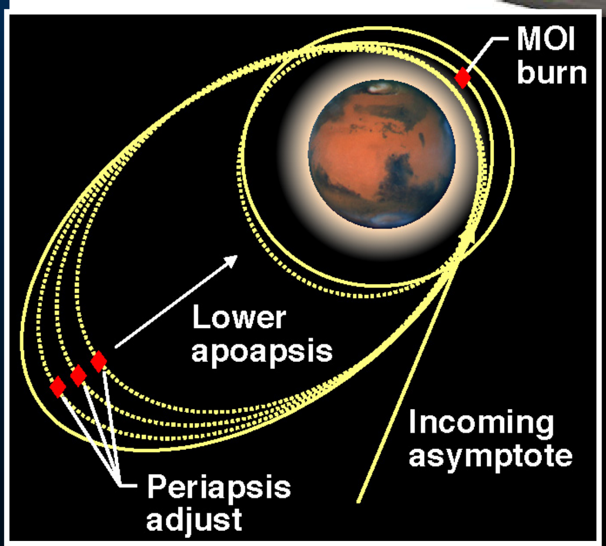
QuickTime™ and a
Sorenson Video 3 decompressor
are needed to see this picture.

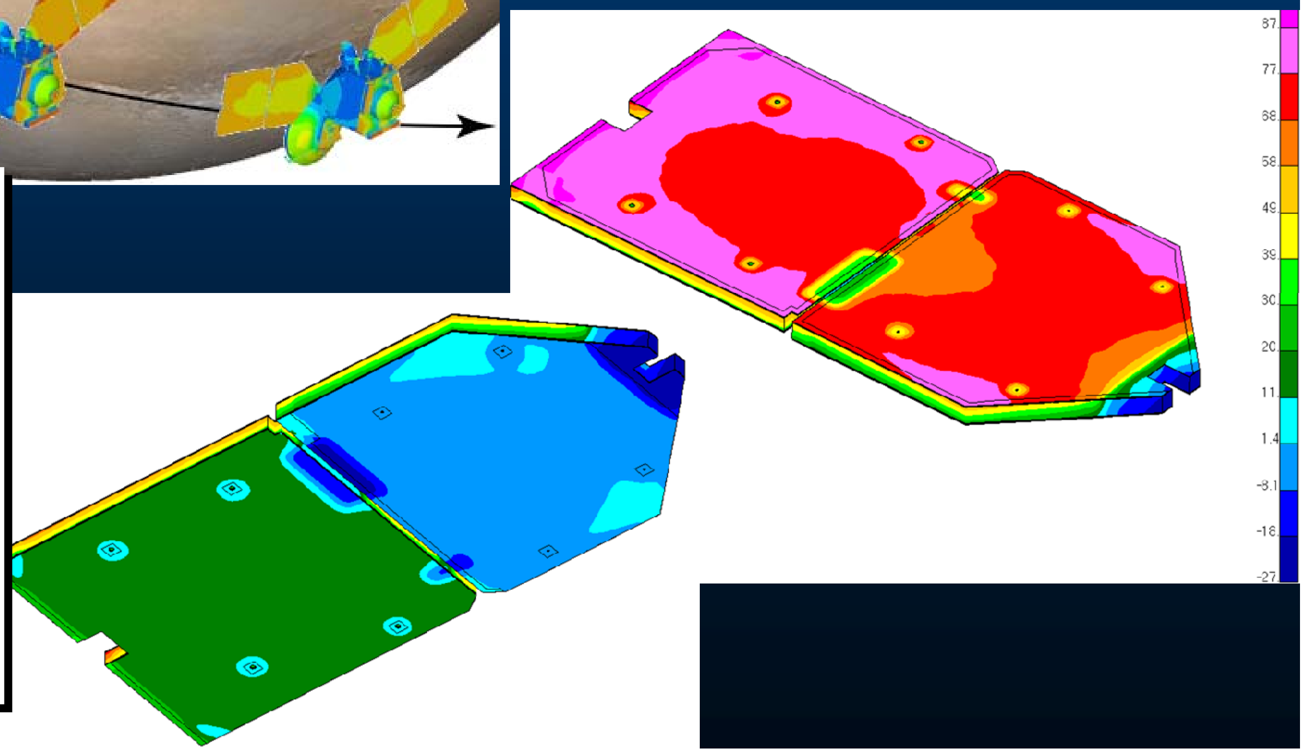
NASA Langley MRO Expertise



Team of 9 Engineers:

Aerodynamics
Aerothermodynamics
Flight Mechanics
Thermal Analyses

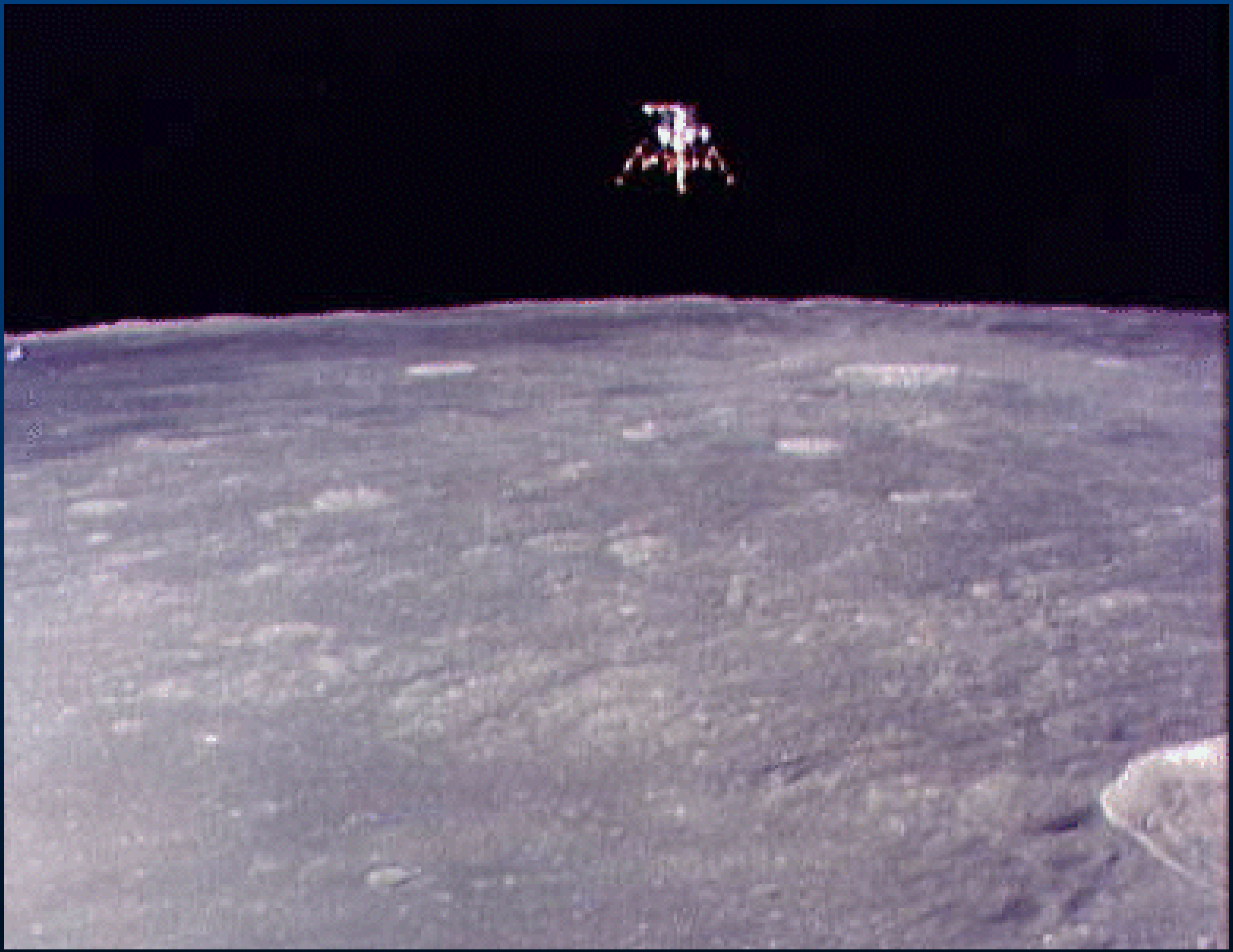




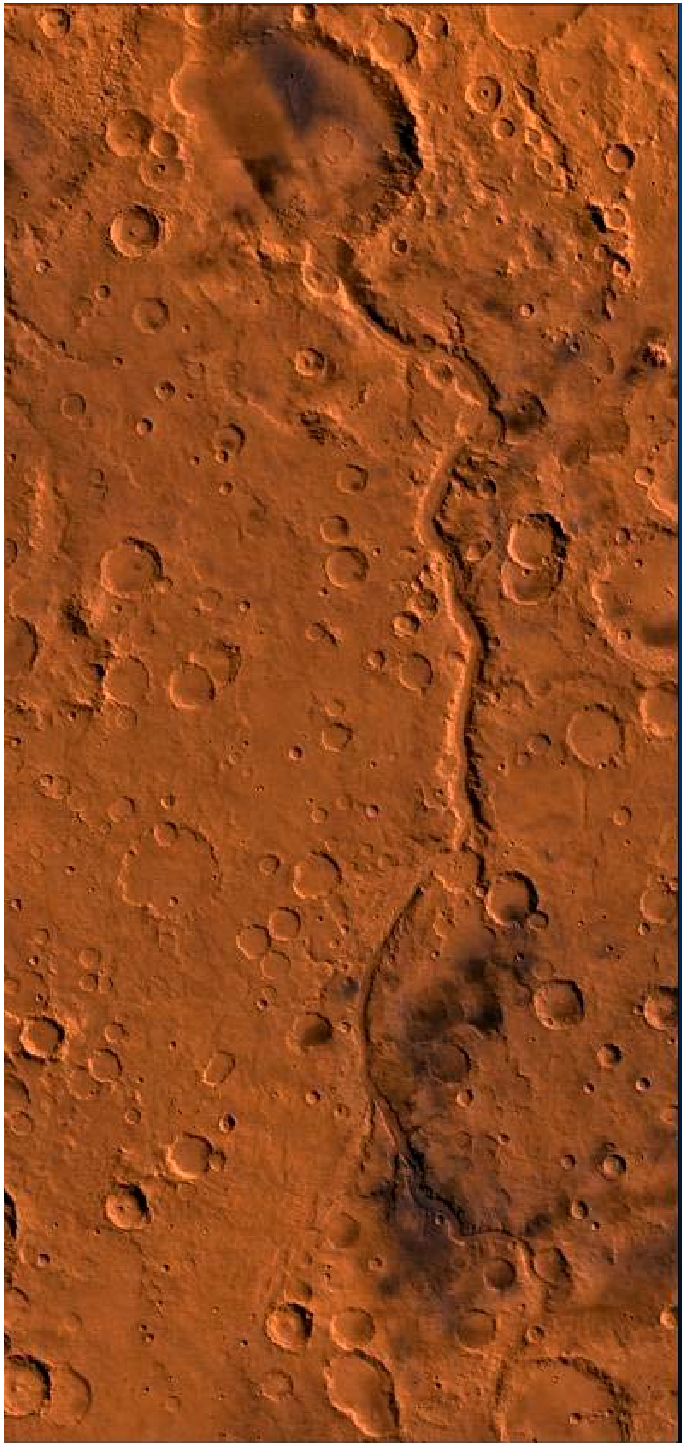
Areas of Improvement

- Robustness, load management and flexibility are of primary interest to CFD
  - CFD is mostly MPI, overall performance depends on performance of all tasks, there is no partial credit
- Robustness of the system I/O
  - Sharing of RAM between CPU
- Load management
  - If several CPUs per node (single or dual quad-core) there are advantages to smaller problems (they fit entirely on one node, no network communication)
- Trajectory Simulation - fast processors, less memory sharing, faster I/O

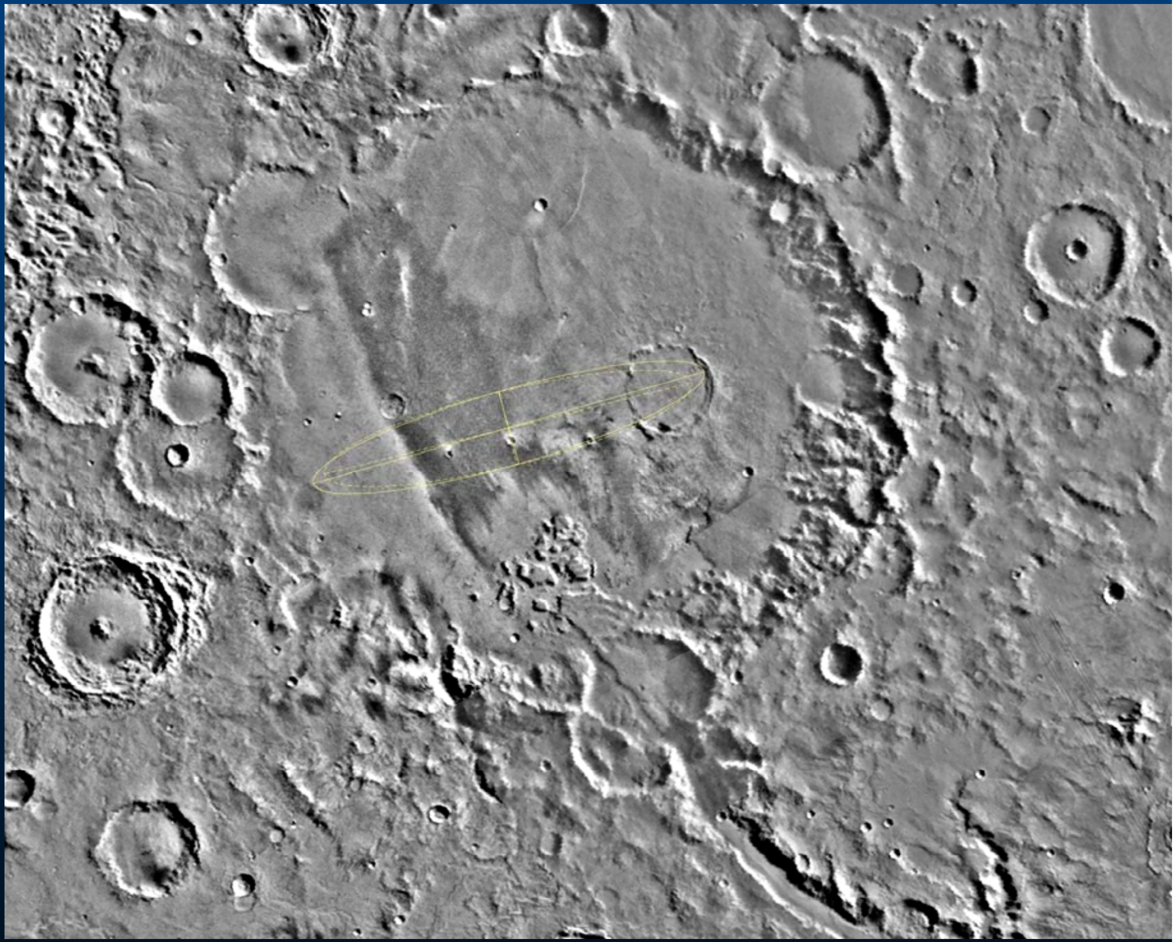
Lunar Landing



Backup Slides



Gusev Crater

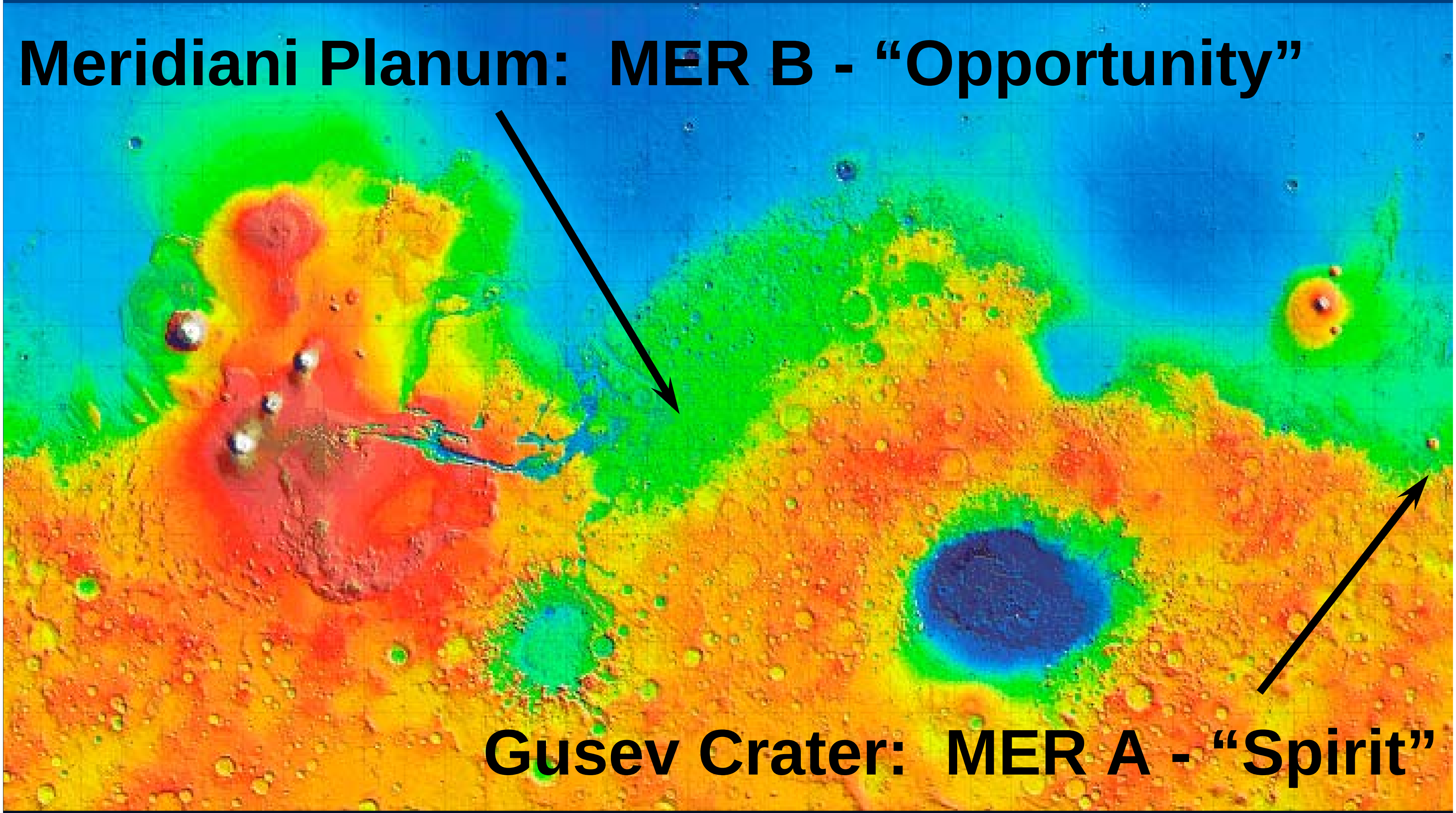


Rover/Payload Elements

- **Rover**
  - 6-wheel drive, 4-wheel steered vehicle
  - Wheelbase: 1.4 m long, 1.2 m wide
  - Height: 1.5 m tall at the top of mast
  - Ground clearance: 30 cm
  - Average speed: 1 cm/s; top speed: 5 cm/s
  - Stereo navigation cameras on mast
  - Front and rear mounted stereo hazard cameras
  - Peak solar panel production: 100 W near local noon early in the mission

- **Remote Sensing Instruments**
  - Panoramic Camera (Pancam)
  - Miniature Thermal Emission Spectrometer (Mini-TES)

- **In-Situ Payload Elements**
  - Microscopic Imager (MI)
  - Mössbauer Spectrometer (MB)
  - Alpha Particle X-Ray Spectrometer (APXS)
  - Rock Abrasion Tool (RAT)
  - Magnets (multiple arrays)


Meridiani Planum: MER B - “Opportunity”
Gusev Crater: MER A - “Spirit”