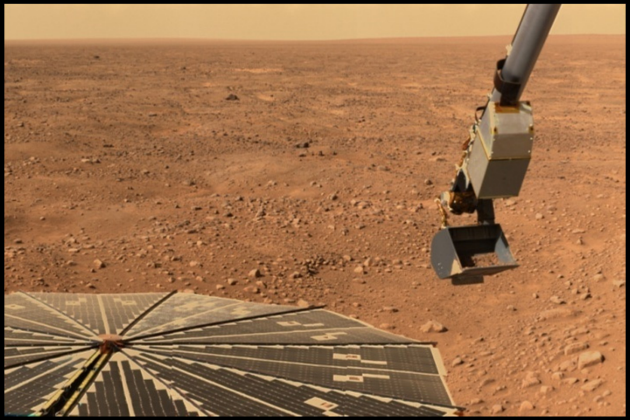
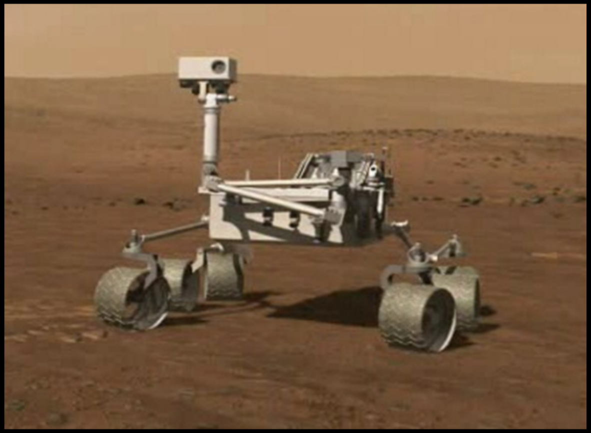
In-situ Science Sample Acquisition and Handling on Mars: The 2007 Phoenix Lander and 2011 Mars Science Laboratory





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Mobility And Robotic Systems Section

NASA-JPL

California Institute Of Technology

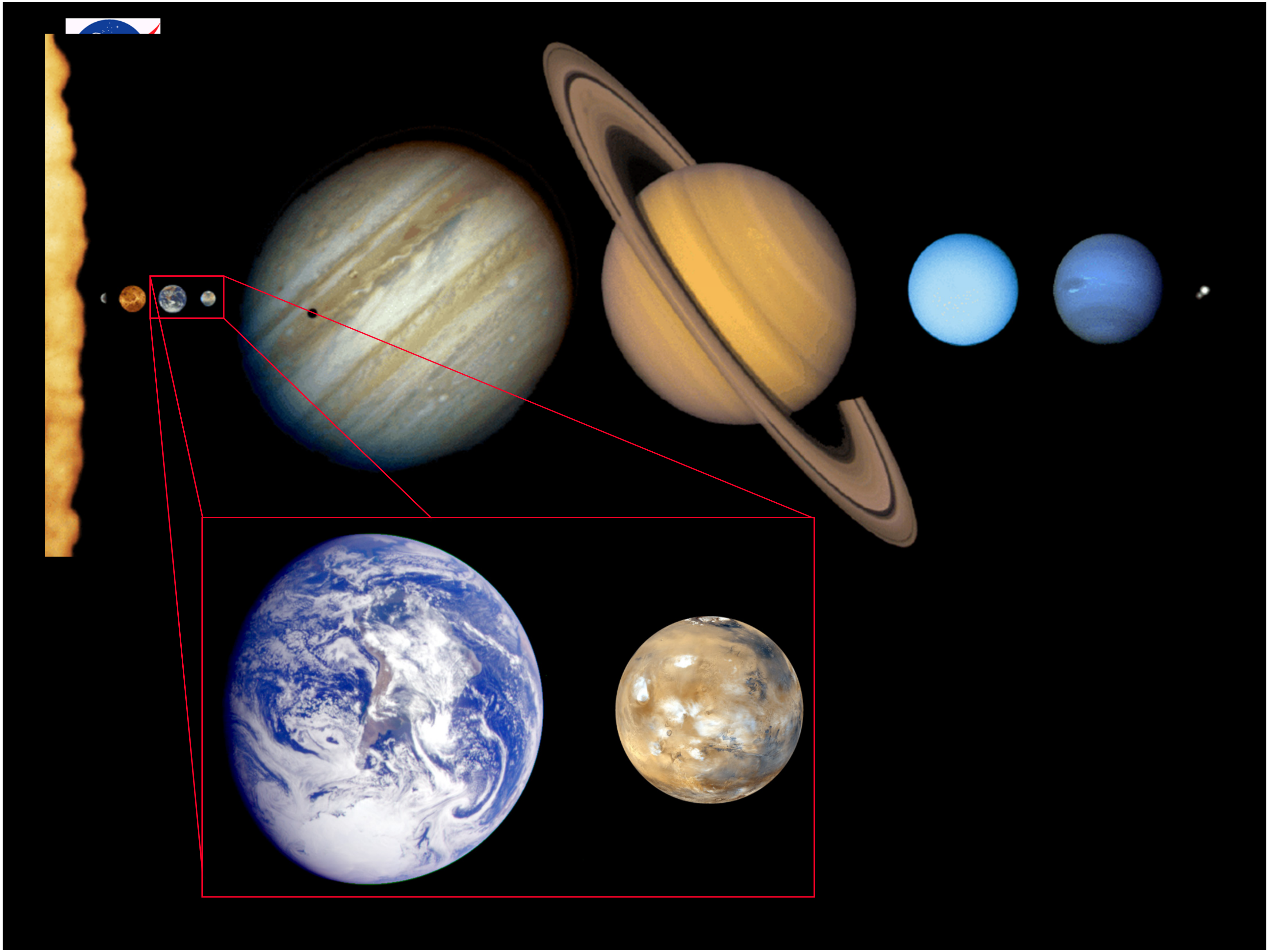
XVII SOMIM Conf

San Luis Potosi, Mexico

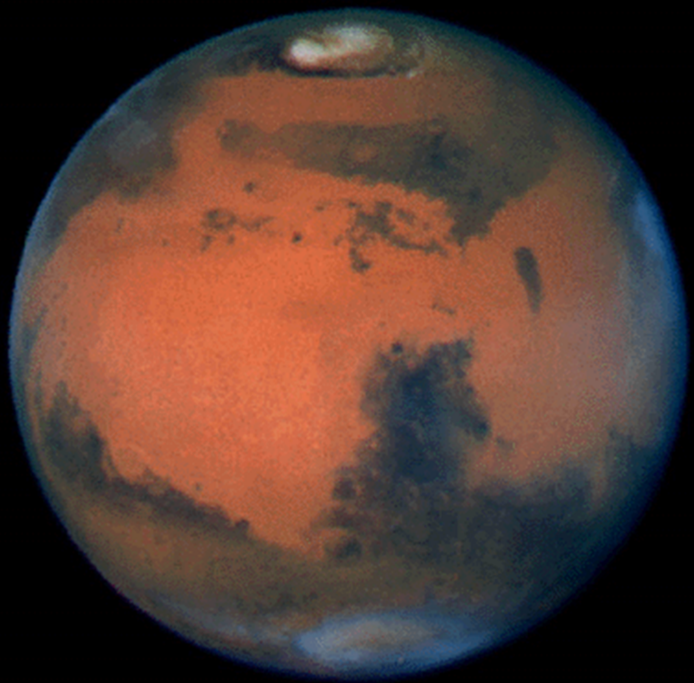
September 23rd , 2011

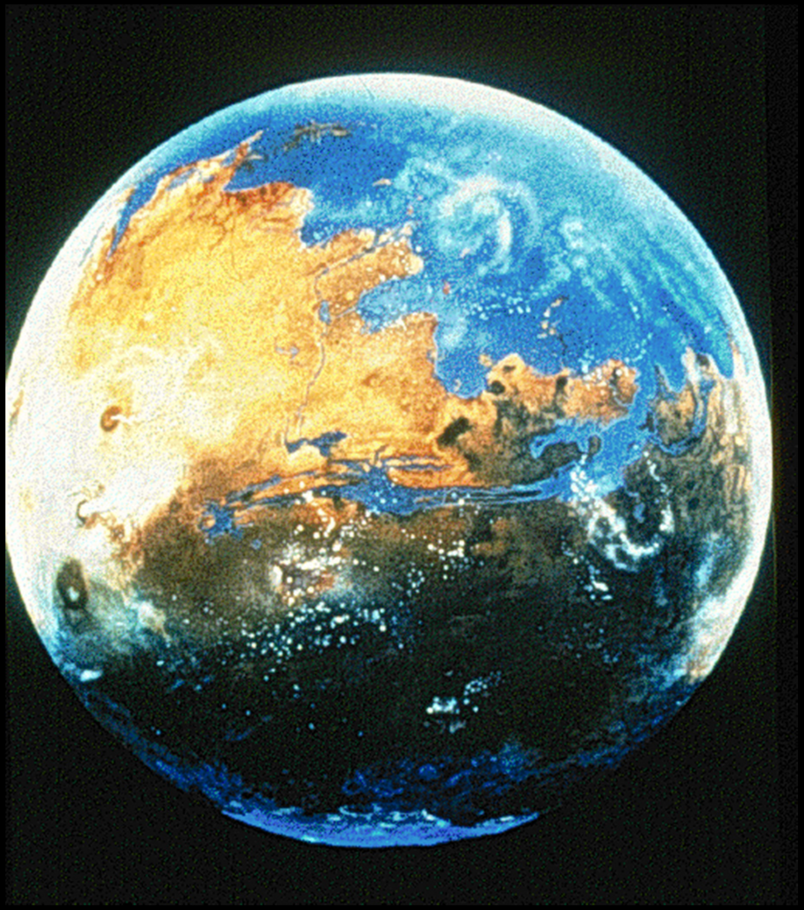
Talk Outline

1. *Introduction to Mars Program – Why Mars?*
2. *2007 Phoenix Lander*
3. *2011 Mars Science Laboratory*
4. *Future Mars Missions*
5. *Summary*

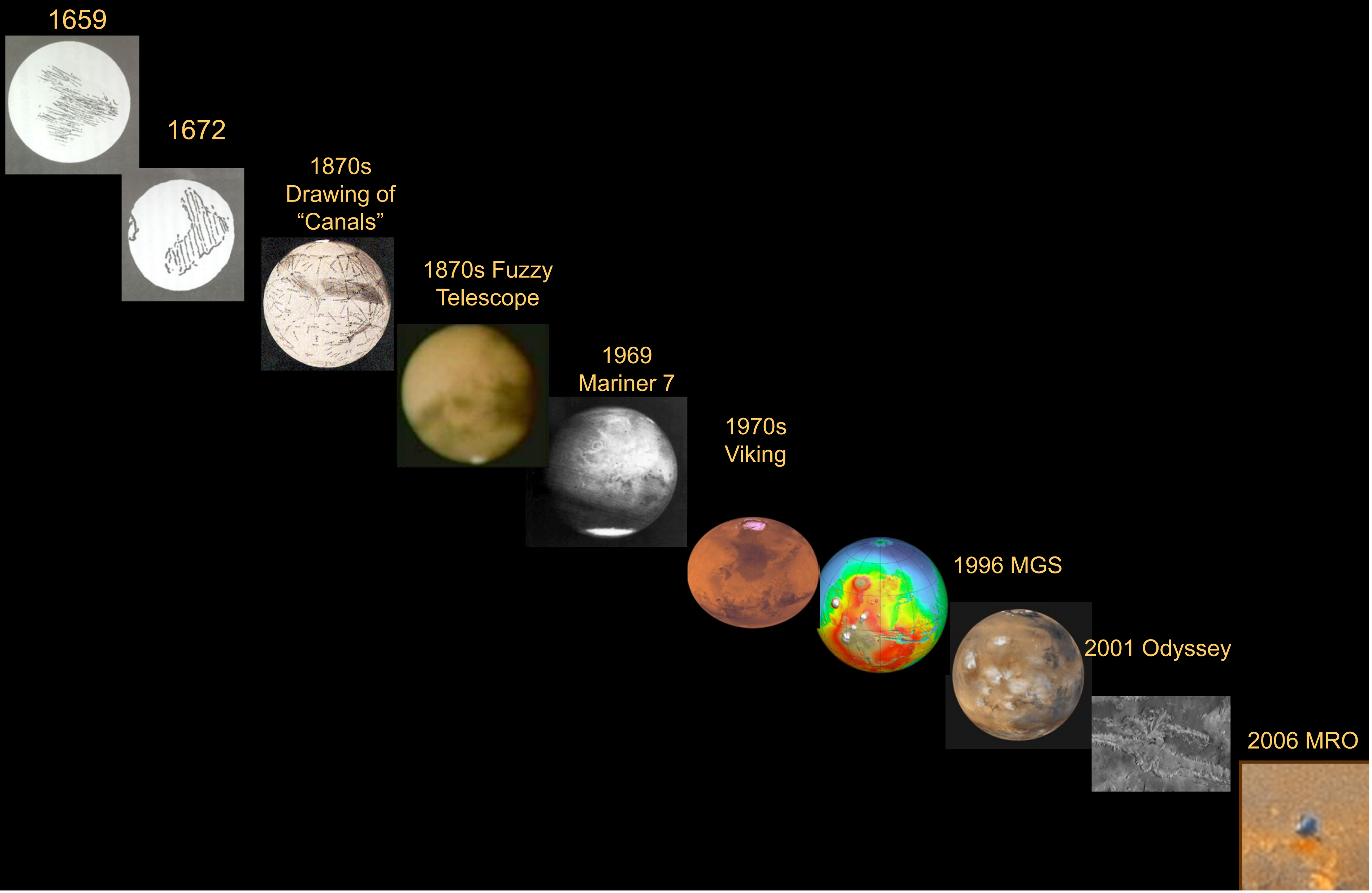


Mars today…and in the past





Changing Faces of Mars



The Mars Science Strategy: "Follow the Water"

- When was it present on the surface?
- How much and where?
- Where did it go?
- Did it persist long enough for life to have developed?

Understand the potential for life

Characterize the present and past climate and climate processes

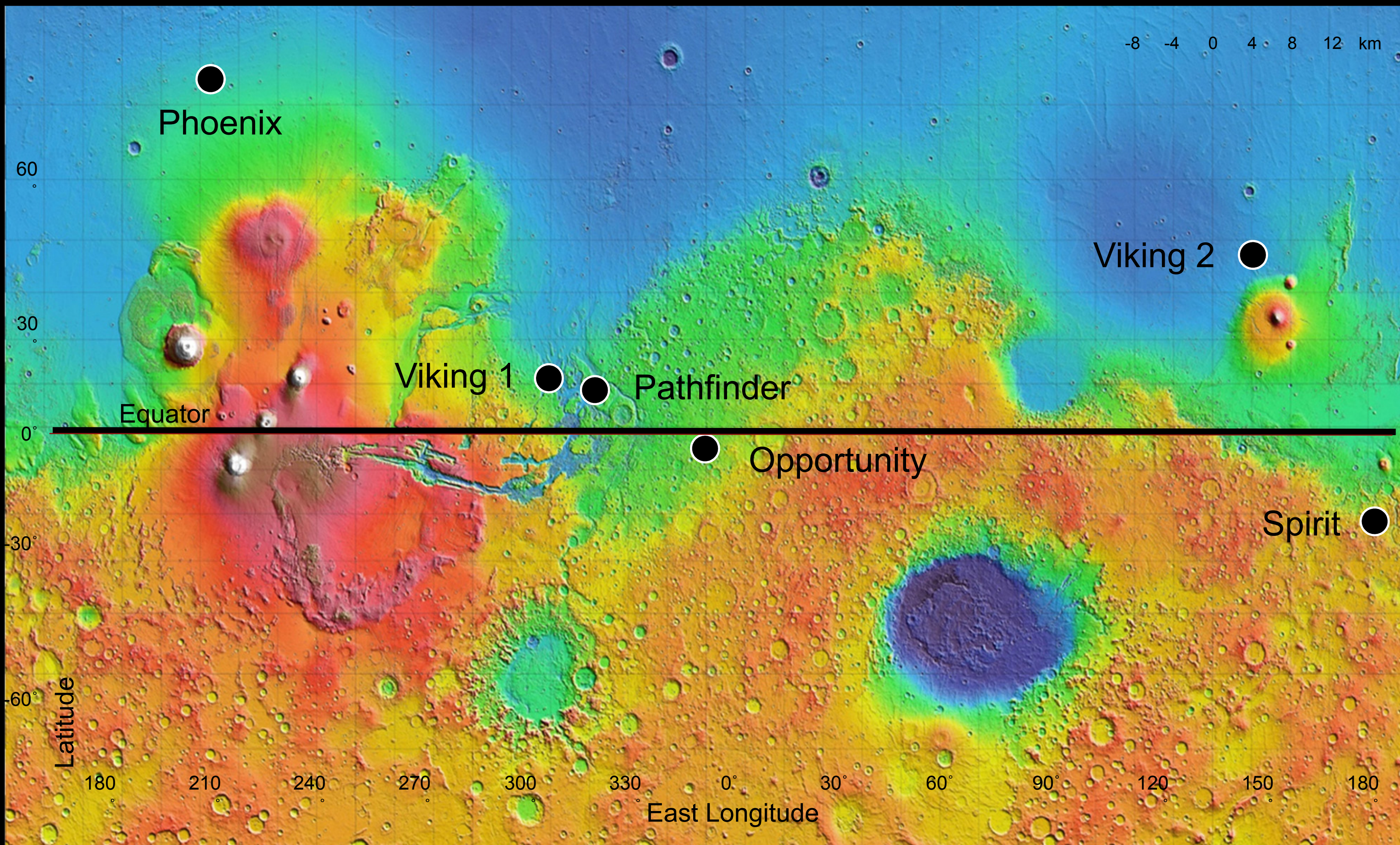
Understand the geological processes

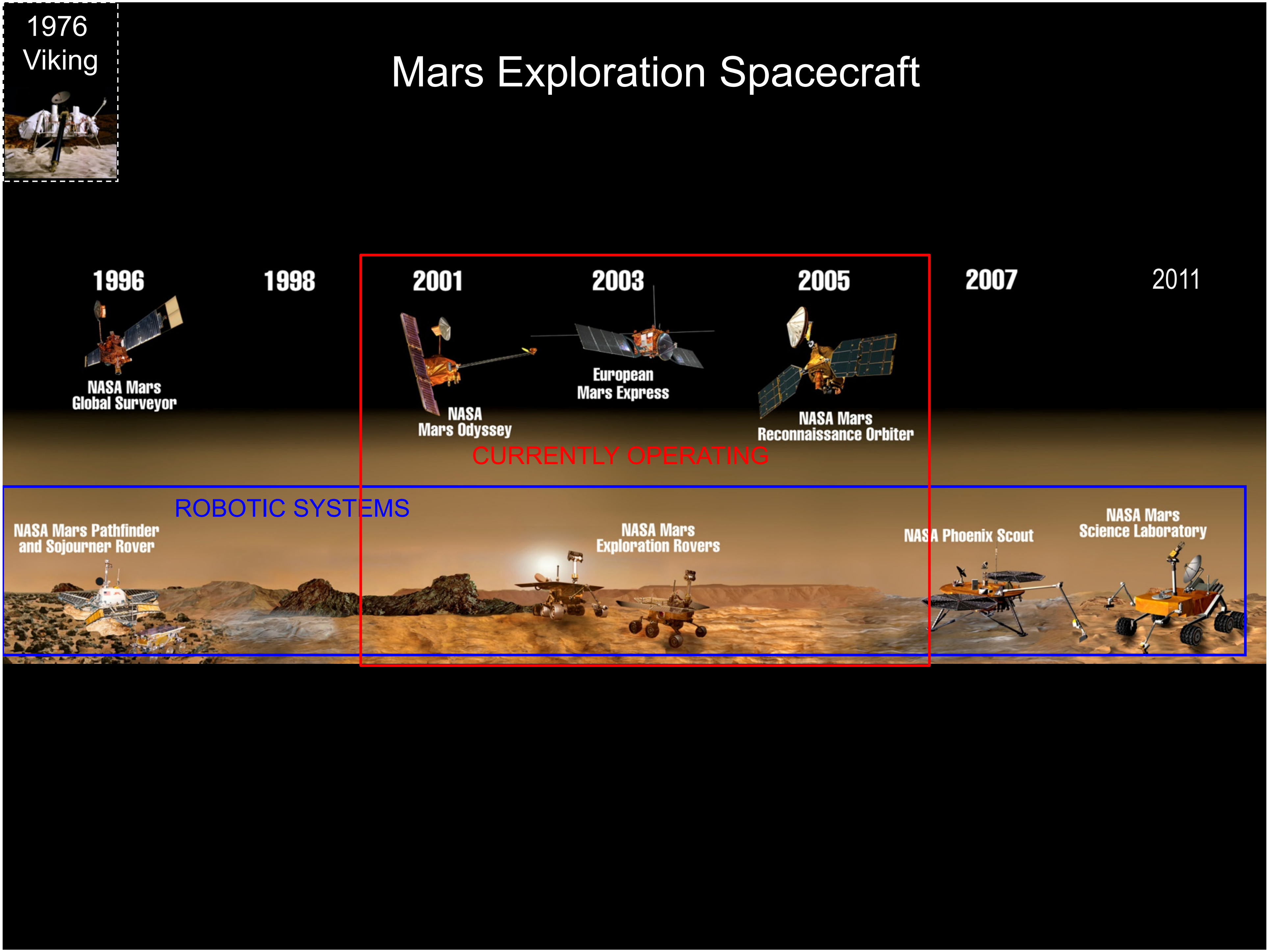
Support Future Human Exploration

When • Where • Form • Amount

Robotic Exploration of Mars

Comparison of Mars Landings




1976
Viking
Mars Exploration Spacecraft
1996
1998
2001
2003
2005
2007
2011
NASA Mars
Global Surveyor
NASA
Mars Odyssey
European
Mars Express
NASA Mars
Reconnaissance Orbiter
CURRENTLY OPERATING
ROBOTIC SYSTEMS
NASA Mars Pathfinder
and Sojourner Rover
NASA Mars
Exploration Rovers
NASA Phoenix Scout
NASA Mars
Science Laboratory

Mars In Situ Exploration:

Viking: Lander with Arm (1977)

Pathfinder: Sojourner Rover (1997)

Mars Polar Lander: Robotic Arm (1998)

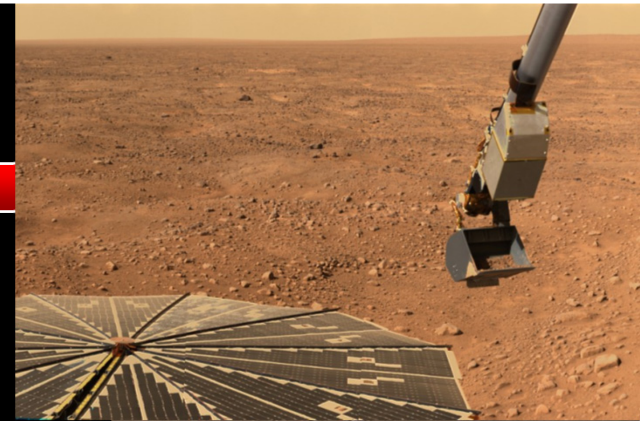
MER: Mars Exploration Rovers (ongoing from 2003)

Phoenix: Robotic Arm (2007)

MSL: Mars Science Laboratory (2011 launch)

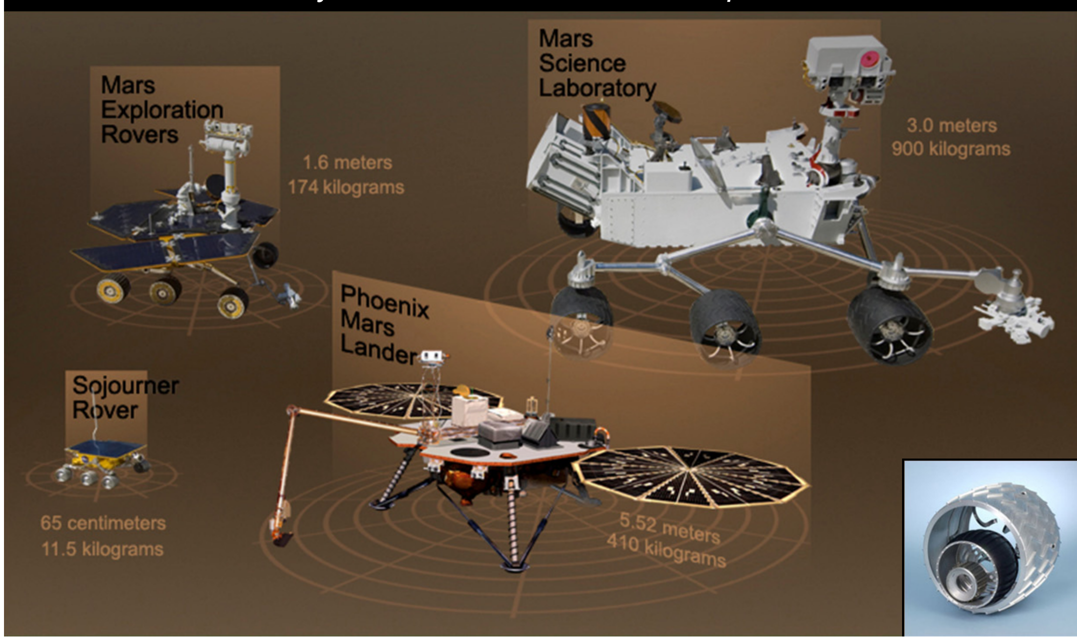
Future: Mars Sample Return.

Phoenix Lander



Sojourner Rover

Mars Systems' Size and Mass Comparison

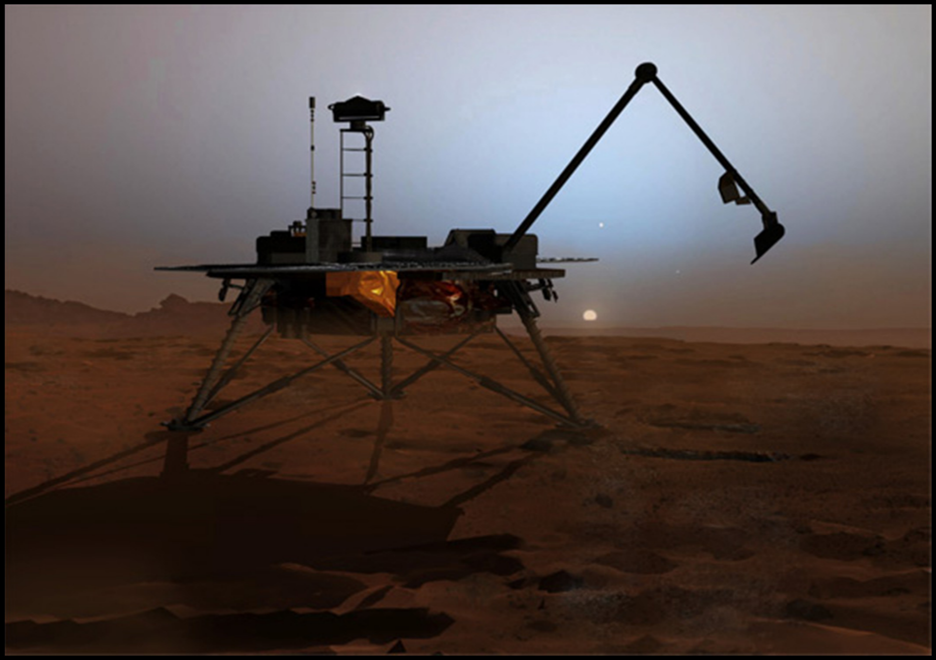


MER Rover next to Sojourner

2007 Mars Phoenix Lander Mission

Phoenix is NASA's first Scout Mission to Mars. It was awarded to Principal Investigator Peter Smith at the University of Arizona.

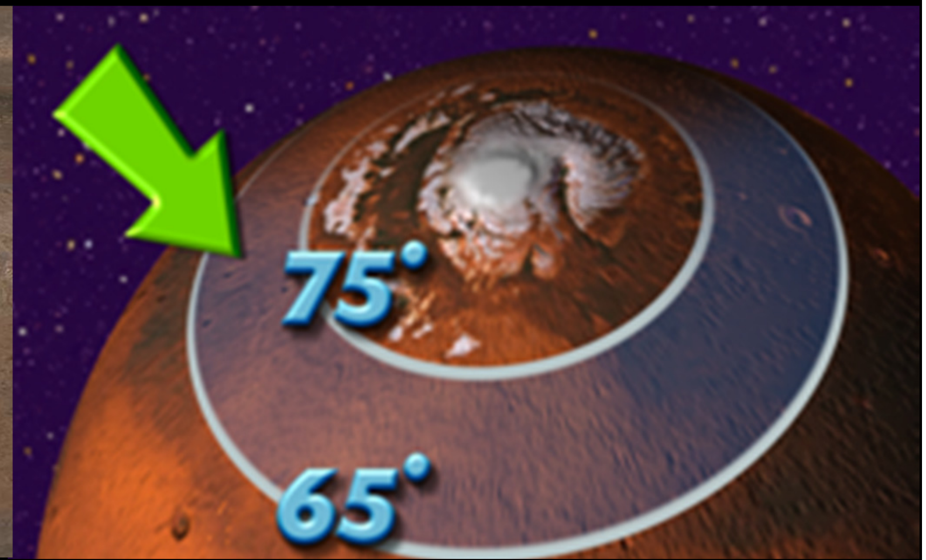
The Phoenix Mission won the competitive bid process in 2003 with partners including JPL, CSA, Lockheed Martin, and multiple university co-investigators.

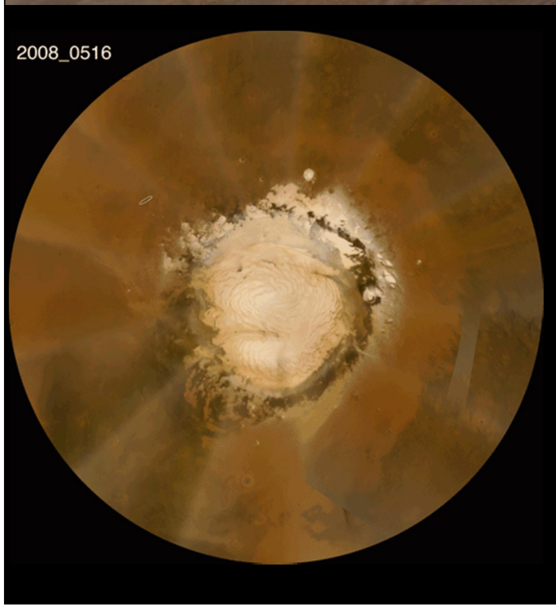


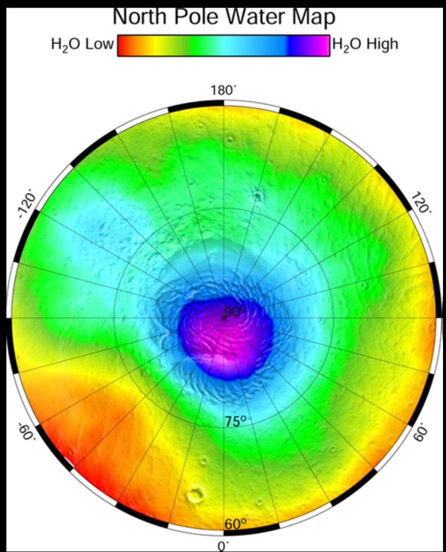
Scouts were designed to be relatively low-cost and innovative complements to NASA's Mars Exploration Program.

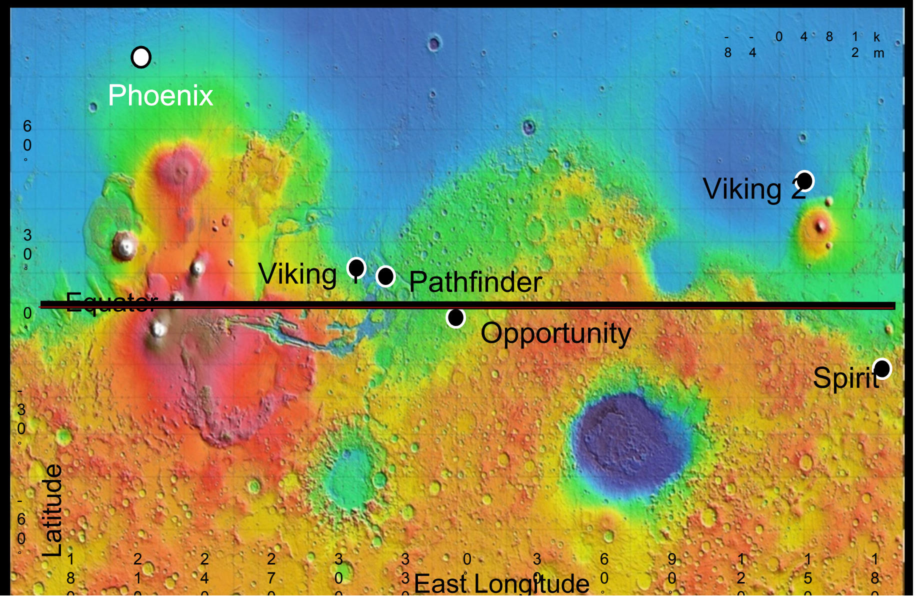
Objective : Confirm Water in the Northern Martian Terrain

Land in the northern latitudes of Mars and conduct the first chemical analysis of the regolith and ice. The Terrain contains as much as 80% water-ice close to the surface

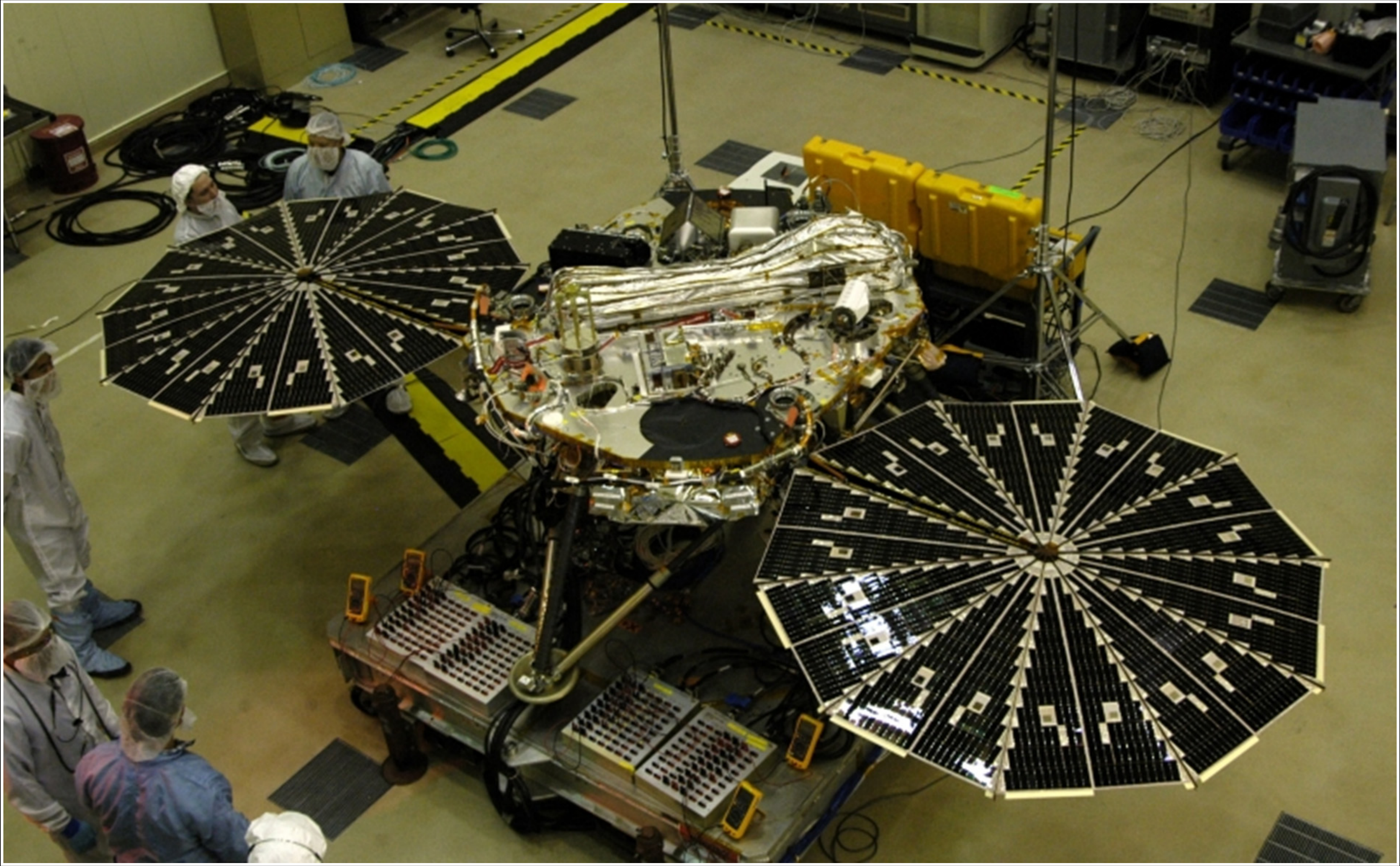








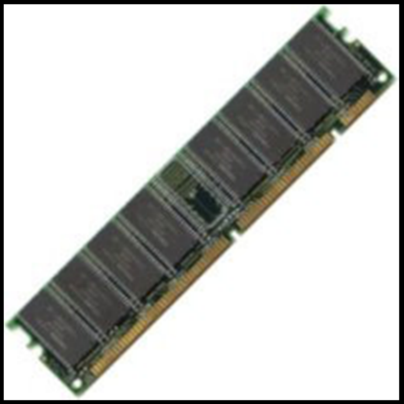
Phoenix at Lockheed Martin

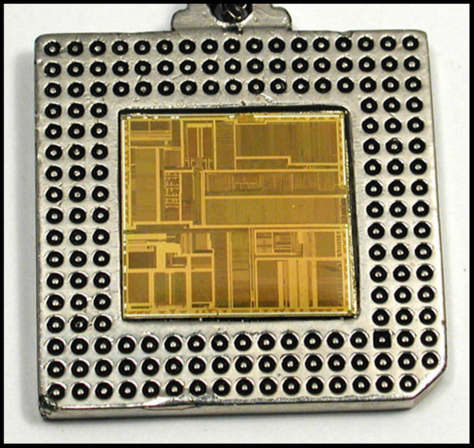


CPU/Memory Constraints

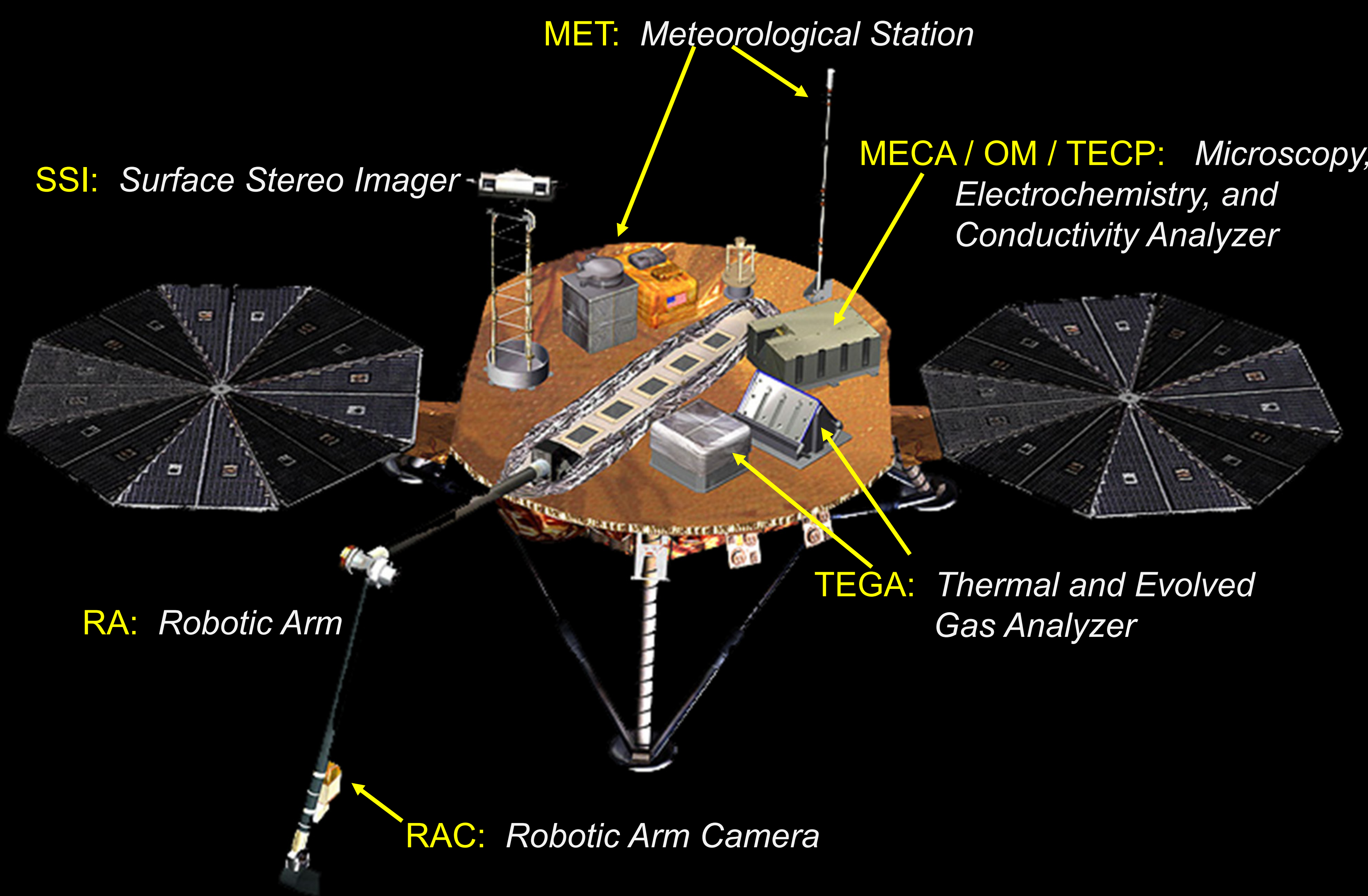
System Limitations

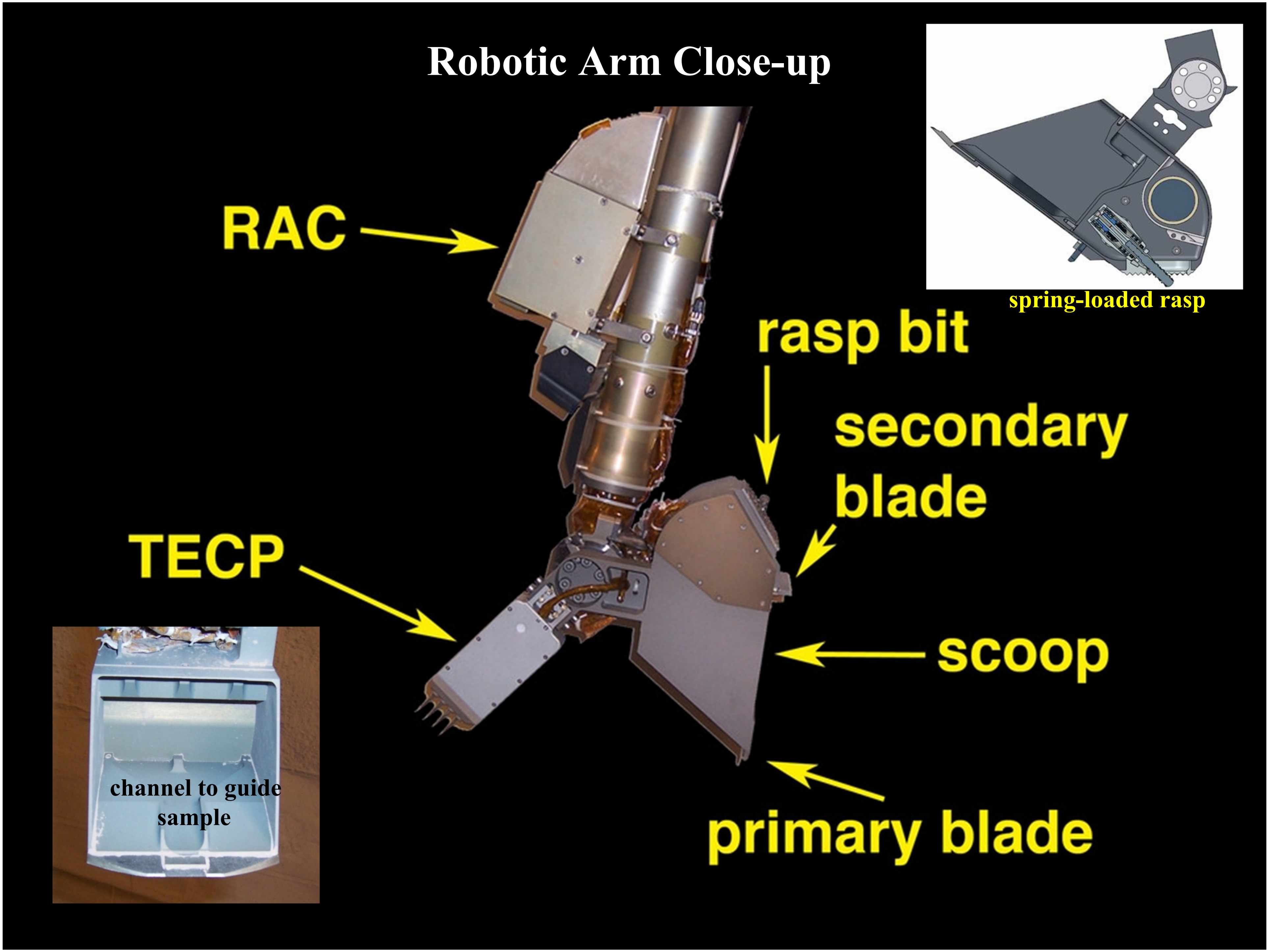
- 20Mhz Processor (Shared by 97 Tasks)
- 13 Mbytes DRAM For Navigation
- Limited Bandwidth for Telemetry Downlink

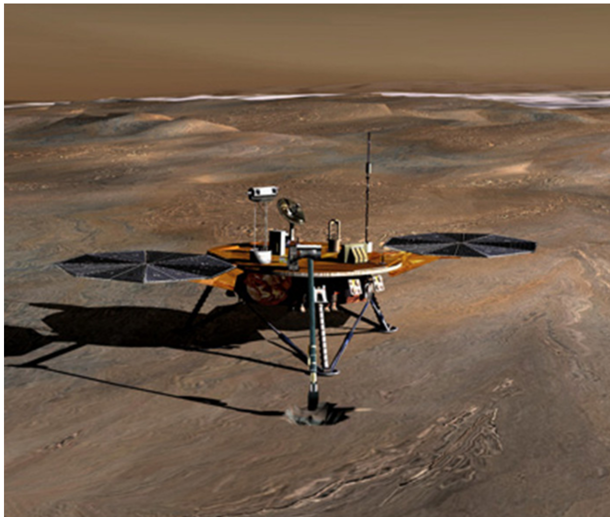


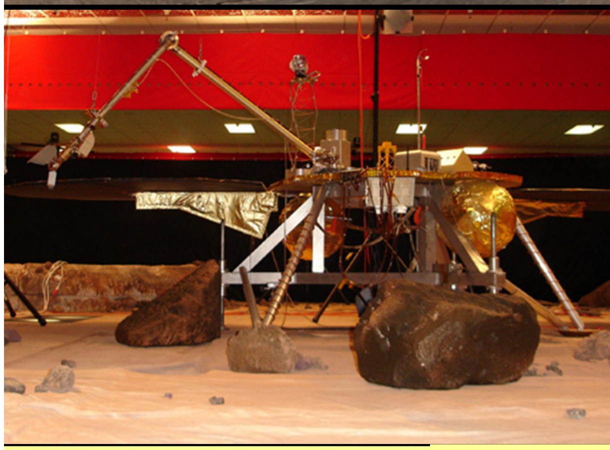


Phoenix's Instruments




Robotic Arm Close-up
spring-loaded rasp
RAC
rasp bit
secondary blade
TECP
scoop
primary blade
channel to guide sample

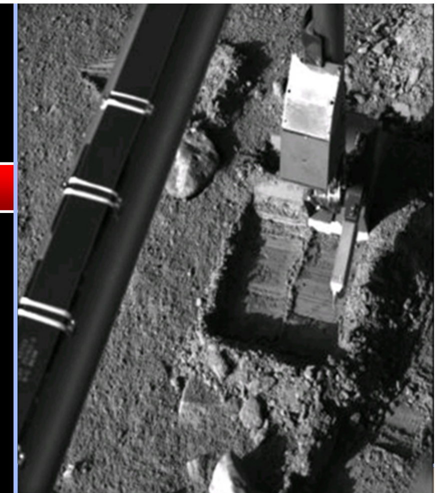


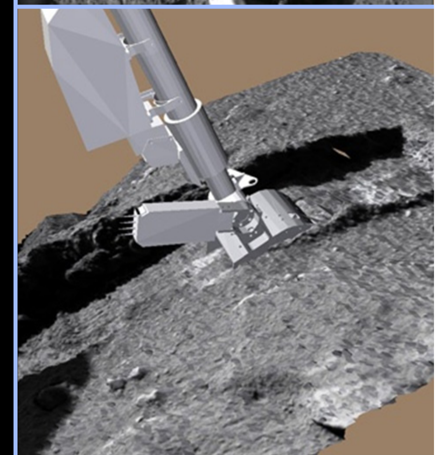


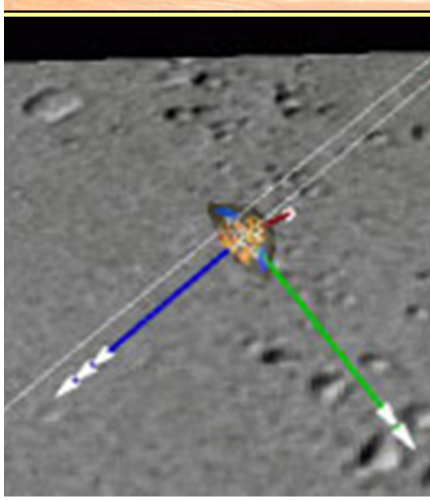
2007 Phoenix Mars Lander

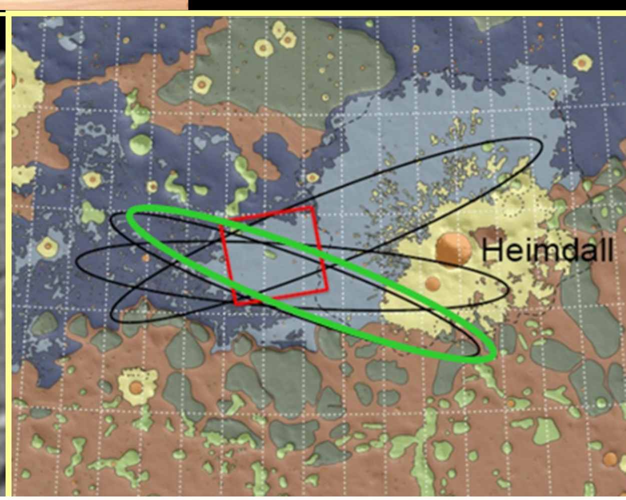
Robotics contributions

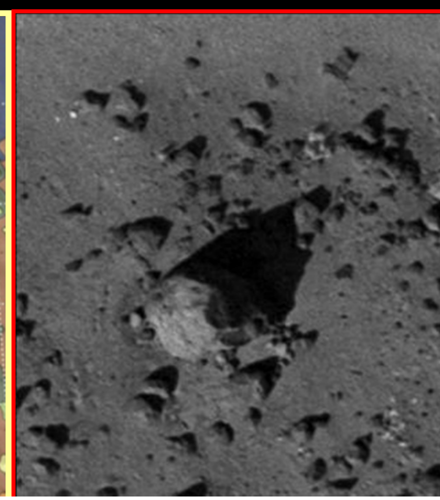
1. Visual hazard analysis of landing sites
2. Simulation of entry and descent for mission planning
3. Operations tools:
   - collaborative science planning software system (Maestro/PSI)
   - robot sequence and visualization (RSVP)
4. Manipulator control

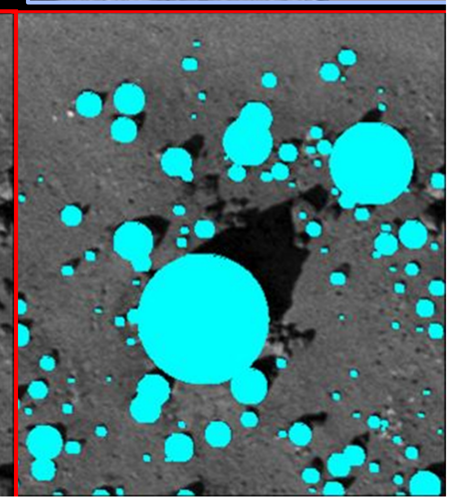




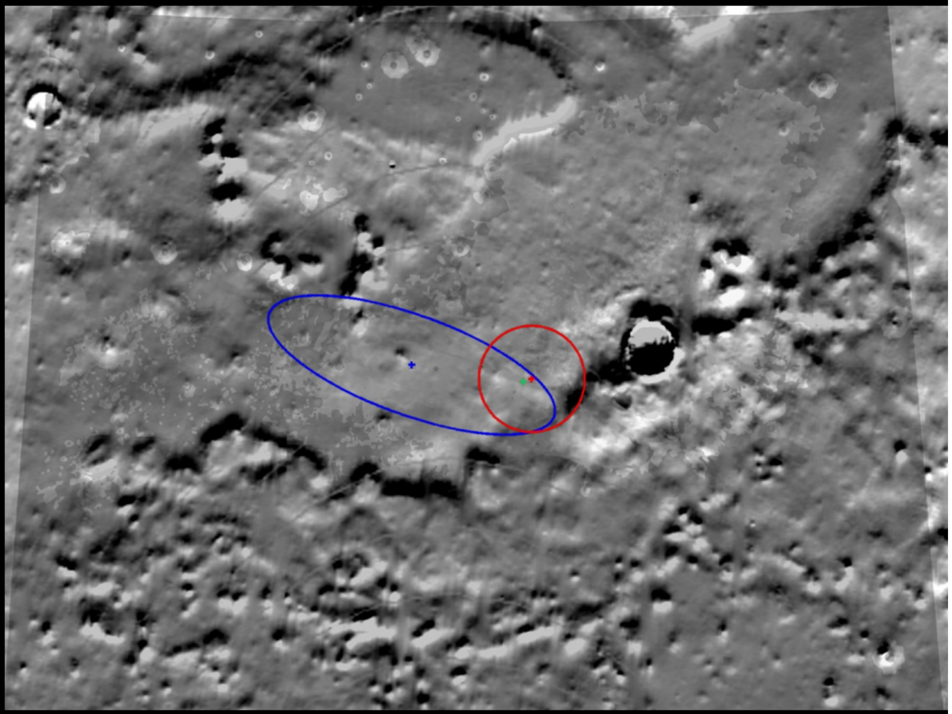








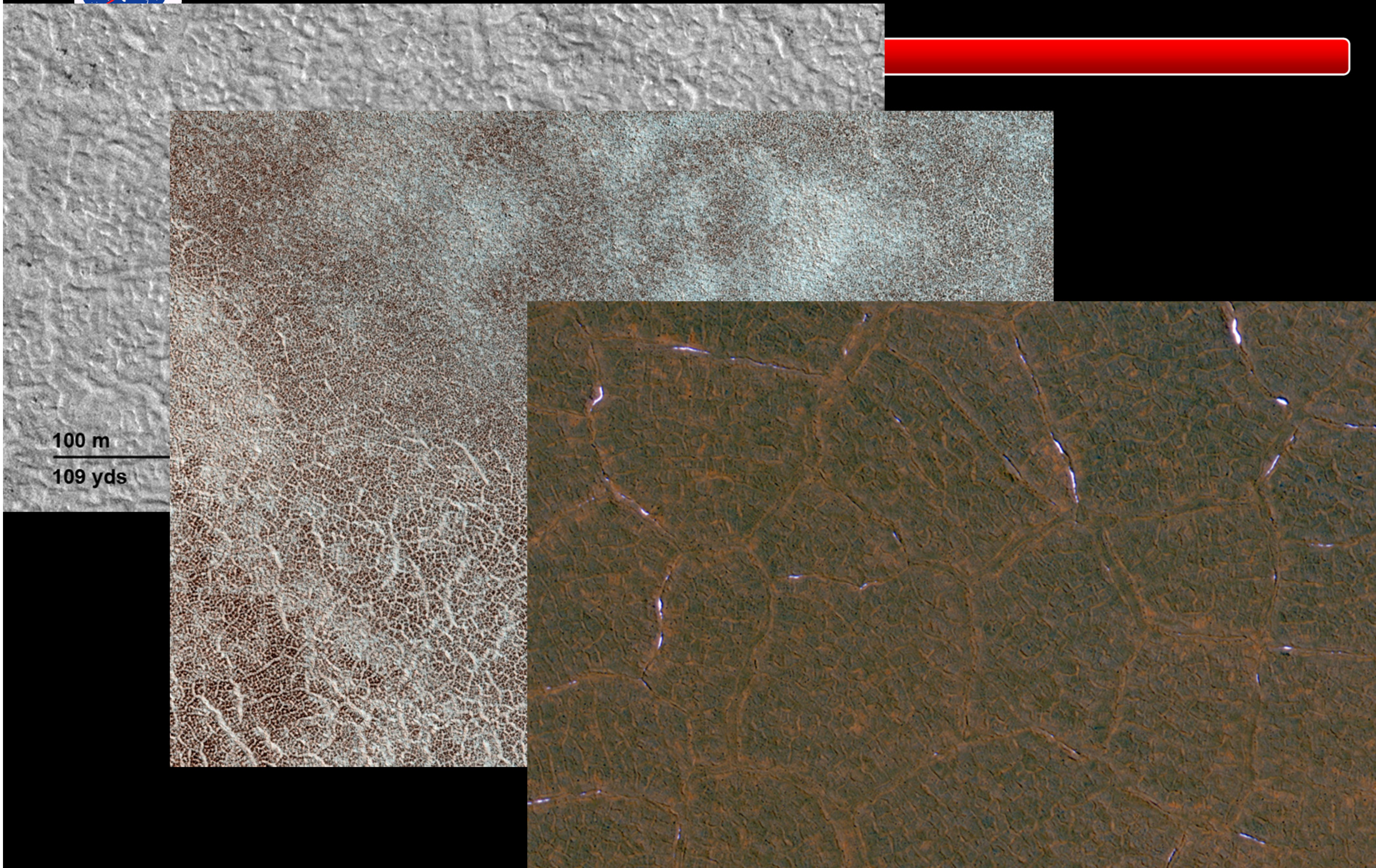
Launch and Landing



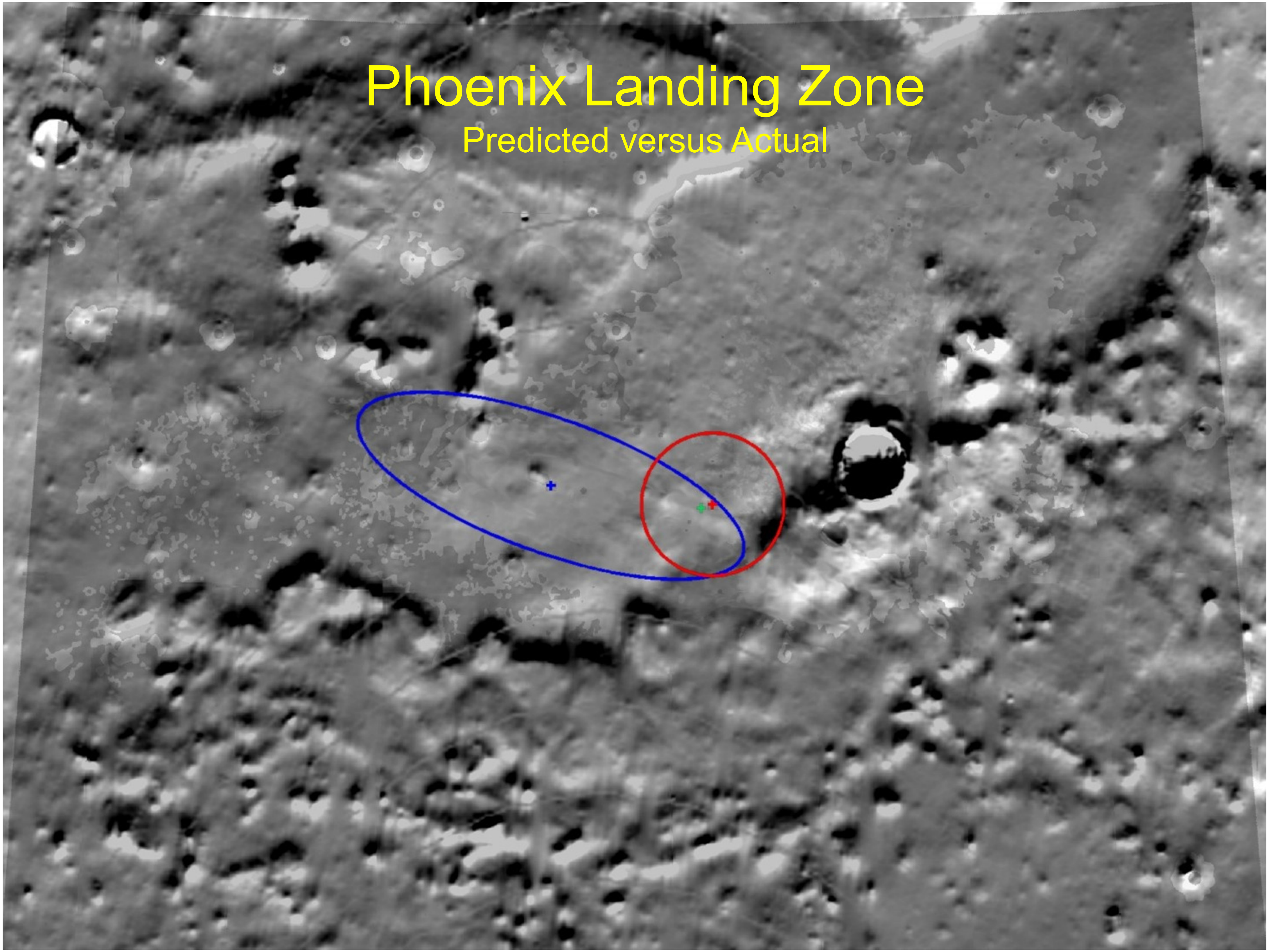
Launched Delta-2 rocket from Cape Canaveral on August 4, 2007 at 5:26 am ET.

Landing Zone on May 25, 2008 – predicted versus actual.

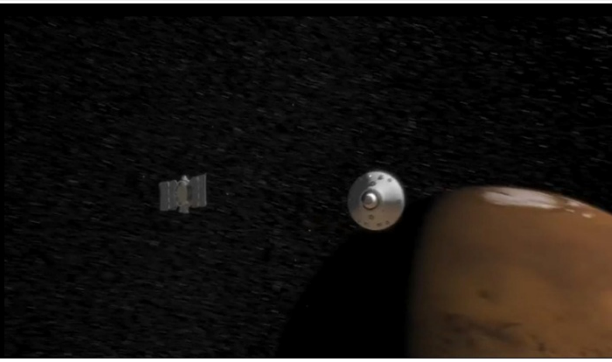
HiRISE views of landing

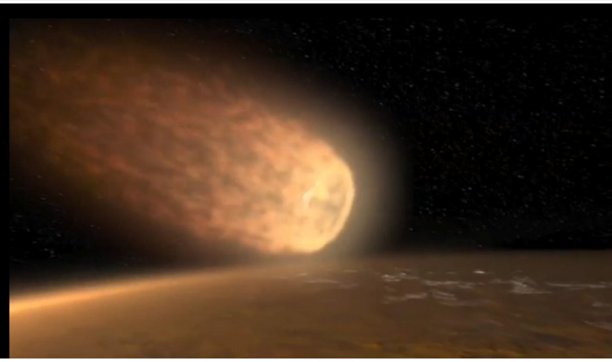


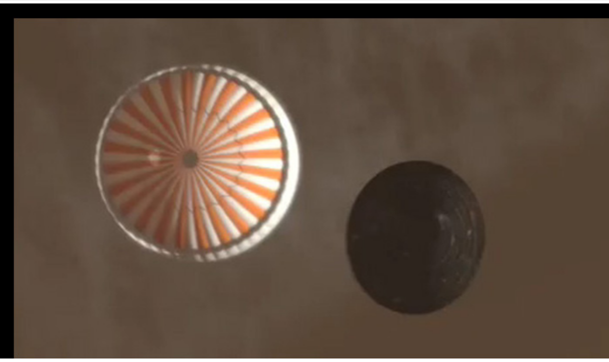
Landing ellipse size compared


Phoenix Landing Zone
Predicted versus Actual

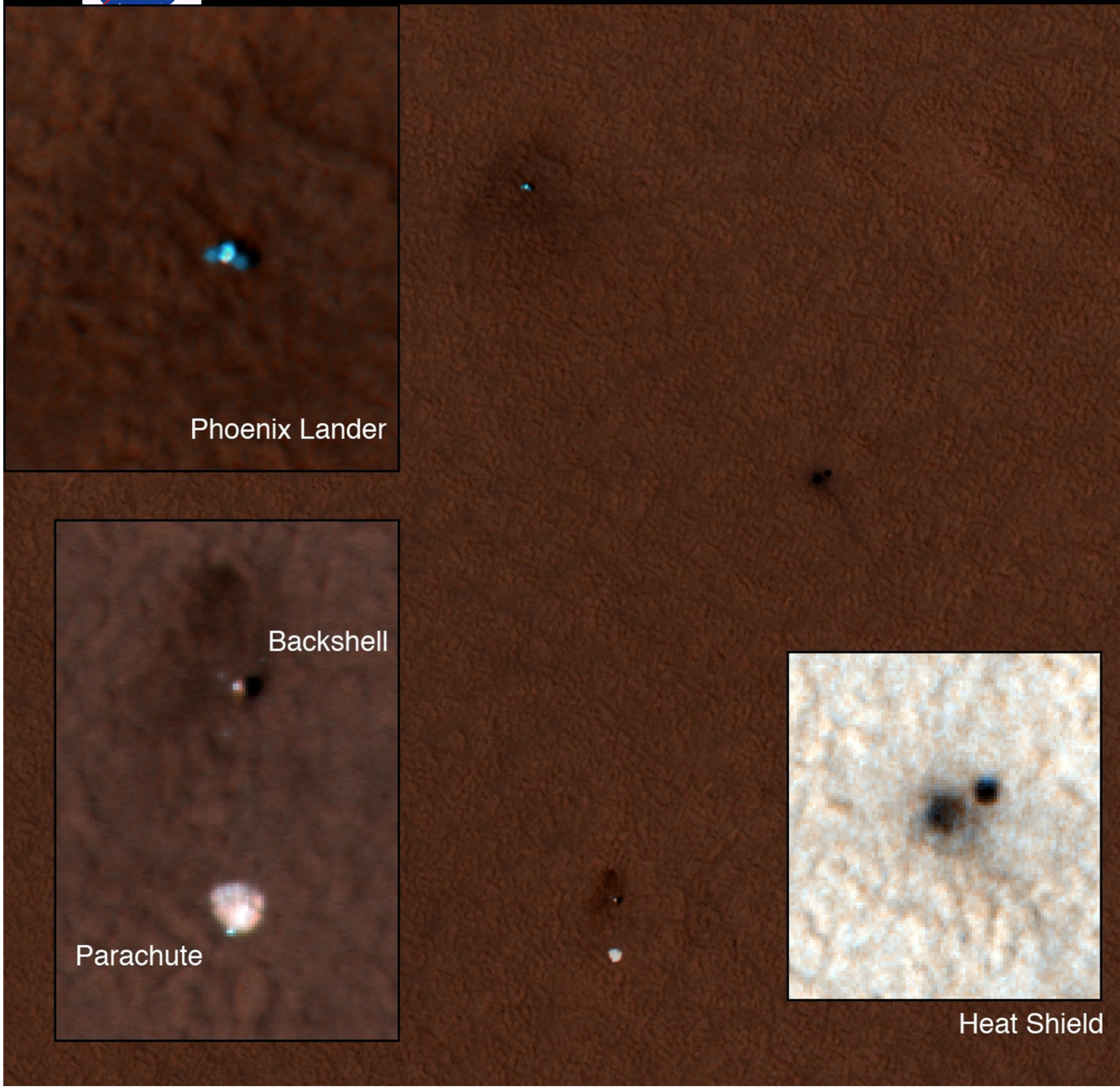
Orbital View of Phoenix's Descent



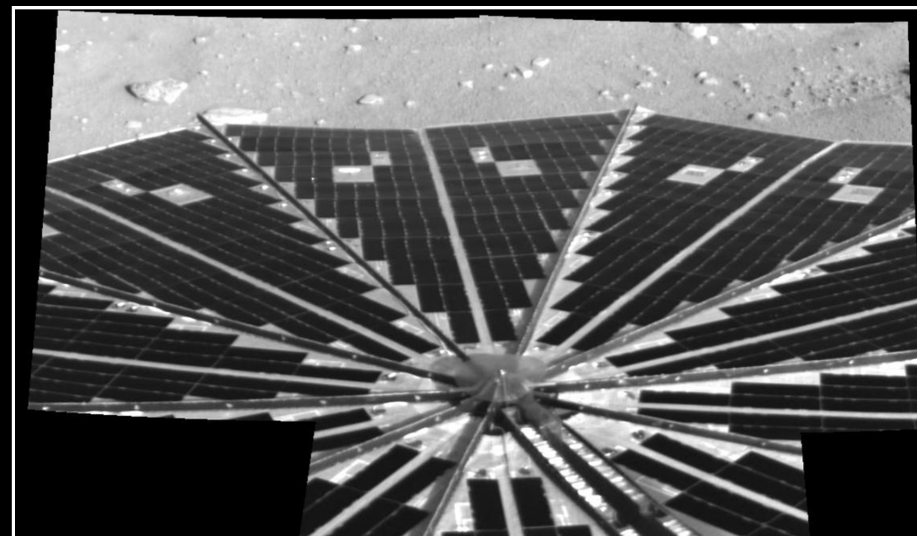


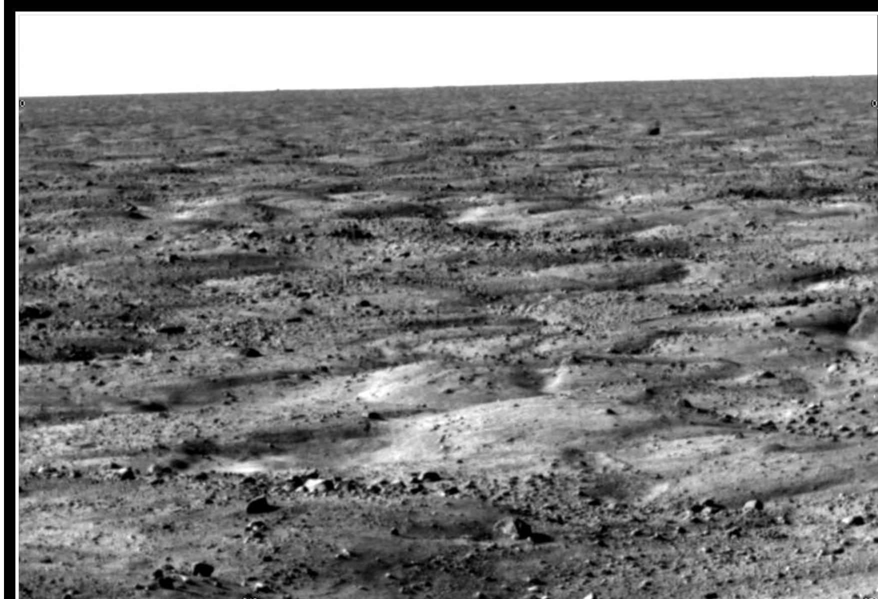


Orbital View of Phoenix Landing Site

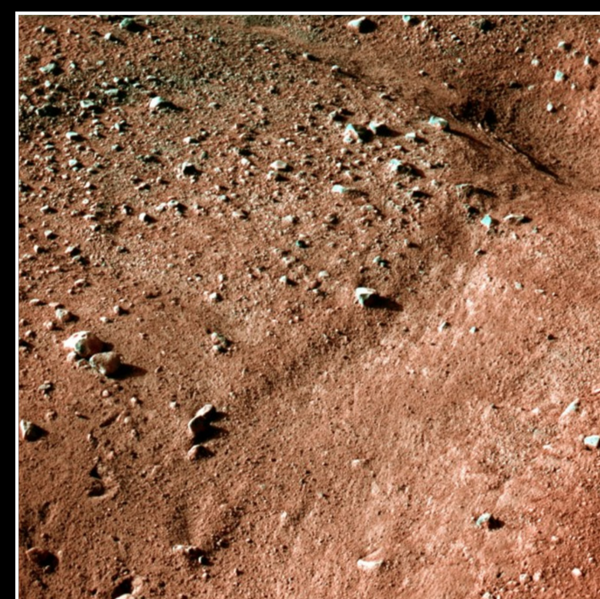


First Images From Phoenix

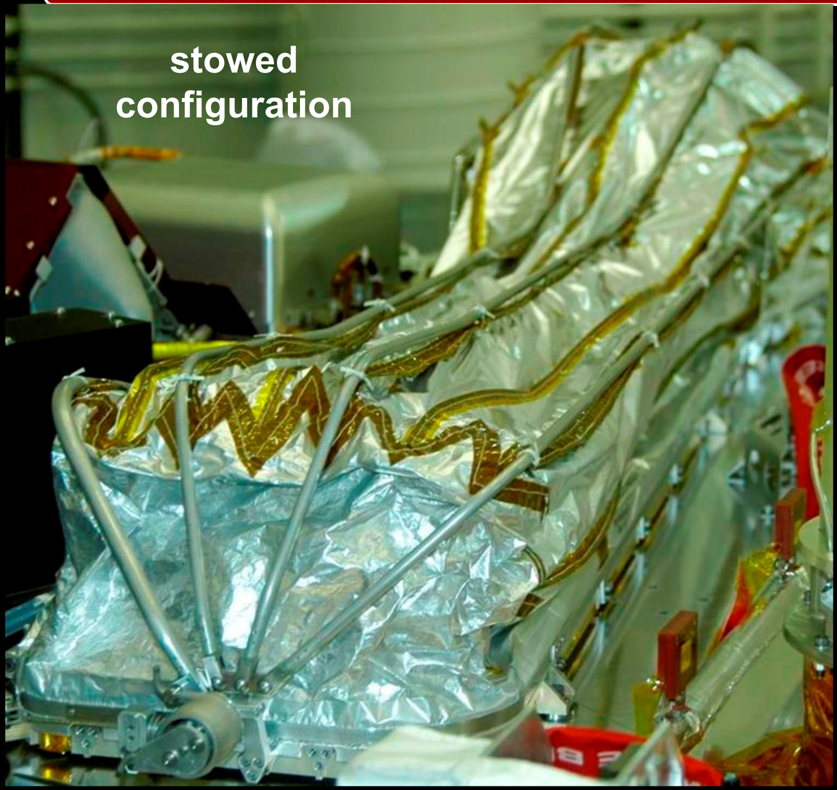




Polygonal Terrain as expected – a level landing is a pleasant surprise. **Polygonal terrain indicates cooling and heating cycles**

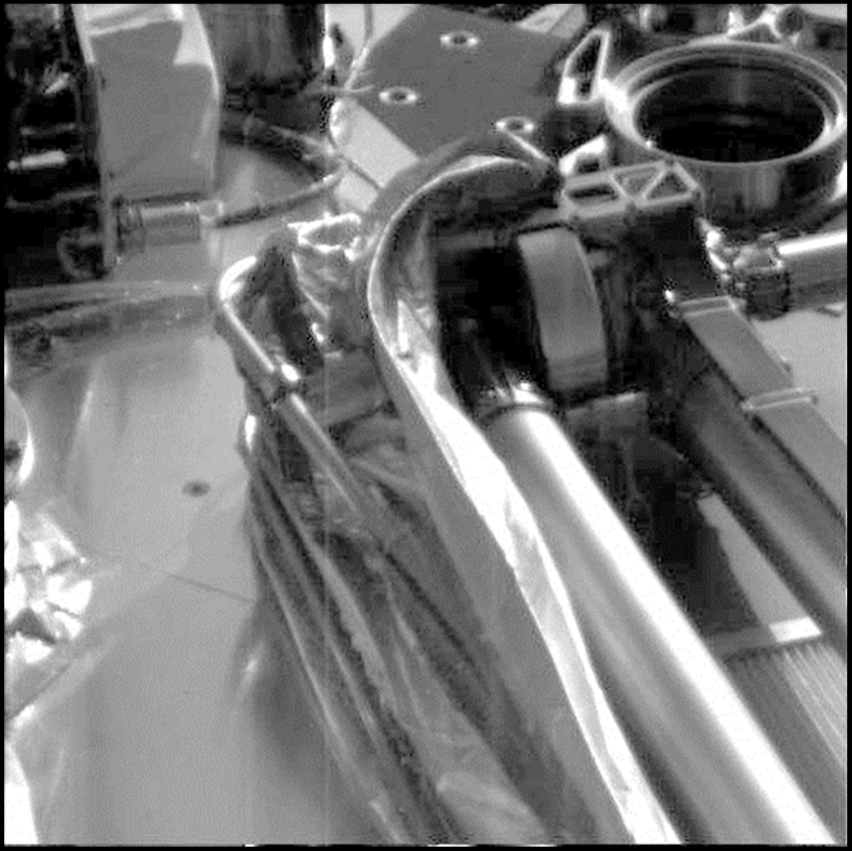


Sol 0 - Deploying the Bio-barrier

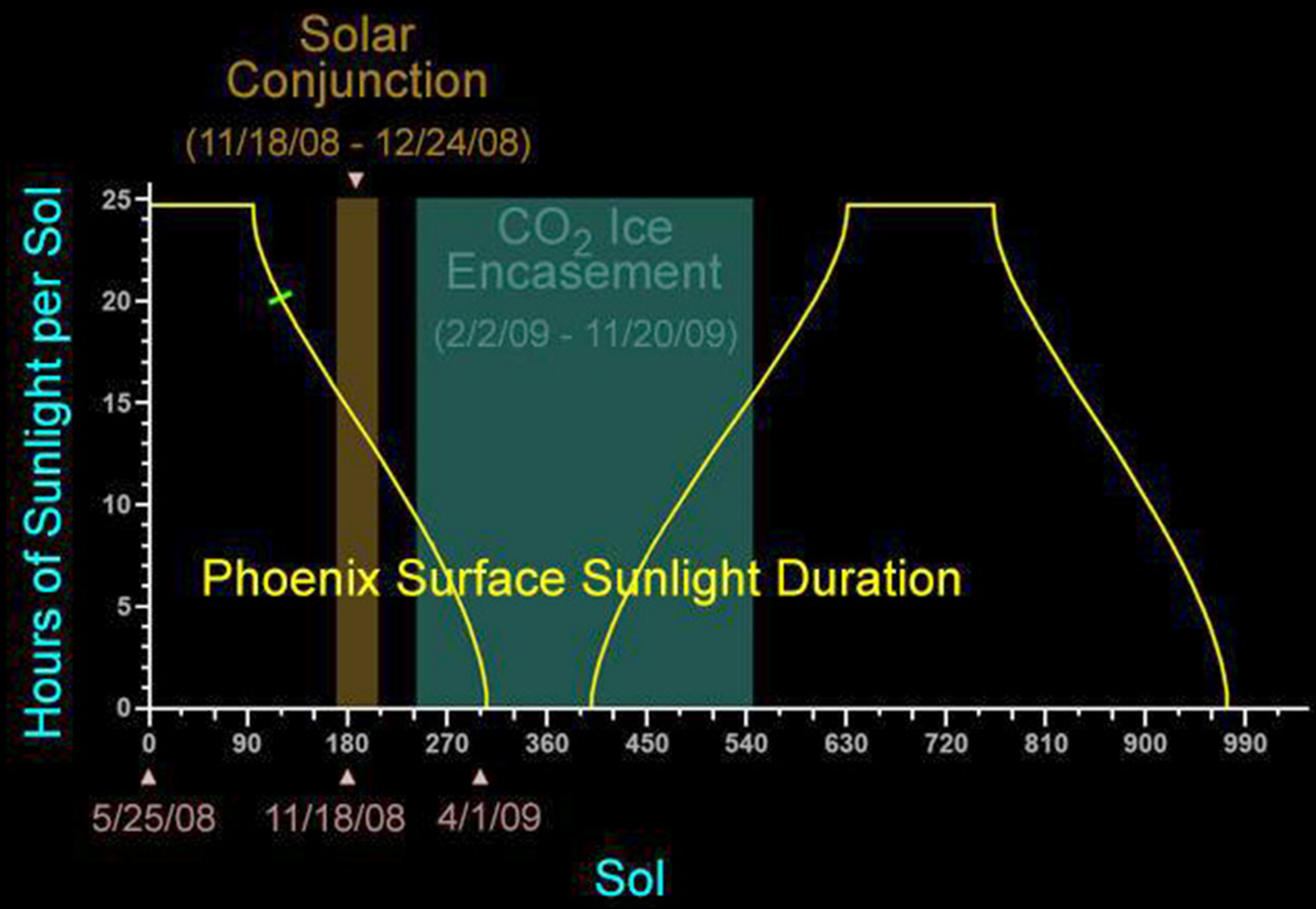


Bio-barrier encased arm to keep it sterile so as to not contaminate the sub-surface with microbes brought from Earth

Bio-barrier deployed, but some material draped over RA elbow

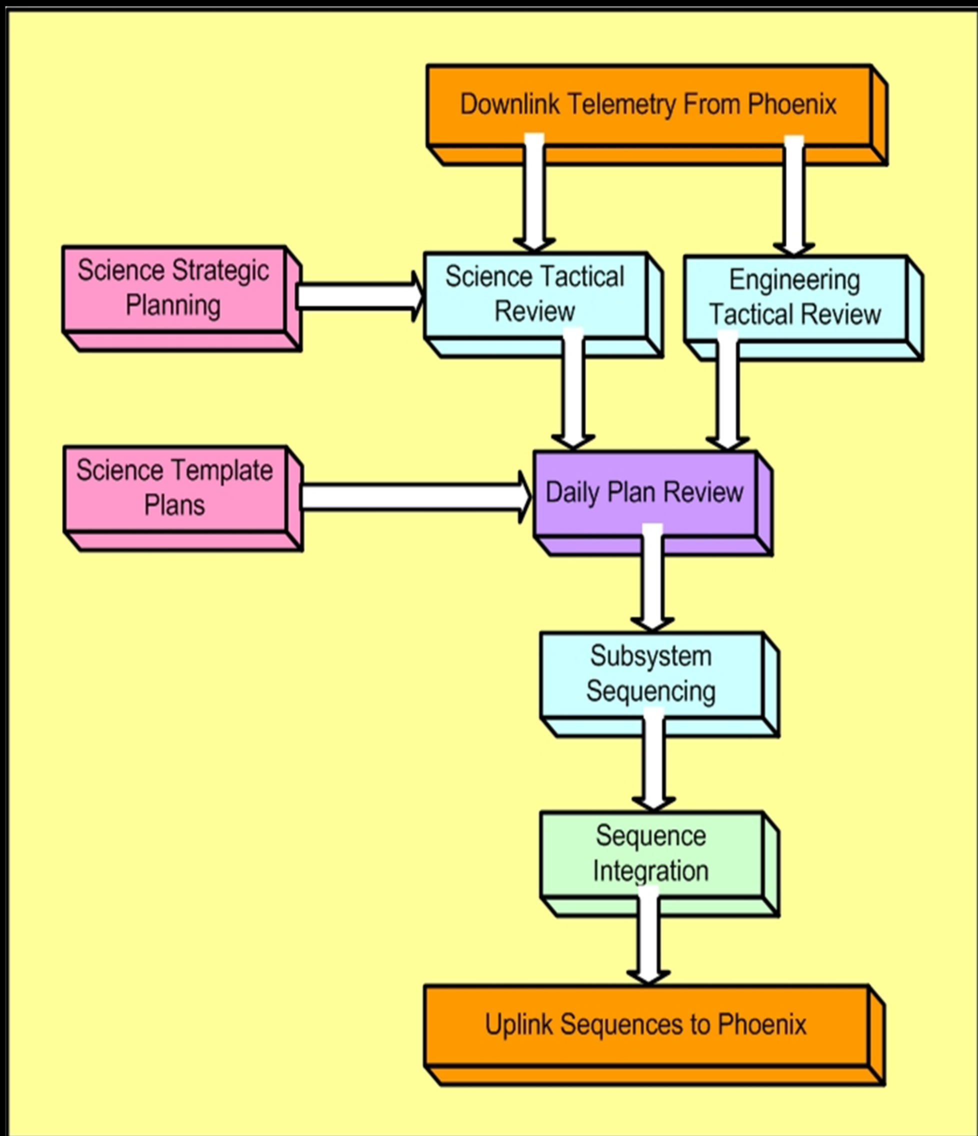


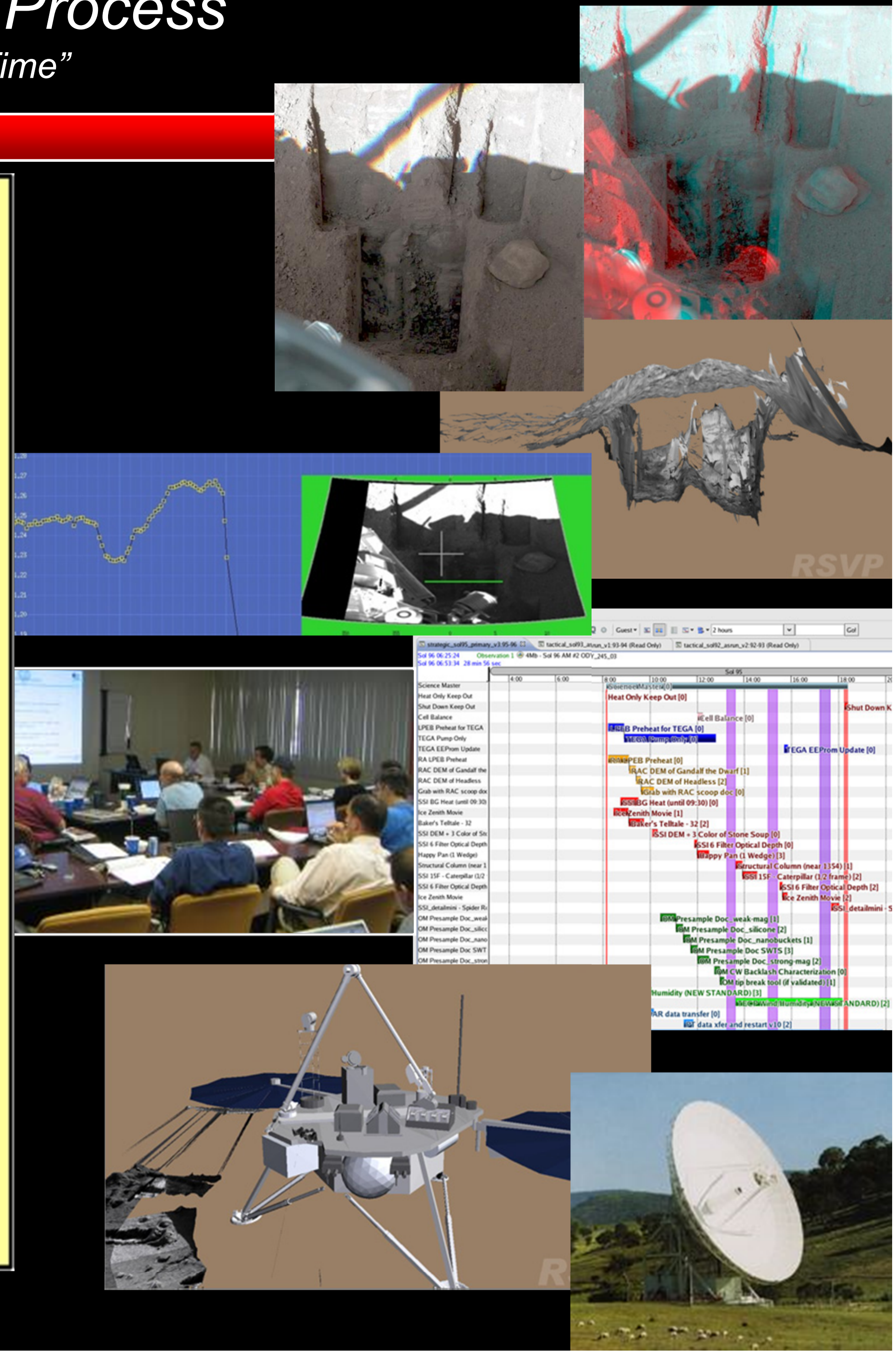
Phoenix mission Surface Sunlight Profile



Phoenix Operations Process

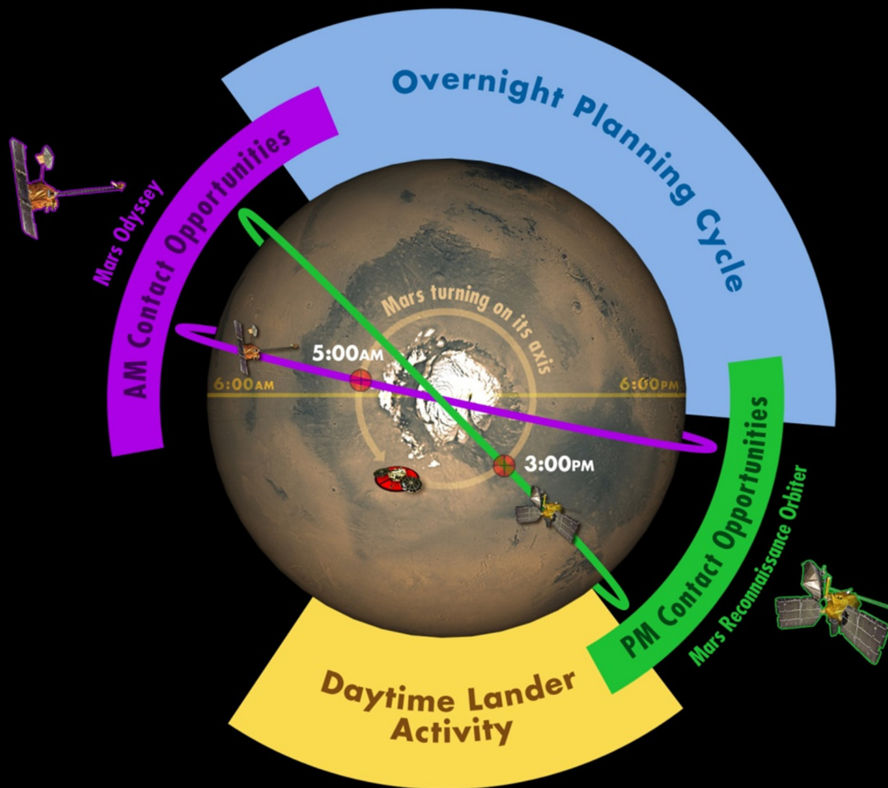
"14 hour shifts on Mars Time"



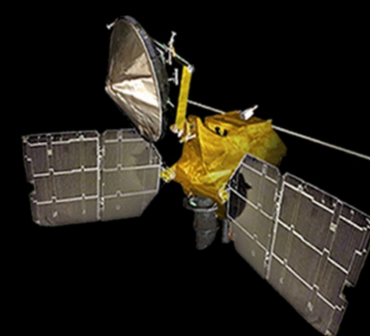


Communication strategy

Mars Odyssey
Orbiter



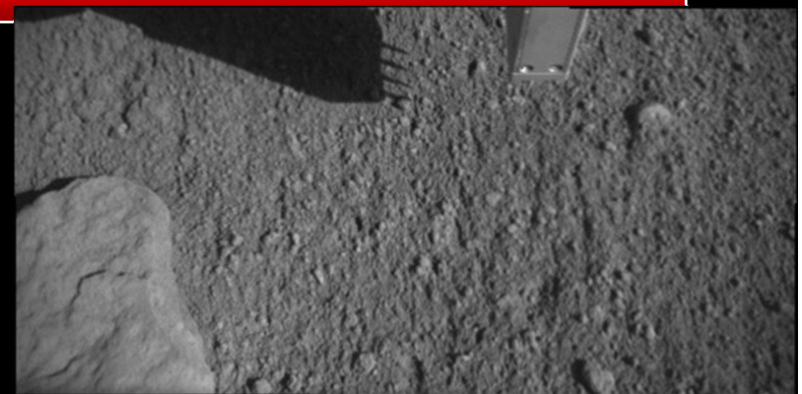
Mars Reconnaissance
Orbiter



Phoenix Operations Challenges

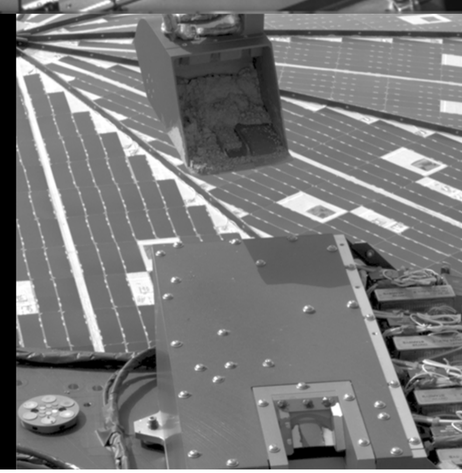
Terrain Interaction

- unknown soil characteristic and ice depth
- kinematic limitations and resolution
- stereo imaging range resolution (SSI, RAC)
- lighting, viewing geometry, resolution, etc.
- target specification by scientists



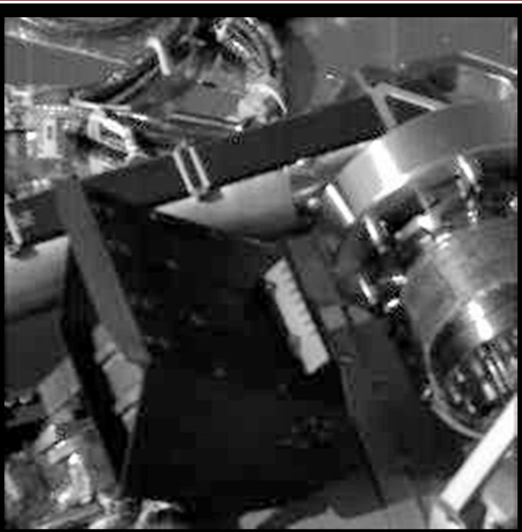
Sample Delivery

- acquisition confirmation
- prevention of cross contamination
- sample quantity and rate (dump v. sprinkle)
- de-lumping
- shadowing for viewing and melt prevention
- protection of optics (RAC, lidar)
- avoiding self collisions
- anomalies (TEGA doors)
- wind

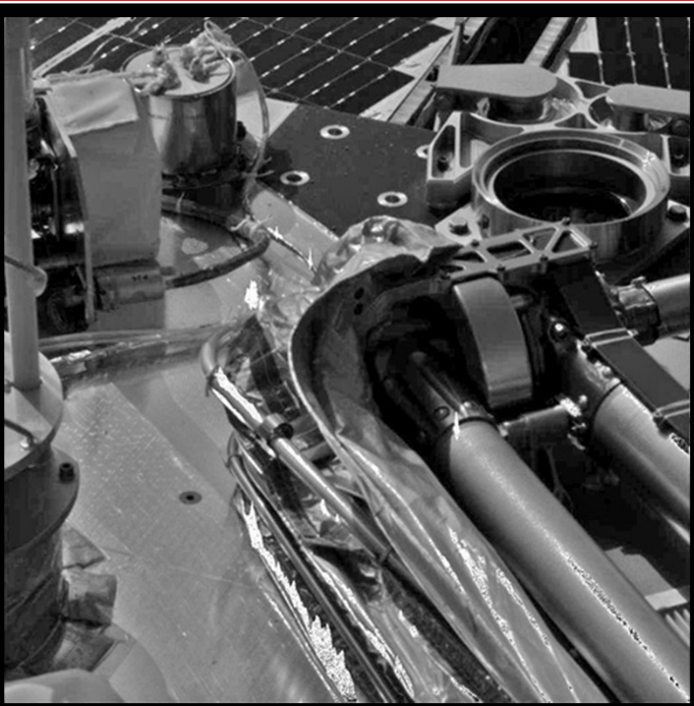


All this with limited life!

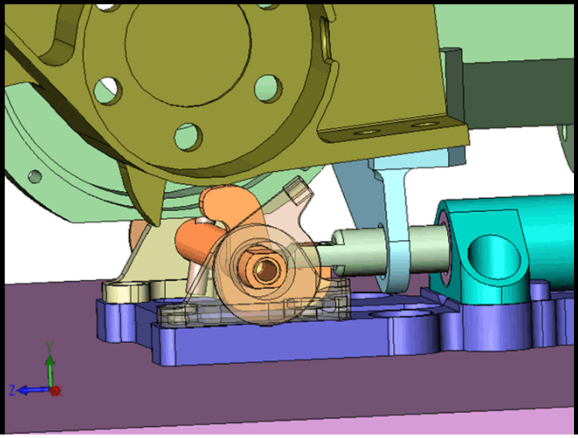
Sol 3 - Unstowing the Arm



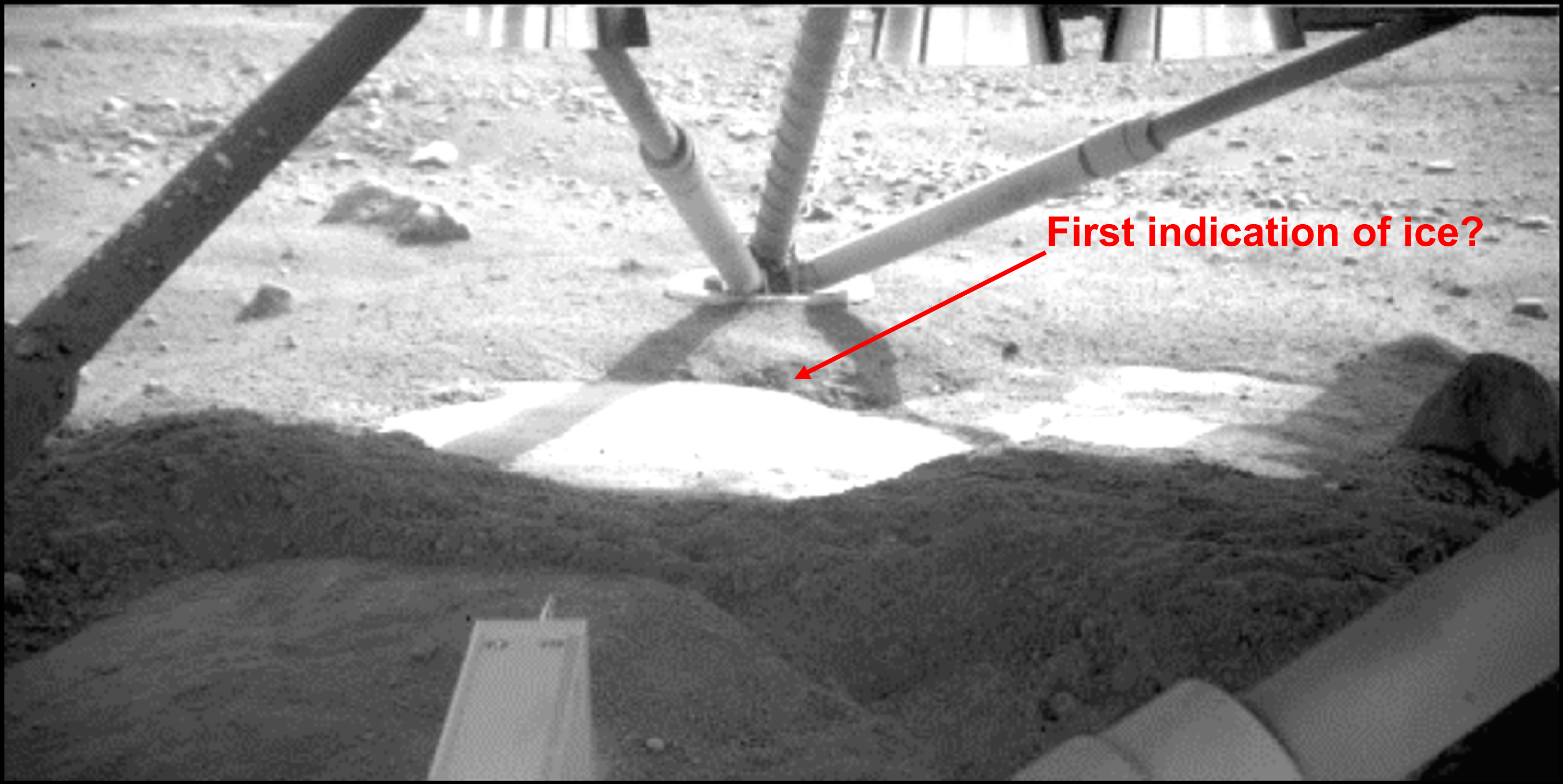
Using the wrist joint to release a pin that restrained the forearm during launch and landing



Releasing the elbow by moving the upper arm off of its restraint pin



Early Sol Checkout and Characterization

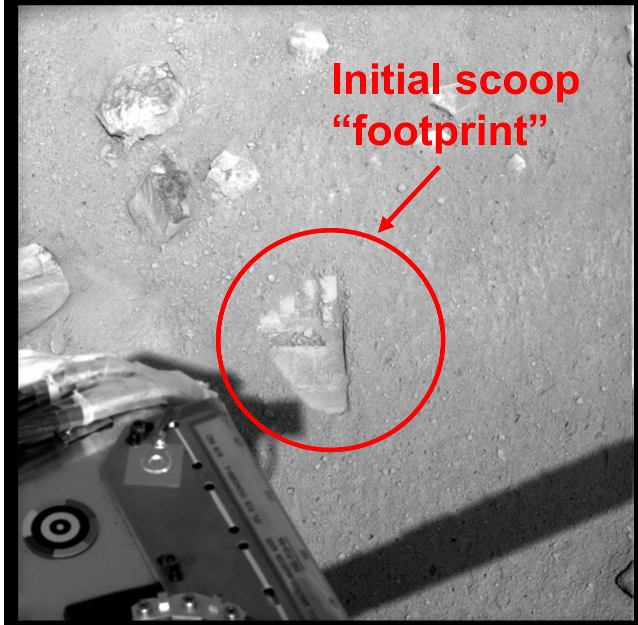


Holy Cow!

Sol 5 - RAC Image used to access lander stability prior to digging

Thrusters apparently cleared off loose regolith during landing, revealing ice layer beneath

Early Sol Checkout and Characterization

King of Hearts	Knave of Hearts	Dodo
		

Sol 6

Move scoop to contact surface to access goodness of stereo maps

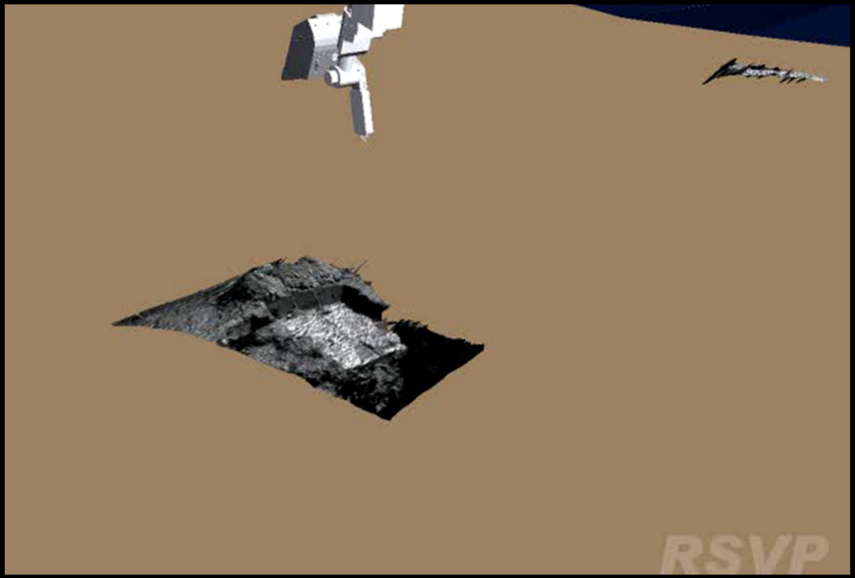
Sol 7

1st practice scoop and dump

Sol 9

2nd practice scoop and dump

Phoenix Movies

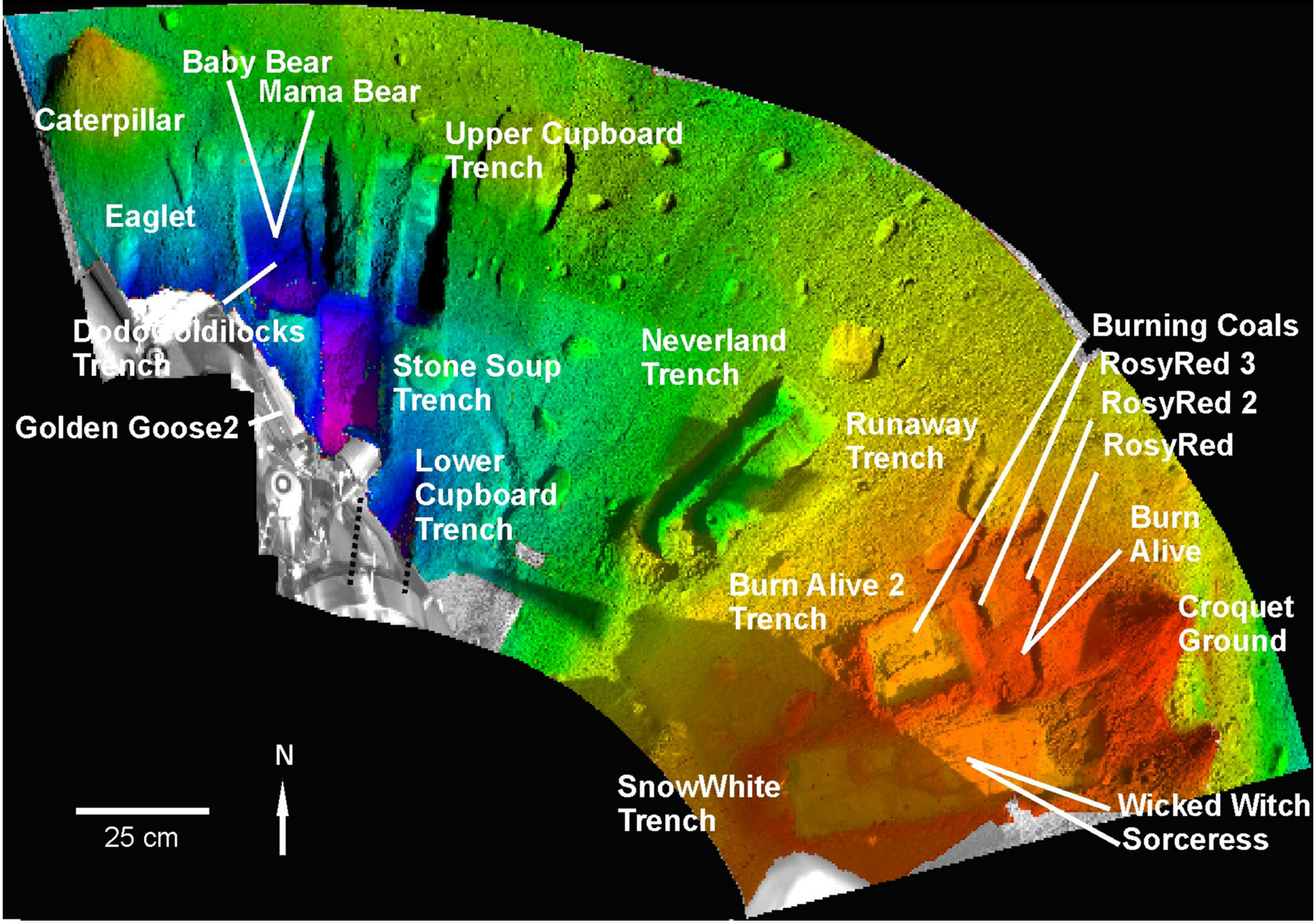


RSVP Simulation of sol 32 Dig

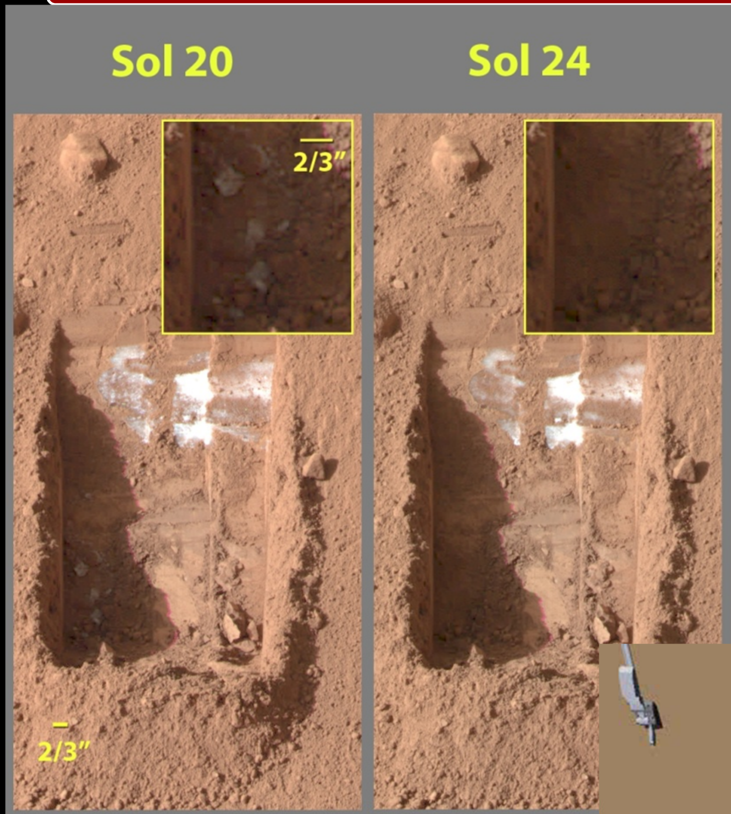
Payload integration testbed (PIT)

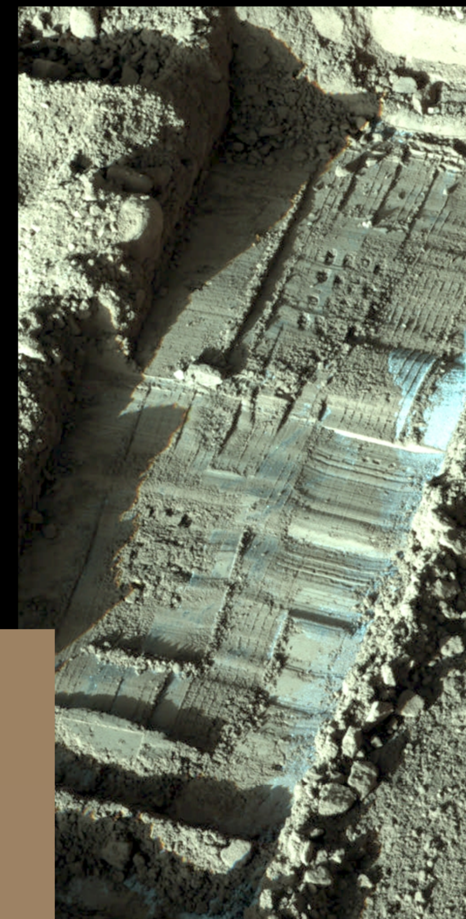
The Phoenix Mission is led by Principal Investigator Peter H. Smith of The University of Arizona, supported by a science team of CO-Is, with project management at NASA's Jet Propulsion Laboratory and development partnership with Lockheed Martin Space Systems. International contributions for Phoenix are provided by the Canadian Space Agency, the University of Neuchatel (Switzerland), the University of Copenhagen, and the Max Planck Institute in

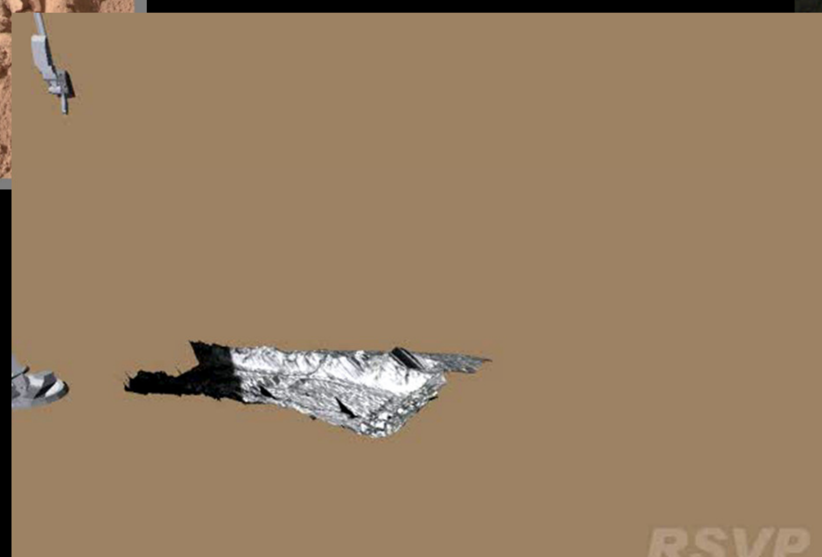
Phoenix Dig Summary



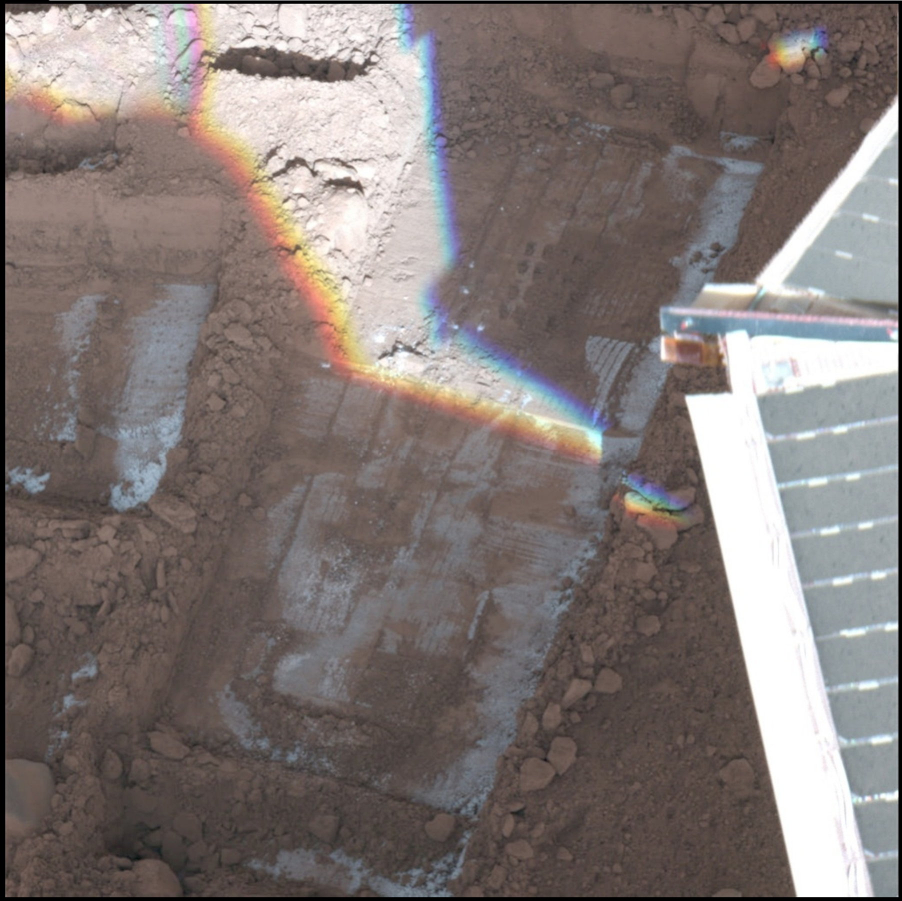
Exposing Water Ice By Trenching/Scraping

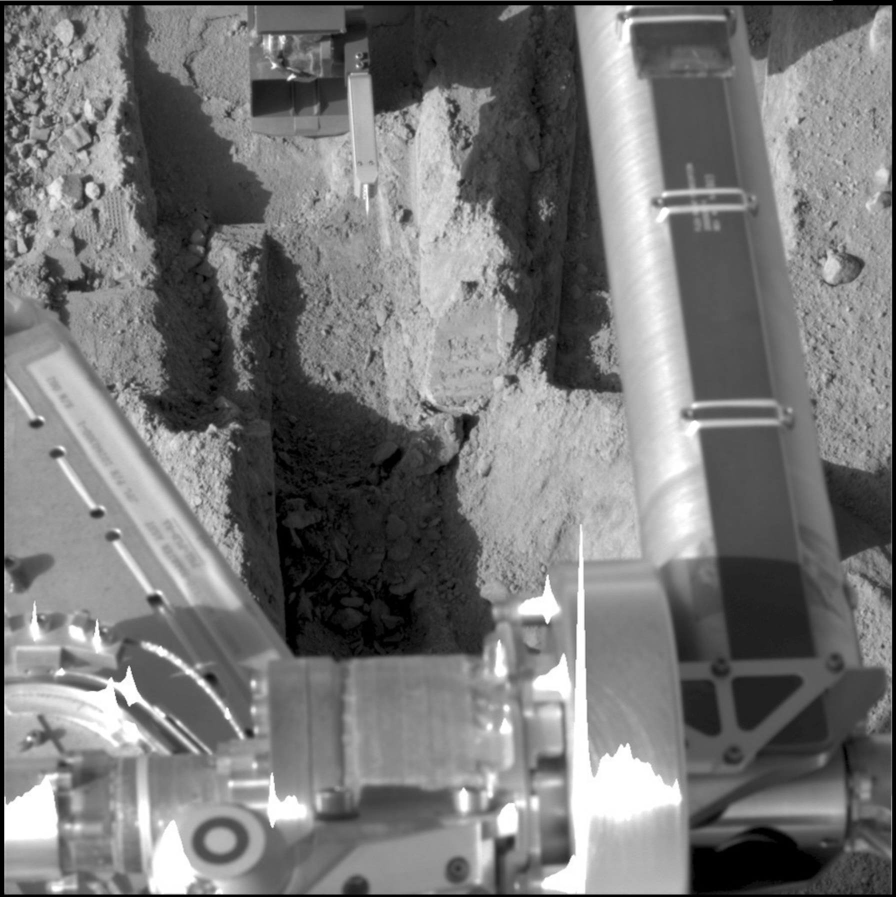






Exposing Water Ice By Trenching





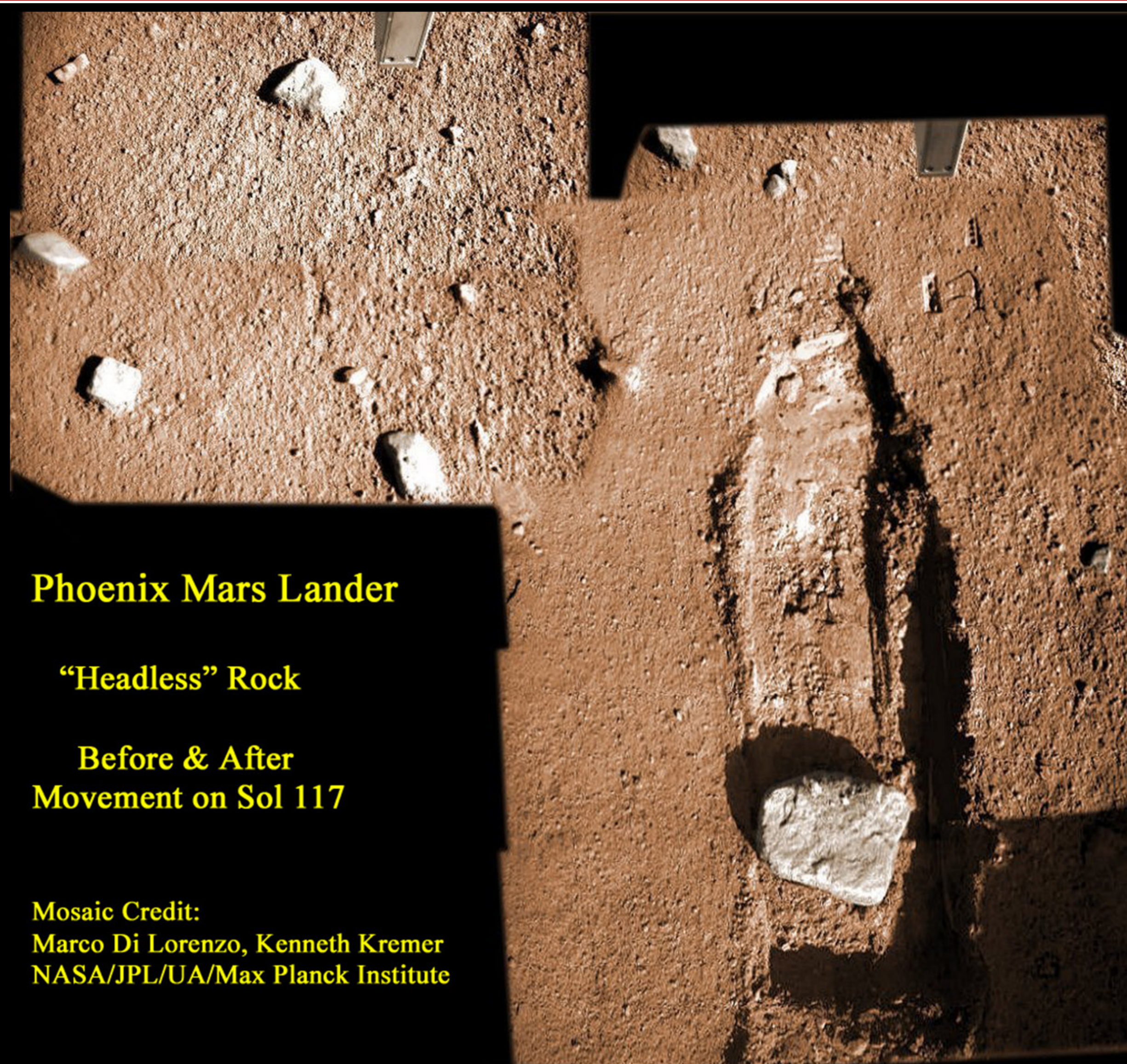
Snow White trench on sol 141 with frost accumulation

Hard layer encountered from 2 to 7 cm deep

Rasp holes are visible in the upper portion

- Digging algorithm accommodates to surface once joint torques exceed preset thresholds.
- At higher thresholds, arm stops, backs out and tries again a few times.
- Right-side of the tip of the RA scoop encountering a hard spot during digging a trench on sol 140

Rock Sliding



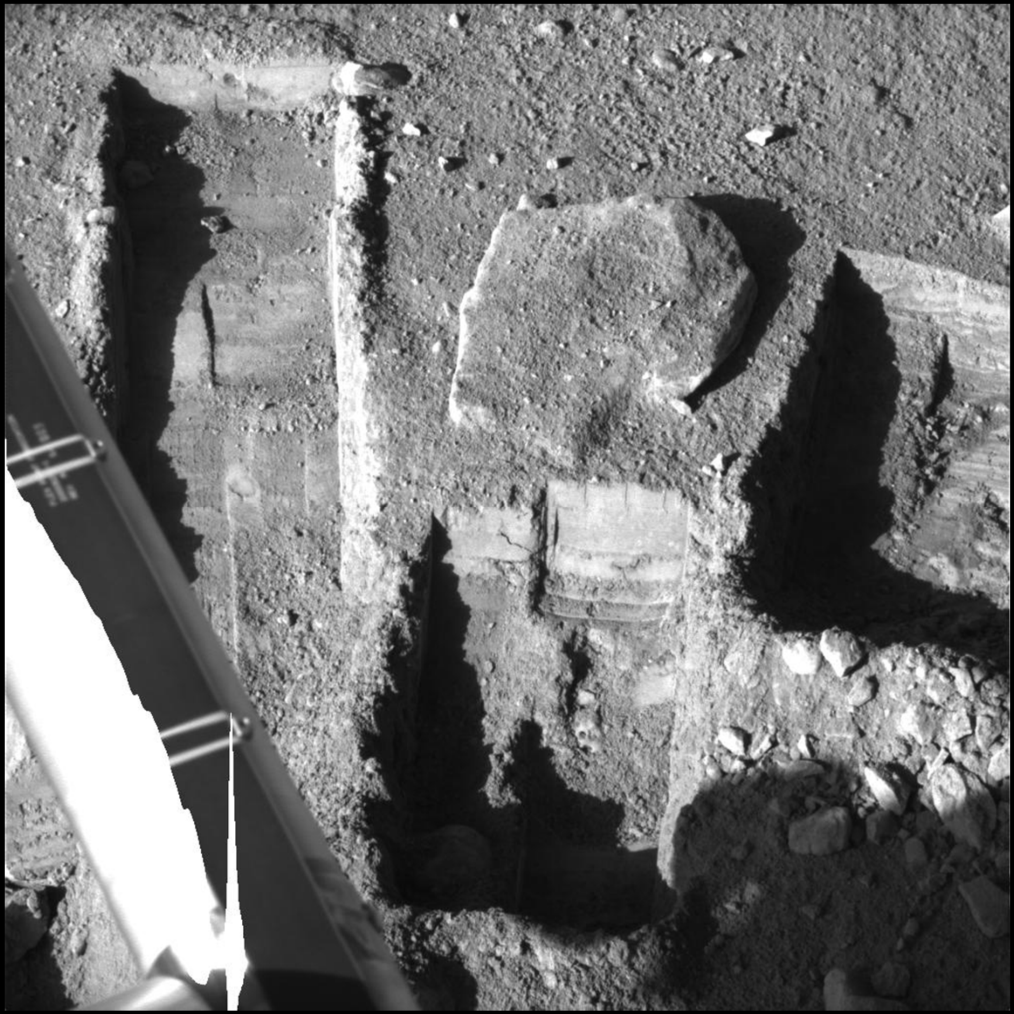
Phoenix Mars Lander

"Headless" Rock

Before & After
Movement on Sol 117

Mosaic Credit:
Marco Di Lorenzo, Kenneth Kremer
NASA/JPL/UA/Max Planck Institute

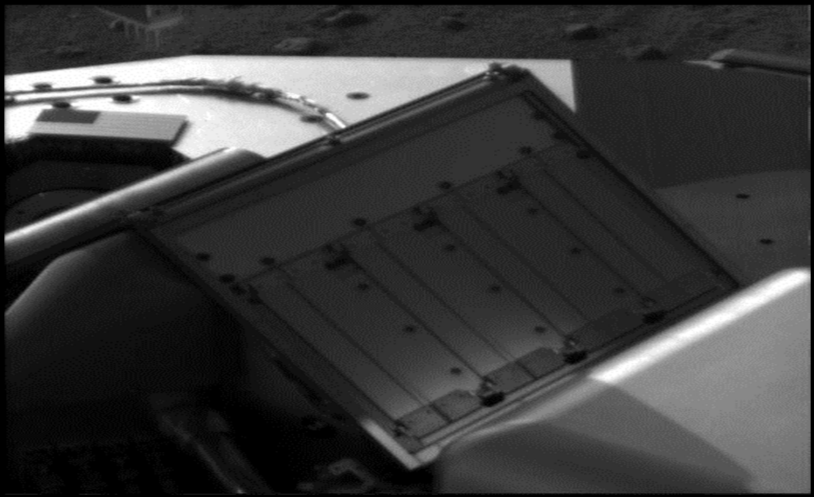
Rock Sliding

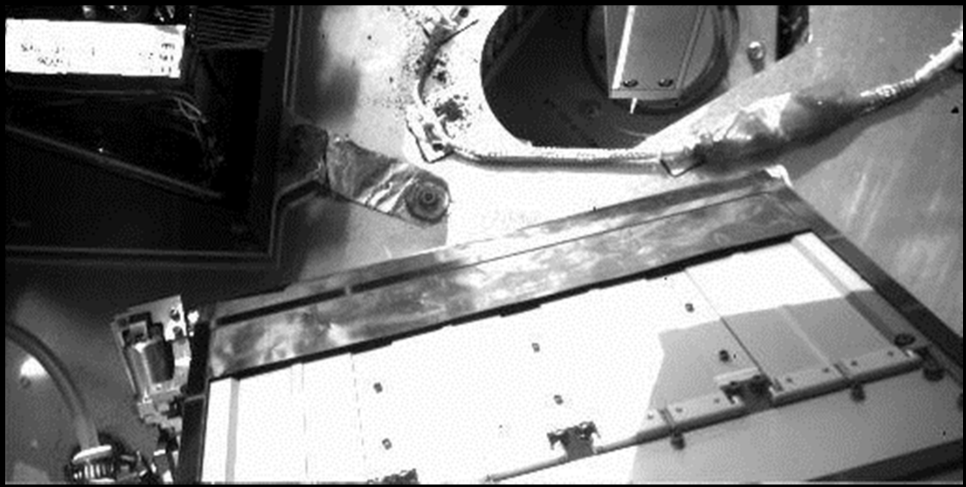


So Many Mouths to Feed

- Deliveries
  - Thermal Evolved Gas-Analyzer (TEGA)
  - Wet Chemistry Lab (WCL)
  - Optical Microscope (OM)
- Attached to the Arm
  - Thermal and Electrical Conductivity Probe (TECP)
  - Robotic Arm Camera (RAC)

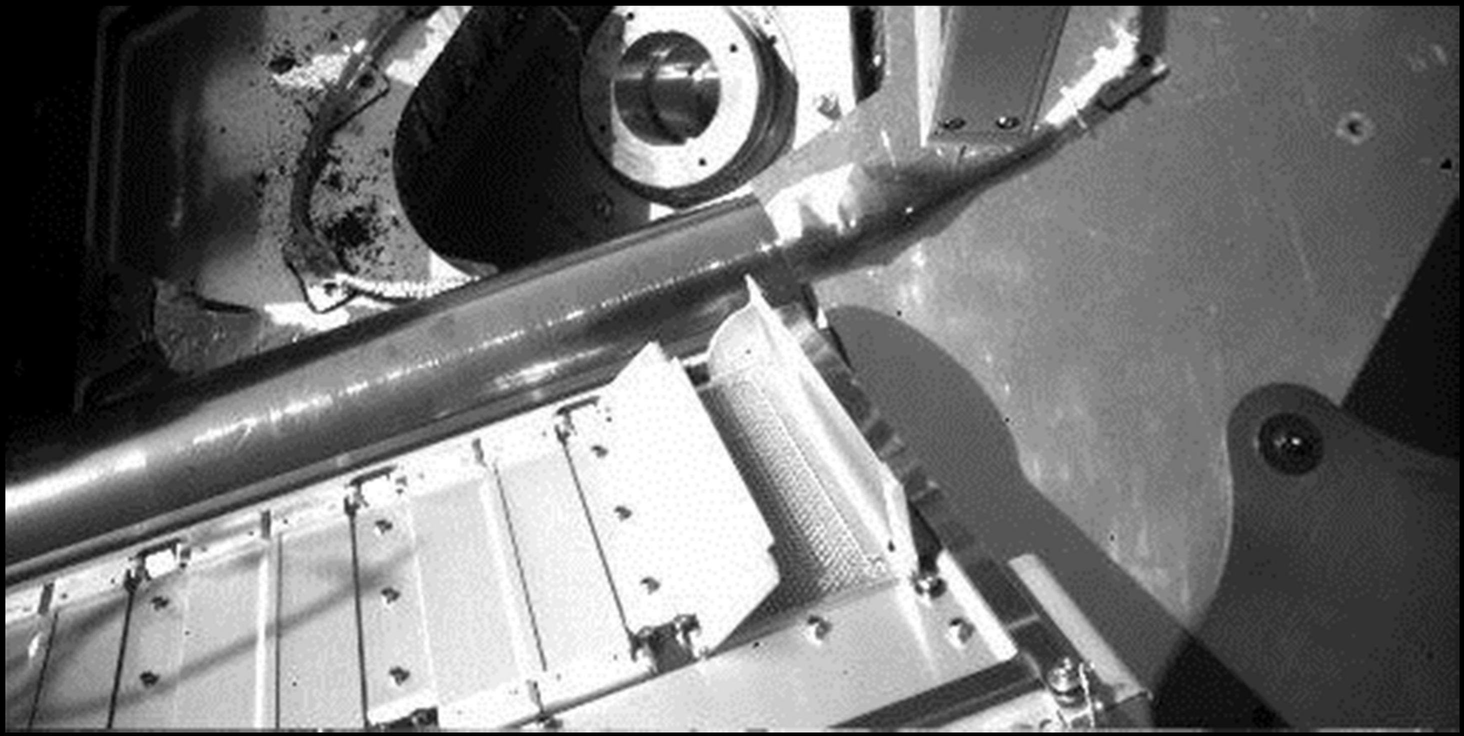
Thermal Evolved-Gas Analyzer (TEGA)
Sniffing the Ice





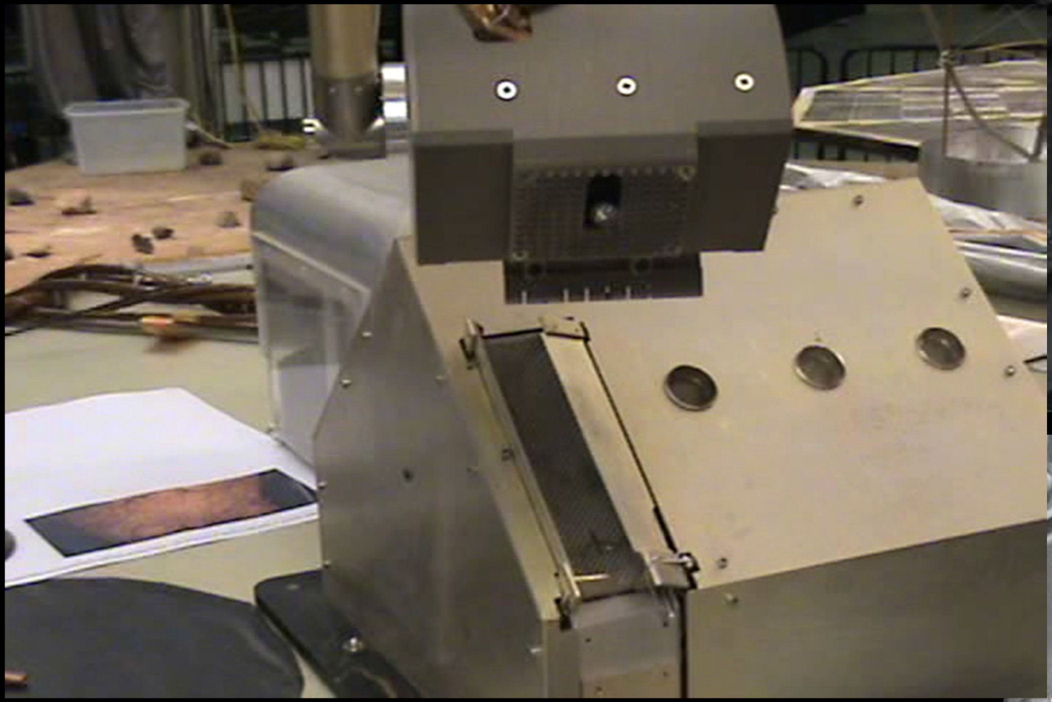
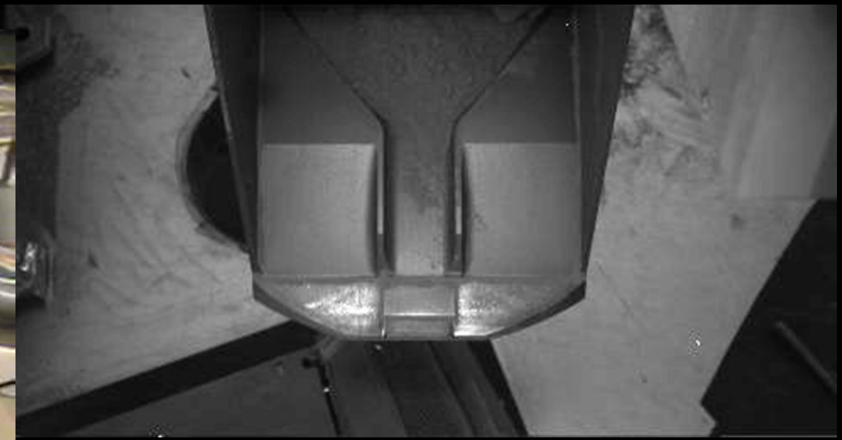
Sample Delivery Begins

Sol 8 RAC Image



The door is only partially open.

Delivery Testing in the PIT

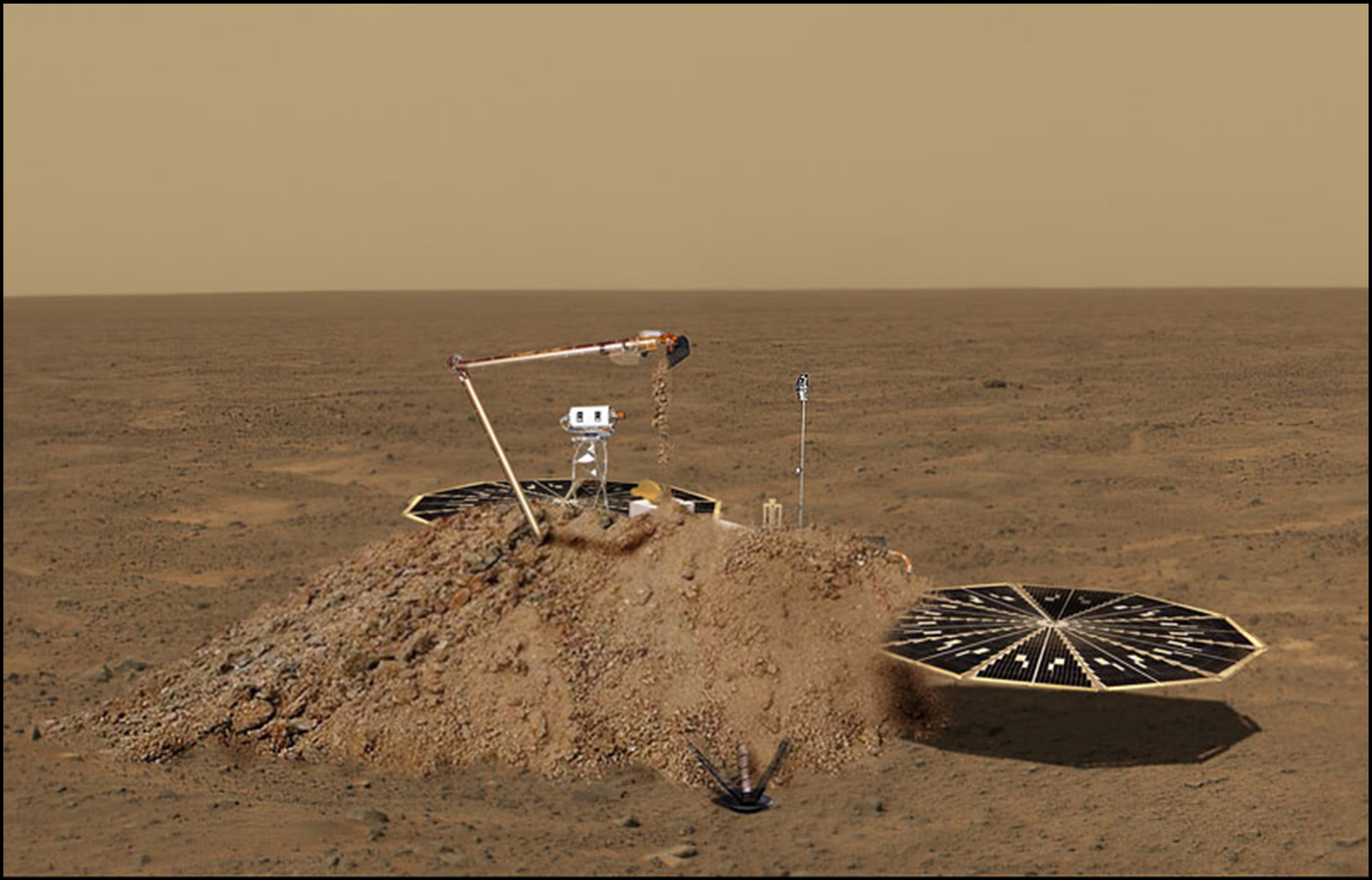

Sol 11 Sample Acquisition . . .

Sample "Baby Bear"

RAC image of
Sample in Scoop

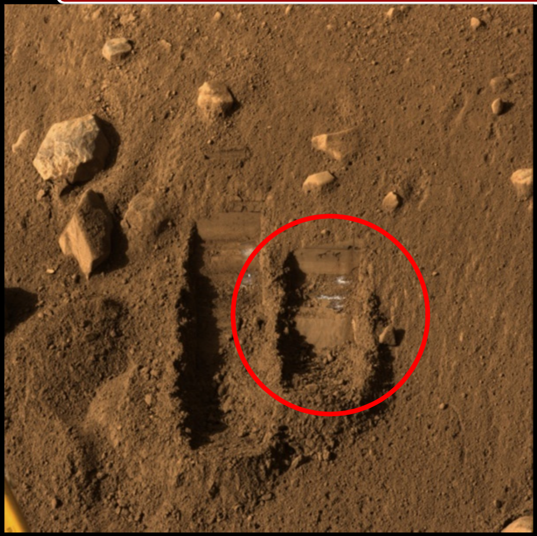
And Delivery to Tega Cell 4 on Sol 12

You may have heard we had a little trouble with our sample deliveries…



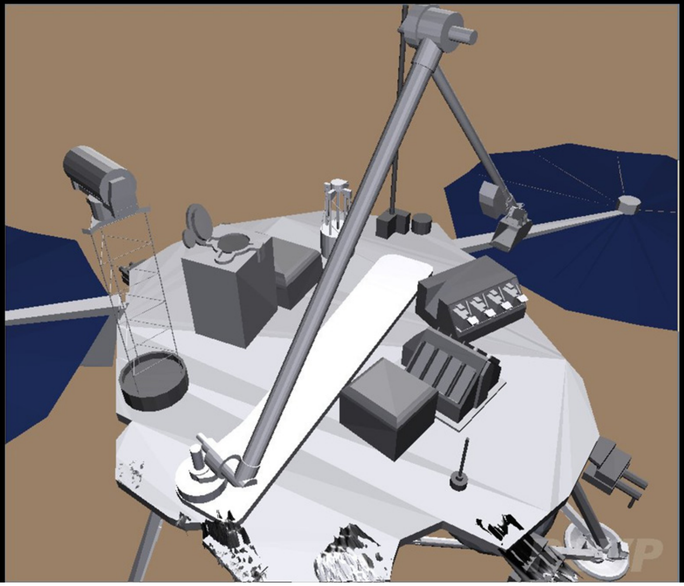
Phoenix attempts another sample delivery!

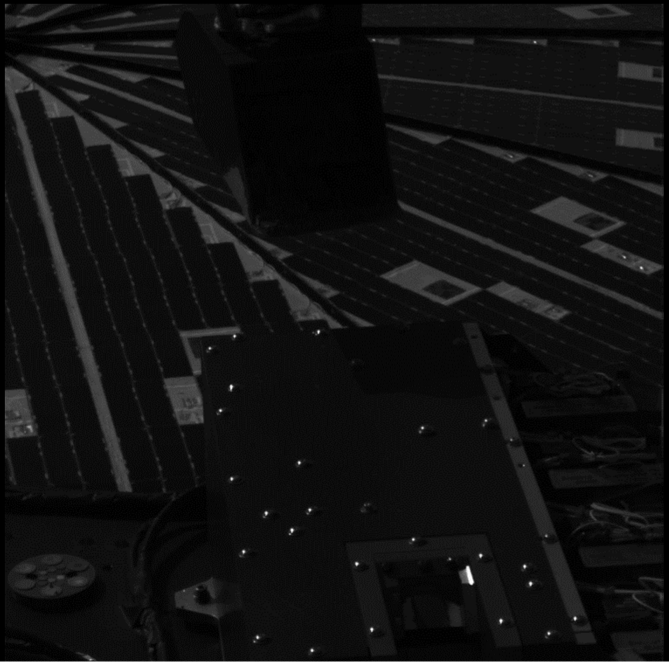
Practice Sample Delivery Sols 14 - 15



Sol 14: Acquire Sample
Mama Bear

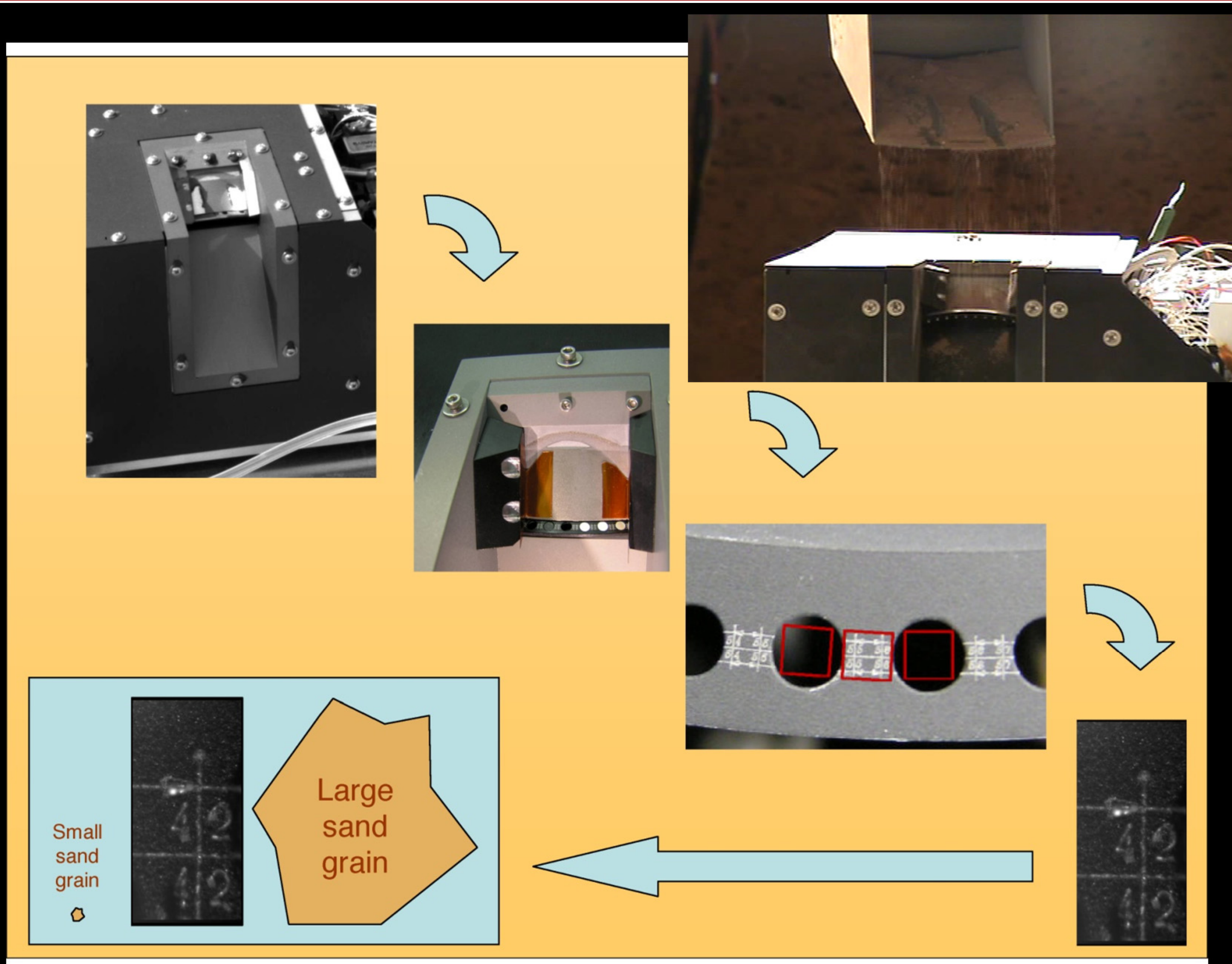
Sol 15: Practice sprinkling on MECA box





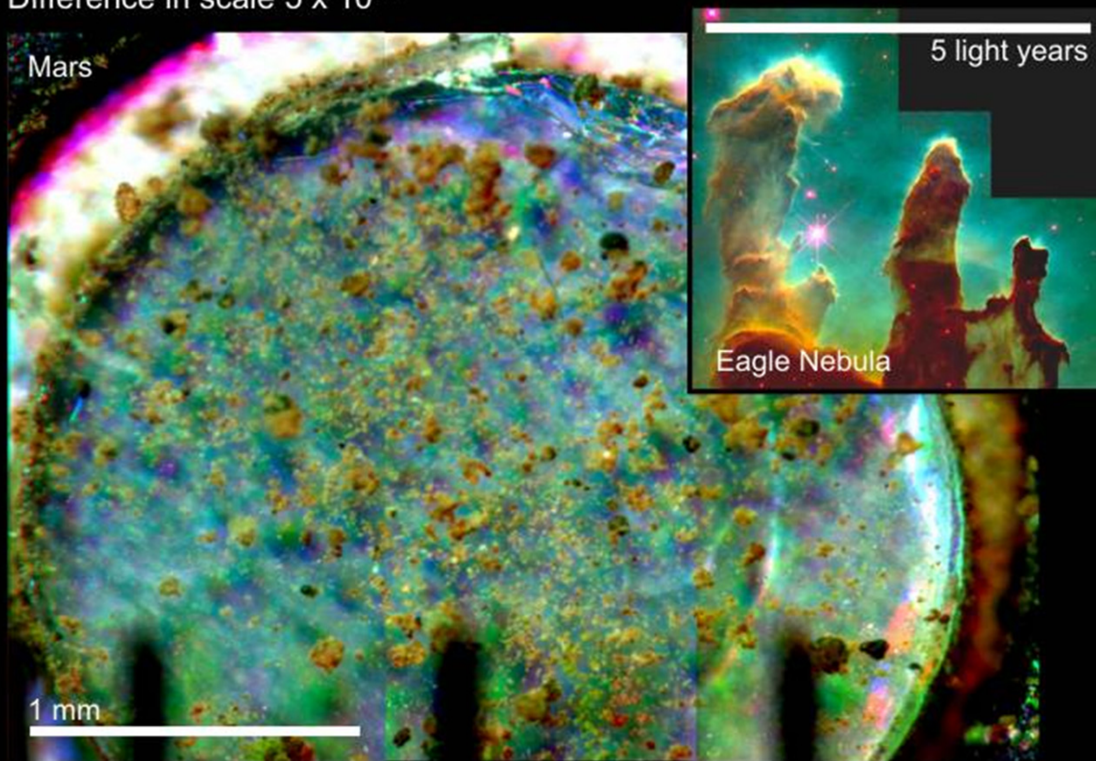
Sol 17 - Remaining Sample Delivered to MECA OM

Optical Microscope (OM)/Atomic Force Microscope

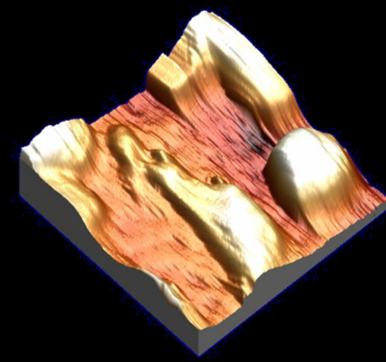


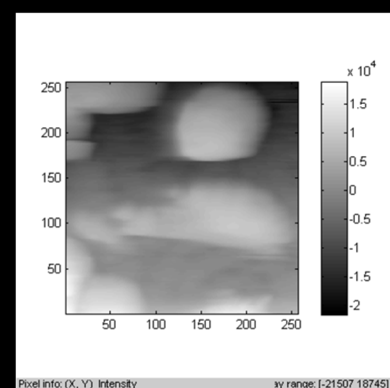
From the small dust on Mars to dust clouds in interstellar space

Phoenix and Hubble: two views of dust in our Universe
Difference in scale 5×10^{16}



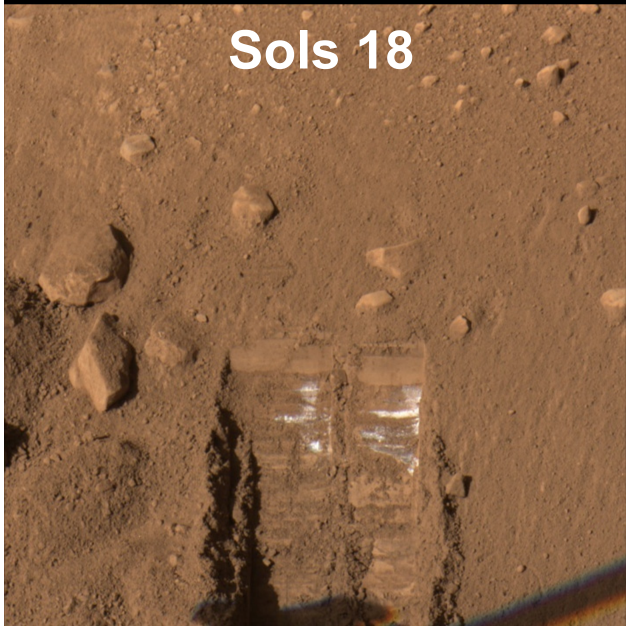
The Atomic force Microscope
Images over a 15 x 15 micron area
(~ 4x4 pixel area)

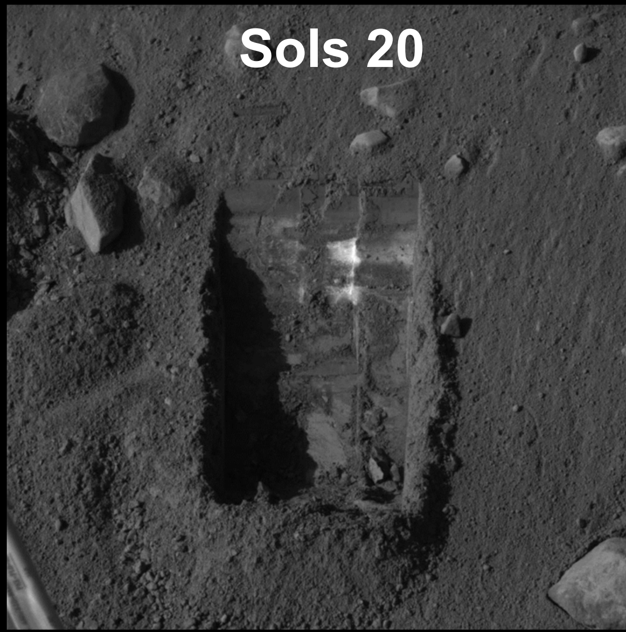


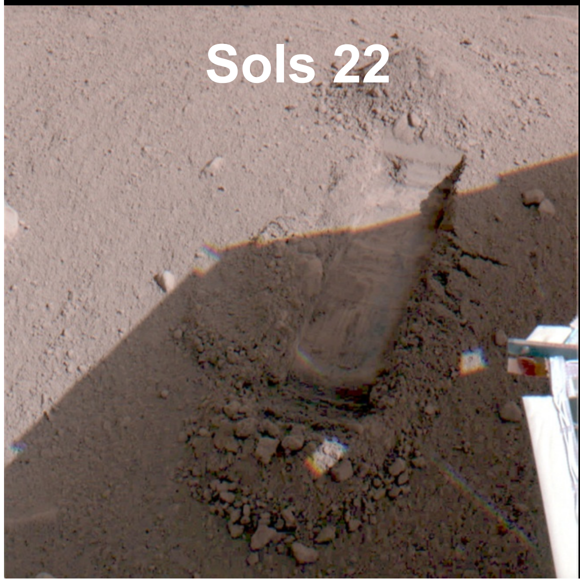


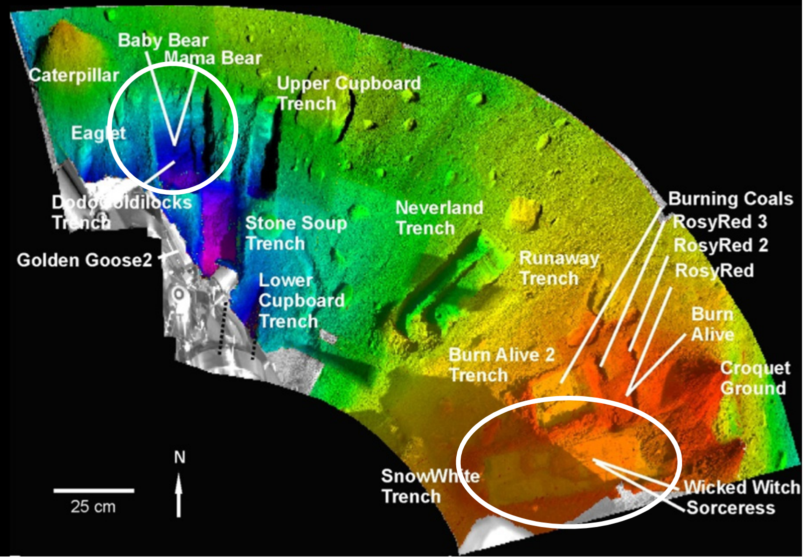
Optical Microscope Images of Martian Dust and Hubble astronomical

Sols 18 - 24 – Primarily Trenching Sols

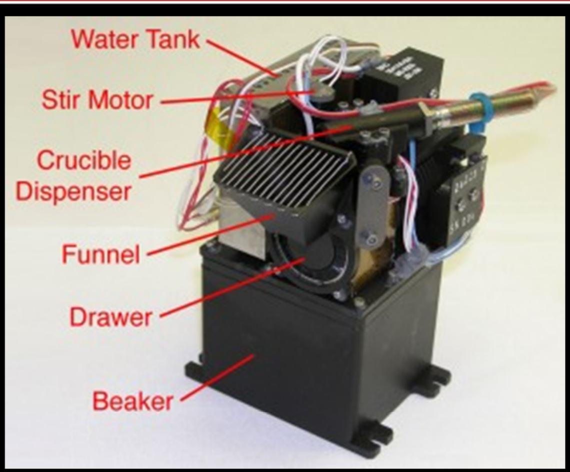


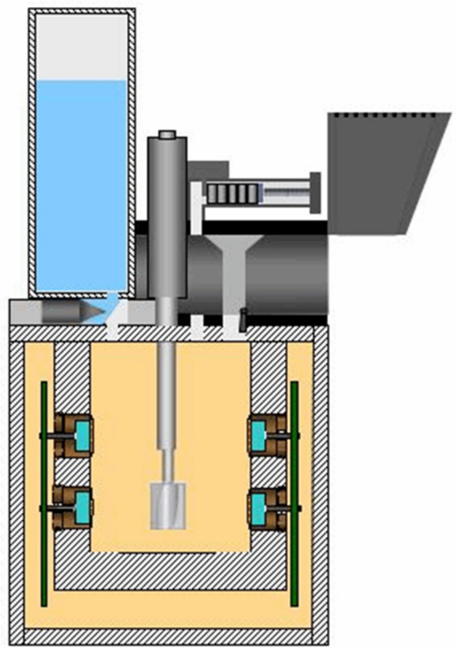


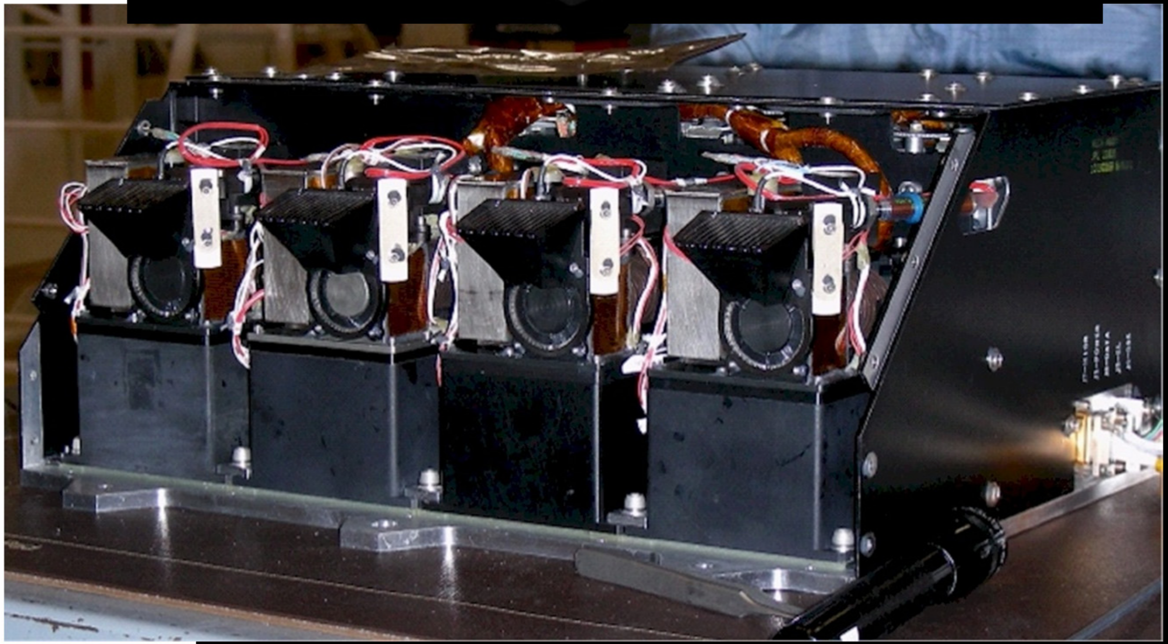




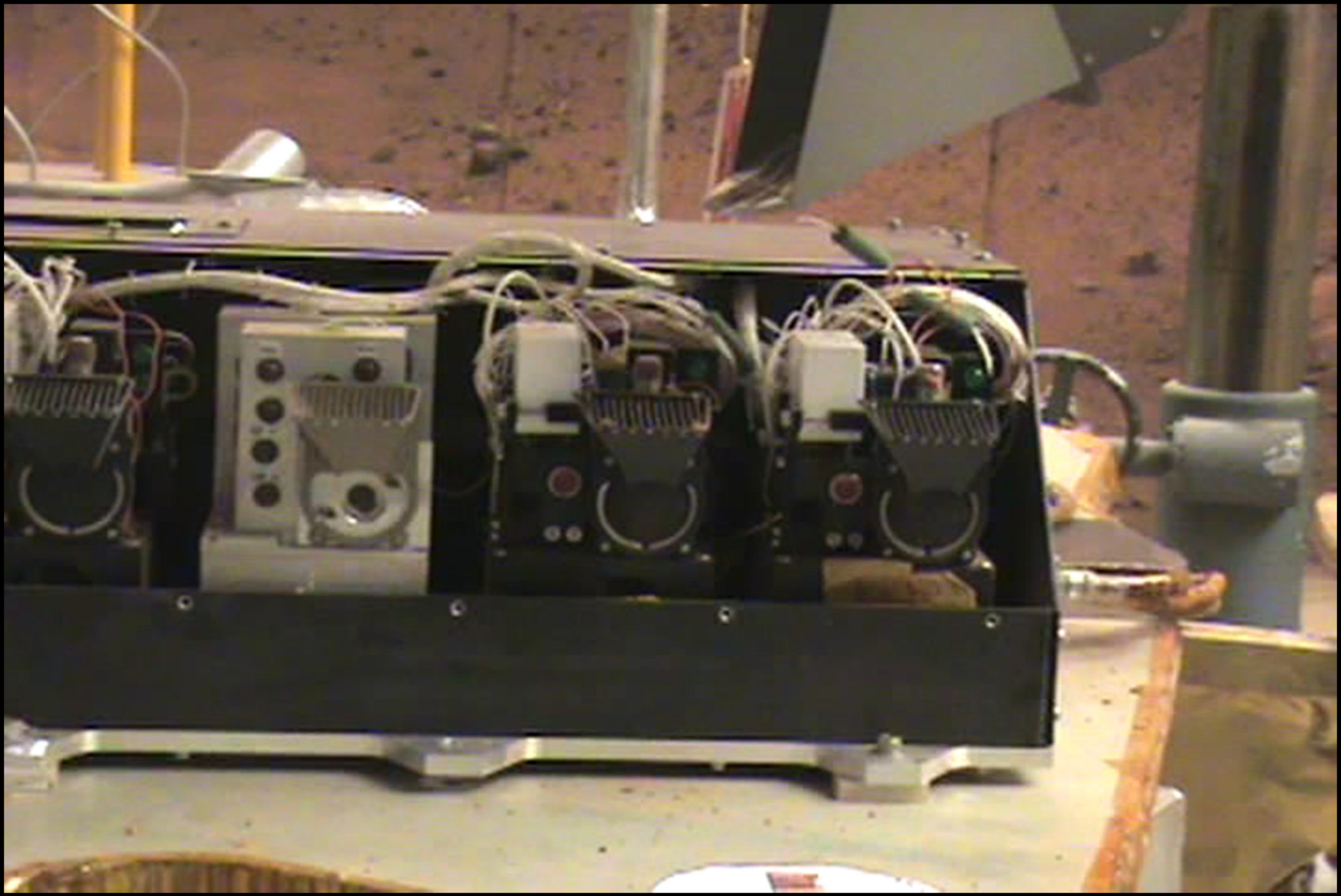
Wet Chemistry Lab (WCL) Tasting Mars





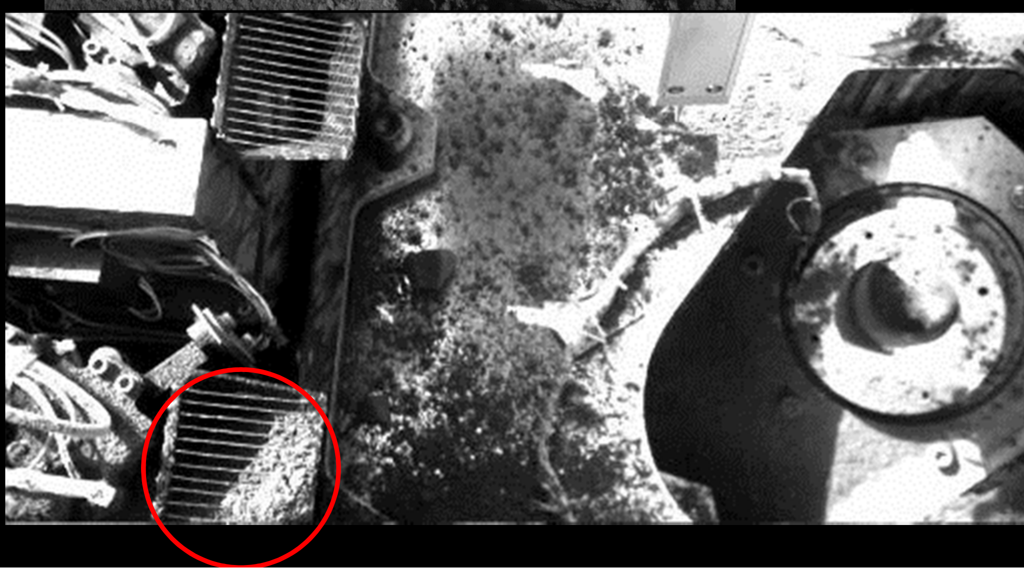


WCL Delivery Testing



Sol 30 - First WCL Delivery

Sol 25: Acquire Sample
Rosy Red



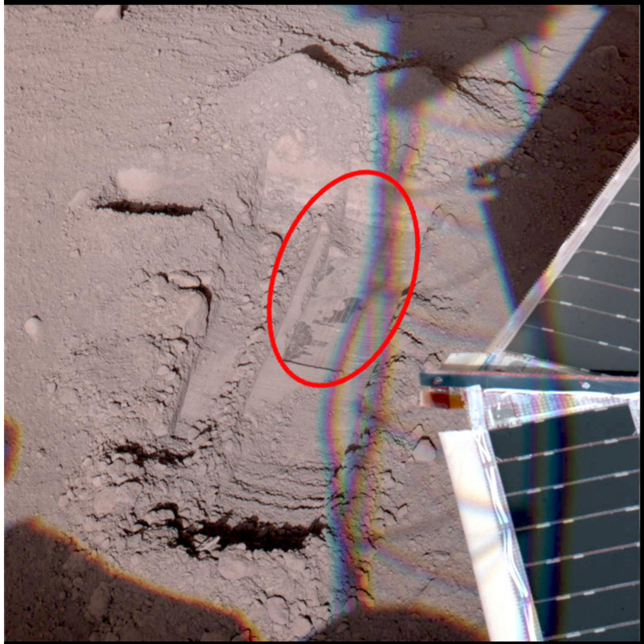
Sol 30: Deliver to WCL 0

TEGA Port 5

Five days earlier (Sol 25) Door opened and imaged with RAC

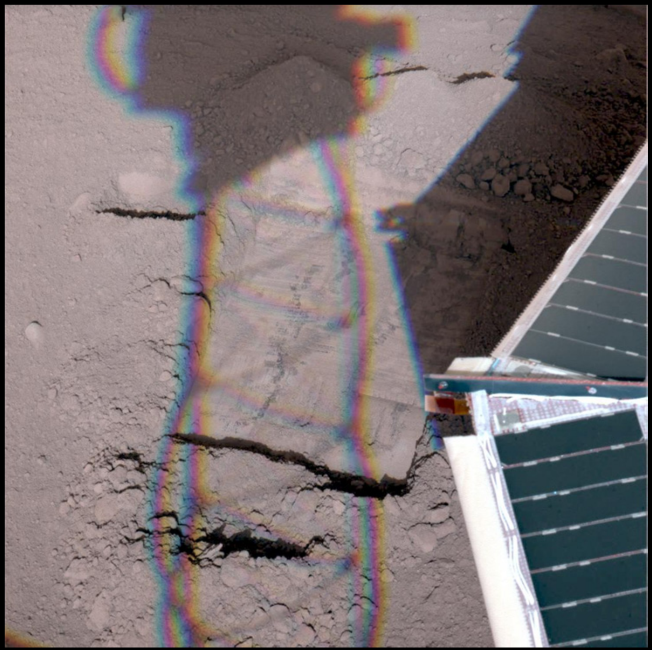
Practice TEGA Sprinkle Delivery To Tent Doors

Sols 31 - 33 – Excavating Wonderland



Sol 31

Scraping Snow White trench



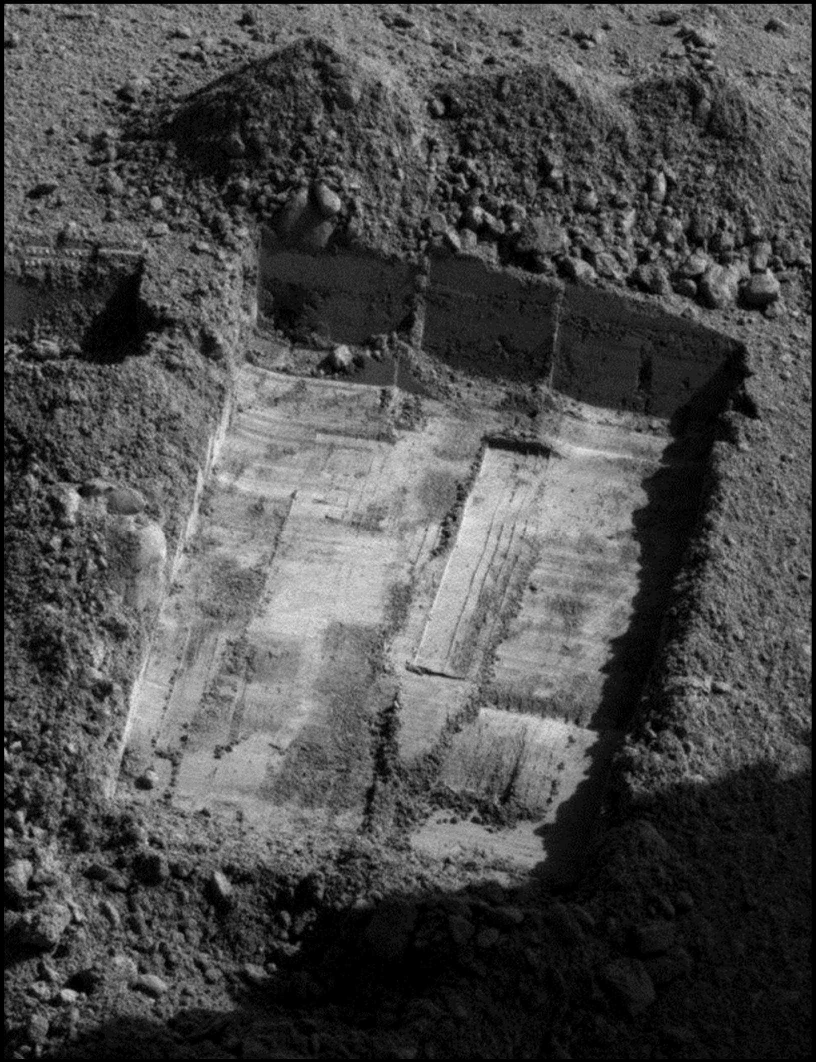
Sol 32

Clean trench and widen by 1 scoop width

Sol 34

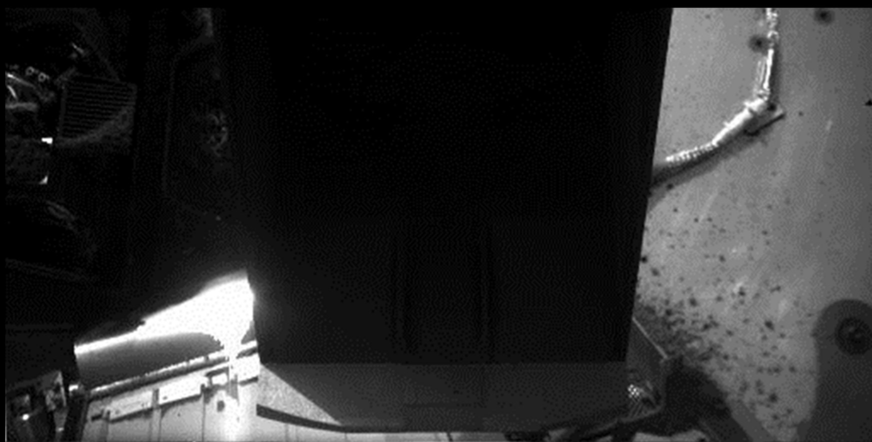
Scraping to create tailings pile

Acquired Sample intended for TEGA Port 5



Delivered to OM and WCL 1 Instead

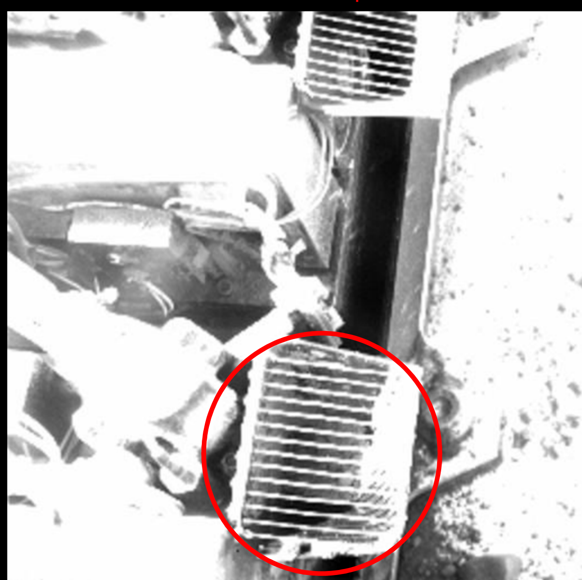
Sol 35, Parked over TEGA



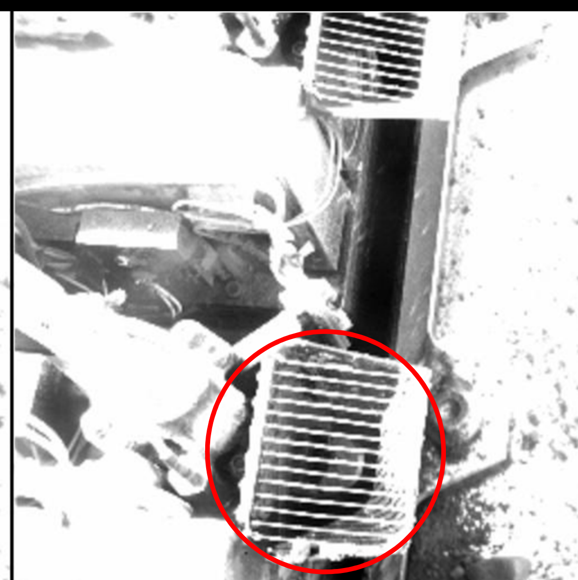
Sol 38, Dump a little on OM

Sol 41, Deliver to WCL 1

After Dump



Drawer Closed and Re-opened

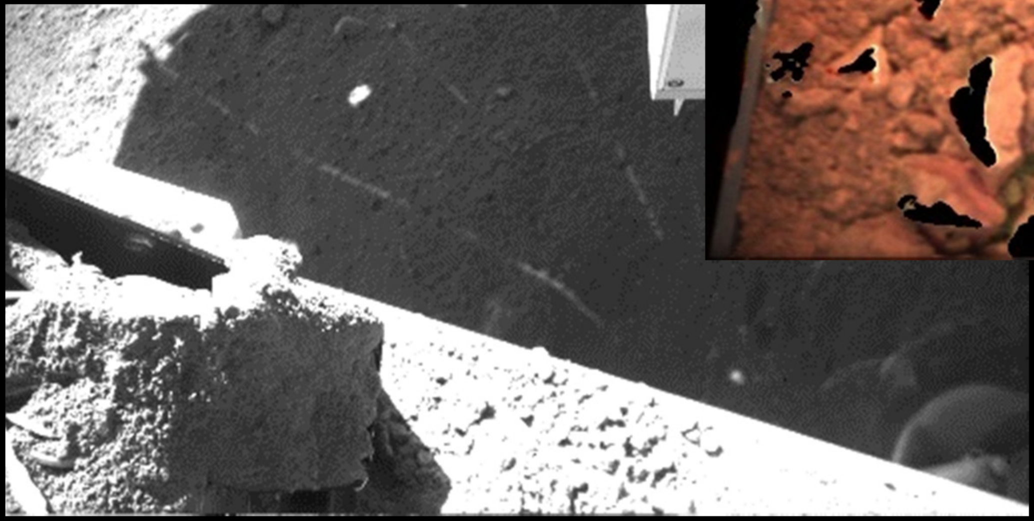


WCL3

Sol 96 – Nothing into drawer!

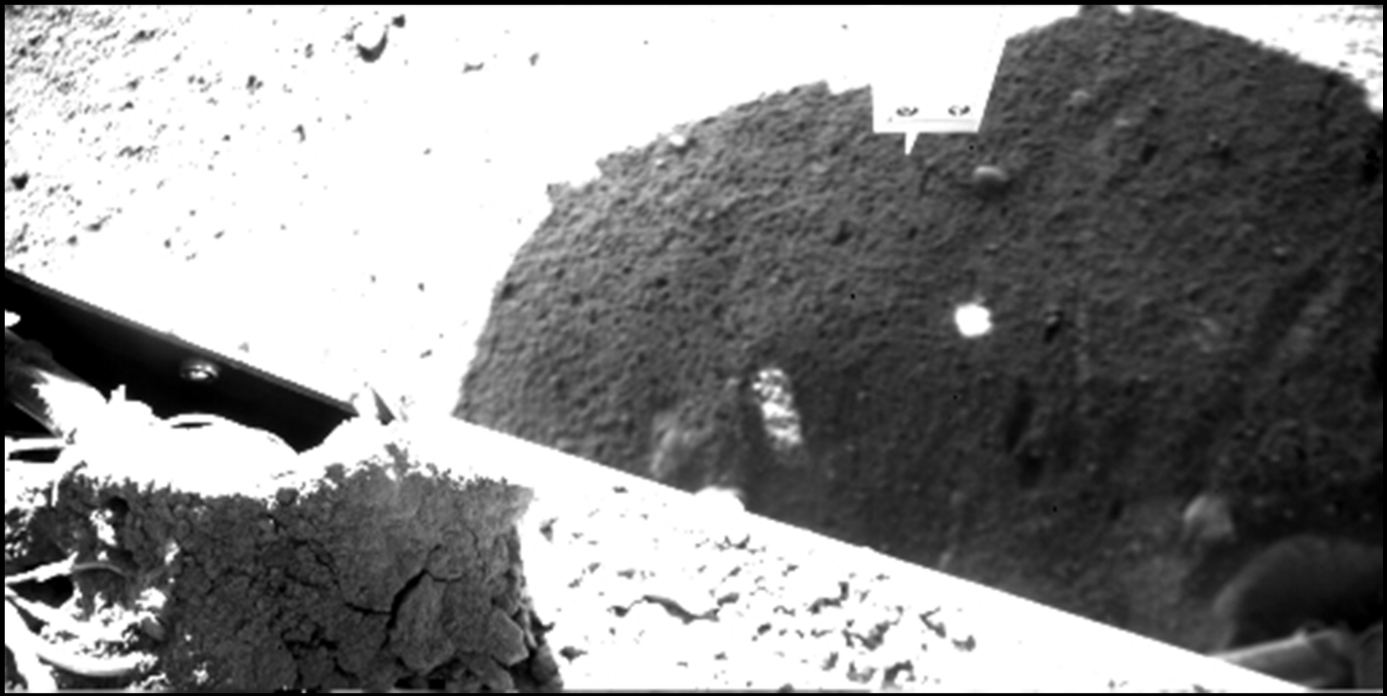
WCL3

Sol 102 – Try again



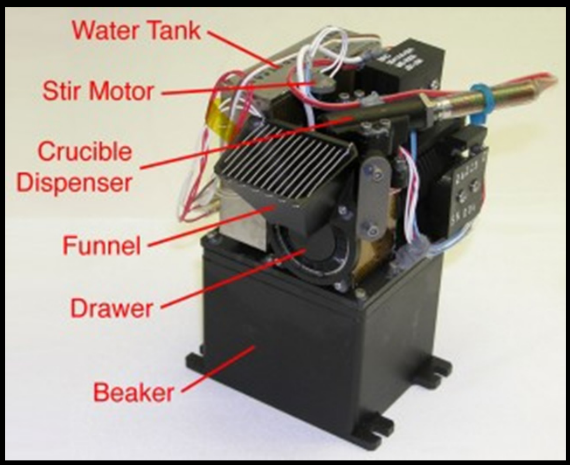
WCL3

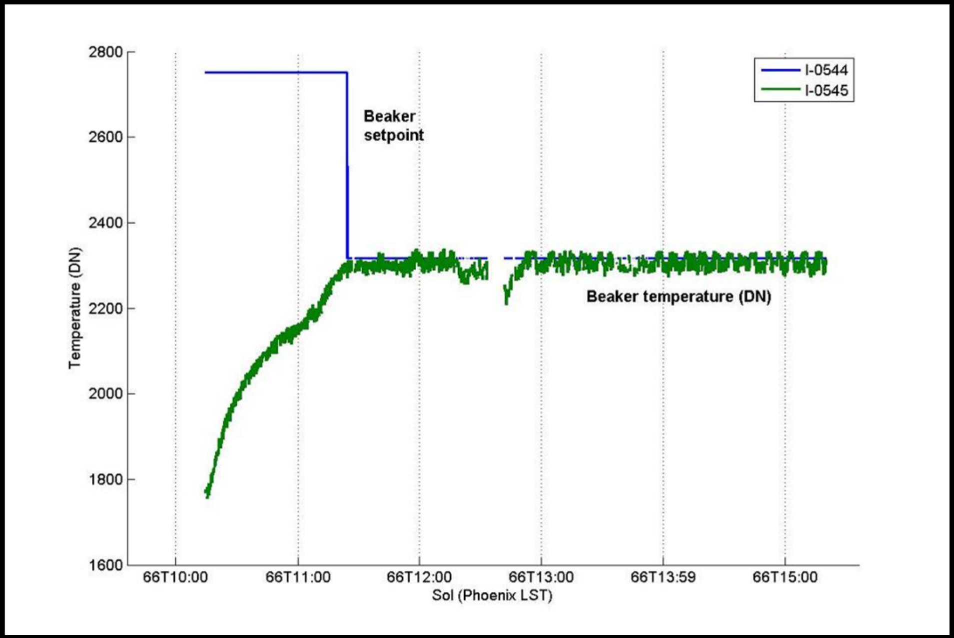
Sol 147 – Push that dirt in



MECA WET CHEM

MECA WET CHEM drawer | Rosy Red sample



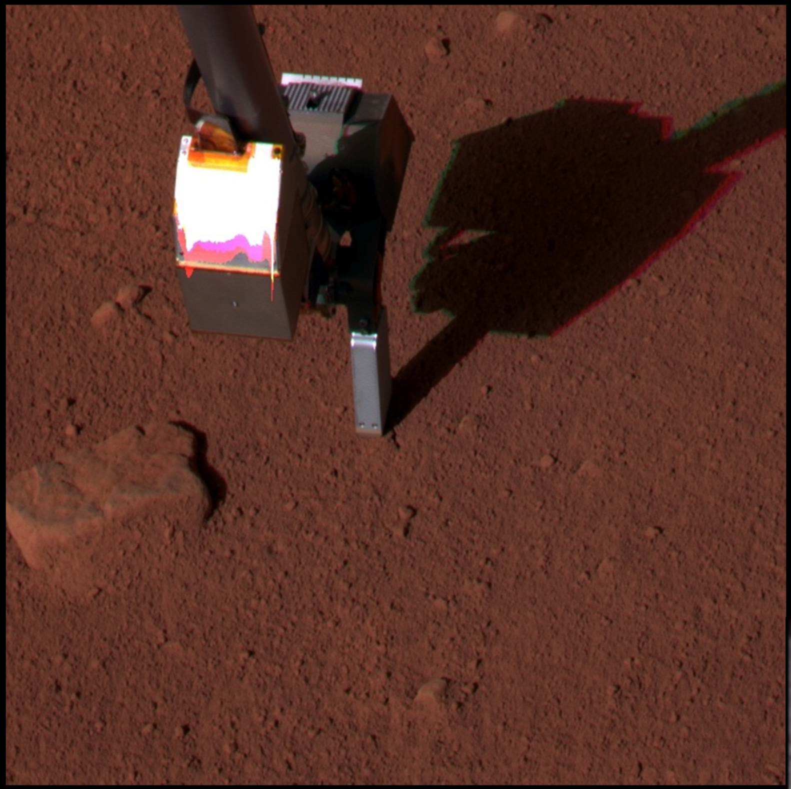


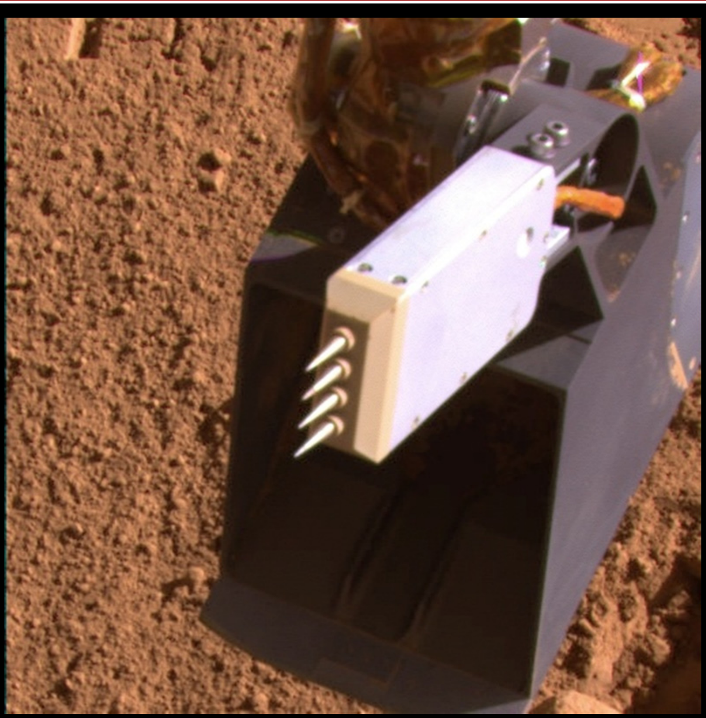
Results to Date

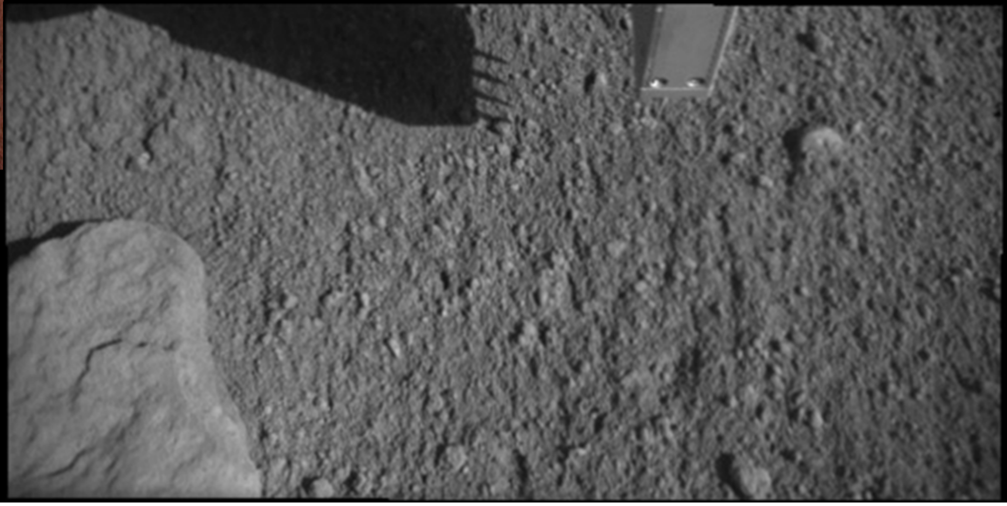
Ions Detected In Solution	
Ion	Rosy Red Sample
Na^+	Present
K^+	Present
$NH4^+$	Not Detected
Ca^+	Possibly Present
Mg^+	Present
Cl^-	Present
$ClO4^-$	Large Amount Present
pH	Slightly Basic

Thermal and Electrical Conductivity Probe (TECP)
Measuring Moisture

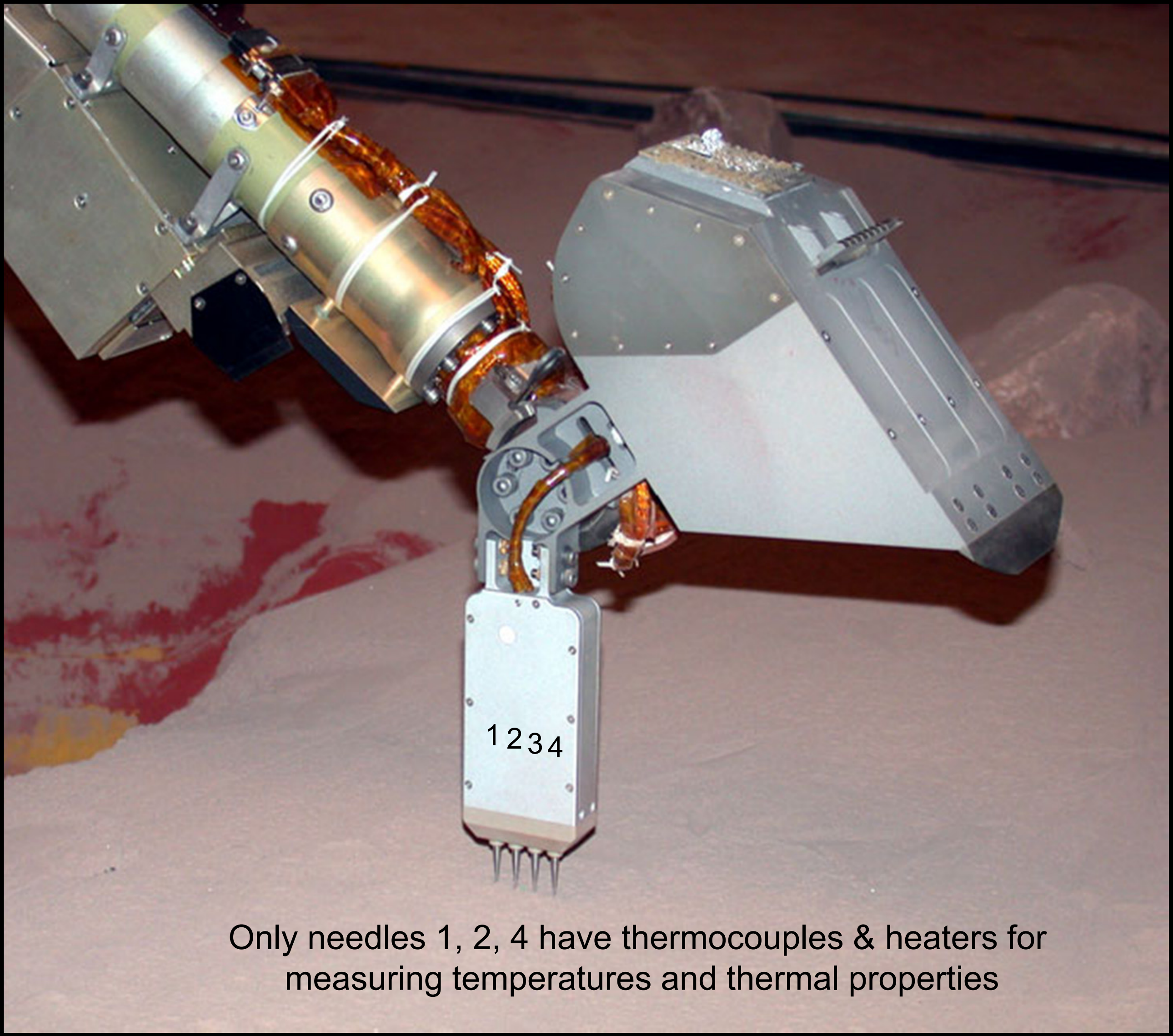
Sol 43 Insertion

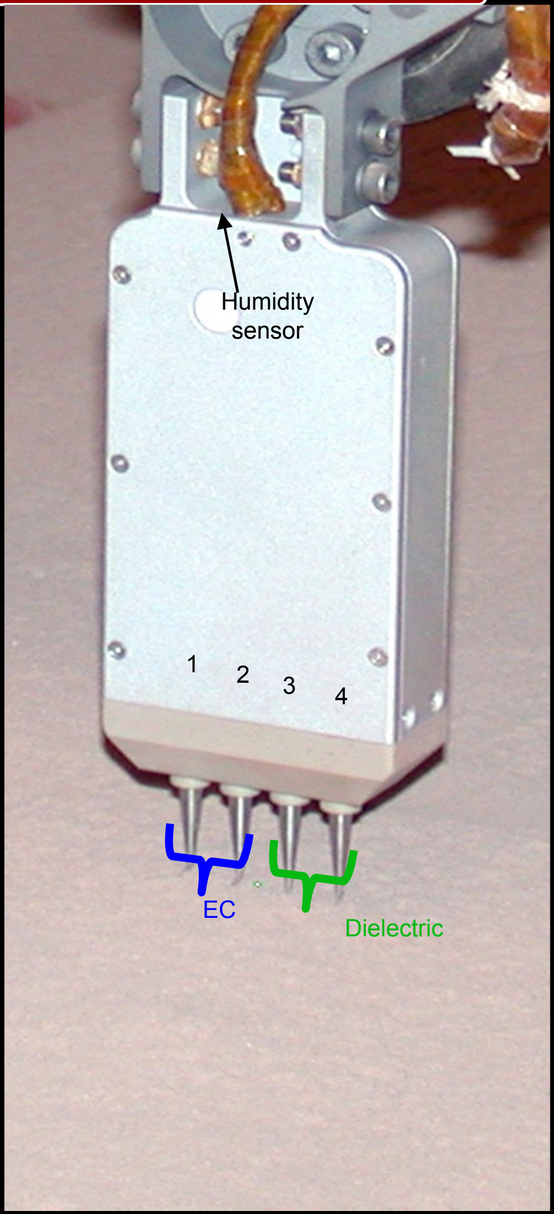






TECP Needle Functions

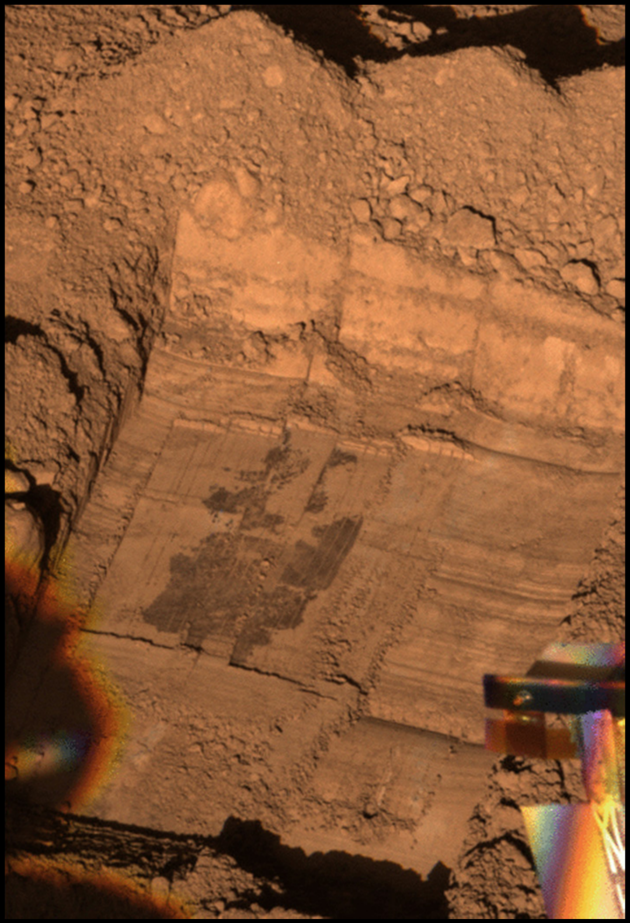




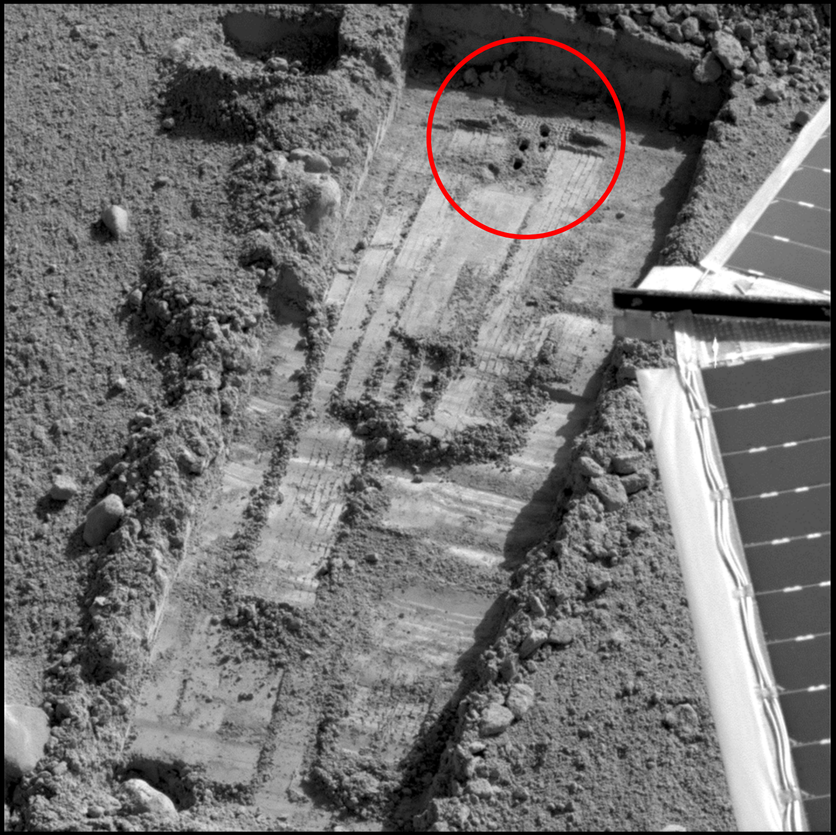
Icy Soil

- Rasp placement
  - Have to push down with the right amount of force
  - Arm compliance can result in bad placements
  - Can’t do anything to compensate for surface roll
- Icy Soil Delivery
  - Acquisition and delivery all has to happen as quickly as possible to minimize sublimation
  - Tight multi-instrument coordination
  - Best to do it early in the morning when it’s cold
    - Power and heating issues

Initial Rasp Test Placement

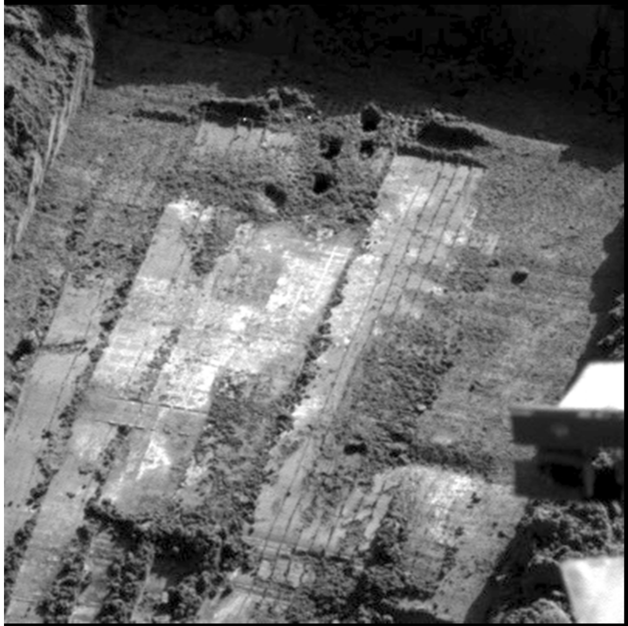


Sol 50 Initial Rasps



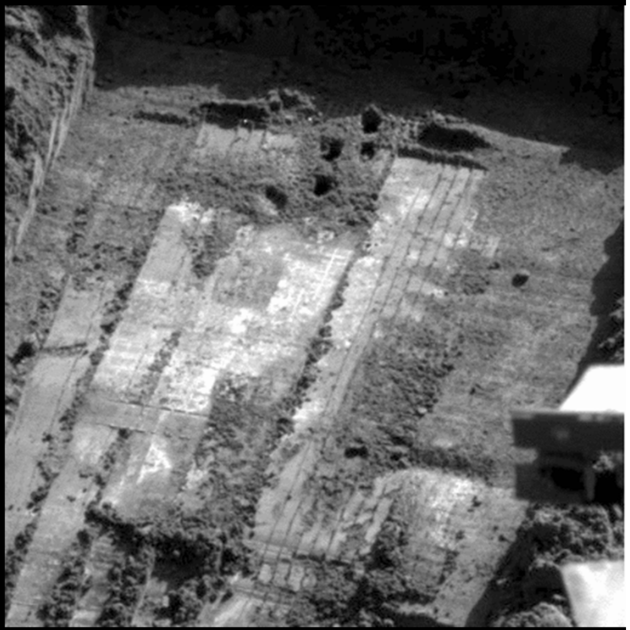
Sol 53 More Test Rasps

Sol 56 - Practice Scrape, Rasp and Blind Acquire



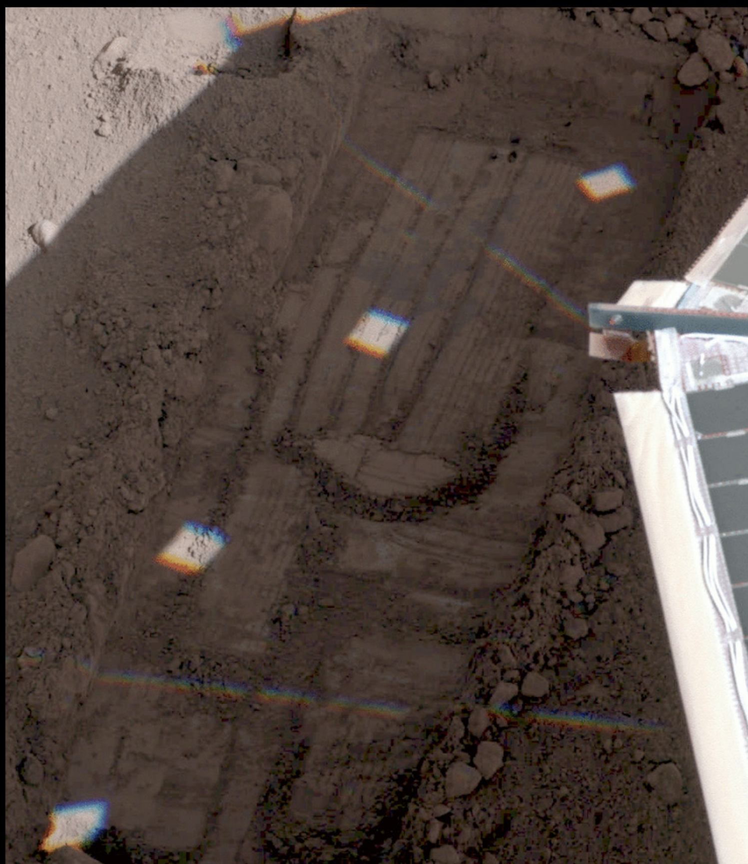
Pre and Post Scrape

Rasp and Blind Acquire



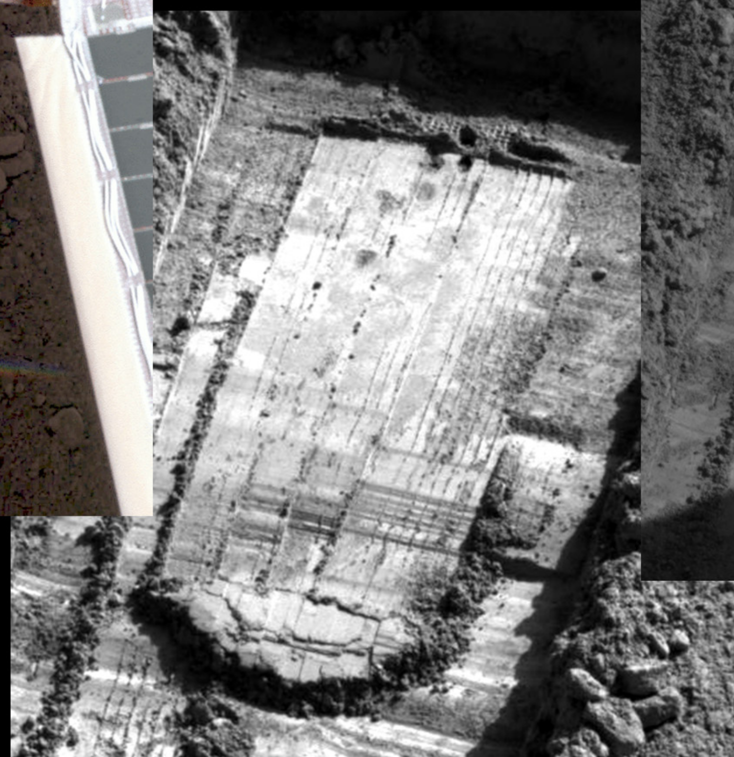
Scrape, Rasp and Blind Acquire

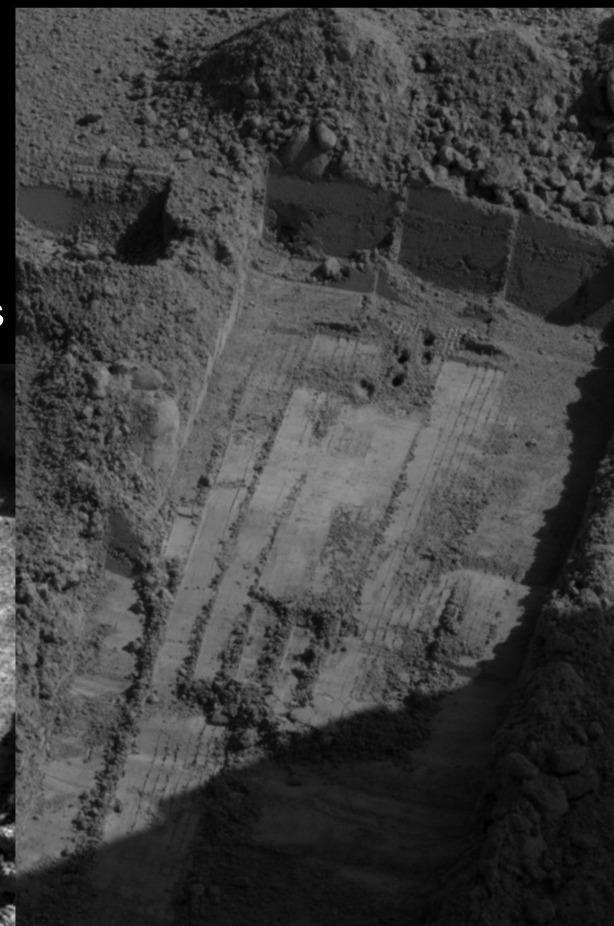
More Test Placements



Sol 57 Trench Grooming

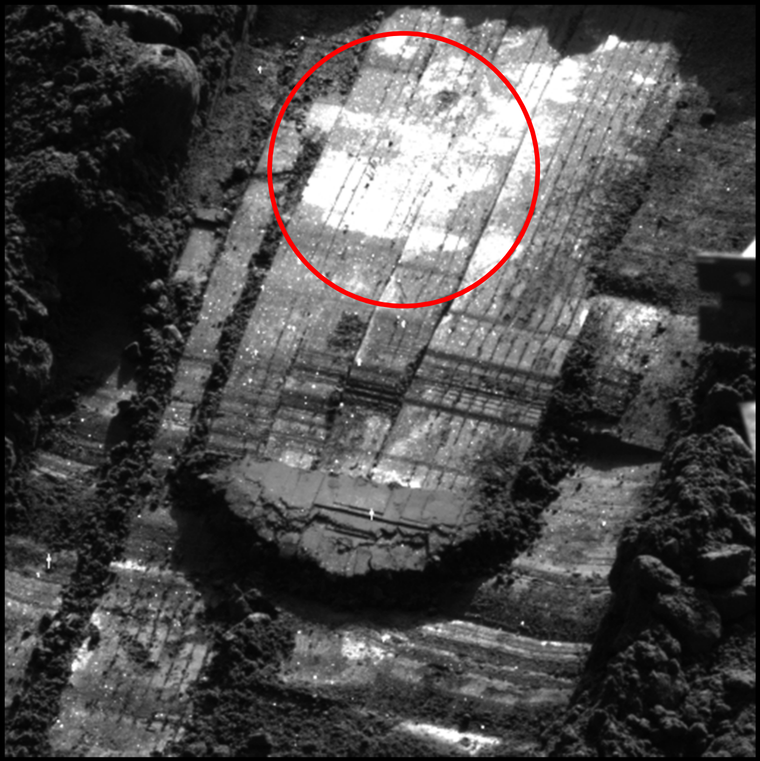
Sol 58 Test Placements





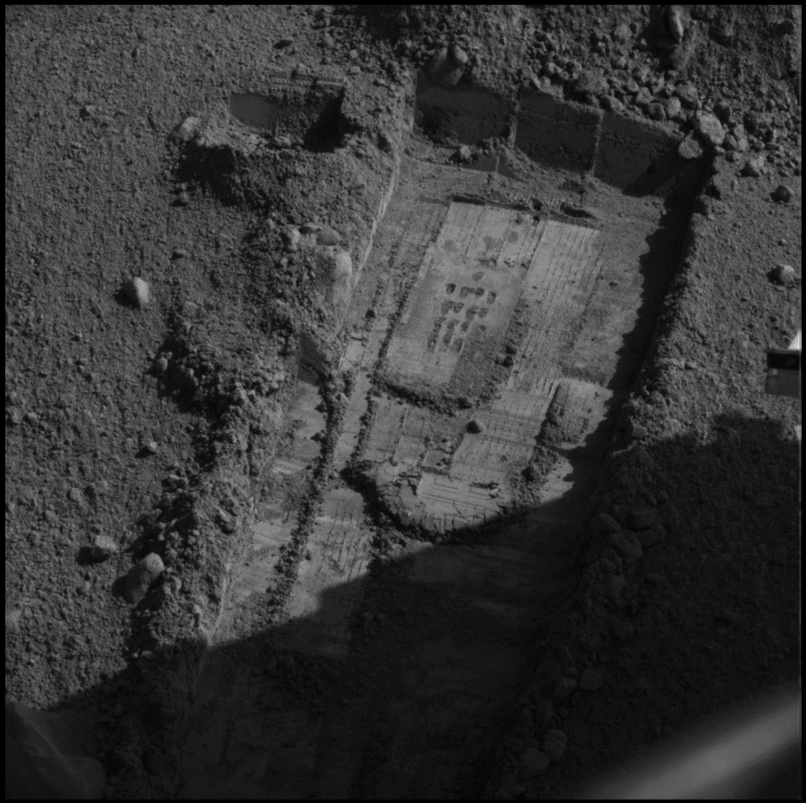
Sol 60 – 1st Icy Soil Attempt Acquisition

4x4 Rasp Pattern



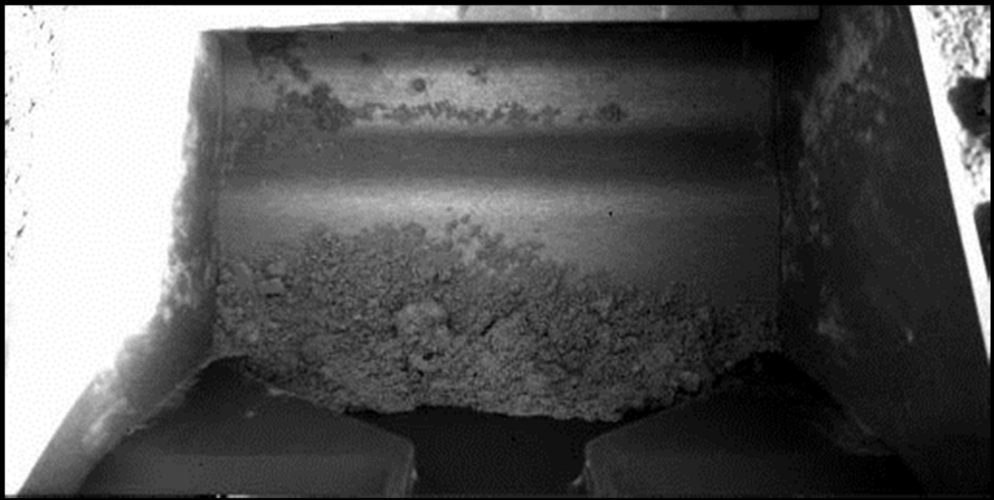
Scrape and Rasp

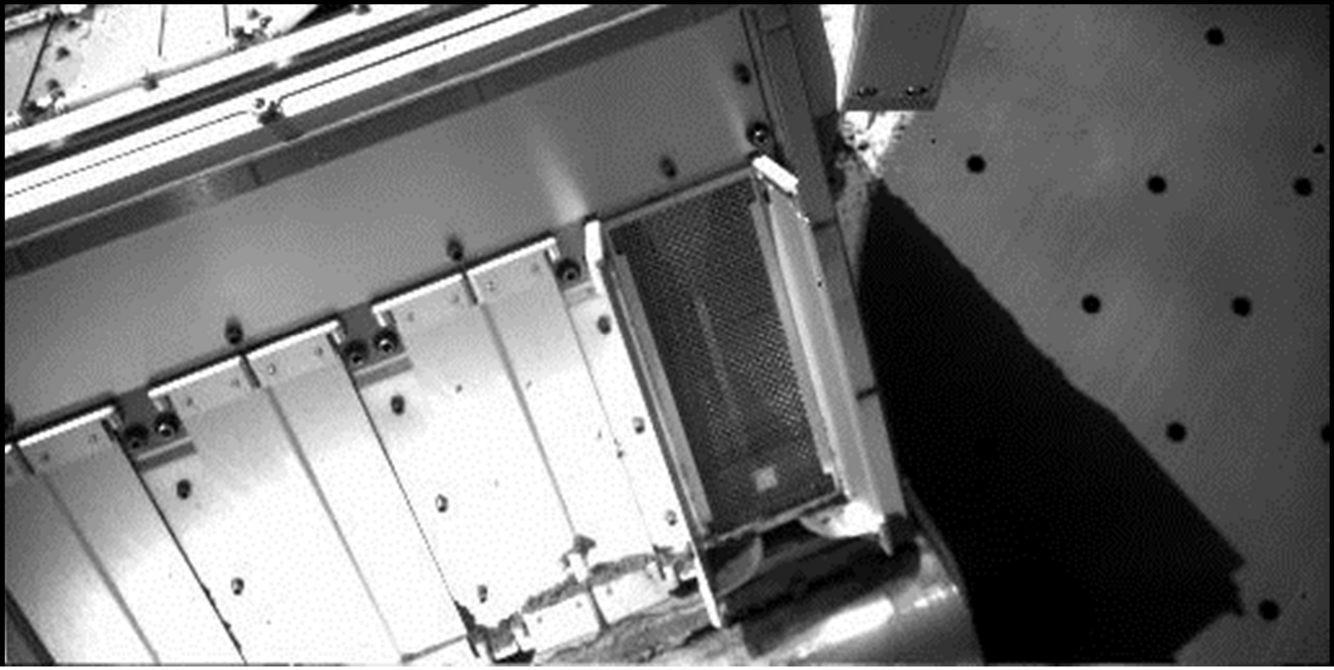
+



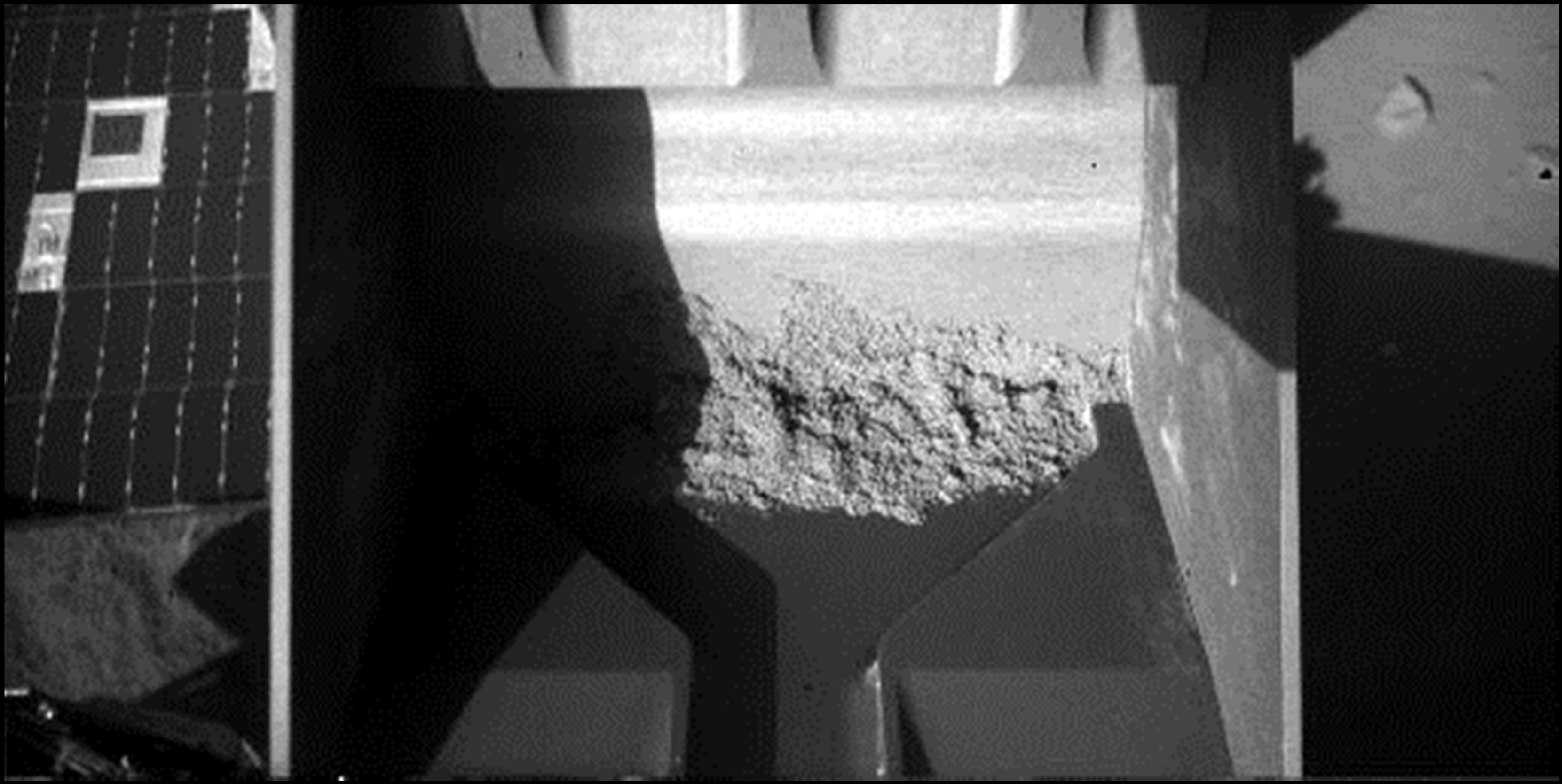
Blind Acquire

Sol 60 – 1st Icy Soil Attempt Delivery



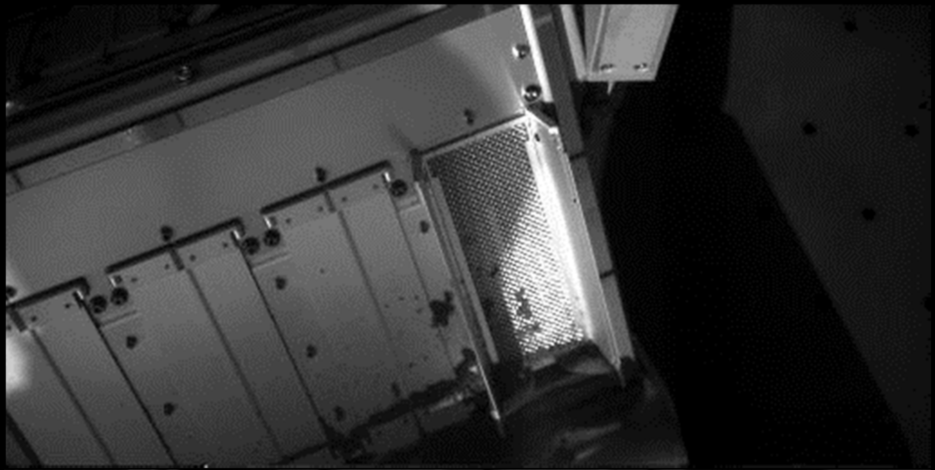


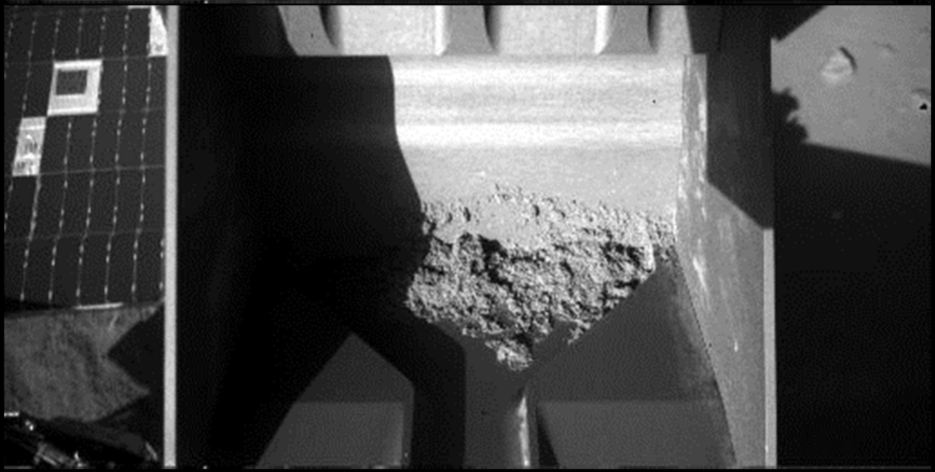
“Empty” Scoop



Try Again

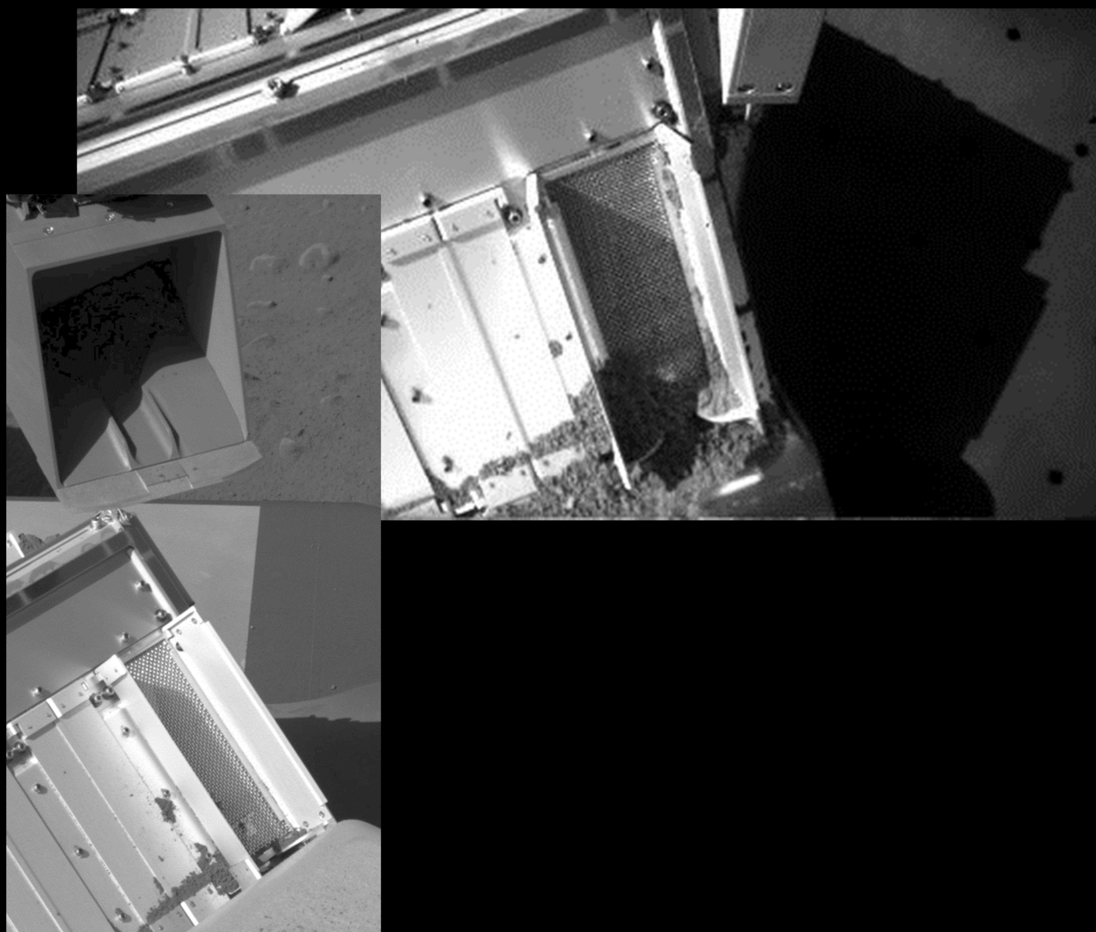
Sol 62, Same story, different day





3rd Time's a Charm (sort of)

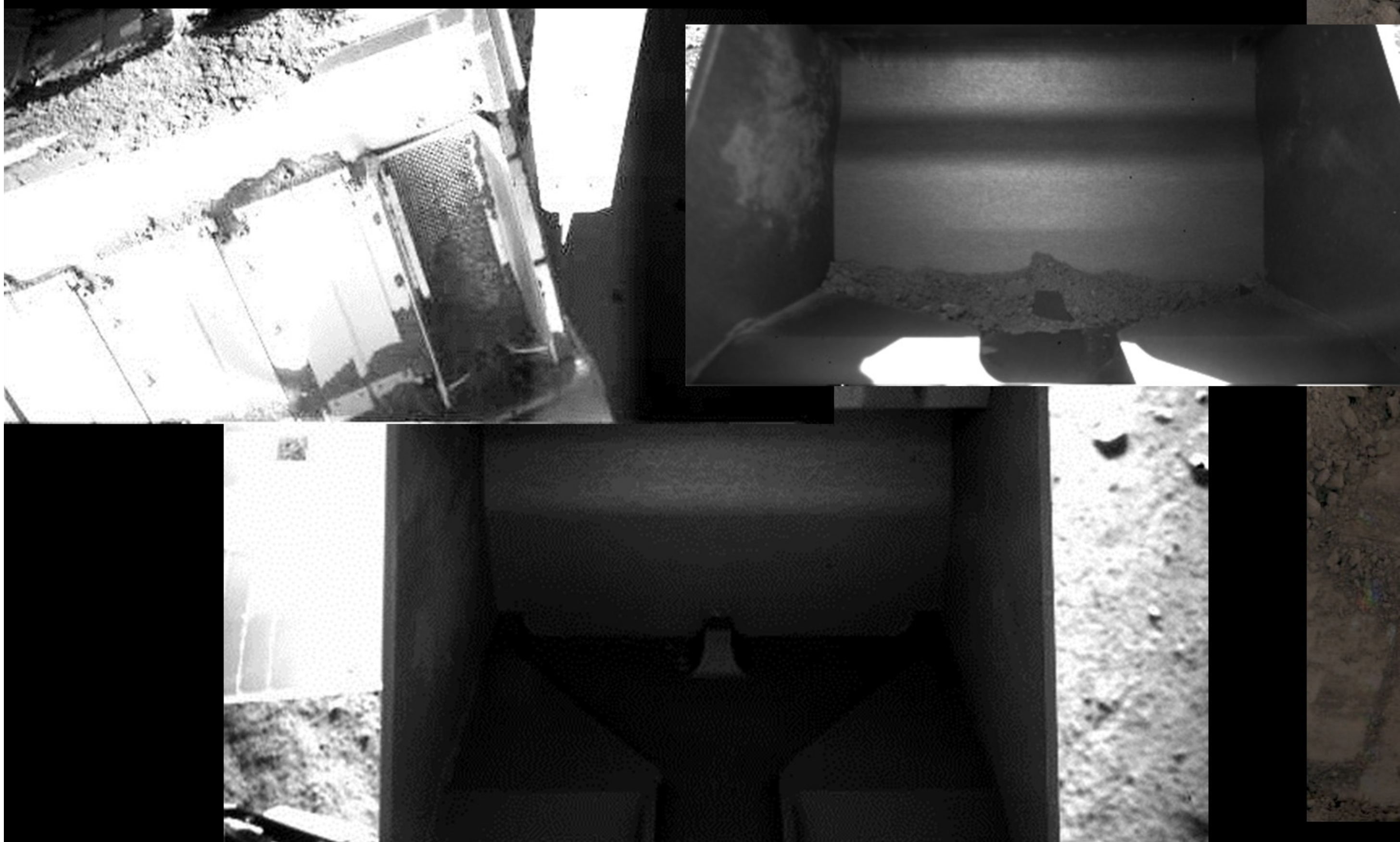
Sol 64, Grab a scrapings pile

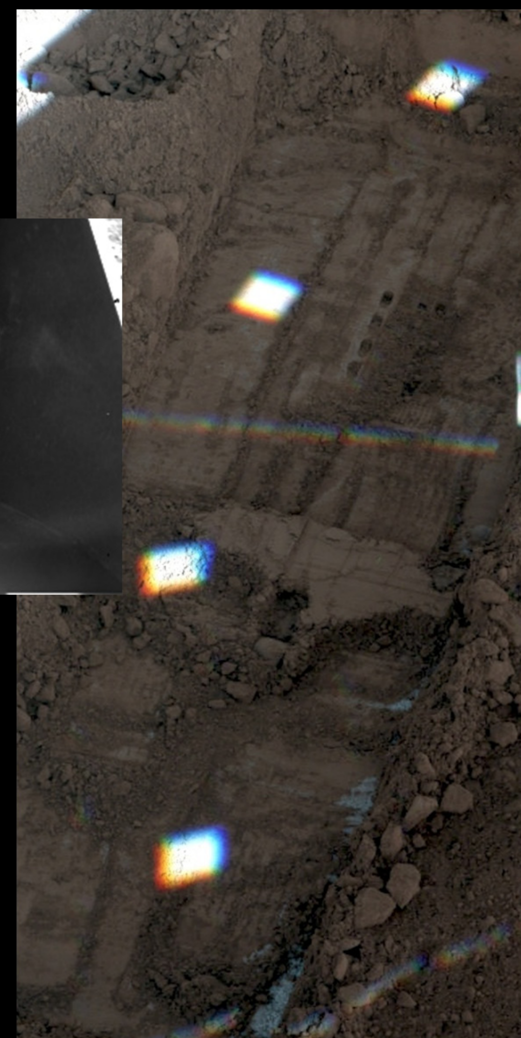


Not Done with Icy Delivery Yet

Sol 94, Icy delivery test

Keep sample in the shade





More Icy Delivery

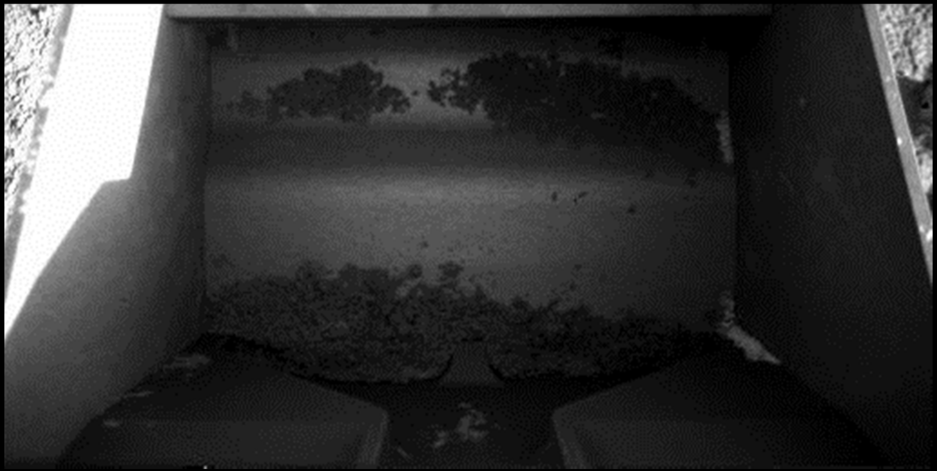
Sol 97 – Pulled tactically due to power constraints

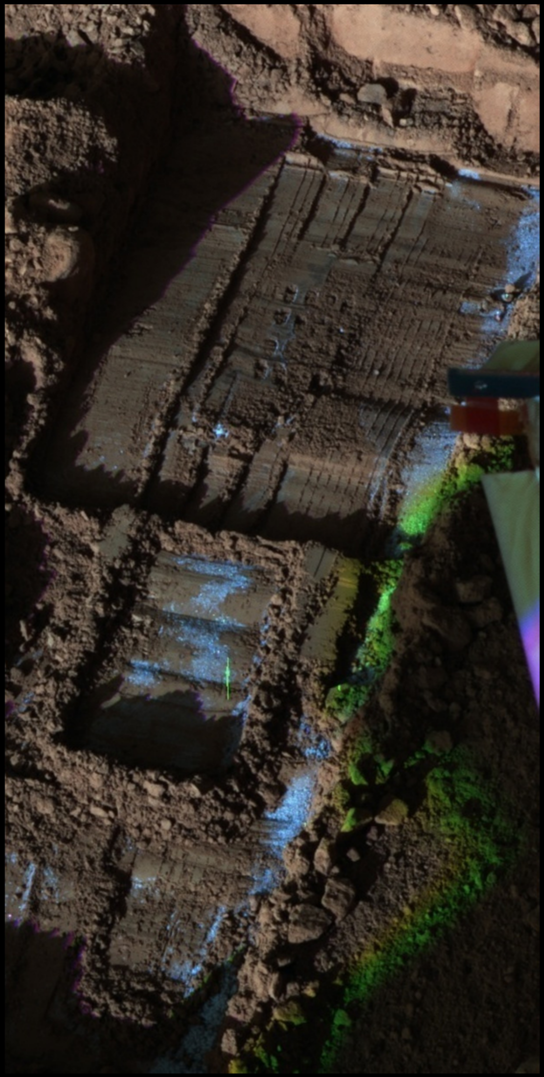
Sol 103 – TEGA valve problems, delivery pulled

Sol 108 – Uplinked the delivery, but a sequence naming error results in the runout sequence executing instead

Icy Delivery Actually Runs

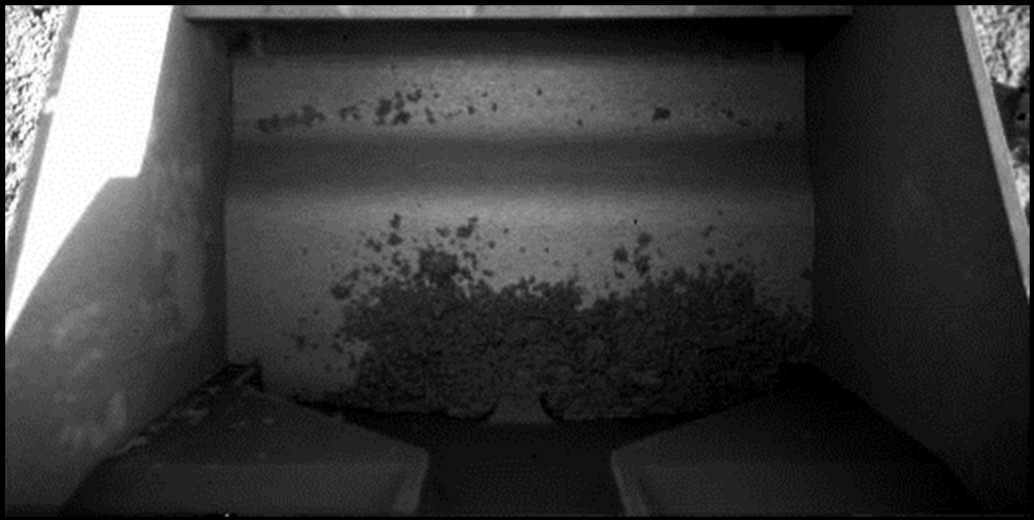
Sol 113, TEGA Port 1, No oven full

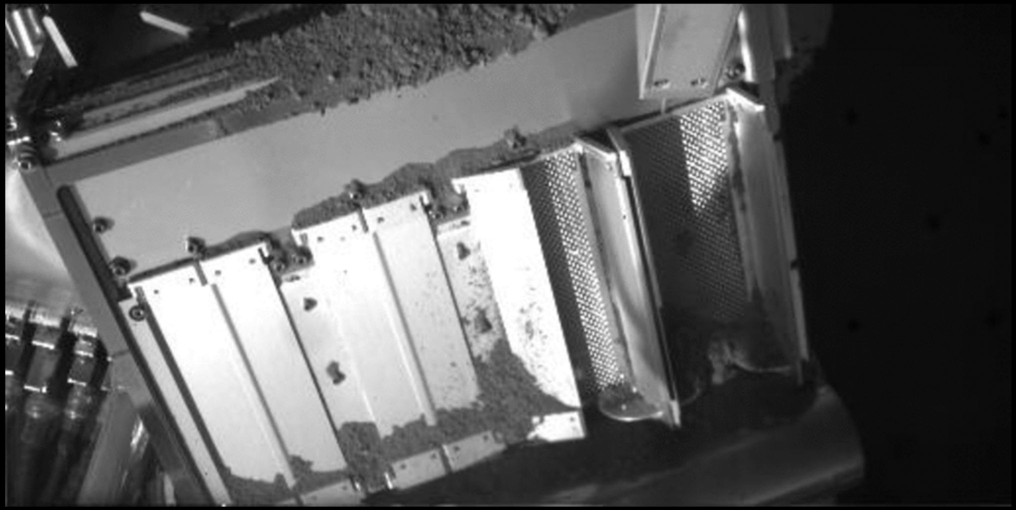


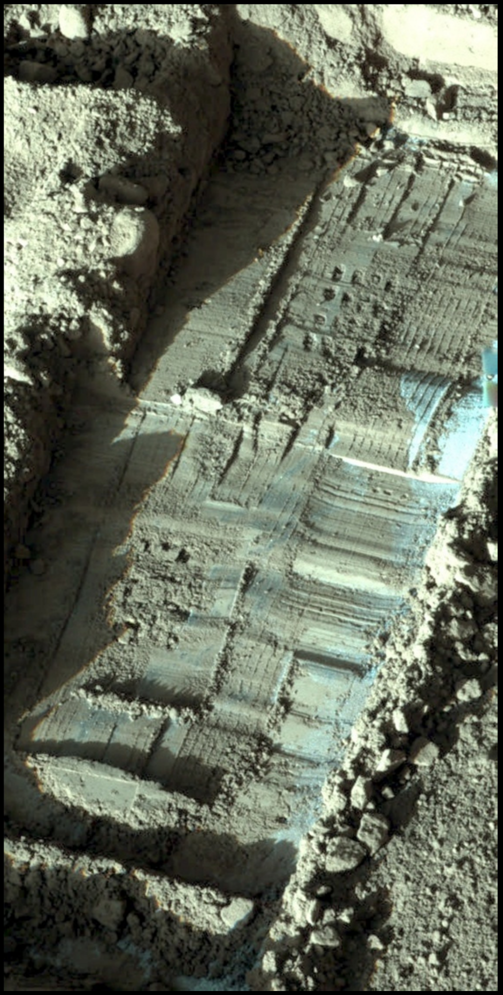


Try Again

Sol 120, Still no oven full

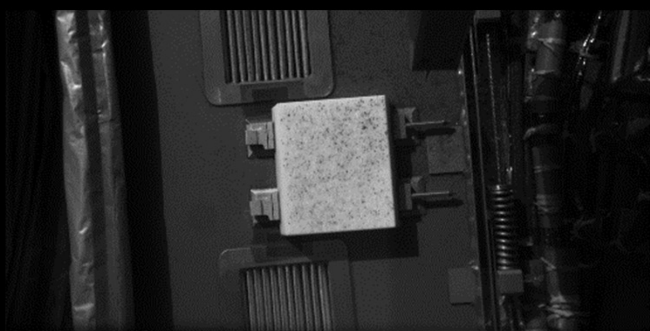


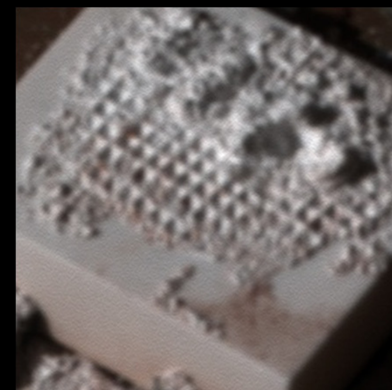


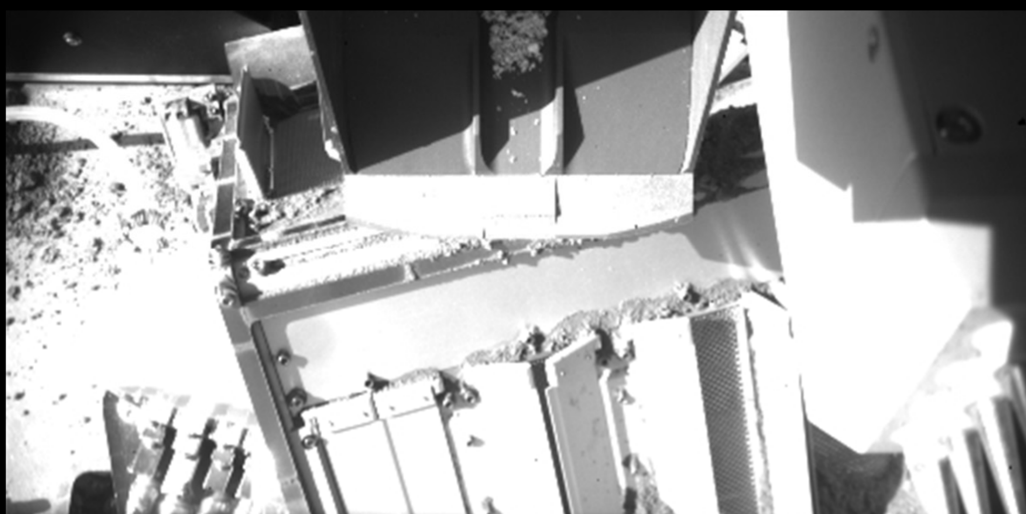
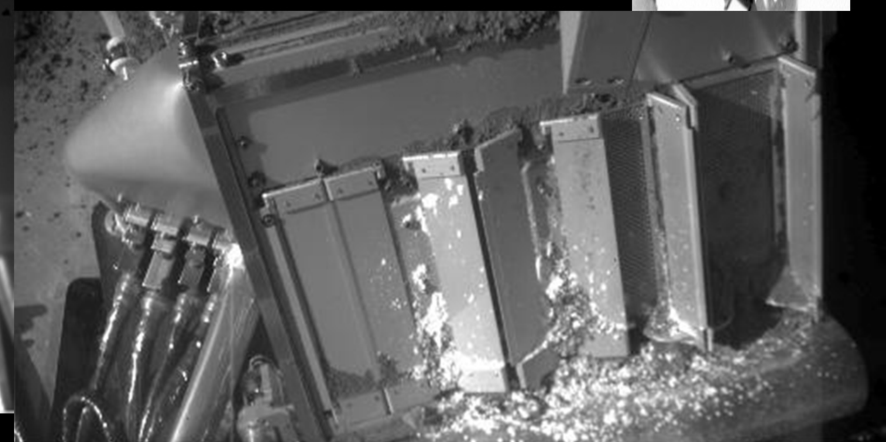


OFB Delivery

Sol 122, Organic Free Blank delivery





The Final Hour!!

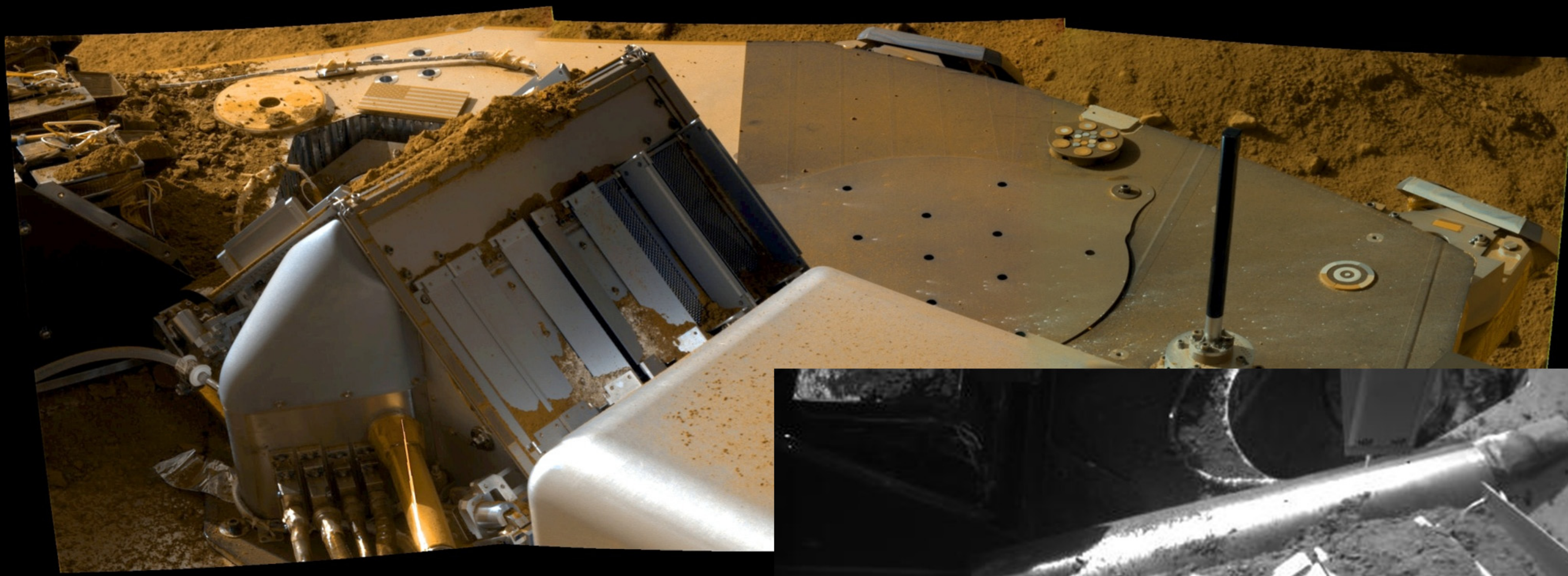
Sol 151 – TEGA 3 high temperature ramp

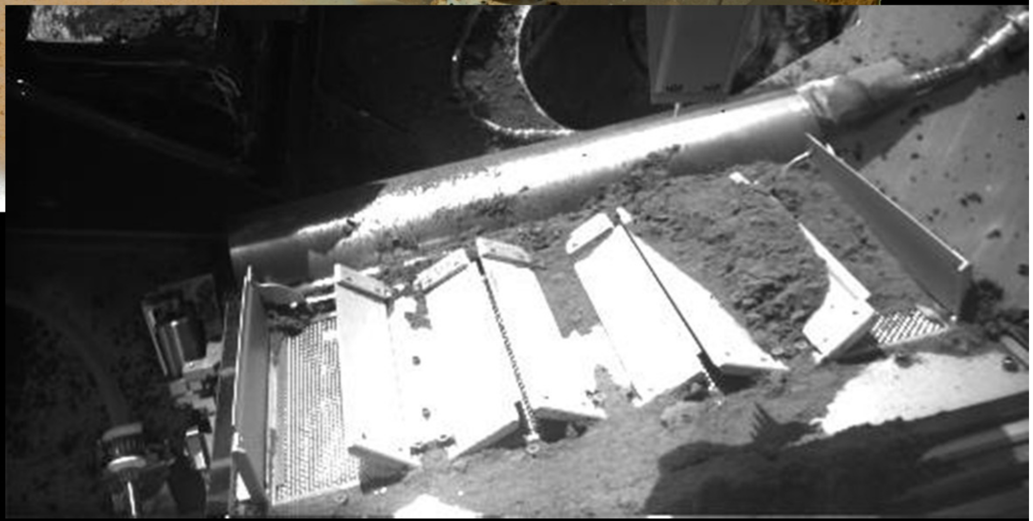
Phoenix safes that evening due to low power

Battery heaters come on for the first time the morning of sol 152

Batteries completely depleted the morning of sol 153

TEGA Doors State End Of Mission





It's Not All Bad

Met full mission success criteria

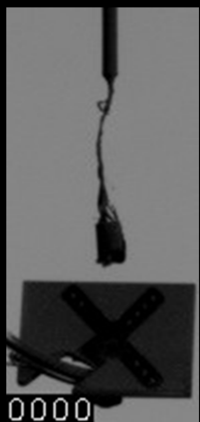
Dug eleven trench complexes

Captured hundreds of RAC images

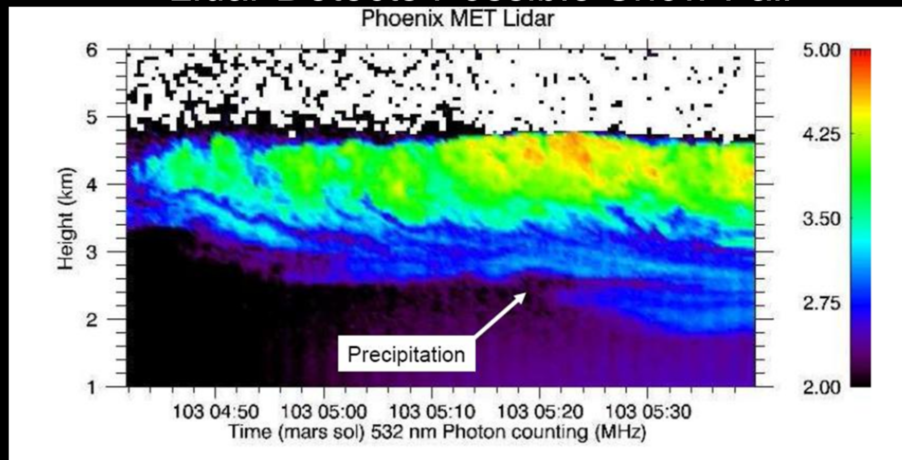
Seventeen successful sample deliveries

A more dynamic Mars – Fall is

Frost Telltale

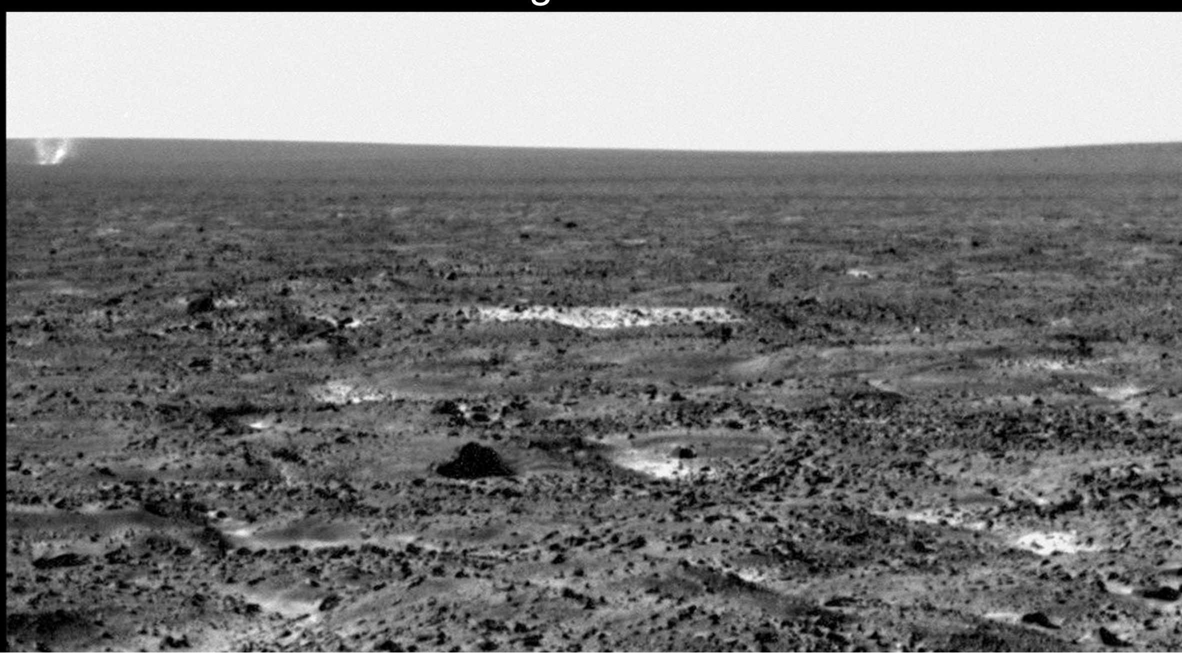


Lidar Detects Possible Snow Fall



Night Time Clouds

SSI watching the Dust Devils!



Phoenix Status

Status

- No communication since Nov 2, 2008. Attempt to call again Spring of 2010.

Sample Delivery

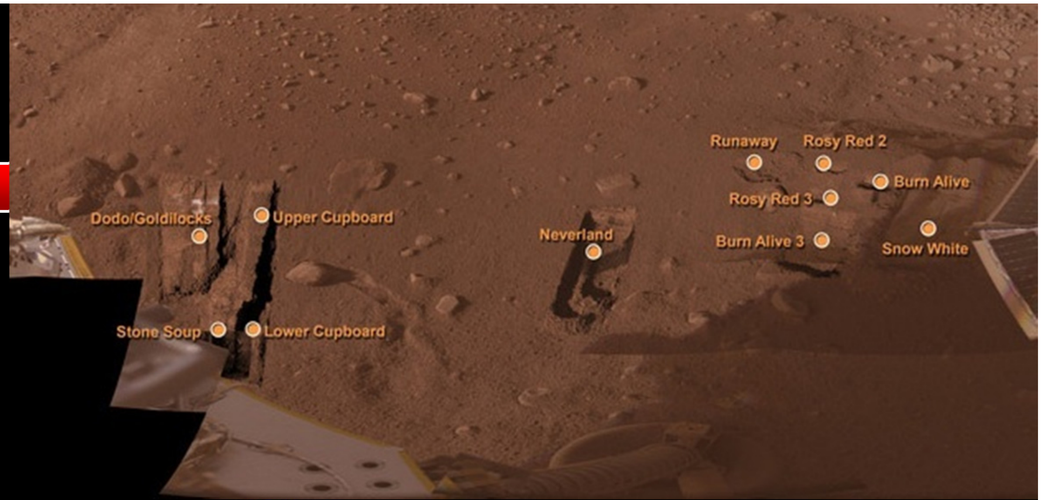
- Completed delivery of samples to all instrument chambers

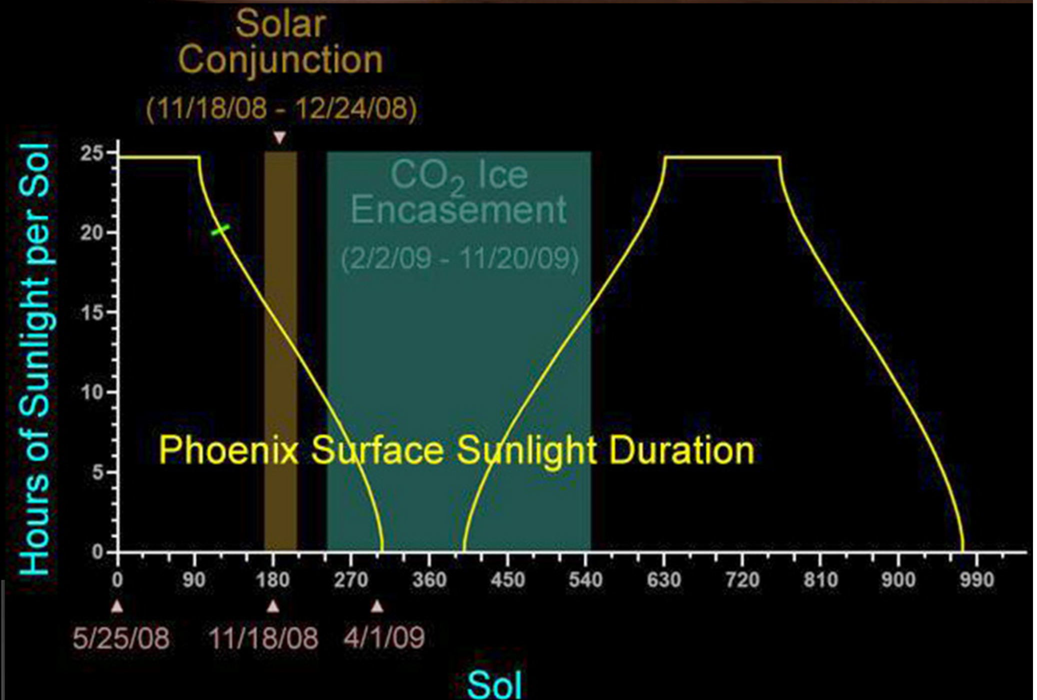
Terrain Excavation

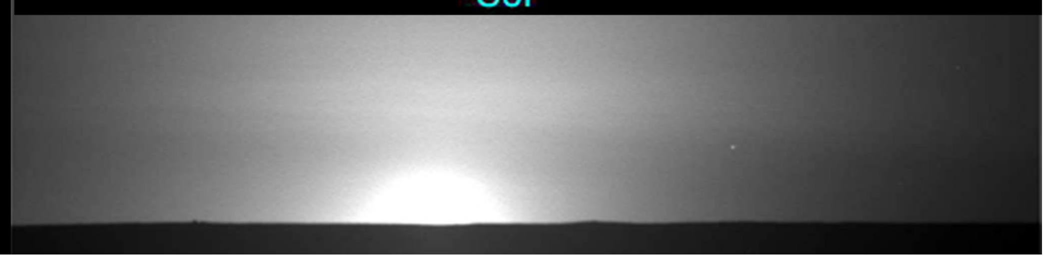
- Revealed and sampled subsurface ice.
- Exposed ice polygon structure from top to edge.

Weather Monitoring

- Recorded weather as seasons changed.
- Measured cloud heights and motion
- Imaged CO2 and H20 ice accumulation







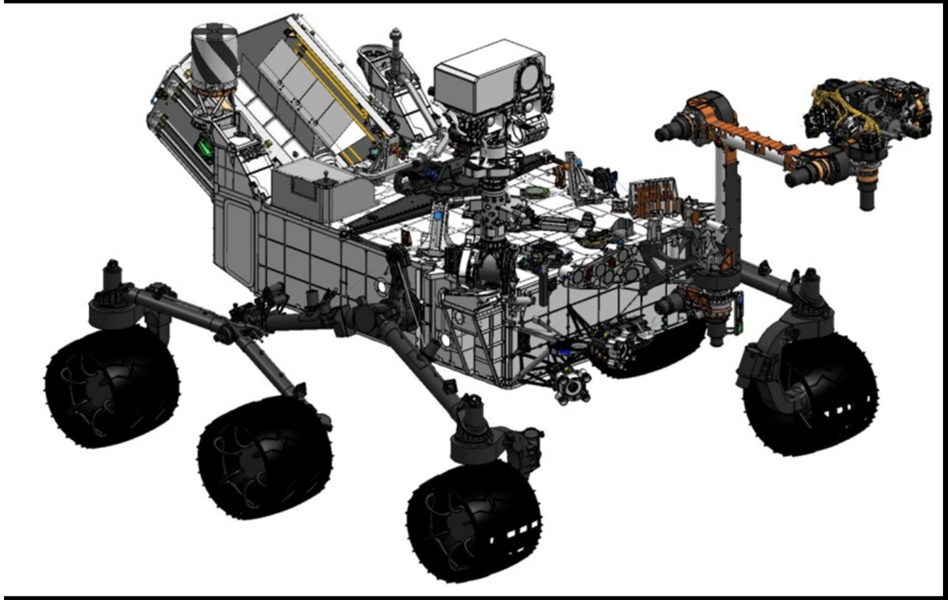
Time For R&R Before Next Project

2011 Mars Science Laboratory (MSL)

MSL Overview

Science

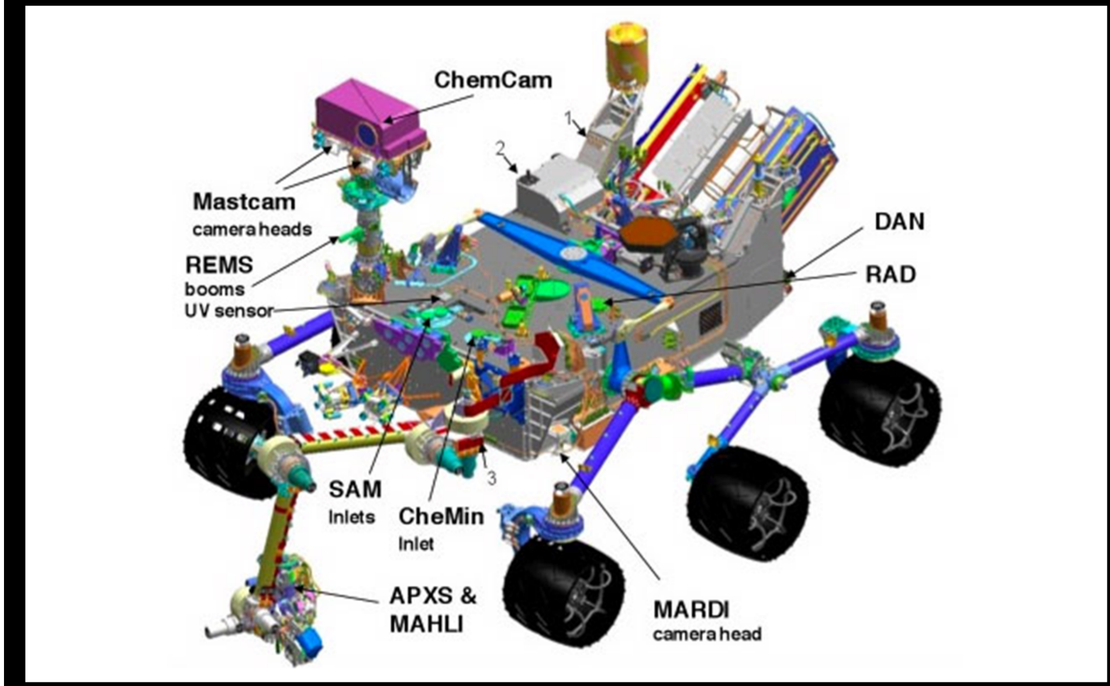
- Focus on Past & Present Habitability of Mars
- Highly Capable Analytical Laboratory
- Next Generation Remote Sensing & Contact



Technical Capabilities

- One Mars Year surface operational lifetime (669 sols/687 days)
- Precision Landing via Guided Entry and Skycrane Propulsive Landing
- Long Distance Traverse Capability (20 km)
- Flexible & Robust Sample Acquisition & Processing

MSL Payload



ChemCam – Laser Induced Breakdown Spectrometer

MastCam - Color Stereo Imager

Contact Instruments (Arm)

MAHLI - Microscopic Imager

APXS - Proton/X-ray Backscatter Spectrometer

Analytical Laboratory (Front Chassis)

SAM - Gas Chromatograph/Mass Spectrometer/ Tunable Laser Spectrometer (Sample Composition / Organics Detection)

CheMin - X-ray Diffraction / Florescence (Sample Mineralogy)

Environmental Characterization (Body-mount)

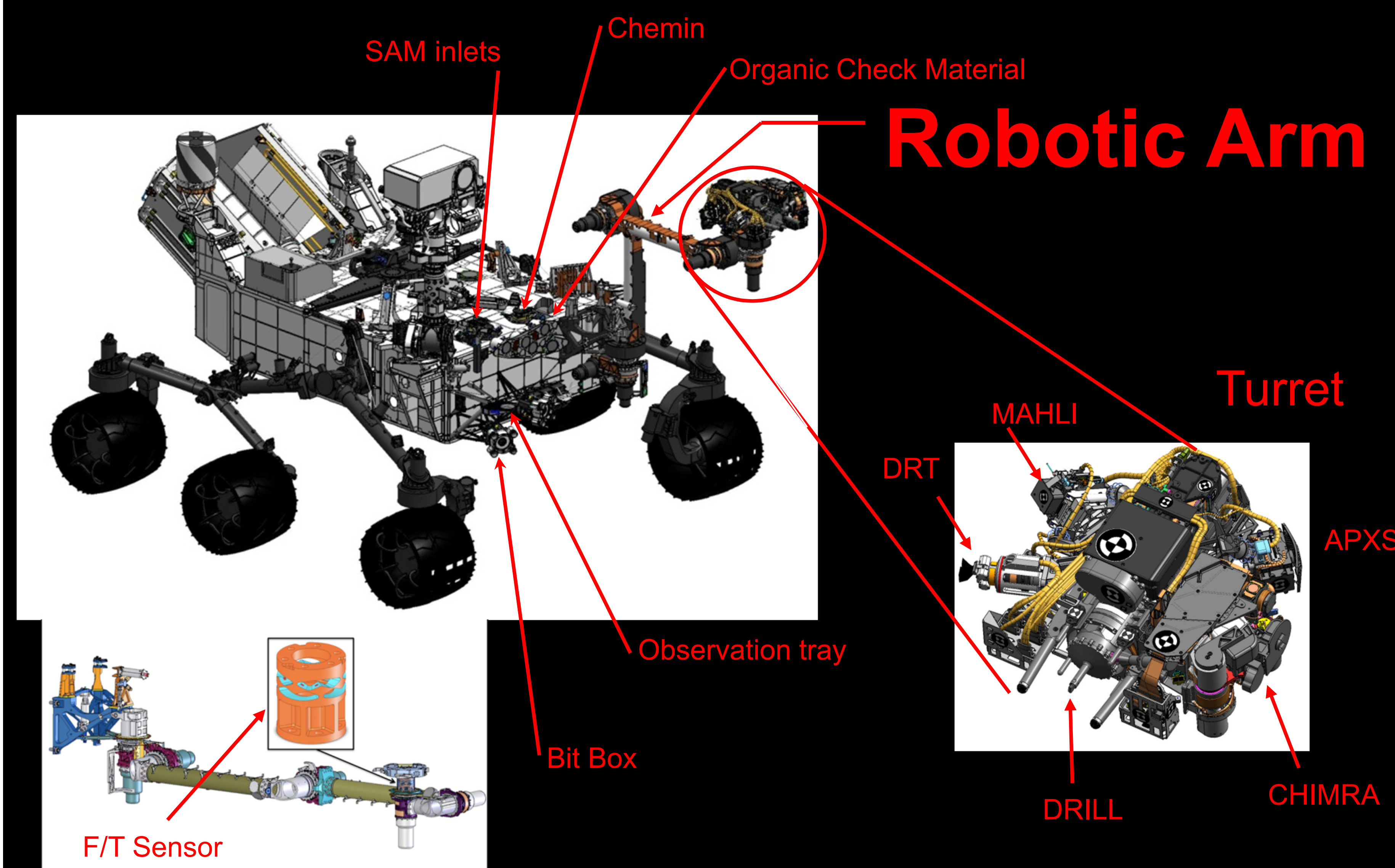
MARDI - Descent Imager

REMS - Meteorological monitoring

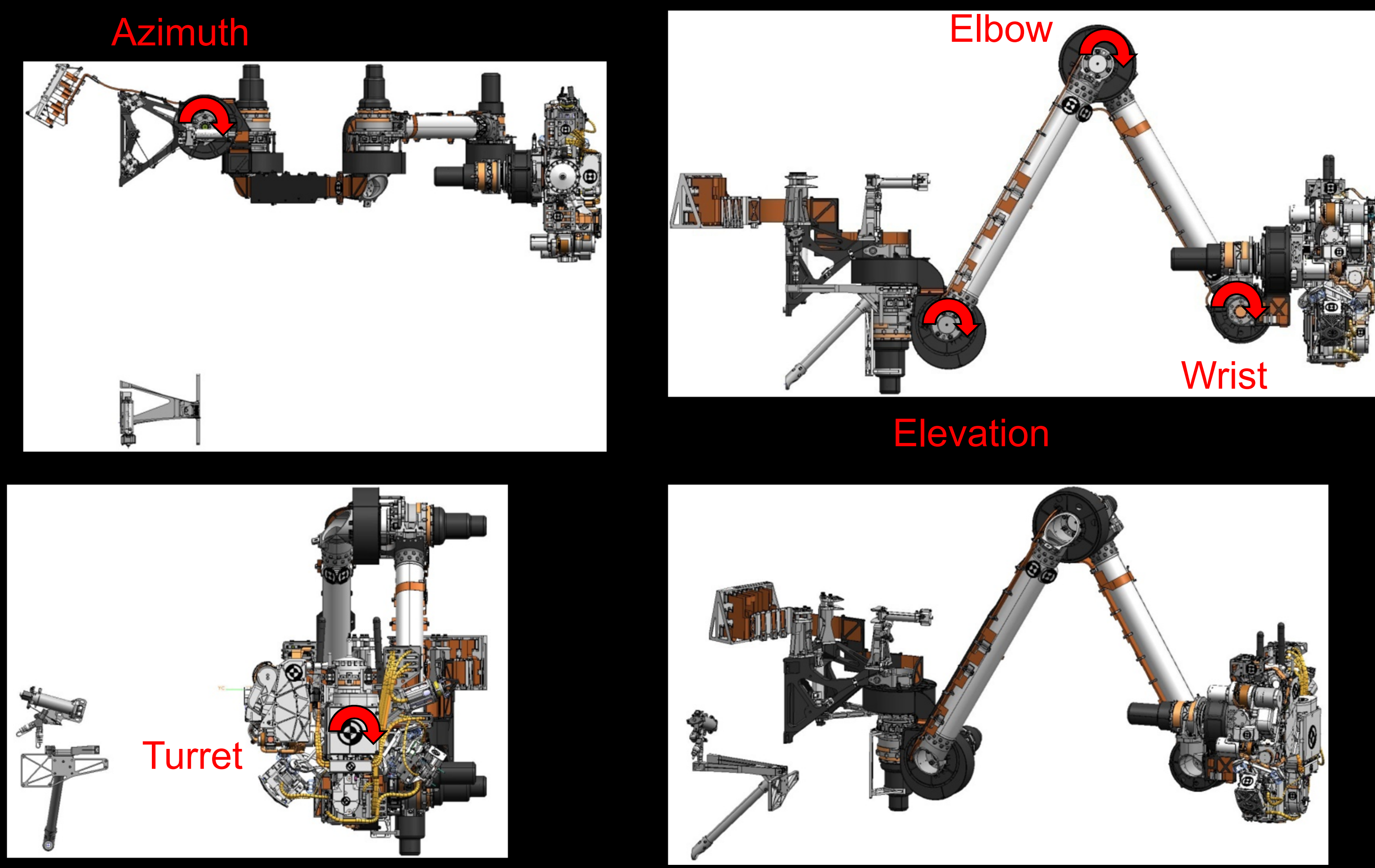
RAD - Surface Radiation Flux Monitor (future human health & safety)

DAN - Neutron Backscatter subsurface hydrogen (water/ice) detection

Sample Acquisition/ Sample Handling System (SA/SPaH)



Robotic Arm



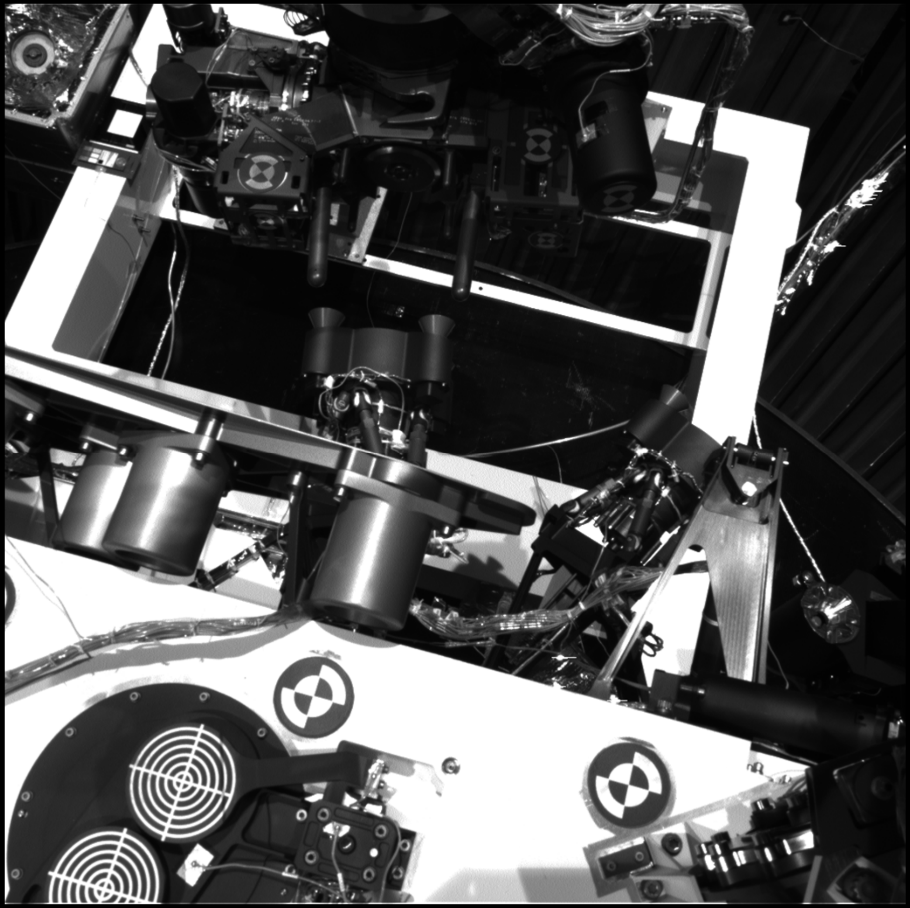
5 Degrees-of-Freedom (DOF) - Positive Dir of Rotation Shown

Robotic Arm Sample Acquisition

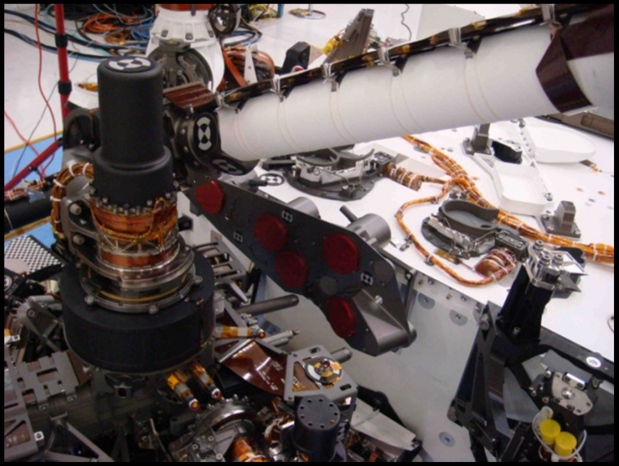
Preload Testing

Scooping

Robotic Arm Testing

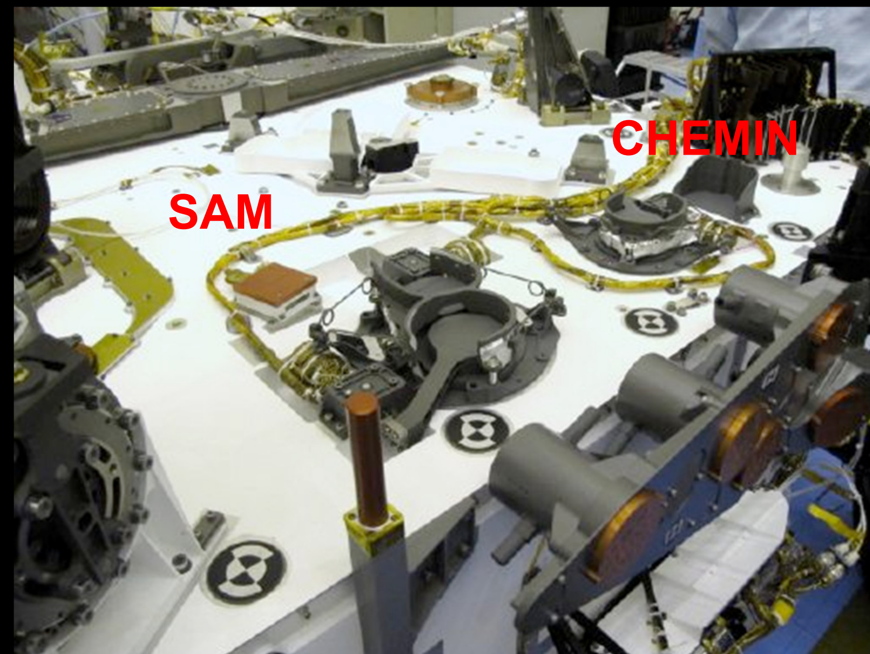


Drill Bit Exchange

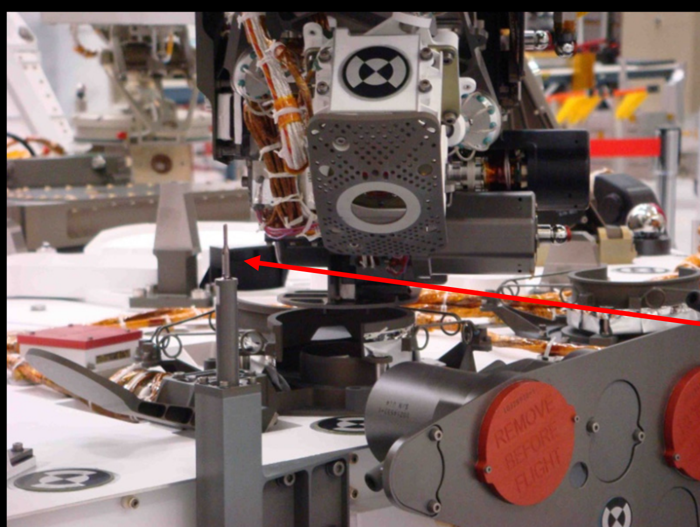


OCM Acquisition

Sample Playground and Robustness Widgets

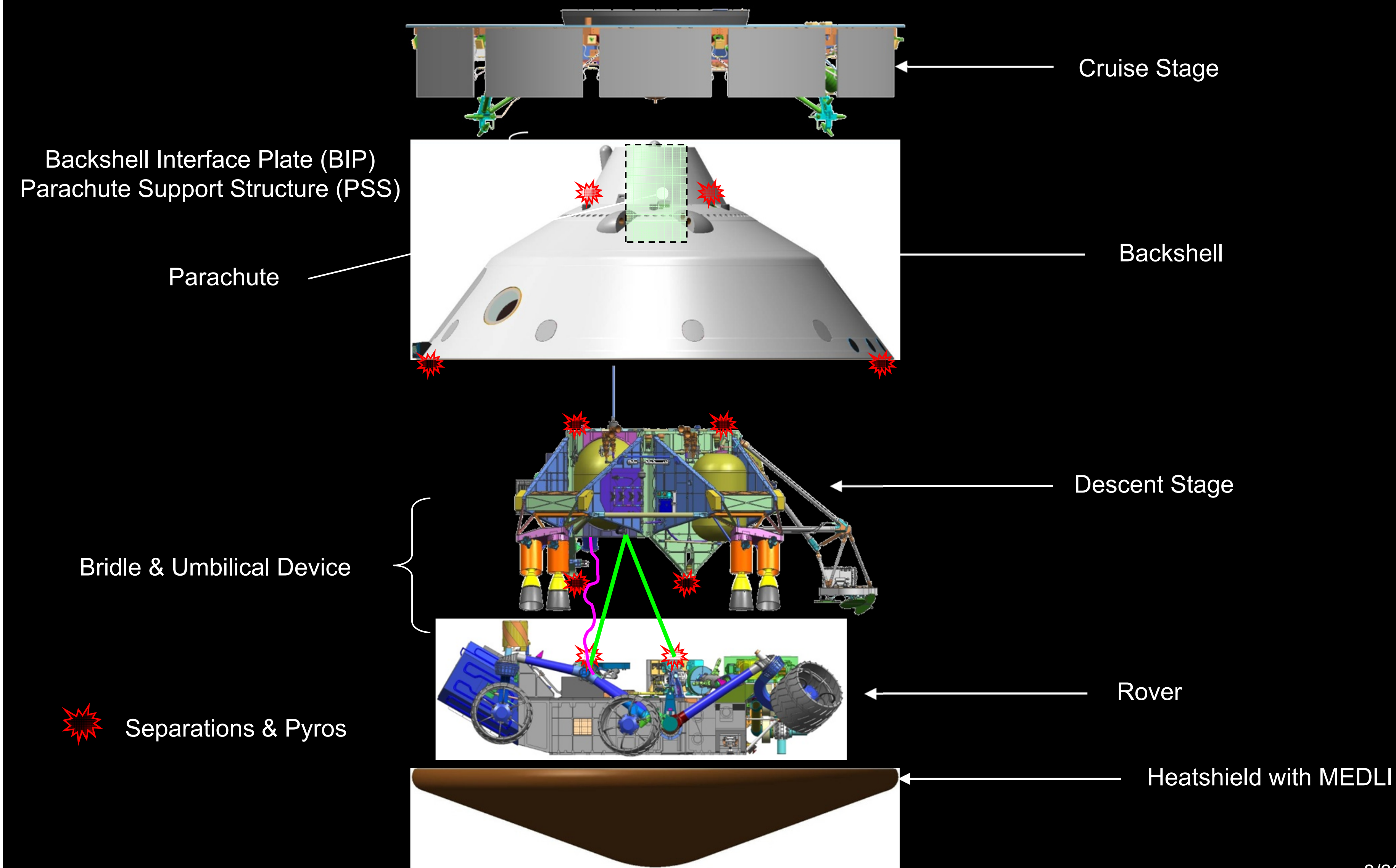


Wind Guards



Pokers

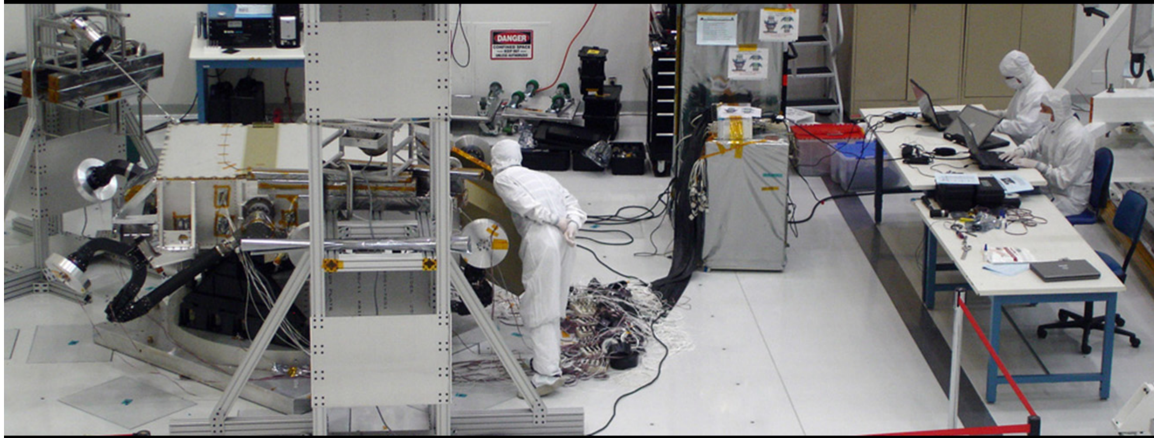
MSL Spacecraft Major Elements



8/30/2012

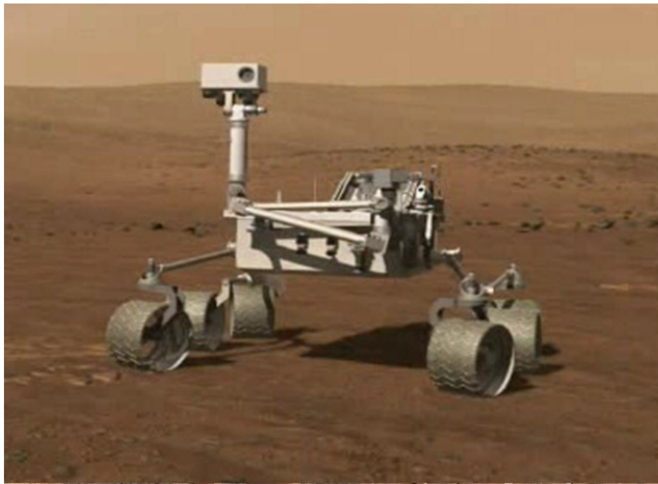
MSL Flight System Development

scheduled for launch in Oct 2011



2011Mars Science Laboratory

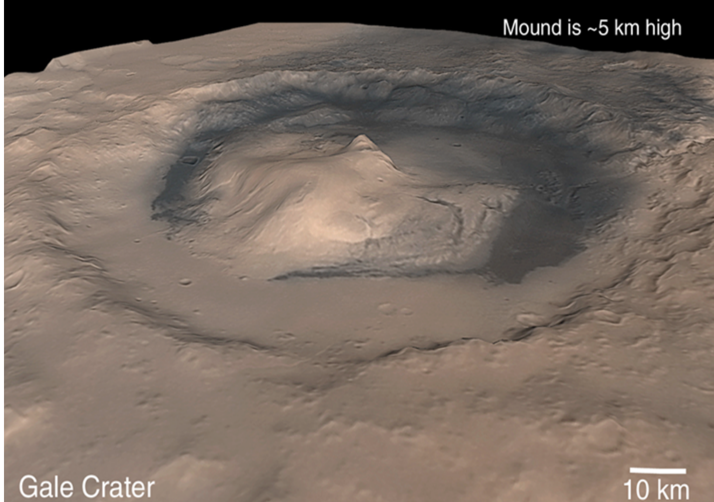
Robotics contributions



MSL on Mars (artist rendering)

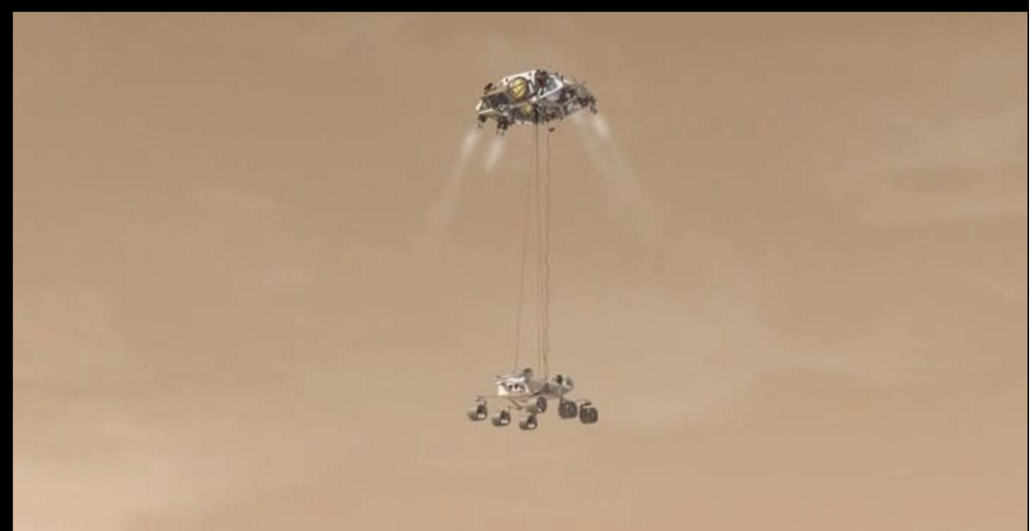
1. All MER technology
2. Improvements on MER baseline in all areas.
3. Simulation for Entry, Descent, and Landing (EDL) mission analysis.
4. Design, development, and operations staff.
5. Manipulation, Drilling, Sample Transfer

MSL 'Scarecrow' Mobility Test



Gale Crater Landing Site

MSL 'Sky Crane' Landing



Upcoming Mars Missions

Possible Future…

2018 Mars Sample Collection and Return

Thank you. Questions?