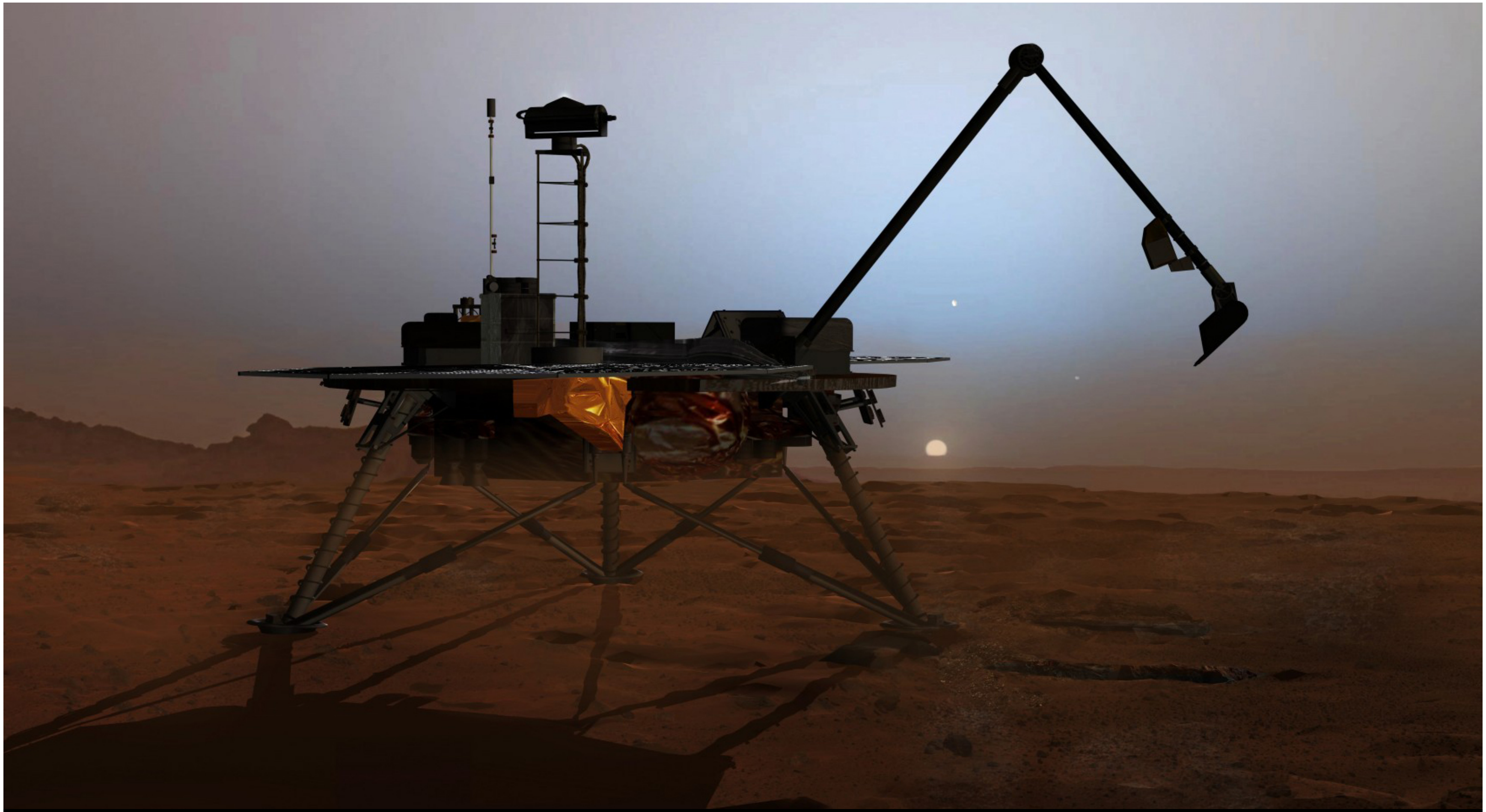
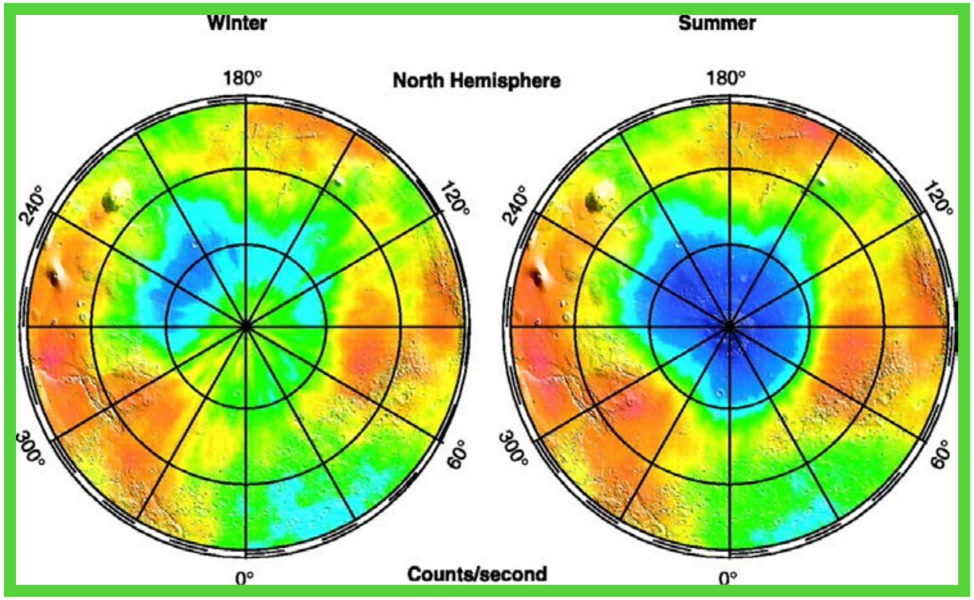


Phoenix: Exploring the Northern Polar Region of Mars

Peter R. Gluck, Project Software Systems Engineer
Jet Propulsion Laboratory / California Institute of Technology

Why Phoenix?



FOLLOW THE WATER

- Analyze Martian ice (water)
- Could the region support life?
- Study Martian weather
- Key to human exploration

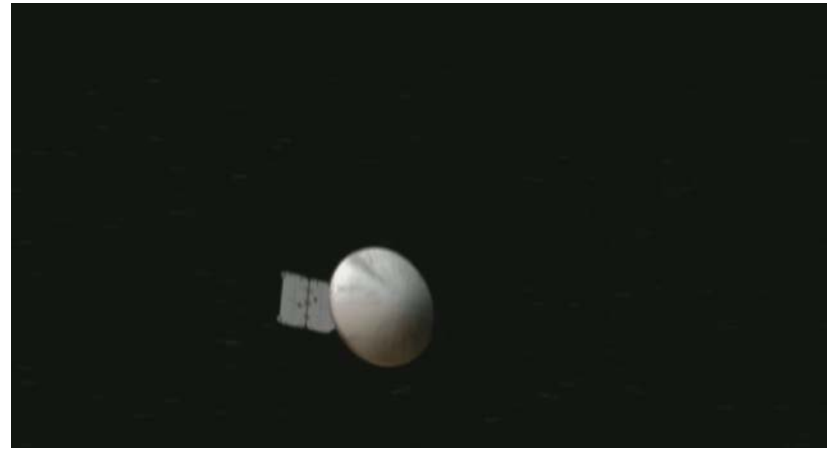
- In 2003, the Gamma Ray Spectrometer aboard the Mars Odyssey spacecraft detects large quantities of hydrogen just below the surface of Mars at the poles
- Water is the most abundant source of hydrogen on planet Earth
- Phoenix was conceived to determine if there is water, and if so, how much there is and whether it may ever have harbored life

Phoenix Partners

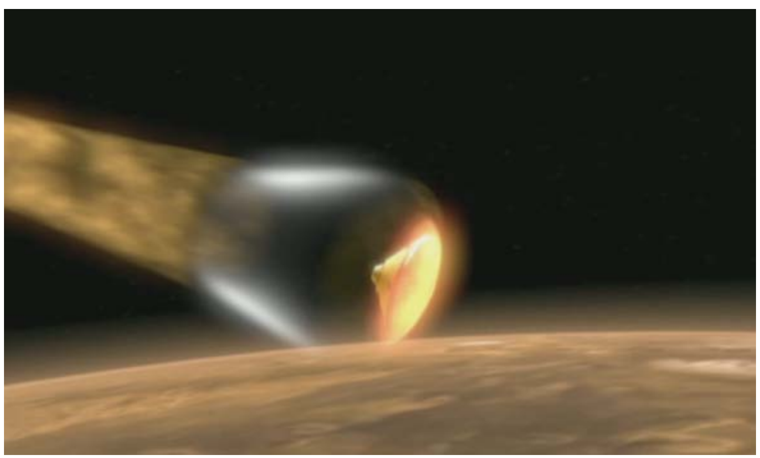
- Phoenix is a collaboration between
  - The University of Arizona, Tucson, AZ
  - NASA's Jet Propulsion Laboratory, Pasadena, CA
  - Lockheed Martin Space Systems Company, Denver, CO
- With international contributions from
  - The Canadian Space Agency
  - The University of Neuchatel, Switzerland
  - The Universities of Copenhagen and Aarhus, Denmark
  - The Max Planck Institute, Germany
  - The Finnish Meteorological Institute, Finland

Mission Phases

Launch



Cruise

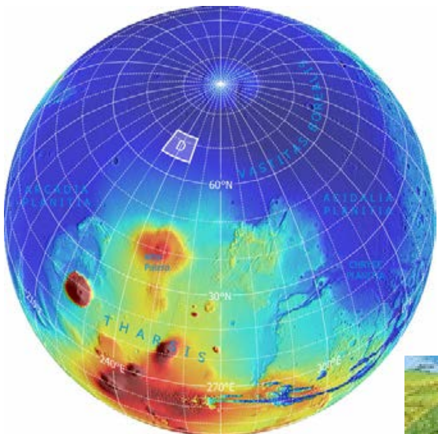


Entry, Descent, and Landing

Surface

Destination

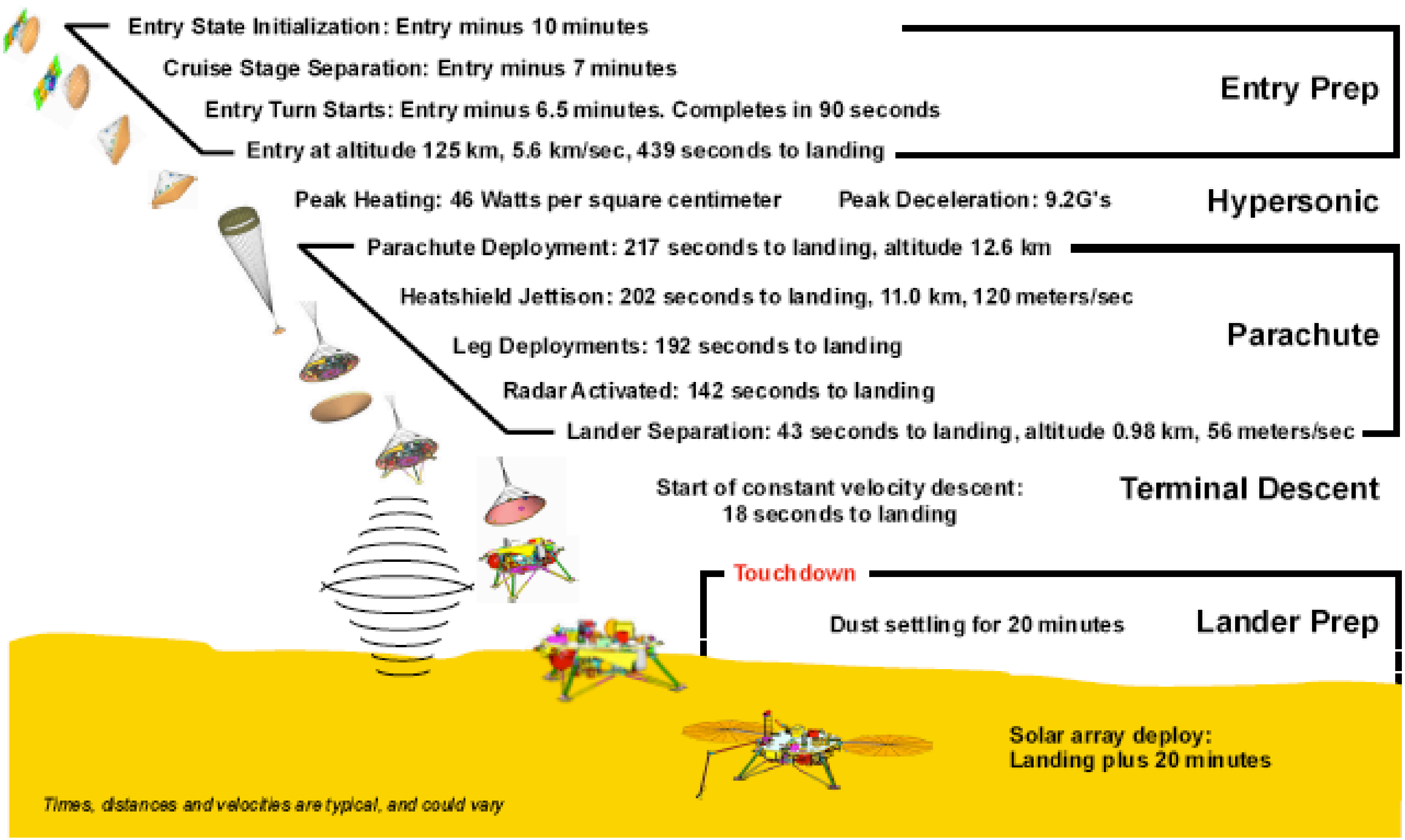
Launch:August 4, 2007
10 month journey of 422 million miles



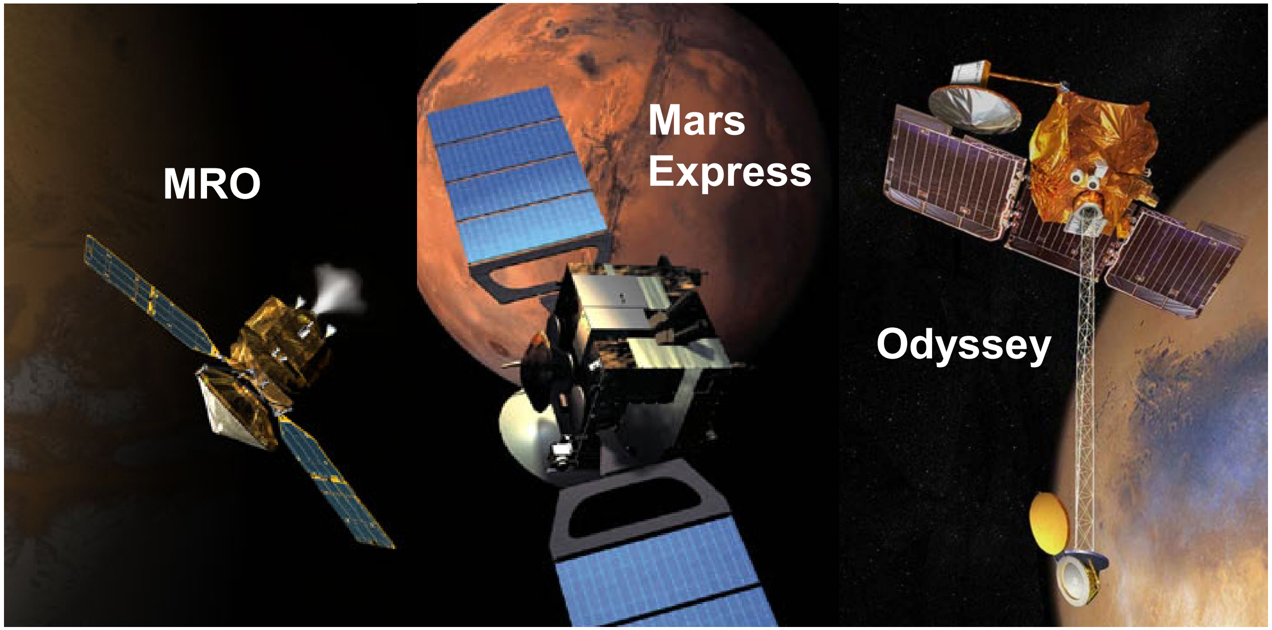
DESTINATION
Mars Northern
Polar Region

EARTH ANALOGY

EDL: Entry, Descent, and Landing



Telecommunication



- Communication with the Phoenix lander is via UHF relay from one of three orbiting assets
  - Mars Reconnaissance Orbiter (MRO)
  - Mars Odyssey
  - Mars Express
  - Several overhead passes from each orbiter each day
- Phoenix does not have a direct-to-earth communcations capability after jettisoning the cruise stage

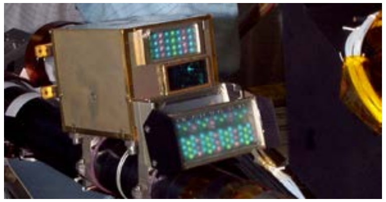
Science Instruments

Surface Stereo Imager (SSI)
University of Arizona

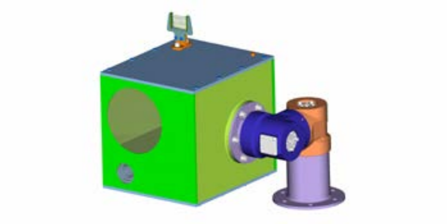
Robotic Arm (RA)
JPL

Microscopy, Electrochemistry & Conductivity Analyzer (MECA)
JPL

Thermal Evolved Gas Analyzer (TEGA)
University of Arizona



Robotic Arm Camera (RAC)
Max Plank Aeronomie



Meteorological Package with scanning LIDAR
Canadian Space Agency

- On the surface, Phoenix operates six (!) instrument packages in complex, coordinated observations

Phoenix Software Challenges

- Multiple Operational Scenarios (Mission Phases)
- Single RAD6000 processor
- Fault Detection and Correction
- Autonomous Operation
  - 170 million miles, 15 minute light-time
  - Sleep Cycles
  - UHF Relay
- Control Spacecraft Functions
  - Attitude
  - Commanding
  - Communications
  - Data Handling
  - Power
  - Propulsion
- Control Multiple Instruments
- Updateable In-Flight
- High Reliability

Mission Phases

Phase	Comm	Activities	Real-Time Sensitivity
Launch	Continuous & instantaneous	Critical solar array deployment, sun-pointing	High (battery depletion)
Cruise	Infrequent (every 3 days) & delayed	Maneuvers	Low
EDL	Continuous & delayed	Critical deployments / jettison of cruise stage, parachute, heat shield, backshell, landing legs, solar arrays	High (high-velocity, battery depletion)
Surface	Infrequent (every 4 - 8 hours)	Science investigations	Moderate (RA delivery of icy samples)

Software Summary & Platform

- **Single RAD6000 processor**
  - Similar to PPC601
  - Radiation hardened for space use
  - First used on Mars Pathfinder
  - Last planned use on Phoenix
    - Supplanted by RAD750
  - 20 MHz clock speed
  - 74+ MB DRAM
  - Additional FLASH memory
- **Software Codebase in 'C'**
  - VxWorks RTOS
  - GreenHills compiler
- **Software Architecture**
  - Multiple tasks with interprocess communication
  - Can be updated in flight

Spacecraft Control

- **Attitude**
  - Sun-pointing (Launch, Cruise)
  - EDL deployments
  - Gyrocompassing on surface
- **Commanding**
  - Immediate and sequenced commands
- **Communications**
  - X-band (Launch, Cruise)
  - UHF (EDL, Surface)
- **Data Handling**
  - CCSDS Telemetry Frames & Packets
    - Consultative Committee for Space Data Standards
  - Overnight storage of "critical" data
- **Power**
  - Cruise solar array (Cruise)
  - Landed solar array (Surface)
  - Battery (All)
- **Propulsion**
  - Trajectory Correction Maneuvers (Cruise)
  - Powered Decent (EDL)

Fault Detection & Correction

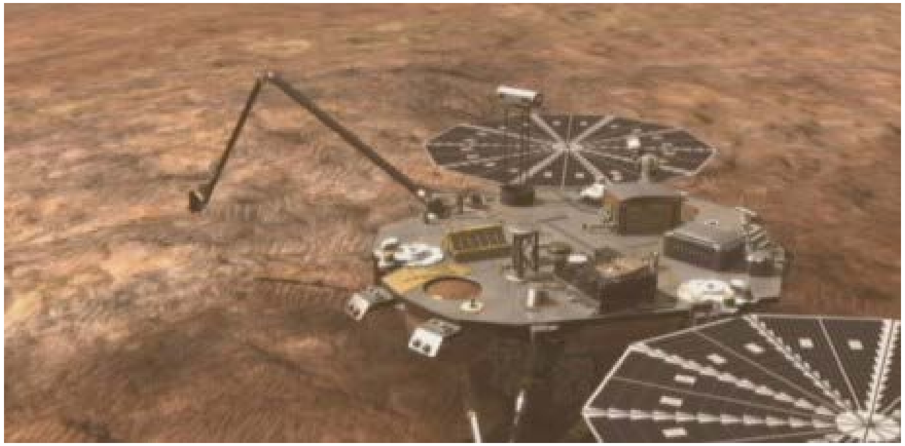
- Operate autonomously for at least 3 days
- Keep the spacecraft safe
- Prevent damage to instruments or components
- Monitor FSW health
  - Reboot system if suspect
- Switch to redundant components or systems

Autonomous Operation

- 170 million miles, 15 minute light-time
  - No maintenance calls
  - No real-time system monitoring
  - Problems can only be overcome by swapping to redundant systems / components or uploading new FSW
- Sleep Cycles
  - Power constrained – only operate during peak daylight hours
  - Sleep at “night” to conserve power
  - Shutdown and restore system
    - Save data to non-volatile memory
    - Restore data and execute appropriate commands upon wakeup
- UHF Relay
  - Establish Proximity-1 link with orbiters at appropriate times

Surface Functions

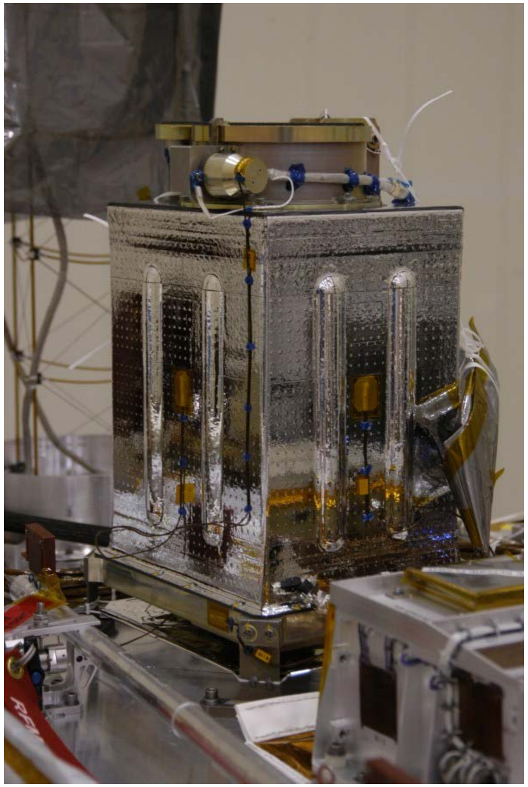
- Control Multiple Instruments
  - MET, RA, RAC, SSI, MECA, TEGA
- Coordinated observations, for example:
  - RA scoops soil
  - RAC images soil sample
  - RA moves to delivery position
  - SSI images RA position
  - RA delivers to TEGA or MECA
  - RAC images delivery
  - TEGA / MECA perform experiments



- GOAL: Deliver icy samples within 10 minutes to minimize sublimation

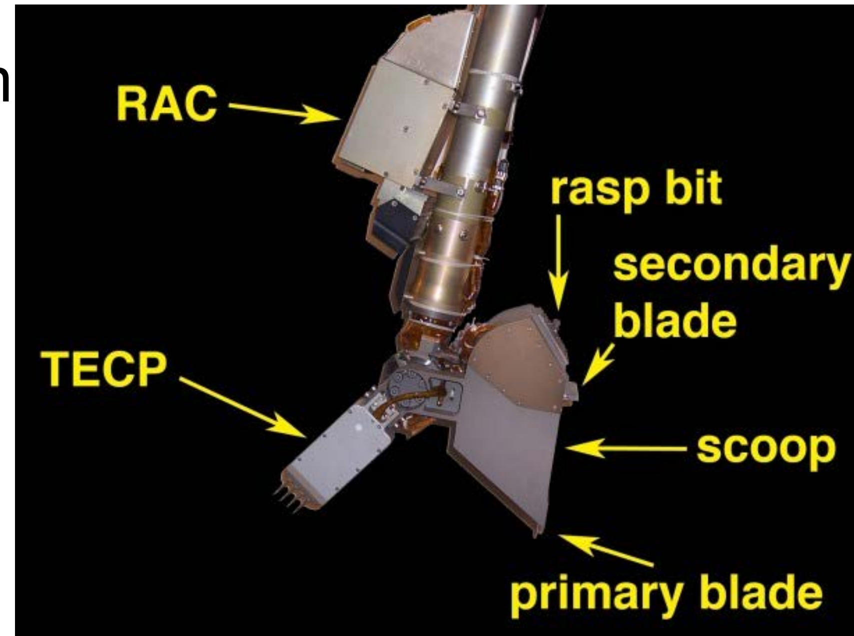
Meteorology Package (MET)

- *OBJECTIVE: Monitor polar weather patterns*
- Pressure-Temperature (PT) Experiment
  - Three temperature sensors mounted on 1m mast
  - One pressure sensor
- LIDAR
  - Zenith-fixed orientation
  - Two-frequency (green, IR) laser system
  - Measures atmospheric opacity, reflectivity
  - Detects overhead dust and clouds
- Coordinates with: SSI atmospheric imaging

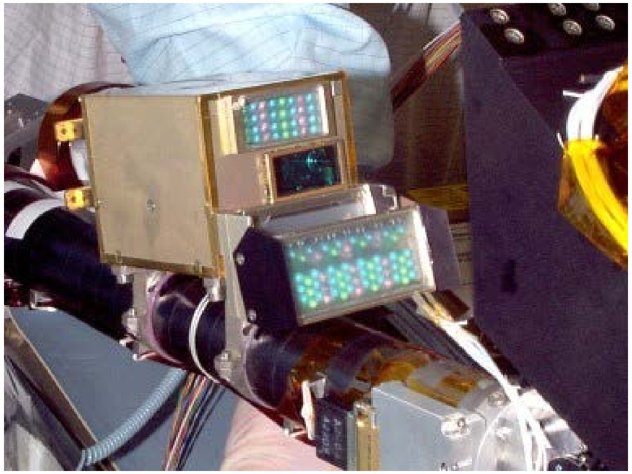


Robotic Arm (RA)

- *OBJECTIVE: Excavate and deliver soil to MECA, TEGA*
- Aluminum / Titanium, 2.35 m
- Four joints
- Equiped with
  - Scoop
  - Scraping Blade
  - Rasp
  - Thermal and Electrical Conductivity Probe (MECA)
  - RAC
- Coordinates with: MECA, RAC, SSI, TEGA

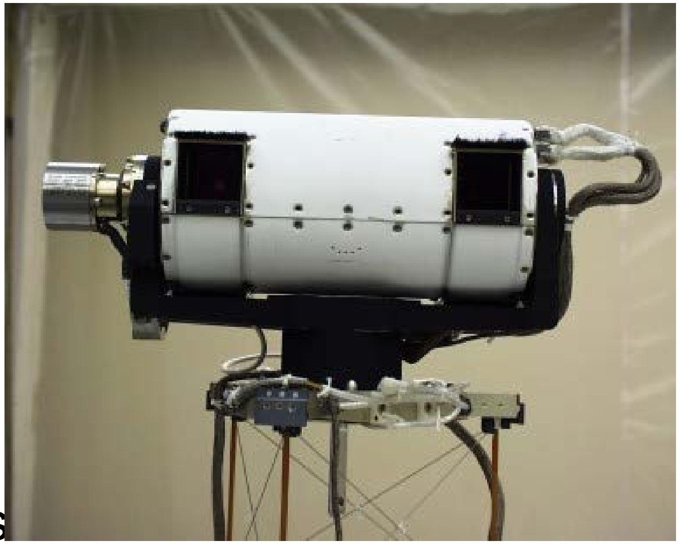


Robotic Arm Camera (RAC)



- *OBJECTIVE: Image surface and soil deliveries*
- Attached to RA forearm
- Provides LED illumination
  - Red, Green, Blue
- Peers into RA scoop or at external targets
- Moveable focus from 11mm to infinity
- Resolution of 23 microns per pixel at closest focus
  - Spirit & Opportunity resolution was hundreds of microns
- Coordinates with: RA, MECA, TEGA

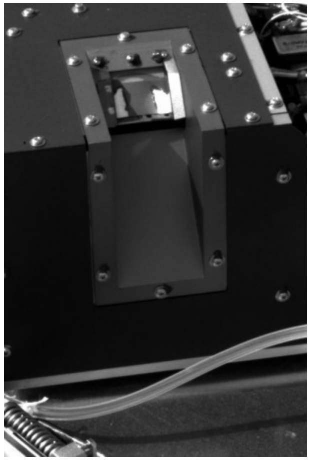
Stereo Surface Imager (SSI)



- *OBJECTIVE: Context imaging and digital elevation mapping (depth perception)*
- Two one-megapixel CCDs
- Twelve filters for each "eye"
  - Includes color, infrared, and clear filters
- Perched 2 m above the surface at roughly human height
- Full 4-pi-steradian field-of-view
  - 360-degree azimuth
  - 180-degree elevation
- Coordinates with: MET, MECA, RA, TEGA

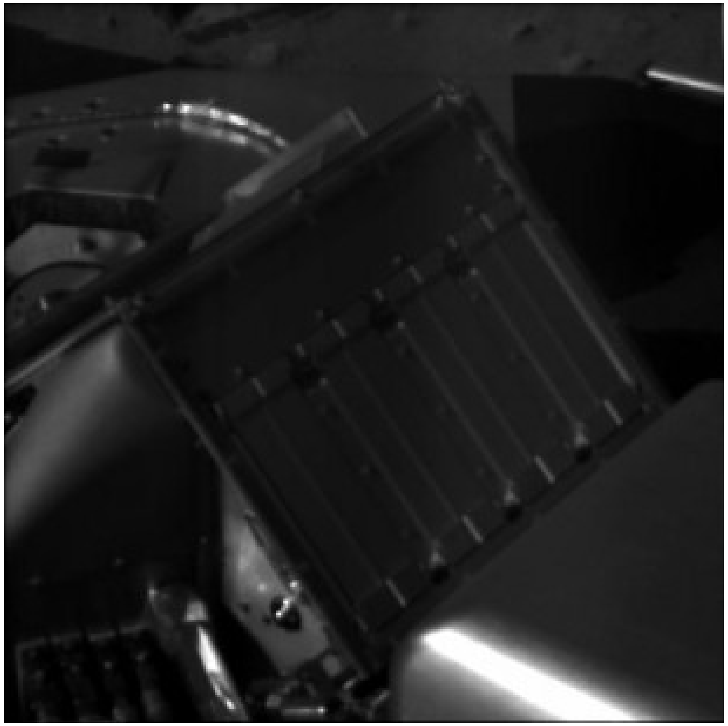
Microscopy, Electrochemstry, and Conductivity Analyzer (MECA)

- *OBJECTIVE: Determine soil composition and chemistry*
- Four-in-one science kit
  - Wet Chemistry Cells (4)
    - Twenty-six electrodes measure pH, ions
  - Optical Microscope
    - Resolution of up to 2 microns
    - Red, Green, Blue, and UV illumination
  - Atomic Force Microscope
    - Resolution of up to 100 nm
  - Thermal and Electrical Conductivity Probe
    - Three-pronged “fork” inserted into soil
    - Located on the Robotic Arm
- Coordinates with: RA, RAC, SSI



Thermal and Evolved Gas Analyzer (TEGA)

- *OBJECTIVE: Determine soil composition and chemistry, including quantity of water*
- Eight Differential Scanning Calorimeters (Ovens)
  - Measures material present by energy of phase change
  - Can bake samples to 1000 C
- Mass Spectrometer
  - Measures atomic masses and isotopes
- Coordinates with: RA, RAC, SSI



Verification and Validation of Phoenix FSW (1 of 2)

- Analysis
  - NASA Independent Verification & Validation
    - Requirements Analysis
    - Software Analysis
    - http://www.ivv.nasa.gov
  - JPL's Laboratory for Reliable Software
    - Static Analysis
    - http://eis.jpl.nasa.gov/lars/

Verification and Validation of Phoenix FSW (2 of 2)

- Testing
  - Functional Verification Testing
    - Verifies software requirements
  - System Verification Testing
    - Validates system functionality
  - Risk Reduction Testing (a.k.a. “Stress” testing)
    - Additional validation of system
    - Explore operational boundaries
- Testbeds
  - Software-based (workstations)
  - Hardware-based (embedded)

EDL: Entry, Descent, and Landing

Questions