The Phoenix Mission: the First Arctic Explorer on Mars

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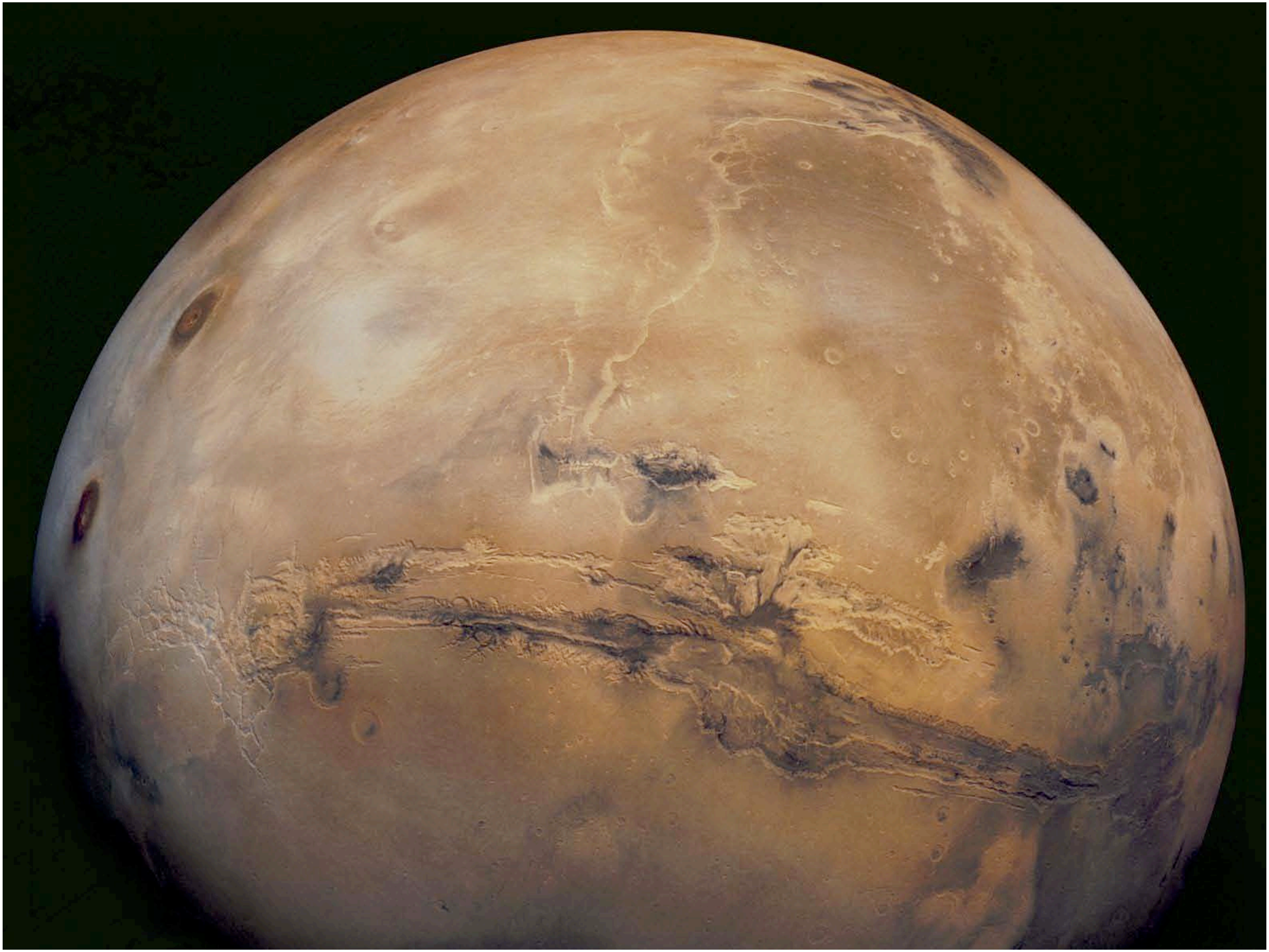
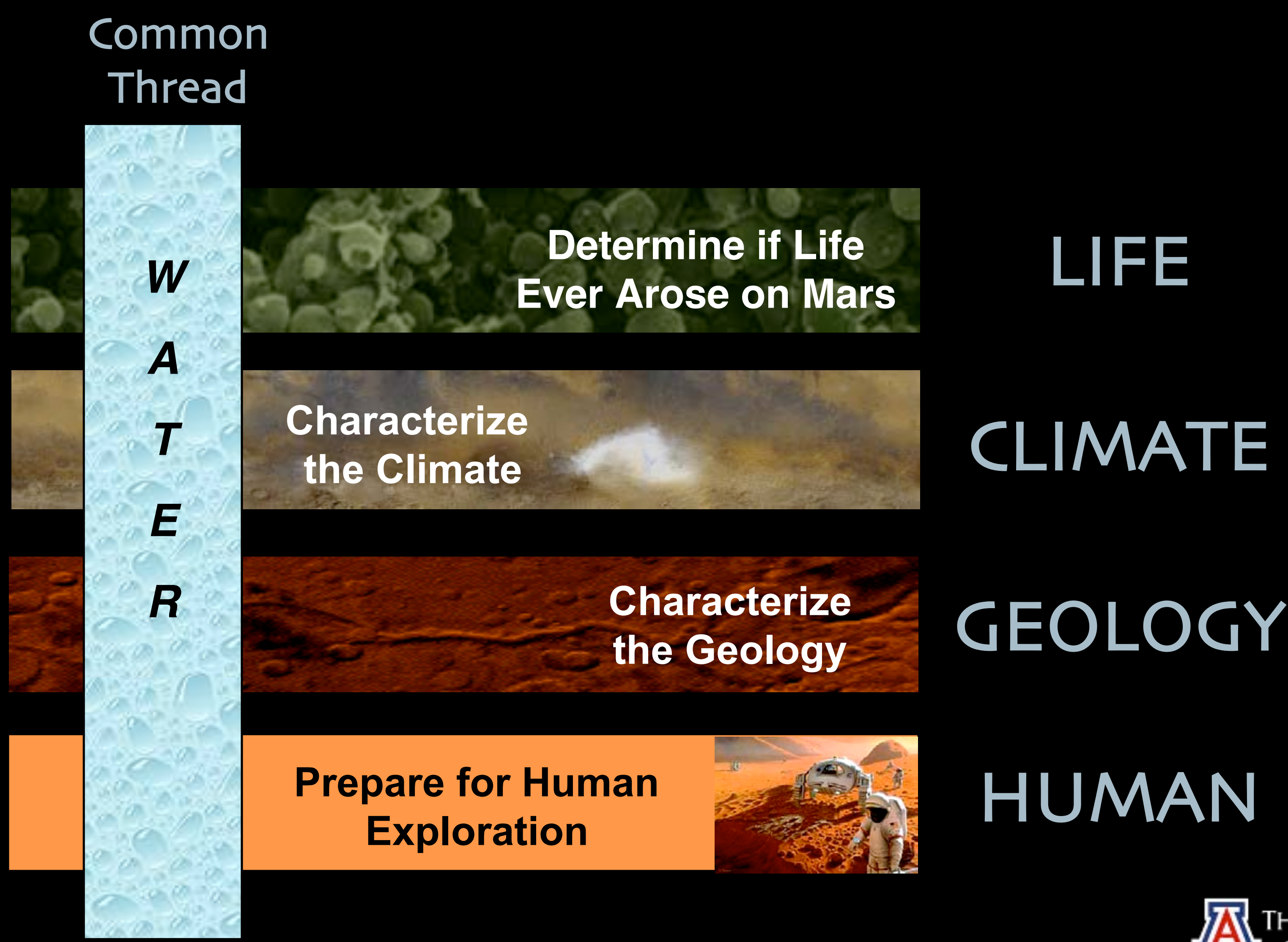
THE UNIVERSITY OF ARIZONA.

Lunar and Planetary Laboratory



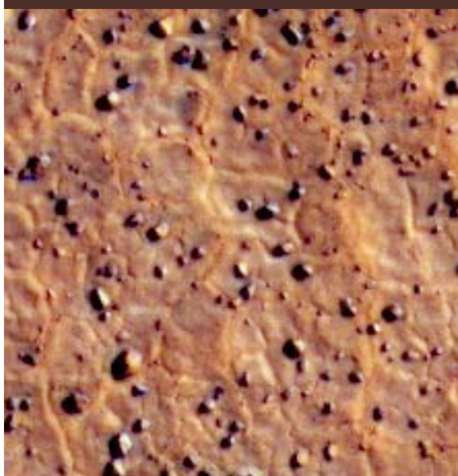
NASA Strategy "Follow the Water"

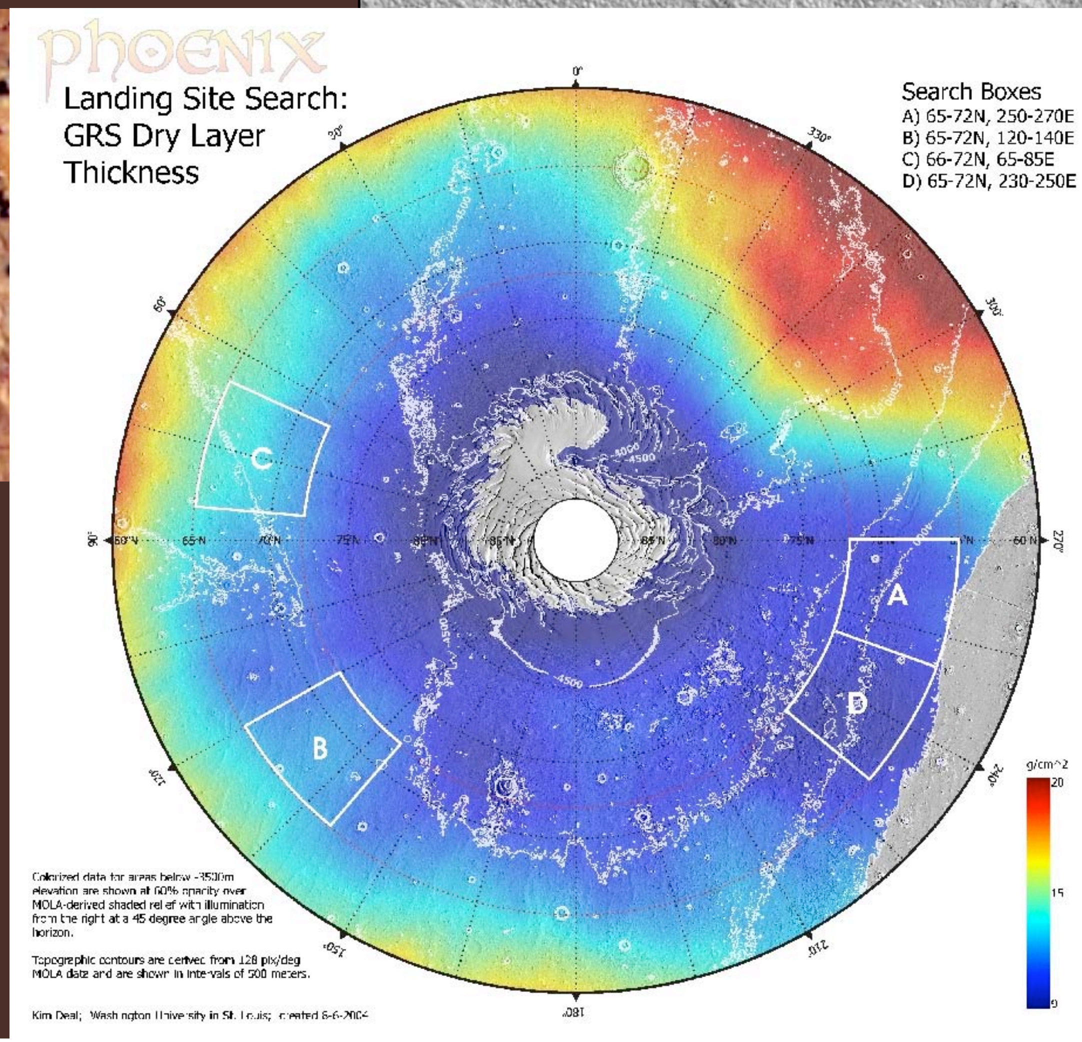


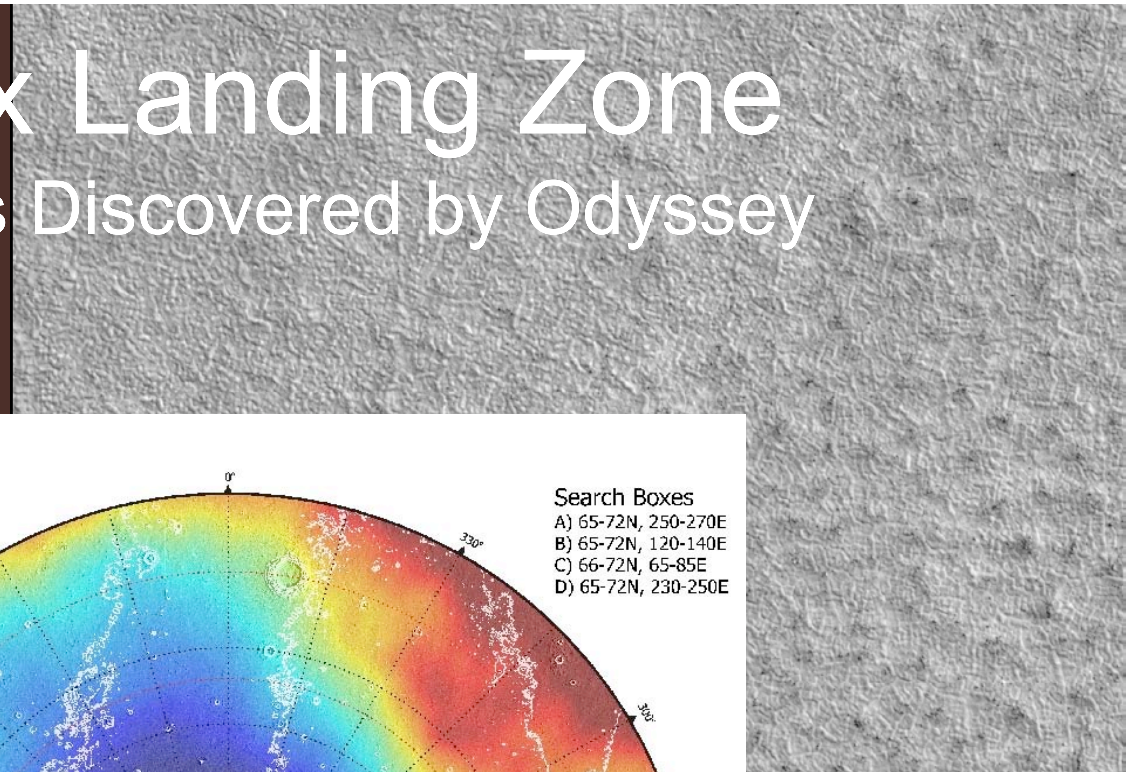
Phoenix Landing Zone

on Ice Fields Discovered by Odyssey

Region B, too rocky

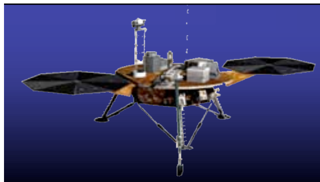






Region D,

Just right



The Big Questions

What happened to the Martian water?

Phoenix will be the first mission to touch and examine water on Mars

Is there biological potenti the northern polar region Mars?

Three components necessary:

Water ➔ Did the ice melt?

Food ➔ Nutrients and organics

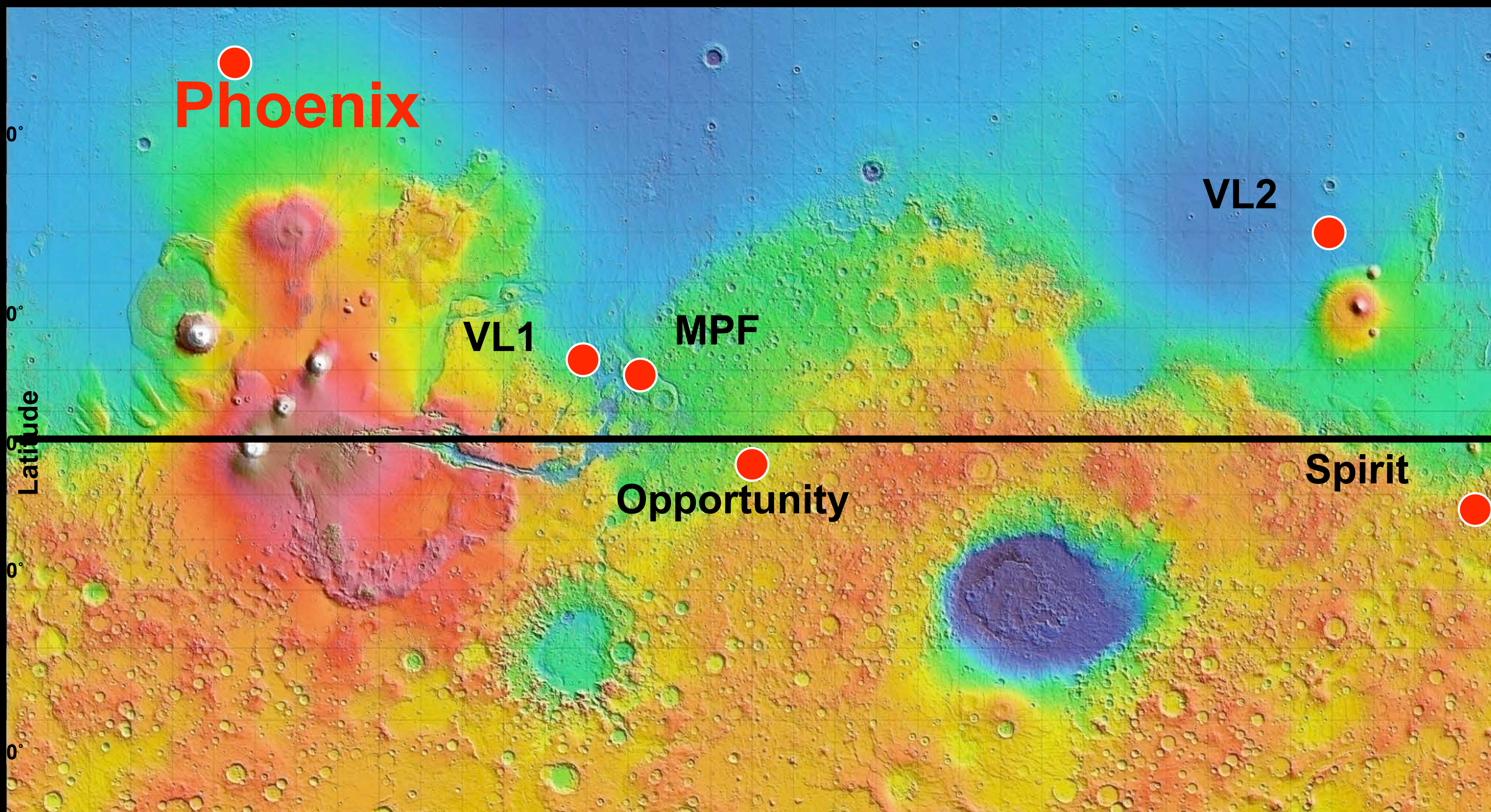
Energy ➔ Solar or chemical

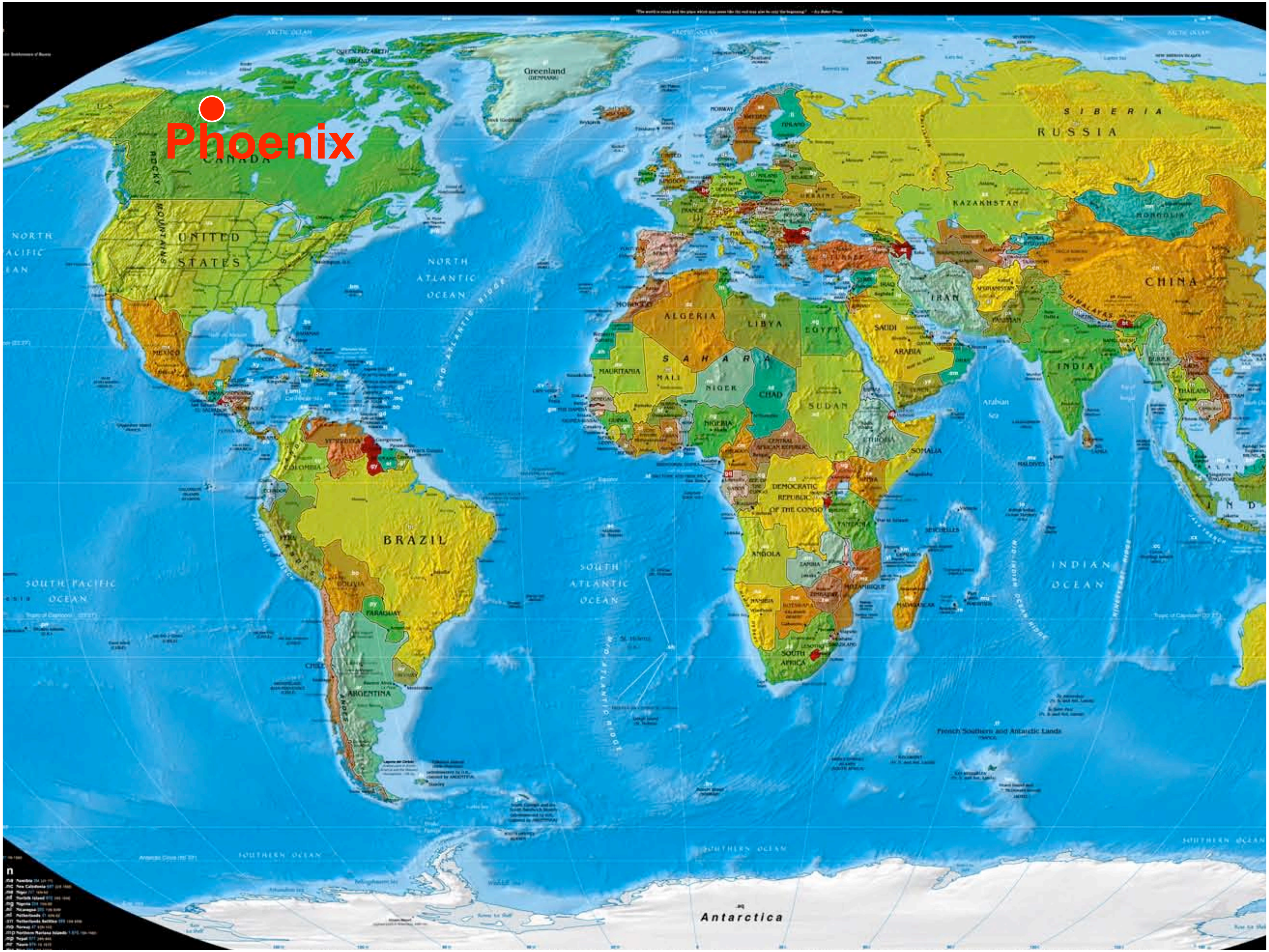
Do the poles indicate glob climate change?

Global climate change is dominated by polar processes

Ancient Mars?

Phoenix Landing Site Is Much Farther North Relative to the Other Landers



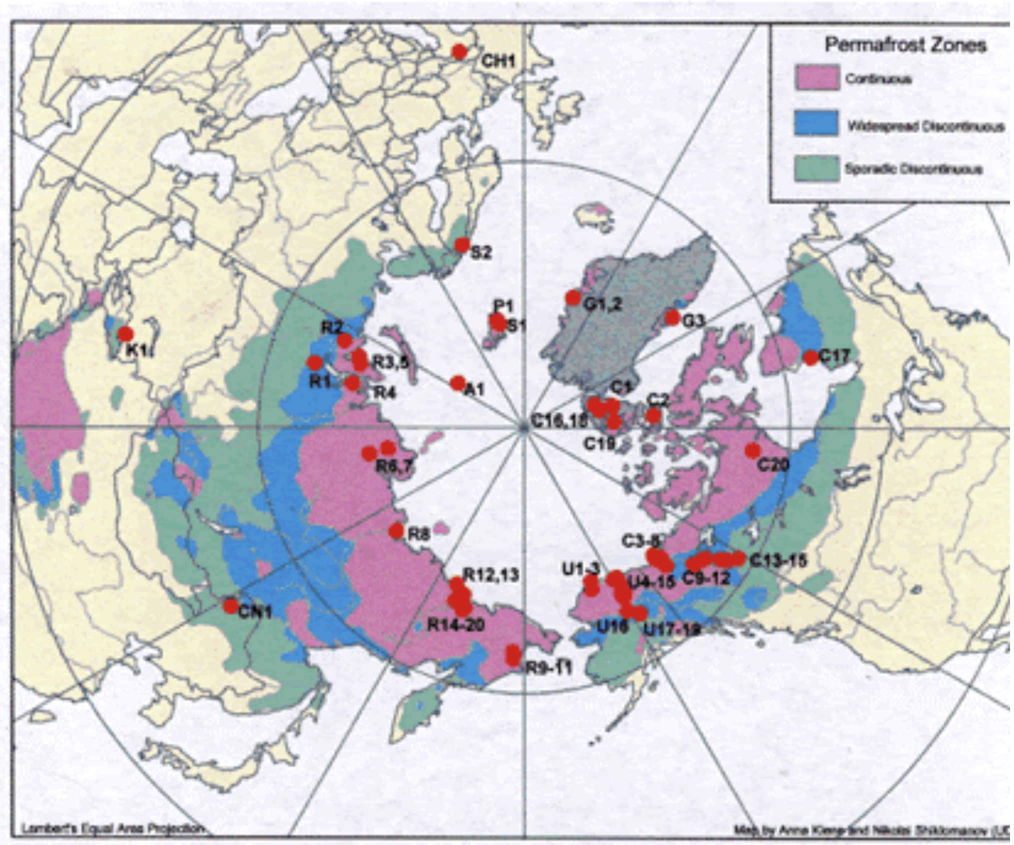


Phoenix
Greenland
(DENMARK)
CANADA
ROCKY MOUNTAINS
UNITED STATES
MEXICO
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
SOUTH PACIFIC OCEAN
INDIAN OCEAN
SIBERIA
RUSSIA
KAZAKHSTAN
MONGOLIA
CHINA
INDIA
IRAN
SAUDI ARABIA
ALGERIA
LIBYA
EGYPT
SAHARA
MAURITANIA
MALI
NIGER
CHAD
SUDAN
NIGERIA
DEMOCRATIC REPUBLIC OF THE CONGO
ANGOLA
SOUTH AFRICA
SOMALIA
MADAGASCAR
COLOMBIA
BRAZIL
BOLIVIA
PARAGUAY
ARGENTINA
French Southern and Antarctic Lands
Antarctica

Permafrost

Compare to the Earth

- 20-25% of terrestrial environments
- Different geological eras yield different layers of different age, 20,000 to 3 million yrs
- A selective environment:
  1) Long-term freezing
  2) Low water activity
  3) Back ground ionizing radiation

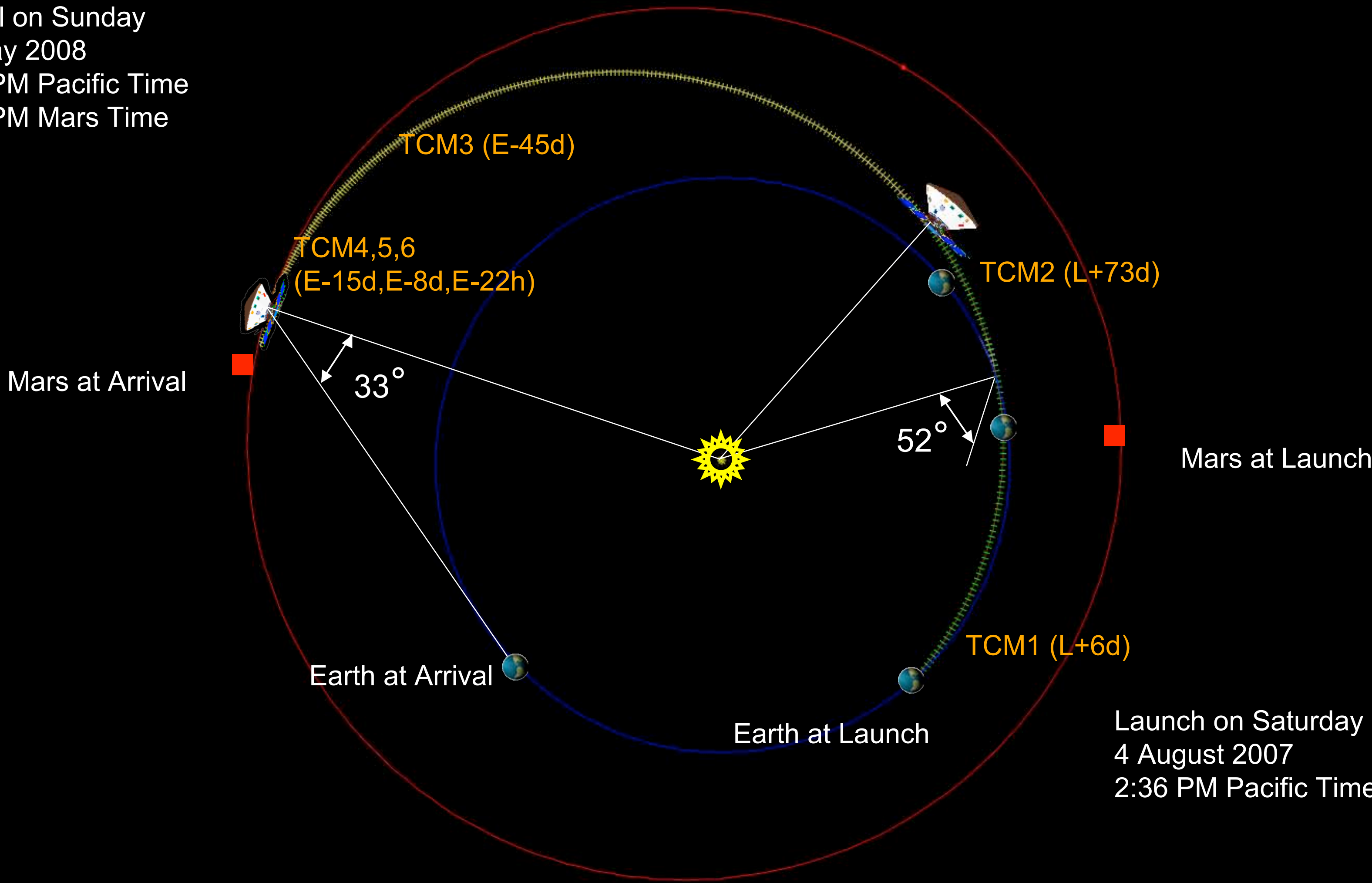



August 4, 2007
USAF
ULA


The Phoenix
Bird has
Risen

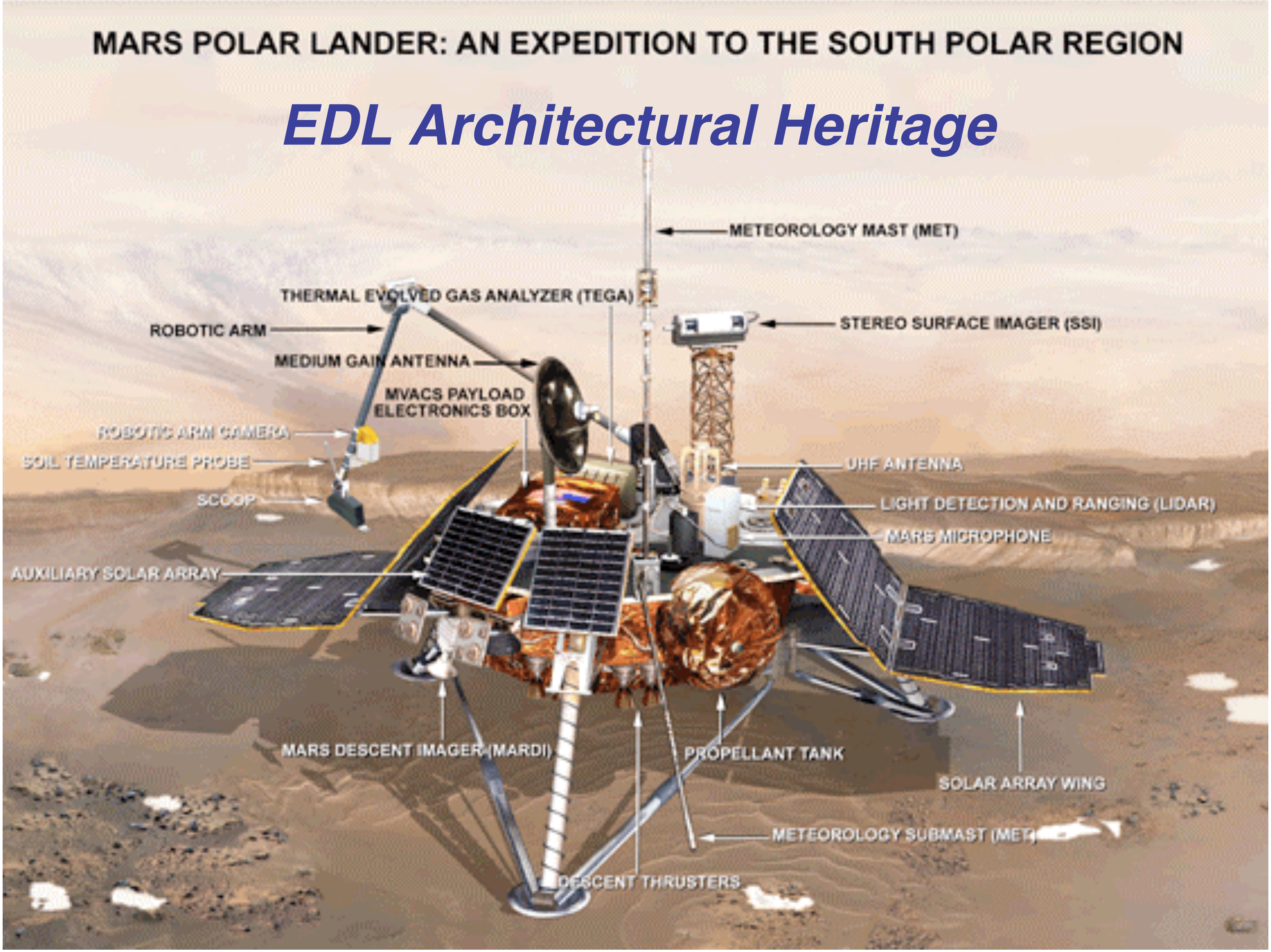
Cruise Trajectory

Arrival on Sunday
25 May 2008
4:36 PM Pacific Time
4:18 PM Mars Time



Launch on Saturday
4 August 2007
2:36 PM Pacific Time

EDL Architectural Heritage



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Phoenix

Project RB/RTF Matrix

	Issue	MPLF RB	'01 RTF	Comments
A	Continuous Communications During EDL	1	1	EDL Communications is baseline.
B	Add LGA Transmit Antenna (Landed Ops)	2	2	Originally in baseline, removed after significant study (Feb. 2005).
C	Ionization Breakdown Tests of MGA / UHF in landed 6 Torr Environment	3		Performed UHF breakdown tests.
D	Conduct End -To-End UHF Verification: to 01 Orbiter and MGS	4		Tests were conducted with ODY and MRO test sets. In addition, MER as a surrogate using CE -505 ran tests with MRO and ODY
E	Satisfactory Propulsion H/W Temps; A. tank outlet & line temps above hydrazine freeze point, B. ensure acceptable op temps for thruster inlet manifolds & catalyst beds, C. monitor propellant valve temps during flight.	5,6,7		Propulsion changes already incorporated into '01 design via RRSs. Additional mitigations include venting of tank pressuring after landing in case of freeze / thaw concern.
F	Limit Propellant Migration between tanks to maintain acceptable levels during All Mission Phases	8	13	Implemented latch valve isolation to assure no migration issues.
G	Perform a high fidelity closed Loop Hot Fire Test of Prop System with at least 3 live engines and flight like plumbing support structure.	9	19	Successful HFTB completed. Models verified.
H	Evaluate Water hammer Effect on thrusters, structures, and controls due to 100% Duty Cycle Thrusters	10	19	Water hammer tests completed. Models verified.
I	Conduct Plume -Soil Interaction Analysis or Test	11	26	Completed and incorporated into all analysis.
J	Ensure compliance with FSW Review and Test Procedures	12		Already part of '01 baseline. Documented in MSP01 Software Development Plan.

	Issue	MPLF RB	'01 RTF	Comments
K	Fix Known Software Problems	13		Completed. Active SPR process in place.
L	Fix Post -Landing Fault Recovery Algorithm/Sequences	14	15	MSP01 fixed these items per SPR FS1898 and FS1886.
M	Validate Lander CG Properties, Ensure Tight Constraints on Mass Properties to Meet CG Offset Requirements	15	13	Significant wet and dry spin testing verified CG properties.
N	Beef Up Propulsion Line Support Structure	16		Support structure beefed up as part of '01 baseline. Additional modifications identified and implemented after HFTB.
O	Perform Heatshield ATLO system first - motion Separation Test	17		Two separation tests were conducted during ATLO.
P	Ensure Thorough Analysis, Simulation, & Test the control system has adequate authority & stability Margins	18		HFTB, ETL, Flight Software into POST
Q	Resolve Small Forces Discrepancies	19	8, 10	Additional calibrations & Delta DOR is documented in Mission Plan and BRM. Thorough thruster calibration program has been conducted during cruise.
R	Improve TCM 5 Flexibility for improved landing site control	20		Mission Design supports flexibility within landing region. End game strategy for Phoenix significantly robust with full landing site imaging.
S	Modify Radar to Reduce Sensitivity to Slopes	21	16	Upgraded Radar has been developed and extensive EDL tiger team effort retired all know risks buttressed with thorough test program.
T	Review Key EDL Triggers to Improve Robustness	22	15	Conducted EDL subphase reviews focusing on triggers. Modified parachute and touchdown triggers to improve robustness.

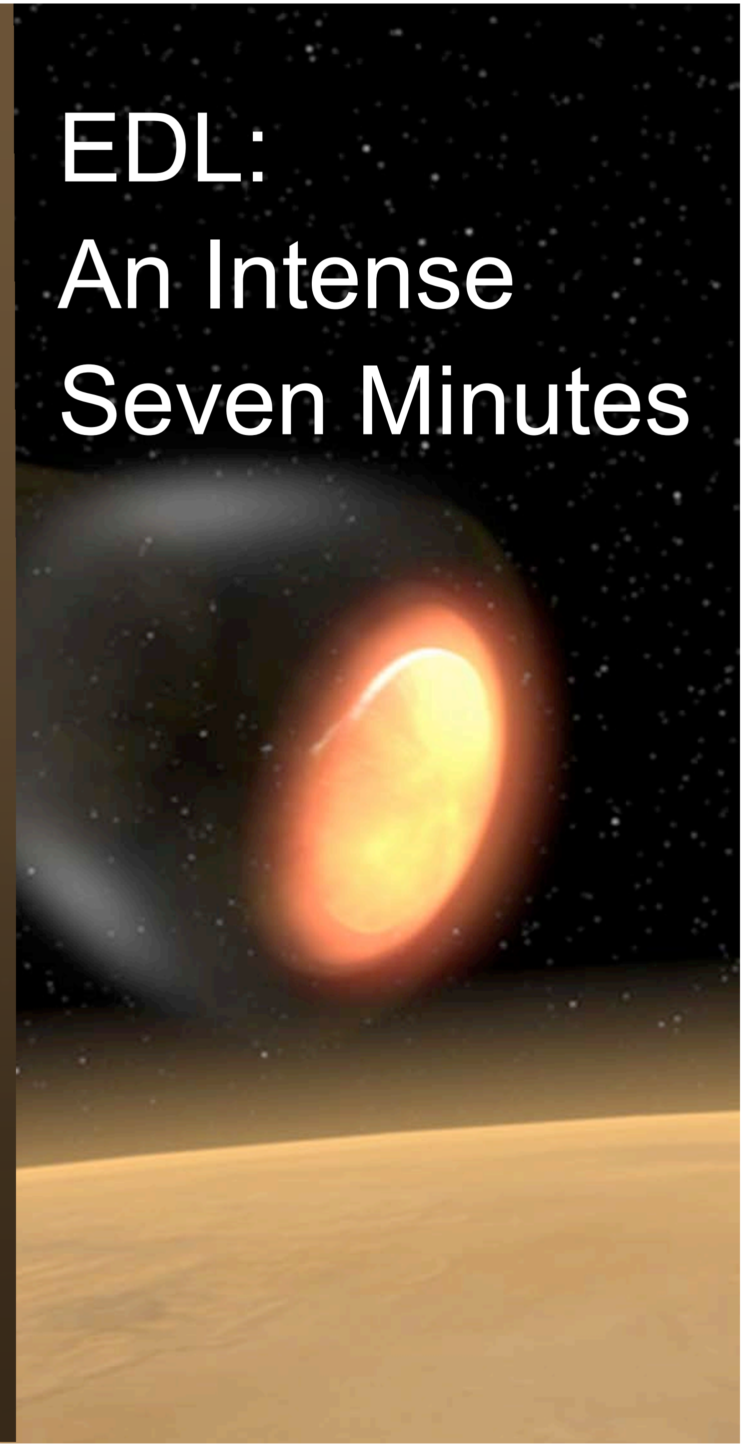
	Issue	MPLF RB	'01 RTF	Comments
U	Confirm Acceptable Probability of Chute Draping over Lander	23		Implemented Backshell Avoidance Maneuver (BAM)
V	Redesign EDL Terminal Descent Nav Filters		3	Accomplished as a result of radar performance Tiger Team effort
W	LGA 4 Pi Steradian X -Band Transmit Capability in Cruise		4	LGA part of the baseline.
X	Steerable X -Band MGA for Surface Operations		5	Originally in baseline, removed after significant study Feb. 2005. (Same as item B)
Y	Heaters for IMU to Allow Gyrocompass Repeat		6	Deletion of steerable X -Band has removed gyrocompassing from list of mission critical functions. Now is info only. (Related to item B)
Z	Heaters for PIU to Eliminate Time Constraint on Landed Deployments		7	Added heaters to work this issue. Eliminated potential flaw in MFB architecture
ZA	Combined with Q			N/A
ZB	Rework TLM SW to Provide Detailed Channelized Instrument TLM.		9	Rejected; MPL & ODY showed current system is sufficient, payload needs are being met. Not related to EDL success.
ZC	Fix Star Camera Stray Light Issue		11	Baseline is different Star Tracker. Same as MRO
ZD	New Aeromaneuvering Technology for '01		12	Aeromaneuvering no longer part of design. Landing site does not require it.
ZE	Combined with M			N/A

Comply	Addressed though separate study

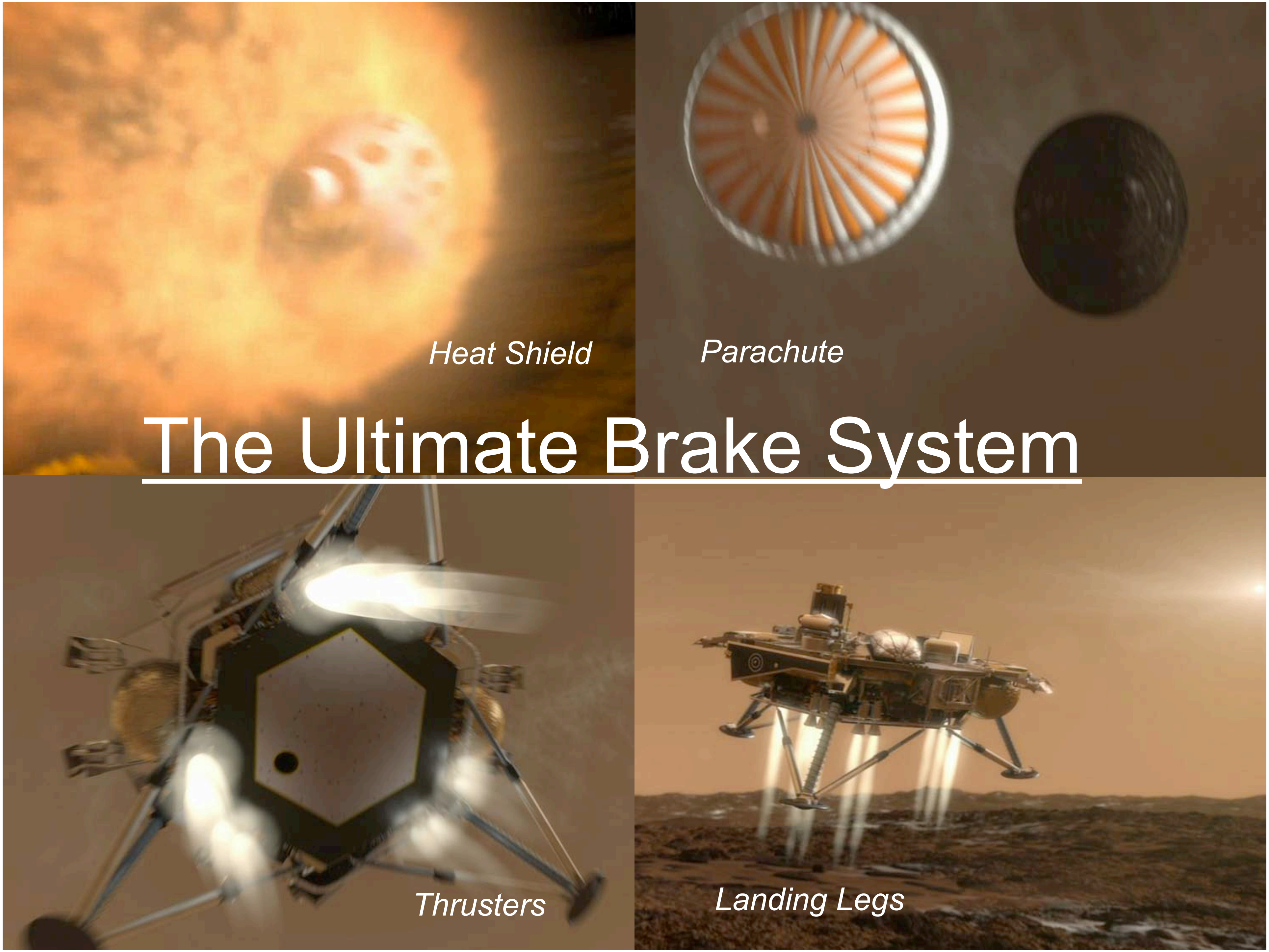
	Issue	MPLF RB	'01 RTF	Comments
ZF	Implement Active Hazard Avoidance		14	Evaluation of complexity risk vs. landing site risk resulted in not including in baseline. Mitigated, to some extent, with the extensive coverage of our landing ellipse by HiRISE
ZG	Combined with S			N/A
ZH	Formal FSW IV&V		17	West Virginia IV&V engaged
ZI	Combined with O			N/A
ZJ	Combined with H & G			N/A
ZK	Ensure RF Compatibility between Radar and EDL Comm System		20	Individual component EMI tests conducted, system level test was also conducted and passed.
ZL	Add flight data recorder (black box)		21	Intent covered by EDL comm.
ZM	Improve Robustness in Gyrocompassing/ Lander Attitude Determination Algorithm		22	Deletion of steerable X -Band has removed gyrocompassing from list of mission critical functions. Now is info only. (Related to item B)
ZN	Improve Operability of STL via Checkpoint Restart		23	ODY showed current system is sufficient.
ZO	Replace Command / Seq / Block / Config File FSW Architecture w/ Command / Seq / Parameter Visible to Ground		24	ODY showed current system is sufficient. S/W style concern.
ZP	Reduce Separation Guide Rail Snags		25	'01 baseline has no guide rails. Analysis shows robust margins.

EDL: An Intense Seven Minutes

- 24 hours out the S/C is traveling at speed of 6,100 mph relative to Mars. During the course of the day, the speed steadily increases
- Deep inside the Mars gravity well, in the last two hours before entry, speed zooms to ~12,600 mph!!
- Entry is an altitude of ~130 km (80 miles) above the surface.
- Mass at entry is slightly over 600 kg. (1,320 lbs)
- During the eventful/fateful next seven minutes, the EDL system must take four zeros off the vehicle speed to prevent an interplanetary train wreck



The Ultimate Brake System



Cruise Stage Separation: 4:24 pm PST

- Seven minutes before entry, the entry vehicle separates from the cruise stage
  - Twelve pyro firings break up six separation nuts

Separation Connector Force Margin

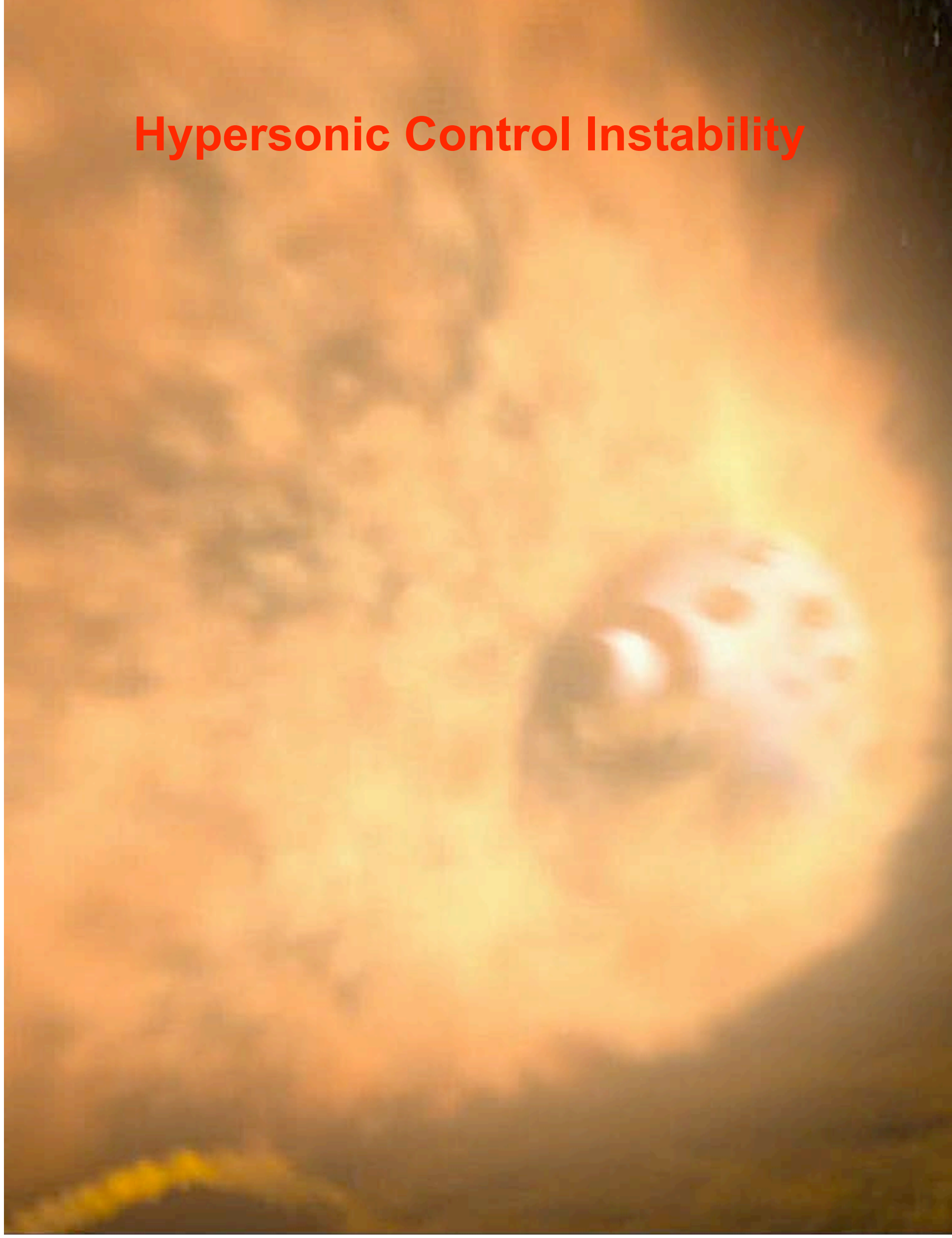
- Vehicle power is now supplied by its internal batteries

- Thirty seconds after separation the entry vehicle conducts an autonomous slew to the entry attitude

Communication now begins with Odyssey and MRO — carrier only for the next five minutes and then 8 Kb/s two minutes before entry

Cruise Stage Re-contact!

The Hypersonic Phase

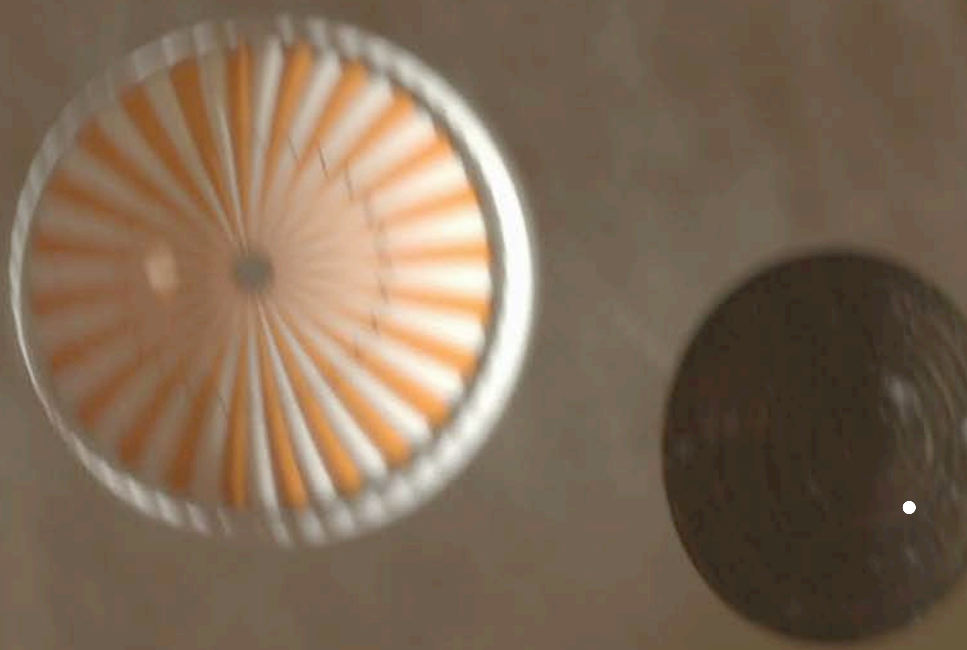


- **Even though Mars' atmosphere is thin (1% of Earth), we use it in the first 4 minutes of entry to dissipate ~94% of the entry vehicle energy and slow it down from ~13,000 mph to ~1,100 mph.**

- **As the vehicle blazes through the atmosphere, the surface of the heat shield reaches a peak temperature of 1,400^{0}C (~ 2,600^{0}F).**

The Parachute

Parachute Loads



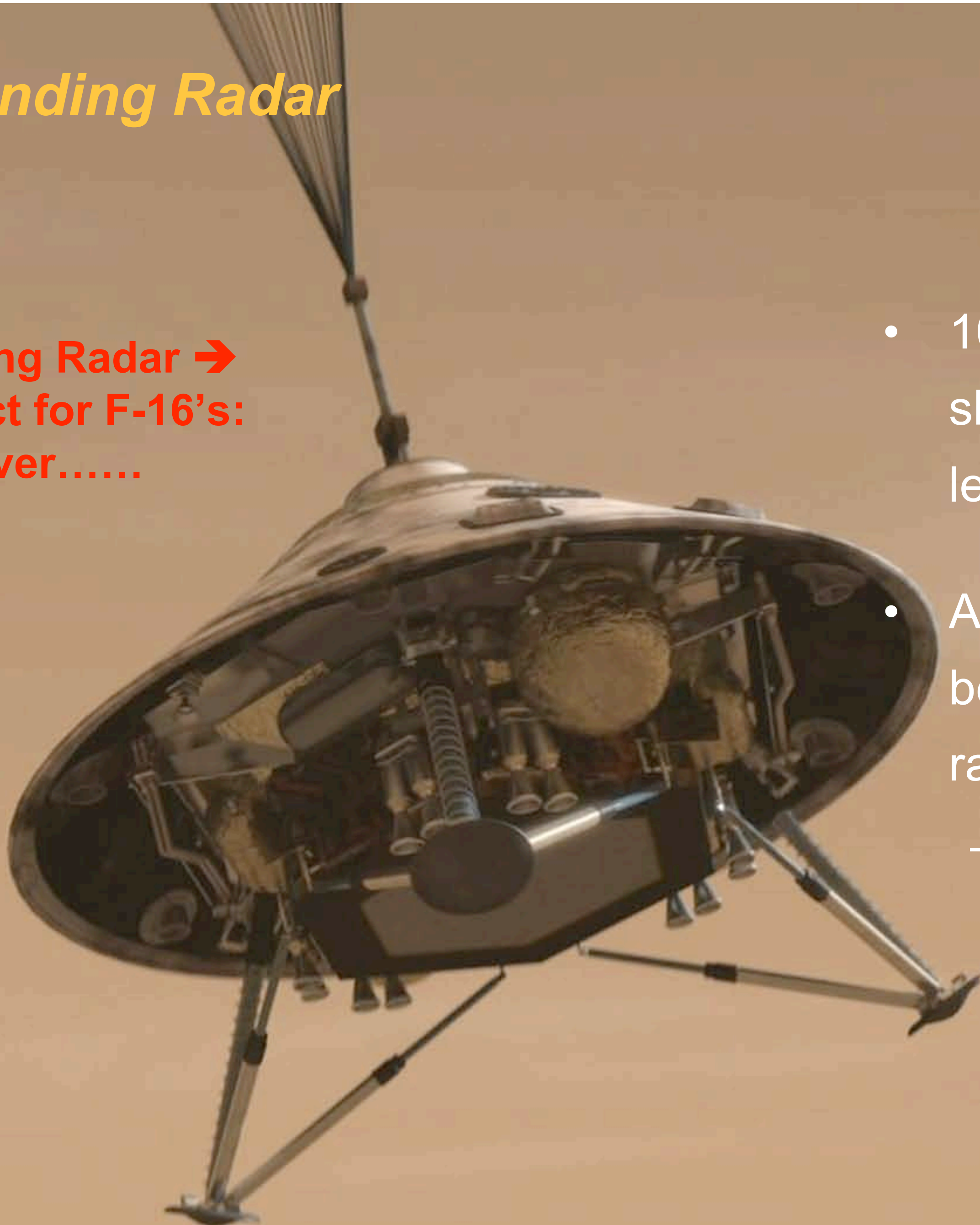
- Still traveling at 1,100 mph but now only 40,000 feet off the surface, a mortar punches through a plate on the back shell, deploying a supersonic chute (Mach 1.5). The timing is controlled by an IMU with a timer as a backup.
- Communication rate to Odyssey and MRO changes to 32 Kb/s.
- It is now ~3 minutes before landing.

Heat Shield Separation

15 seconds after the chute deployment, six pyros cut the heat shield loose and a strong spring action pushes it away.

Problems!

Landing Radar



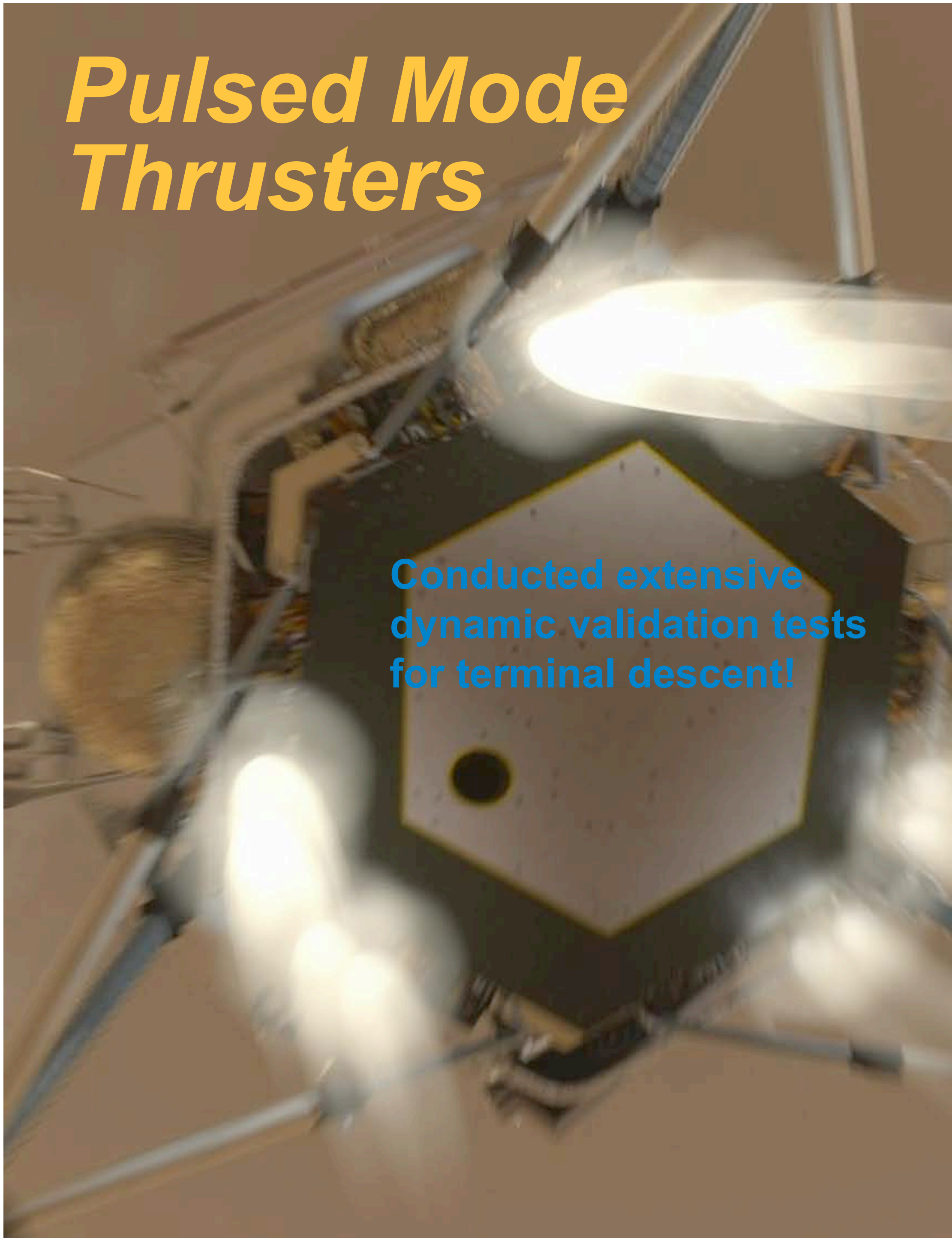
Landing Radar ➔
Perfect for F-16's:
However……

- 10 seconds after heat shield jettison, the landing legs deploy
- At ~3 minutes (160s) before landing, the landing radar activates
  – Acquires the altitude information at ~8,000 feet and three axis Doppler at ~6,000 feet above the surface

Lander Separation

- 37 seconds before landing and at 3,000 feet above the surface, six pyros ignite three explosive nuts which release the lander from the backshell
- The lander is now traveling approximately 120 mph
- The lander will freefall for 0.5 seconds before the thrusters are fired

Pulsed Mode Thrusters



Conducted extensive dynamic validation tests for terminal descent!

- Three seconds after separation, and 34 seconds before touchdown, twelve 68 lb terminal descent thrusters are initiated
- Critical in this time period is interaction between the radar and the ACS system. Altitude knowledge error translate to velocity error
- Phoenix is the first lander since Viking to use thrusting for terminal descent

Touchdown

Carpeted Landing Ellipse with high resolution HiRISE images!

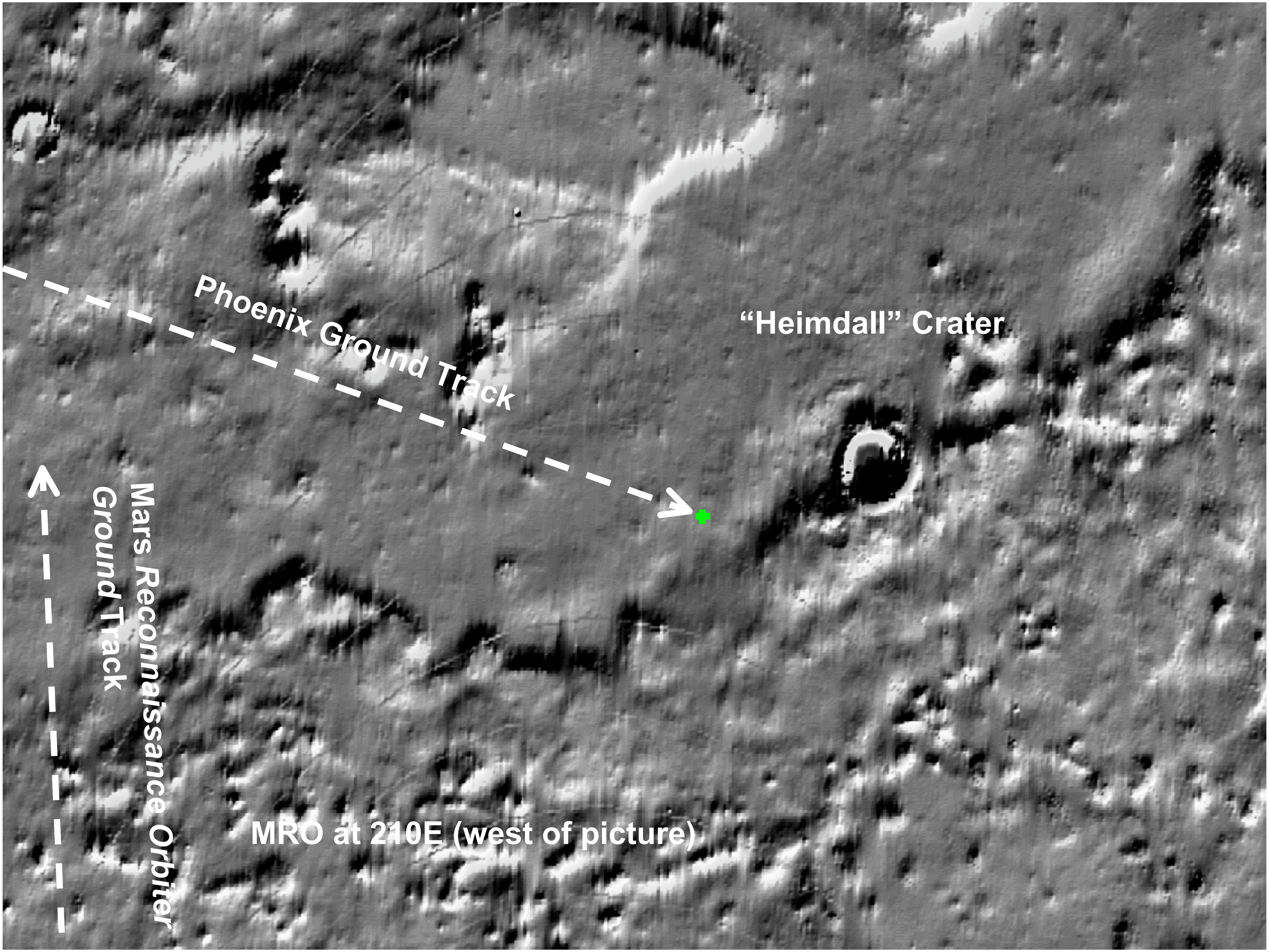
- *Prior to landing, the vehicle 'pirouettes' to establish an east/west orientation of the solar arrays*
- *The lander achieves a constant velocity of 5 mph at approximately 100 feet from the surface*
- *The lander detects the ground with any of three touchdown sensors, terminating the engine thrust*
- *The legs can compress by 6 inches*
- *At touchdown, the mass of the vehicle is now 365kg (approximately 800 pounds)*

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Phoenix

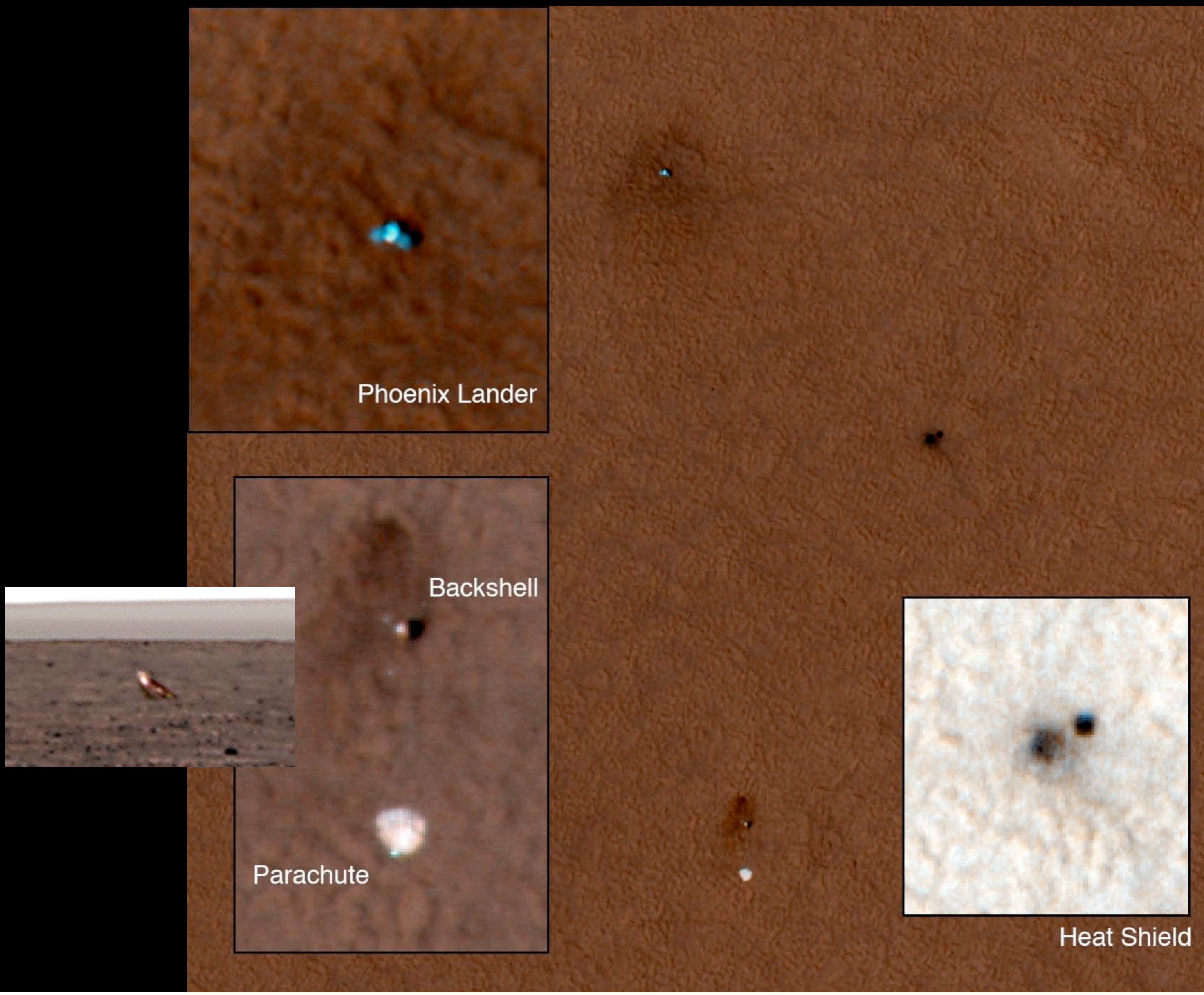
EDL Performance

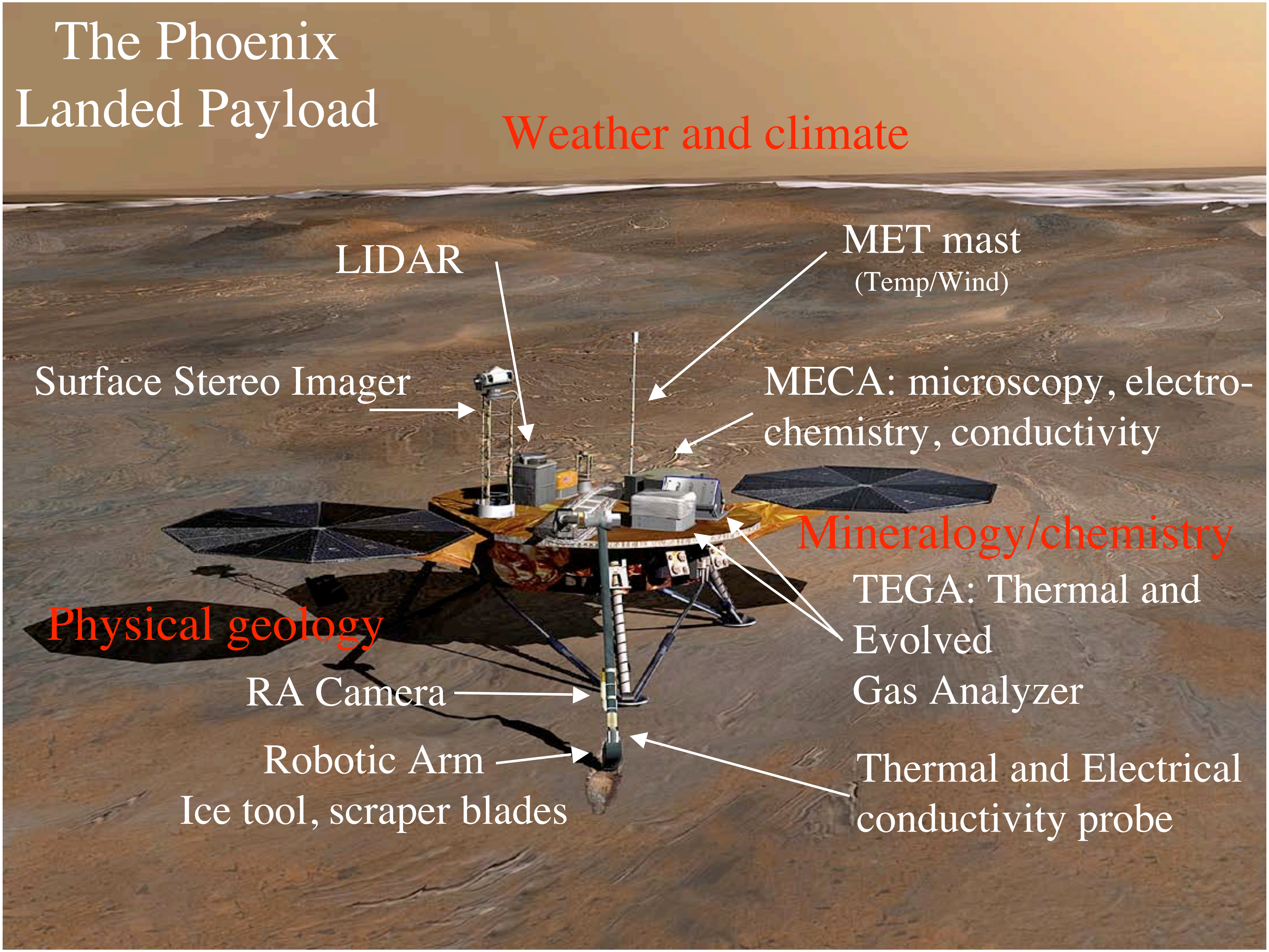
	INFO	DATA	PREDICT	COMMENT
Touchdown	TD Vv (m/s)	2.40	2.40	(req: 2.4 +/-1)
	TD Hv (m/s)	0.15	0.0	(req: < 1.4)
	Tilt (deg, deg)	(0.26, 269.13)	0,0	(rel: vertical, north)
	Lander Azimuth (deg)	-0.68	Arrays Aligned E-W	Dig Area on North
	Latitude (deg north)	68.22	68.25	aerocentric
	Longitude (deg east)	234.30	233.38	
Timeline	Chute Deploy (s)	227.85	221.1	(re: entry time)
	Lander Sep (s)	404.25	398.4	(re: entry time)
	Touchdown (s)	446.25	438.9	(re: entry time)
Surface Ops State	Error Counts	1 FFTfrz, 1FFTdon, 315 ACPM, 531 Radar Reliable	< 800 Radar Reliable Cnts	All explained/expected
	Spacecraft Mode	Nominal	Nominal	
	Battery SOC	91	>90% @ UHF OFF	> 100% @ CSS
	Odyssey Status	Nominal	Nominal	Ready for first Overflight
	MRO Status	Nominal	Nominal	Ready for first Over flight


Phoenix Ground Track
"Heimdall" Crater
Mars Reconnaissance Orbiter
Ground Track
MRO at 210E (west of picture)

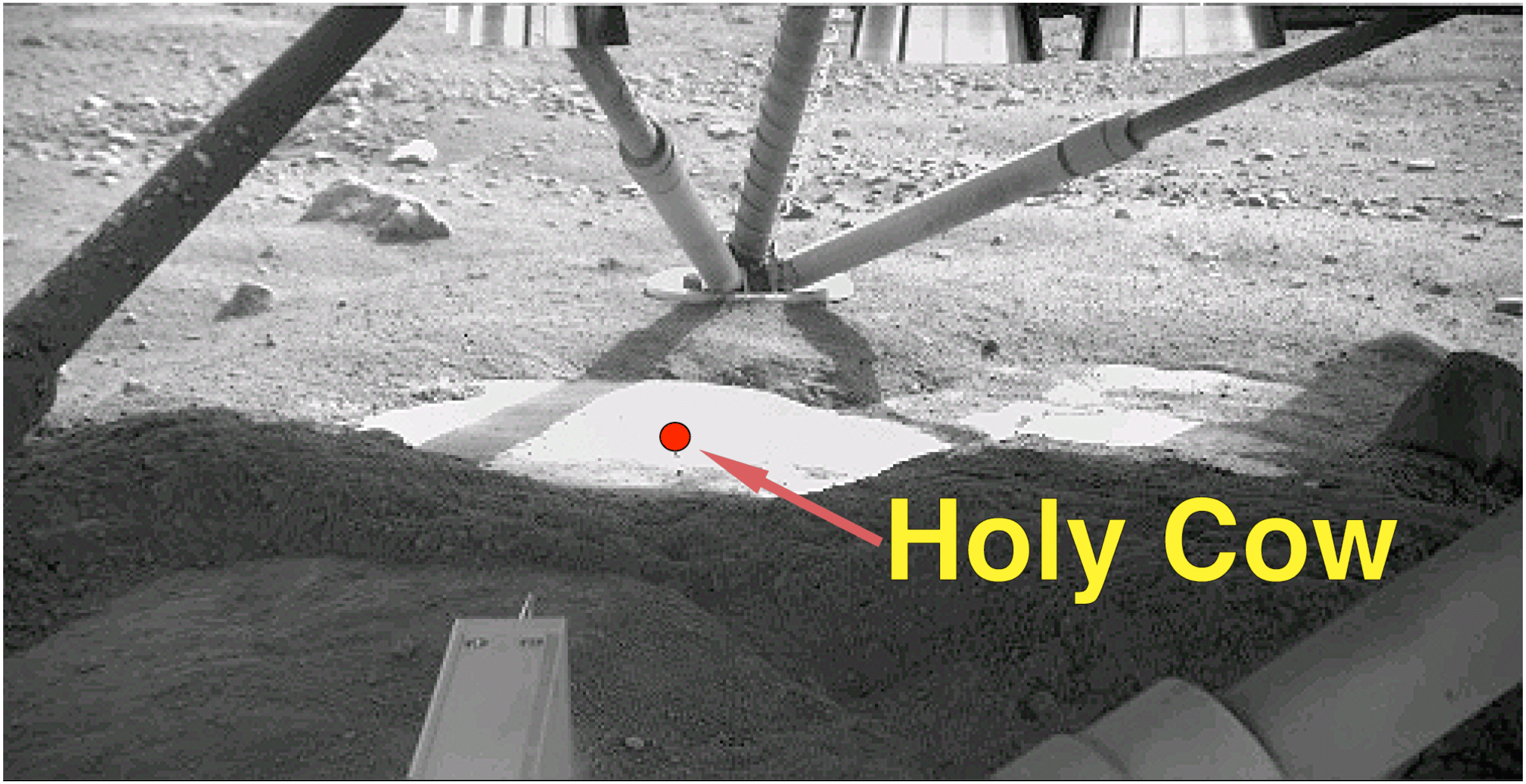
We landed 22 km away from the rim!

Family Portrait



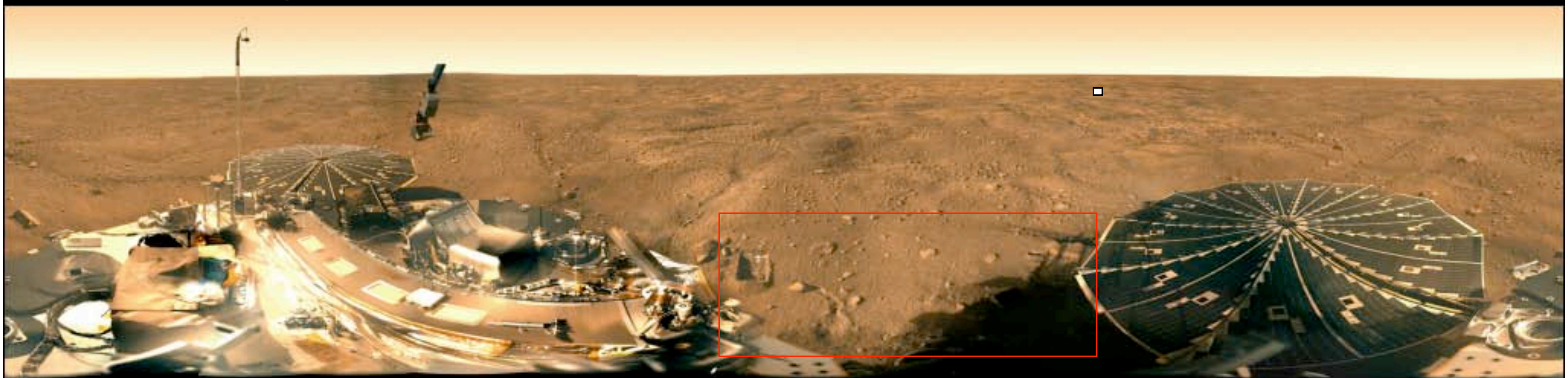

The Phoenix
Landed Payload
Weather and climate
LIDAR
MET mast
(Temp/Wind)
Surface Stereo Imager
MECA: microscopy, electro-
chemistry, conductivity
Mineralogy/chemistry
TEGA: Thermal and
Evolved
Gas Analyzer
Physical geology
RA Camera
Robotic Arm
Ice tool, scraper blades
Thermal and Electrical
conductivity probe

“Holy Cow” Exposed by Rocket Exhaust Under Lander

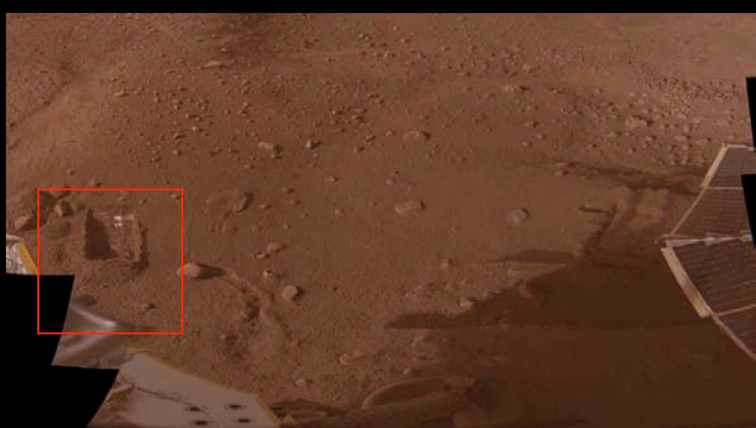


Panoramic of the Mars Surface

- 360 degree mosaic with SSI in color



RA workspace



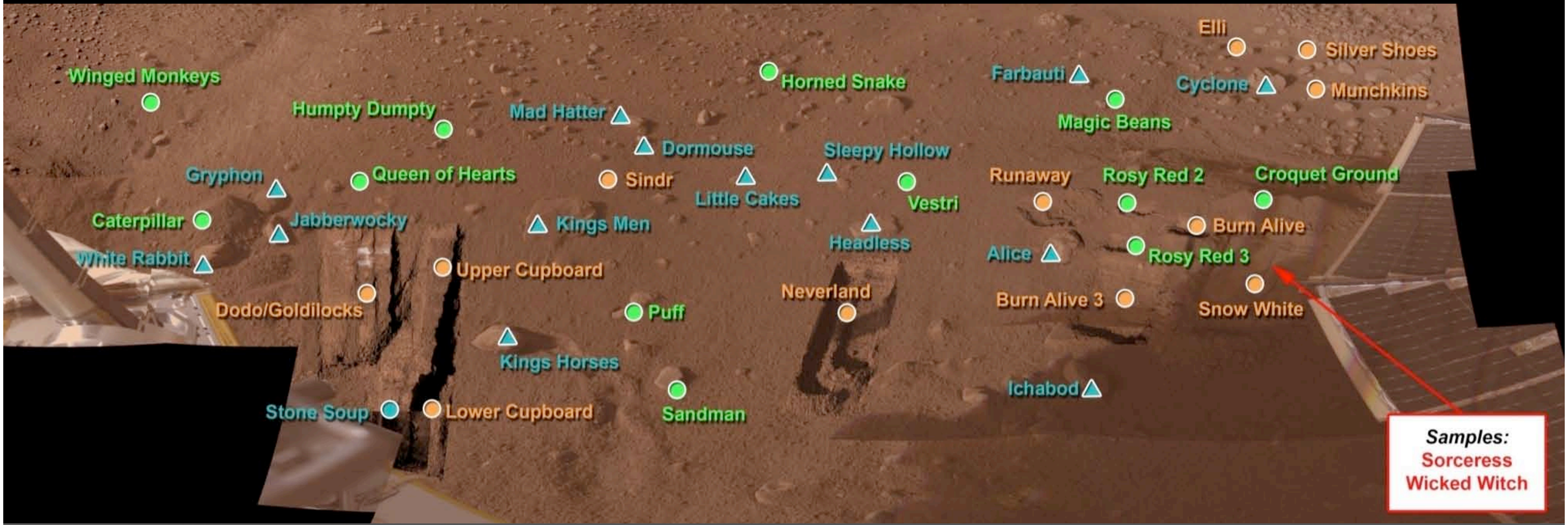
One of our dig trenches

THE UNIVERSITY OF ARIZONA.
Lunar and Planetary Laboratory

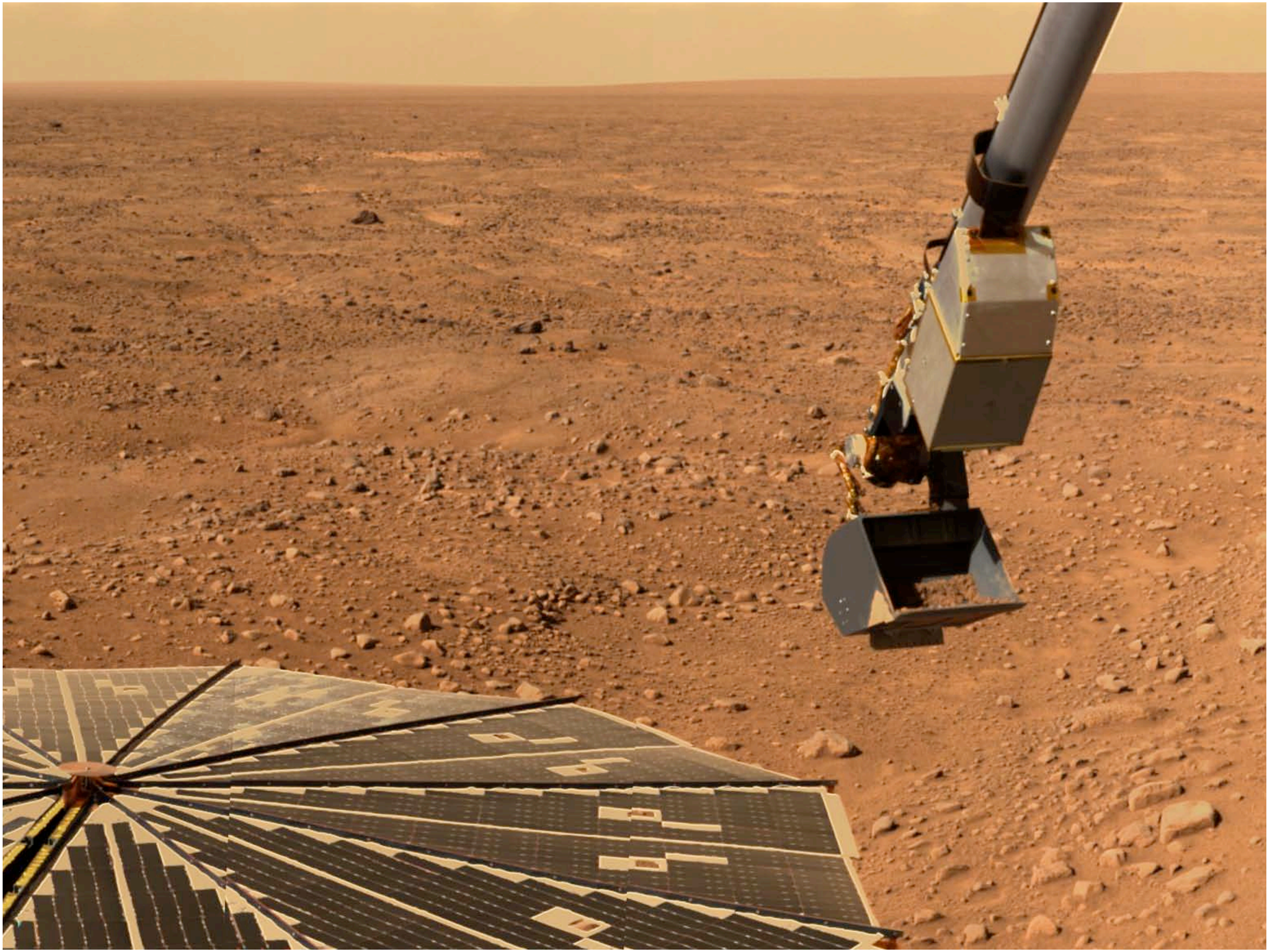
Over 400 images at over 100 positions were combined to make this mosaic panoramic

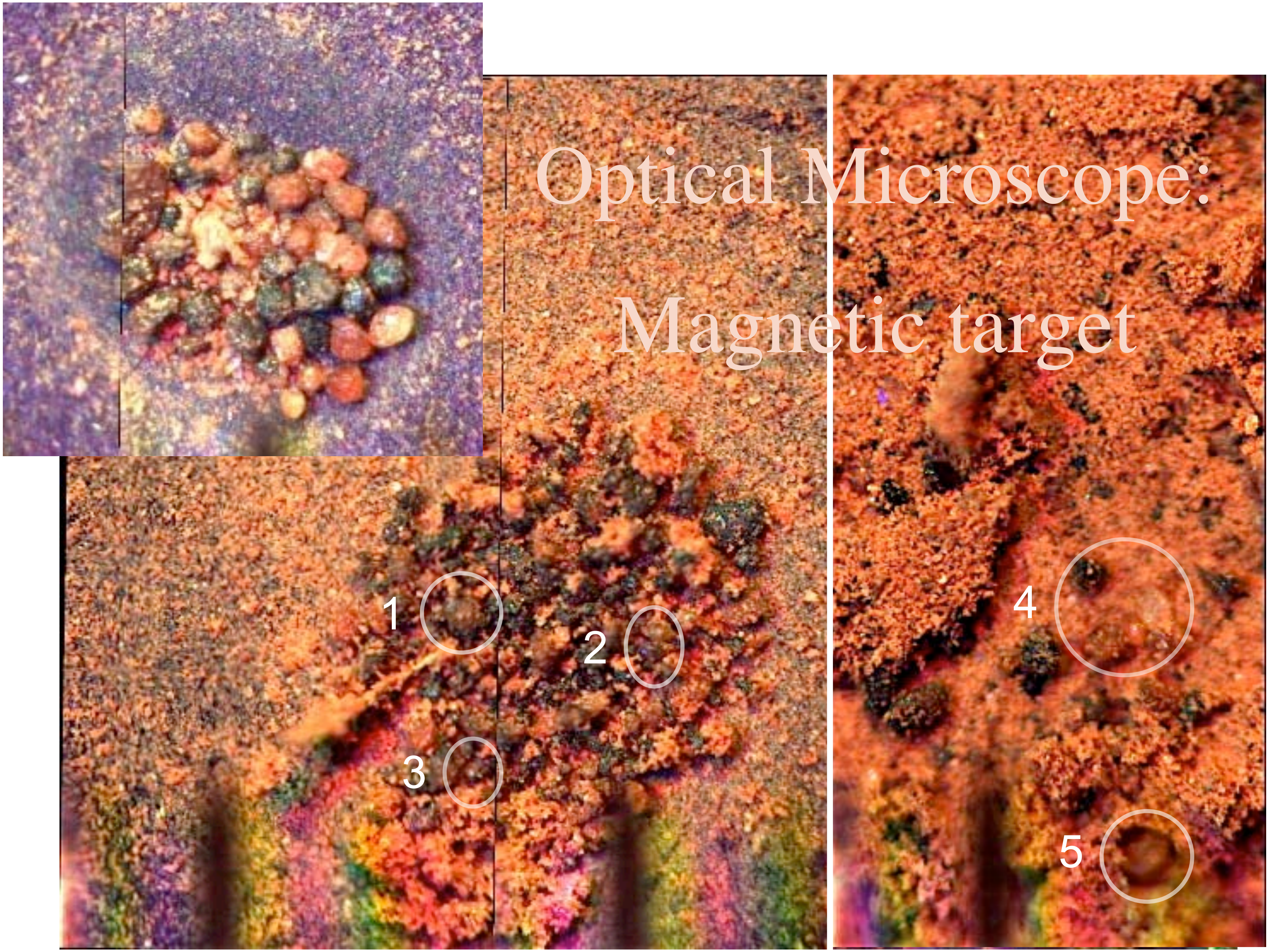

First Ground View of the Mars
Polar Region

Phoenix Highlights

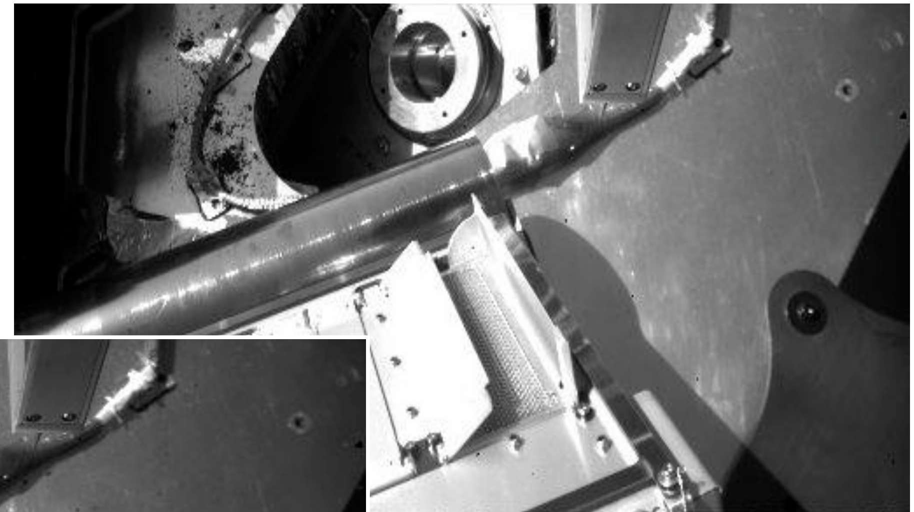


“Around Midnight”




Optical Microscope:
Magnetic target
1
2
3
4
5

TEGA



Sticky soil refuses to

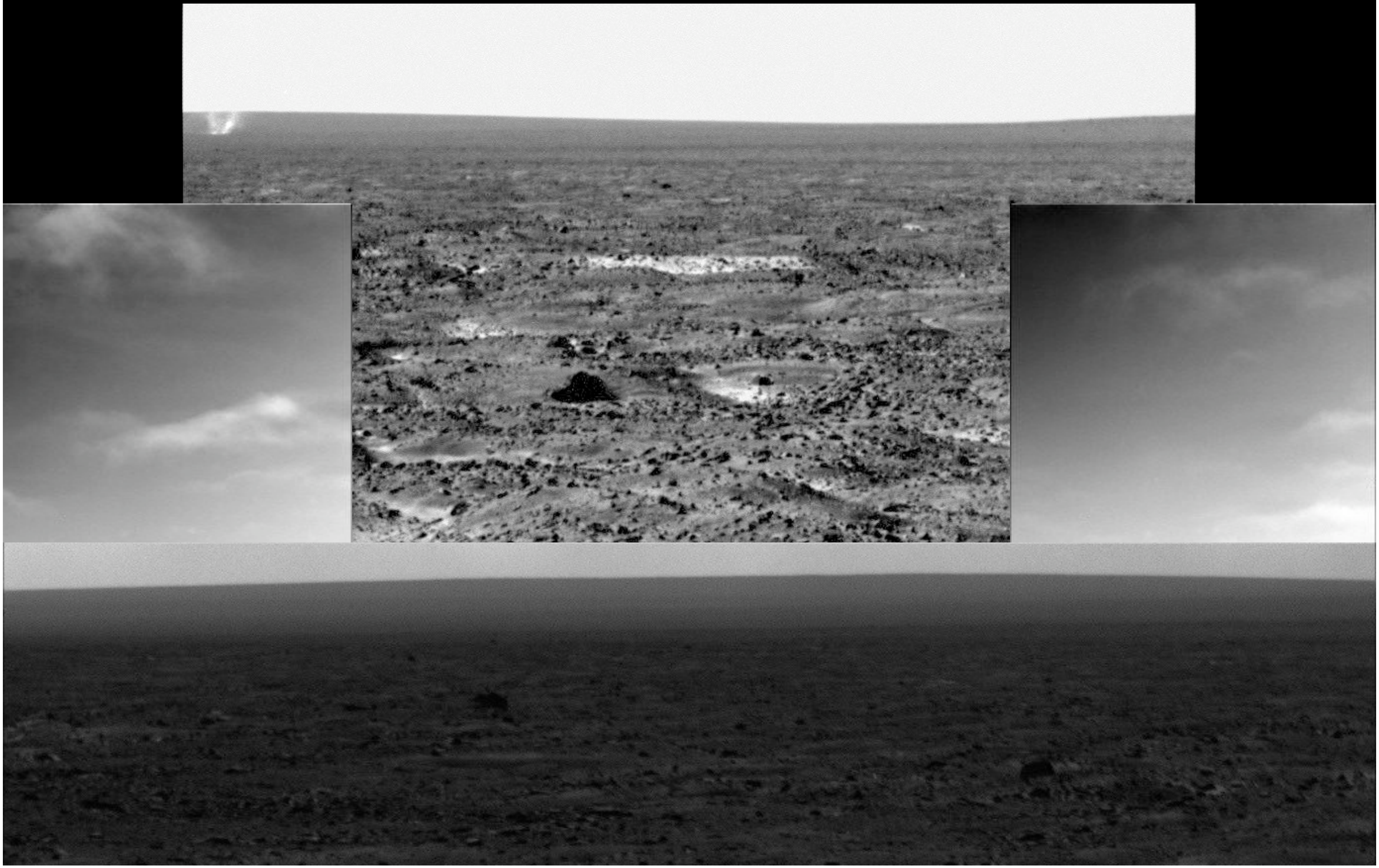
Pass through the screen--

4 days of shaking required

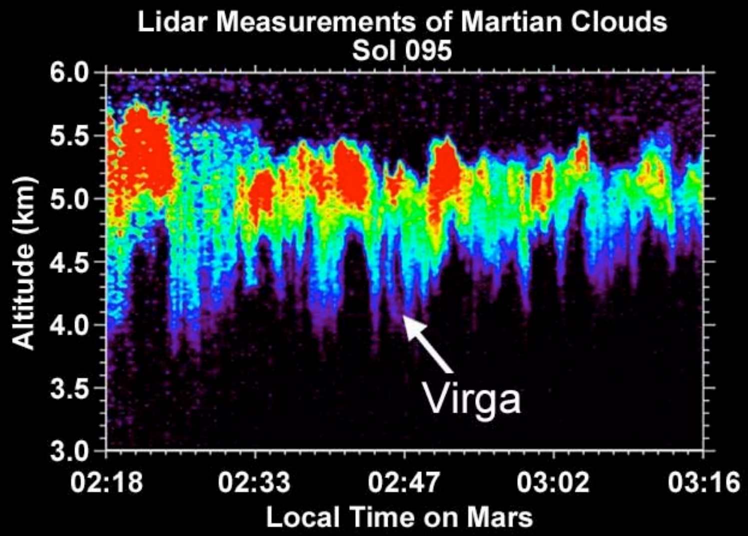
Is This an Environment Suitable for Life?

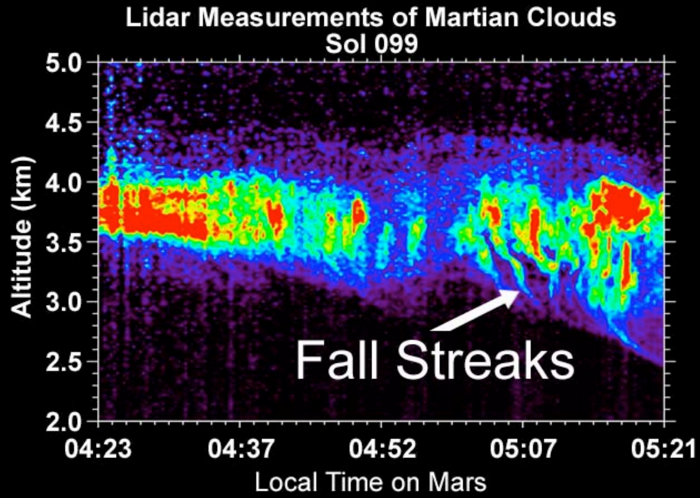
- ✓ Periodic liquid water
  - Minerals in the soil form only in liquid water
    - $CaCO_3$, or limestone, clay
  - Large variations in the polar tilt changes the climate
- ✓ Nutrients
  - Small amounts of Na, K, Ca, Cl, Mg
- ✓ Energy source
  - Large abundance of perchlorate, ClO_4^-
    - Perchlorate-reducing microbes are common on Earth
- ✓ Complex organic molecules
  - Maybe, the science team is analyzing the data now

Phoenix Highlights



Phoenix Highlights



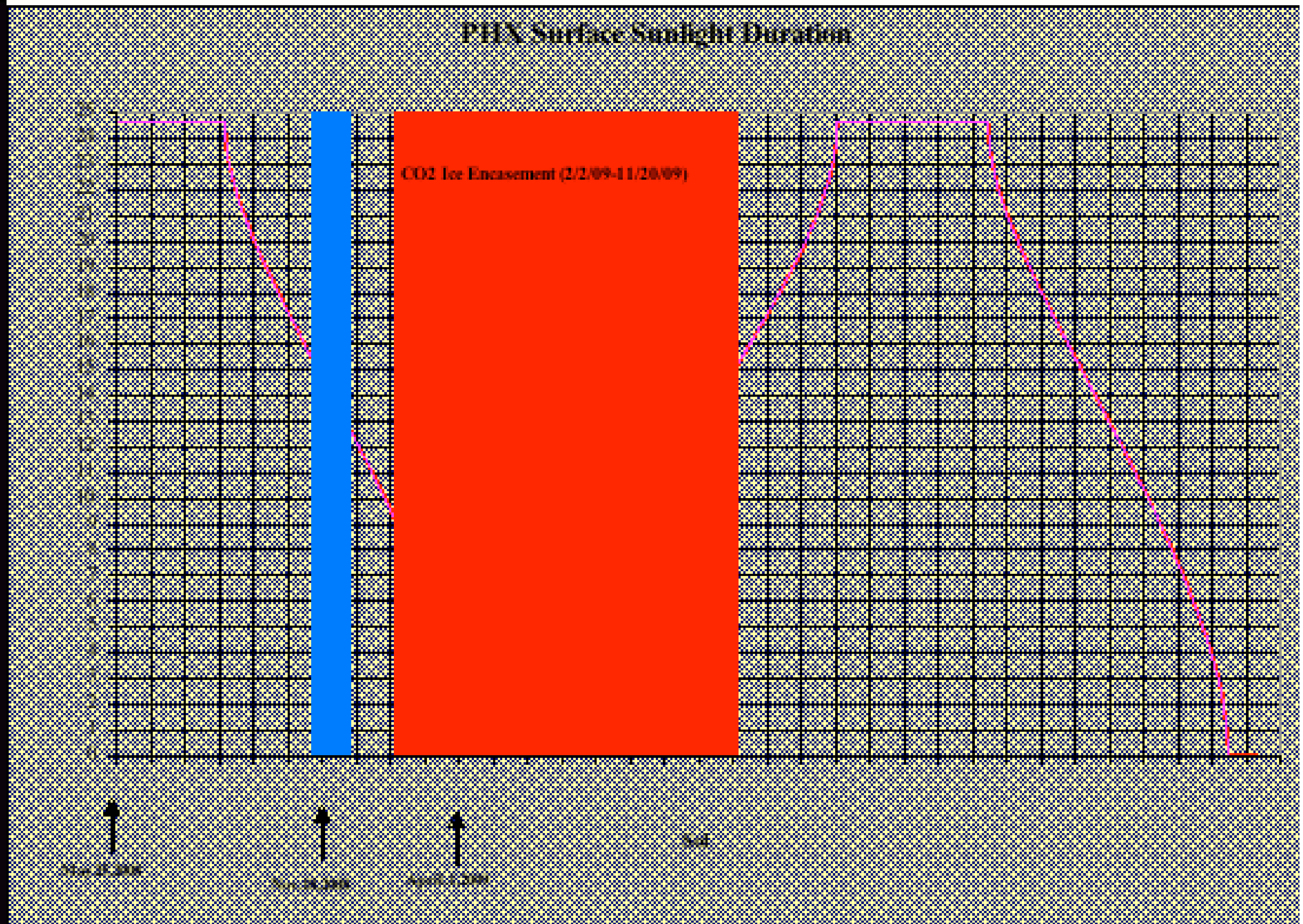



The Phoenix Mission:
Bravely continuing its research as Winter approaches

Q&A

Will Phoenix Have A Mission Life Like the Rovers?

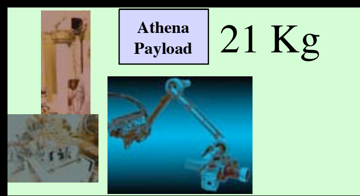
The Sun low on the polar horizon



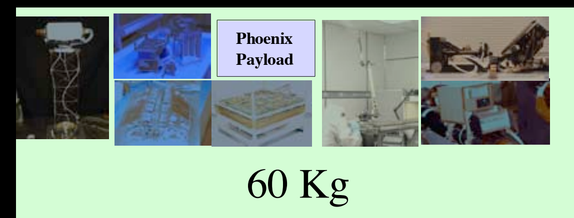
Why not airbags?

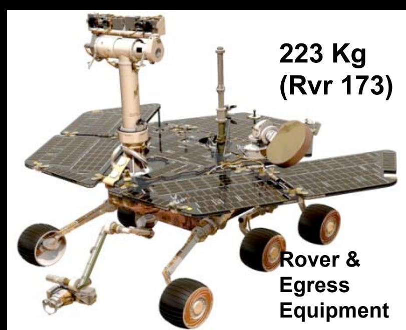
MER

Phoenix



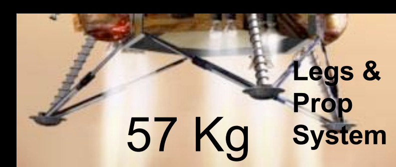
Science Payload





Effective Landed Mass

Touchdown Components



Total Landed Mass

Risk-7: Cruise Stage Breakup

Risk Description

- ➢ Cruise stage components could potentially impact the aeroshell during or after the Cruise Stage breakup.
  - Cruise Stage has components and assembles with ballistic coefficients greater than the aeroshell
  - Cruise stage ring could also breakup after it has passed the Lander

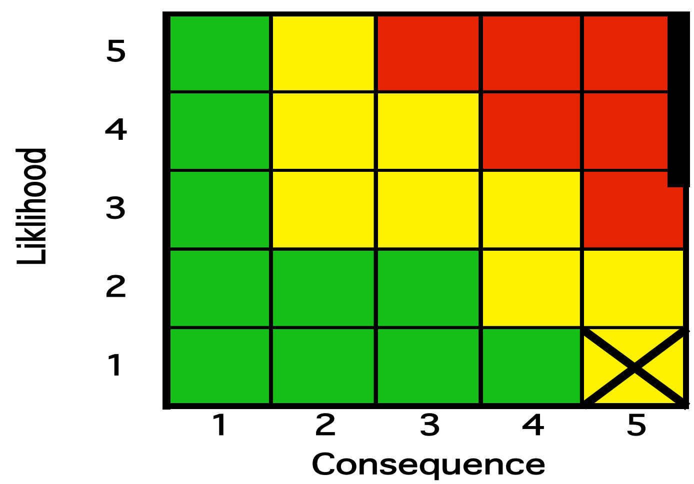
Mitigation

- ➢ Separate Cruise Stage in the sun pointed attitude (~ 60° To Entry Trajectory)
- ➢ Perform a slew maneuver by the Lander after separation
- ➢ Multibody trajectory analysis to characterize minimum separation
- ➢ Cruise Stage breakup analysis to estimate breakup range in trajectory

Mitigation Results

- ➢ Minimum separation distance of 300 meters
- ➢ Trajectory analysis indicates very low risk of re-contact

5X5 Mitigated Risk Matrix



Risk-8: Thruster Efficacy
Residual Uncertainty in Modeling Knowledge

Risk Description

- There is a potential of adverse interaction between the supersonic and hypersonic recirculation flow and the RCS thruster flow
  - Reduces pitch control authority ~50%
  - Can cause reversal of Yaw control
- Primary consequence is vehicle control instability in supersonic regime causing excessive AOA for chute deploy

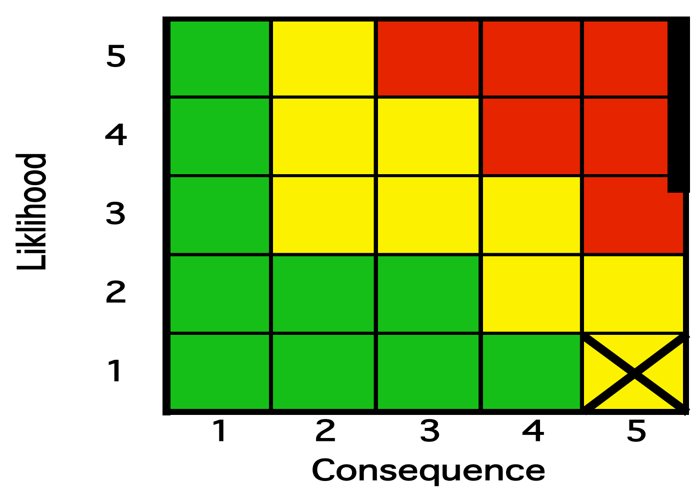
Mitigation

- Extensive CFD analysis (including independent models) to identify issue
- Increased dead-band thresholds for attitude and attitude rate to eliminate thruster firing in the Supersonic and hypersonic regime
- Extensive POST Analysis to verify performance and characterize AOA at chute deploy
- Aero database review to establish appropriate uncertainty range
- Robustness and break it analysis

Mitigation Results

- Very low probability of thruster firing in the expected EDL dispersions range
- 1.5 seconds continuous firing required for control instability
- Acceptable AOA performance at chute deploy (>20% margin, 0.1% out of spec)
- Not possible to test verify
- Large AOA can contribute to the wrist mode risk and also potentially aggravate the radar performance

5X5 Mitigated Risk Matrix



Risk-9: Residual Radar/System Risks

Risk Description

- There is a set of residual radar and radar-system anomalies that have a very low probability of occurrence
  1. Heat shield-induced lock on Barker side lobe of ground
  2. Bad locks from noise in Mini Non Embedded search
  3. Leakage effects
  4. The radar may lock on its own transmit-receive leakage if it breaks track within certain narrow altitude windows

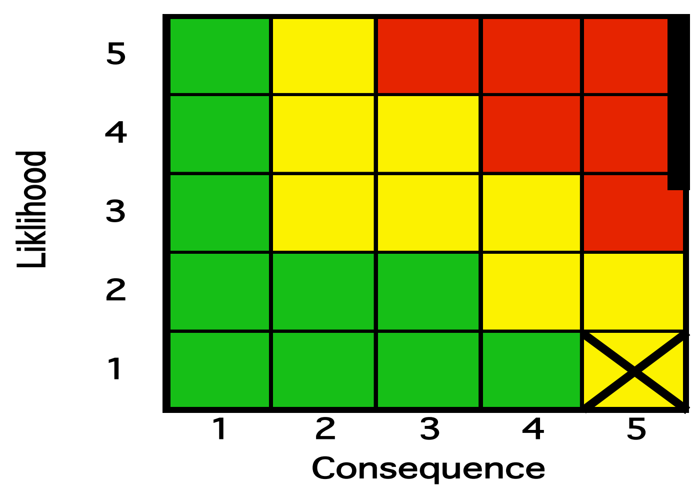
Mitigation

- Detailed Characterization and Simulation
  - 72 flight drops
  - >1000 EGSE drops
  - > 60 hours of field flight tests
  - Detailed performance model
  - >100,000 simulations
  - Robustness and break it tests
- Multiple levels of independent reviews

Mitigation Results

- Very low probability of occurrence <0.5% (considered conservative by EDL team)
- Not seen in system level simulations
- Navigation filter can tolerate the one instance seen in flight tests

5X5 Mitigated Risk Matrix



Risk-11: Site Alteration/Interaction

Risk Description

- Interaction of the descent thruster plume with the surface is inevitable and not deterministic
- It has four classes of potential risks
  - Back pressure on Lander
  - Site alteration
  - Dust cloud
  - Science Impact
- Viking tests were performed in close chambers, OK for Nozzle trades only

Mitigation

- Terminal descent controller is robust to the transient back pressure
- System can tolerate some level of surface alteration ~ 30 cm deep
- Orbital GRS indicates that landing region permafrost layer is no more than 10cm below surface
- Large sample collection area
- Lander deck is tolerant to large dust buildup
- Thruster Exhaust Products Were Measured During ATP

Mitigation Results

- Original Viking and 2008 AMES experiments indicate that large volume of top soil will be displaced
- AMES experiments indicate a worst case deposition on the deck of 3 mm only
  - Mechanical/thermal is robust
- Viking tests and permafrost depth do not indicate TD risk (pits<10cm)
- Alteration of the sampling site cannot be determined based on available data

5X5 Mitigated Risk Matrix