HUMANS TO MARS: THE INTERSECTION OF SCIENCE AND EXPLORATION

MIT HAYSTACK OBSERVATORY

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Presentation for the
Planetary Decadal Survey panel on Mars
29 January, 2021

phoenix
Mars Lander 2007

MOxIE
Mars Oxygen
ISRU Experiment

Part I

Strategic considerations

Assumptions

- Human exploration will be a boon to Mars science.
- The Decadal survey can impact human exploration of Mars in 2 ways:
  - Recommend payloads that will support NASA exploration plans by filling strategic knowledge gaps (SKG)
  - Recommend science-rich approaches to human exploration (e.g. landing site workshops)

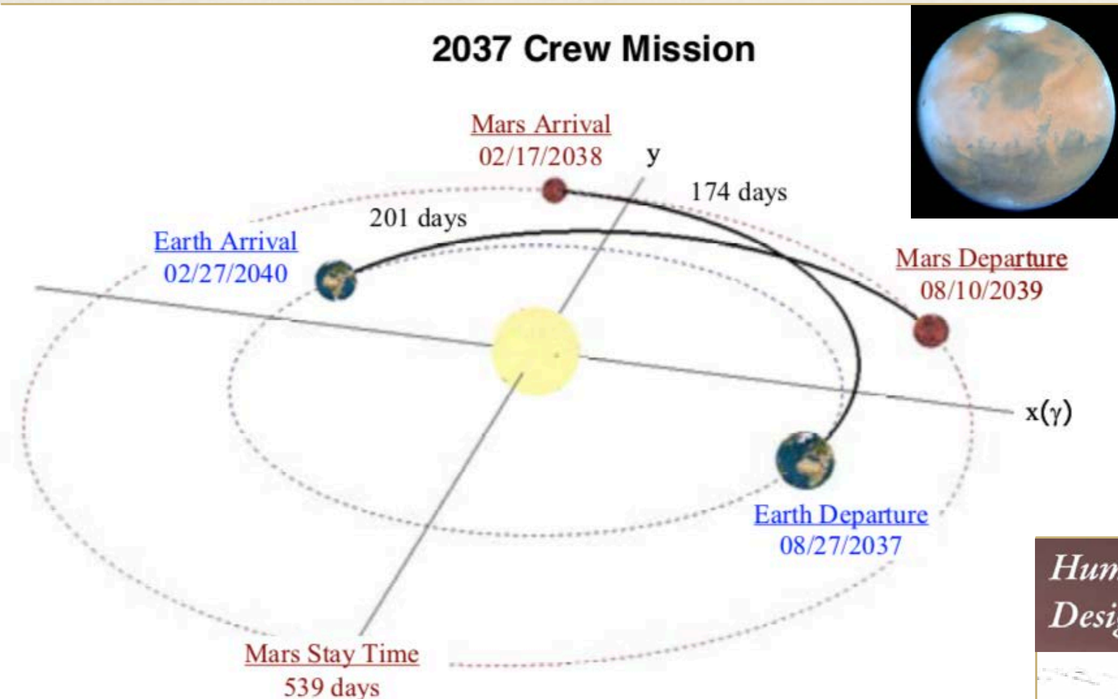
Important References

- MEPAG Goal IV
- SKG studies
- Design Reference Architecture 5.0
- Human landing site workshop proceedings
- Dust in the Atmosphere of Mars and its Impact on Human Exploration (Levine, Winterhalter, Kerschmann)
- M-WIP, SWIM, and other resource studies
- Opposition class mission announcements (in backup)

Exploration knowledge gaps

- Four concerns have dominated HEO precursor mission thinking since the mid-1990s:
  - Dust & Soil
    - Abrasion, corrosion, toxicity, optics obscuration, triboelectricity, filter obstruction, bulk structural properties, effect on mobility…
  - Radiation
  - ISRU (ISPP)
  - EDL
- Others have attracted intermittent attention
  - Planetary protection & biological hazards
  - Meteorological and electrical phenomena
  - See Goal IV for more

The DRA road to Mars

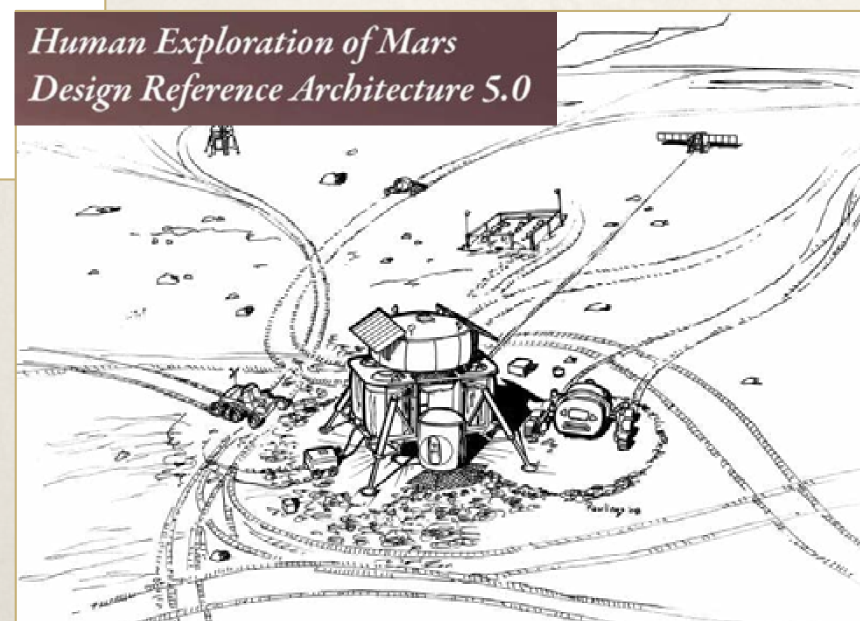


Cargo mission

- HABitat
- Descent/Ascent Vehicle (DAV)
- Rovers (pressurized & unpressurized?)
- 25-30 kW power plant (Kilopower? Photovoltaic?)
- 32 tons propellant (Fuel & oxidizer) or ISRU plant
- …

Human mission

- Mars Transfer Vehicle
- The Crew
- Toothbrush, etc.



Evolving strategies

- The dominant strategy has been the one expressed in the Design Reference Architecture:
  - Conjunction class Holman transfer orbits
  - Pre-deploy infrastructure on one opportunity (habitat, fission power station, surface vehicles, MAV, propellant ISRU)
  - Send 4-6 crew on next opportunity, 26-months later
  - ~500 day stay on surface
- Presidential administrations have brought changes in emphasis on next destination after ISS (Mars, Moon, asteroid)
- Current (Trump era) status:
  - Major push for early moon landing & presence (2024-?)
  - Mars next.
  - Most recently, *opposition* class mission proposed for ~2035!

The opposition mission

- Announced via blog post, web feature, & social media
- What is it?
  - Long cruise (Venus gravity assist?)
  - Short stay on the surface (~30 days)
- What is proposed (as far as I understand)
  - Small, fast mission (2 astronauts, ~20 tons)
  - Hazard of long cruise to be mitigated by high-power nuclear engines – new development priority
  - No ISRU
- Implications for science
  - A crew of 2 on the surface for 30 days is likely to spend most of that time acclimating to gravity and preparing for departure. Limited opportunity for science.

Summary & recommendations

MOXIE
Mars Oxygen ISRU Experiment

* Support for NASA's plan for human exploration is well-documented in MEPAG Goals and elsewhere
* Significant contributions have already been made, both with specific exploration payloads and general knowledge gains (e.g. resource surveys)
* It is important that the science community continue to weigh in on the exploration plan itself by establishing clear objectives and exploring the implementation details (e.g. landing site selection)
* The panel may want to help the exploration community distinguish proven science from solid but speculative results that aren't ready for exploration investment (e.g. water in RSLs) as well as published but unfounded claims.

Part II

Past payload partnerships

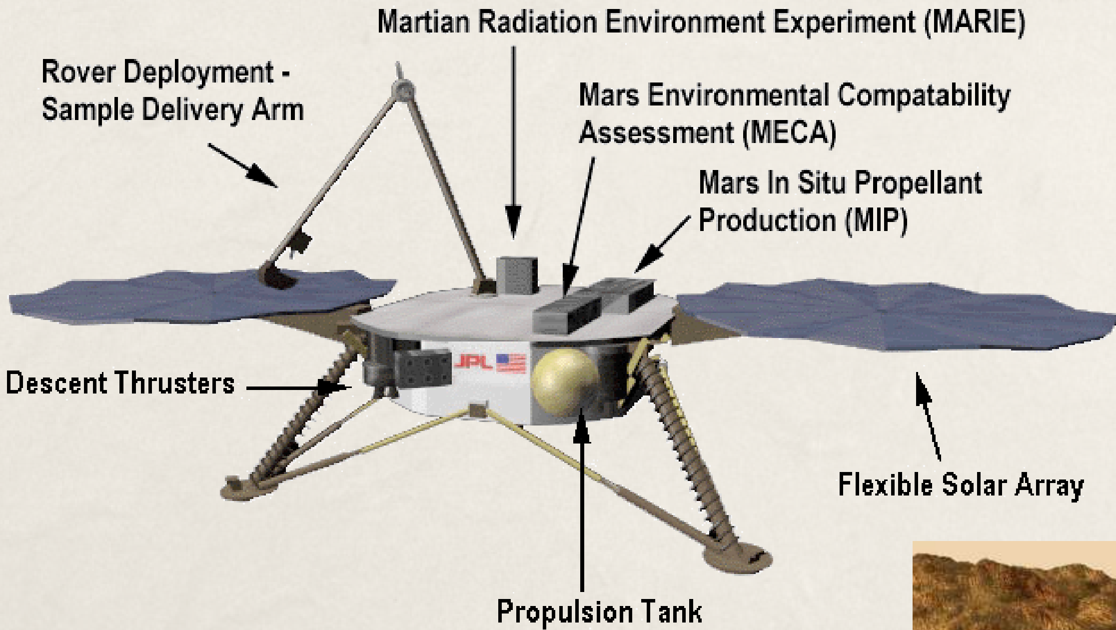
Partial HEO Payload History

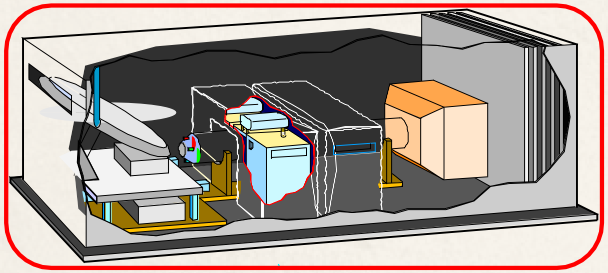
Mars Oxygen ISRU Experiment

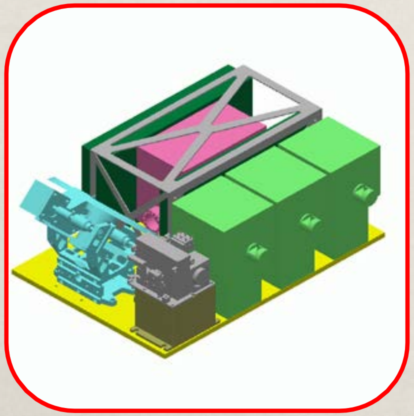
- MARIE orbit (Odyssey)
  - Incident radiation survey
- MARIE surface (~~2001~~) → RAD (MSL)
  - Surface radiation survey
- MECA (~~2001~~) → MECA (Phoenix)
  - Soil & dust propert investigation
  - Found large concentration of perchlorate
- MIP w DART (~~2001~~) → MOXIE, MEDA (M2020)
  - MOXIE will be first ISRU demonstration
  - MEDA to study surface atmosphere, opacity, etc.
- MEDLI (Curiosity, Perseverance)
  - Atmospheric dynamics during EDL
- Magnet experiments (not HEO)
  - Found 1-7% strongly magnetic phase (magnetite)

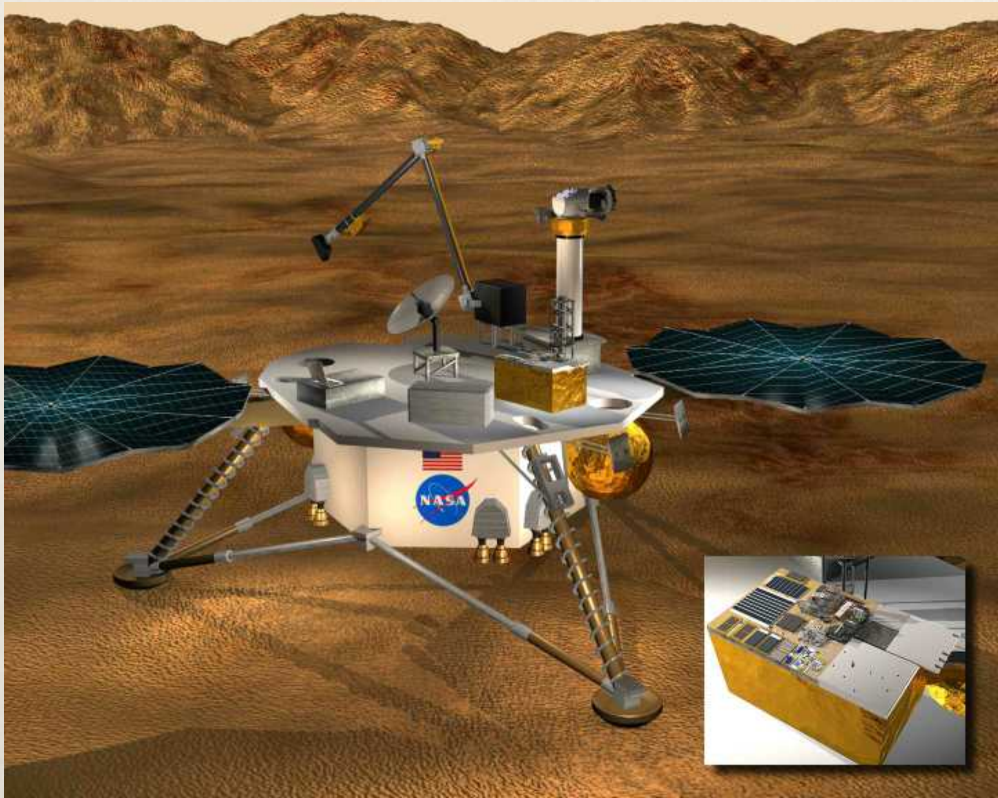
Mars Surveyor 2001 Lander

MECA
Mars Environmental Compatibility Assessment







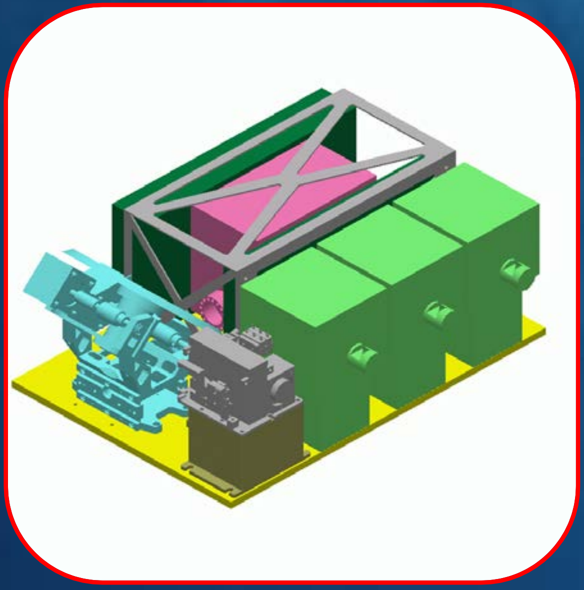


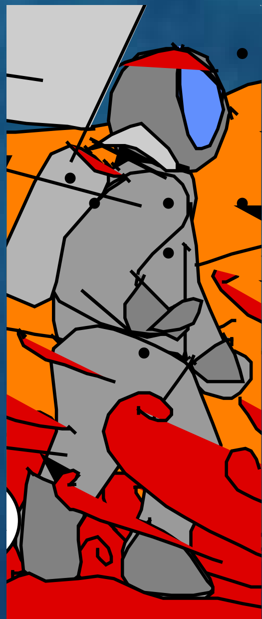
MECA
Mars Environmental Compatibility Assessment

"Characterize martian dust and soil to identify undesirable and harmful interactions with human explorers and associated hardware systems, and to support the design of extravehicular activities (EVA) and habitation systems."

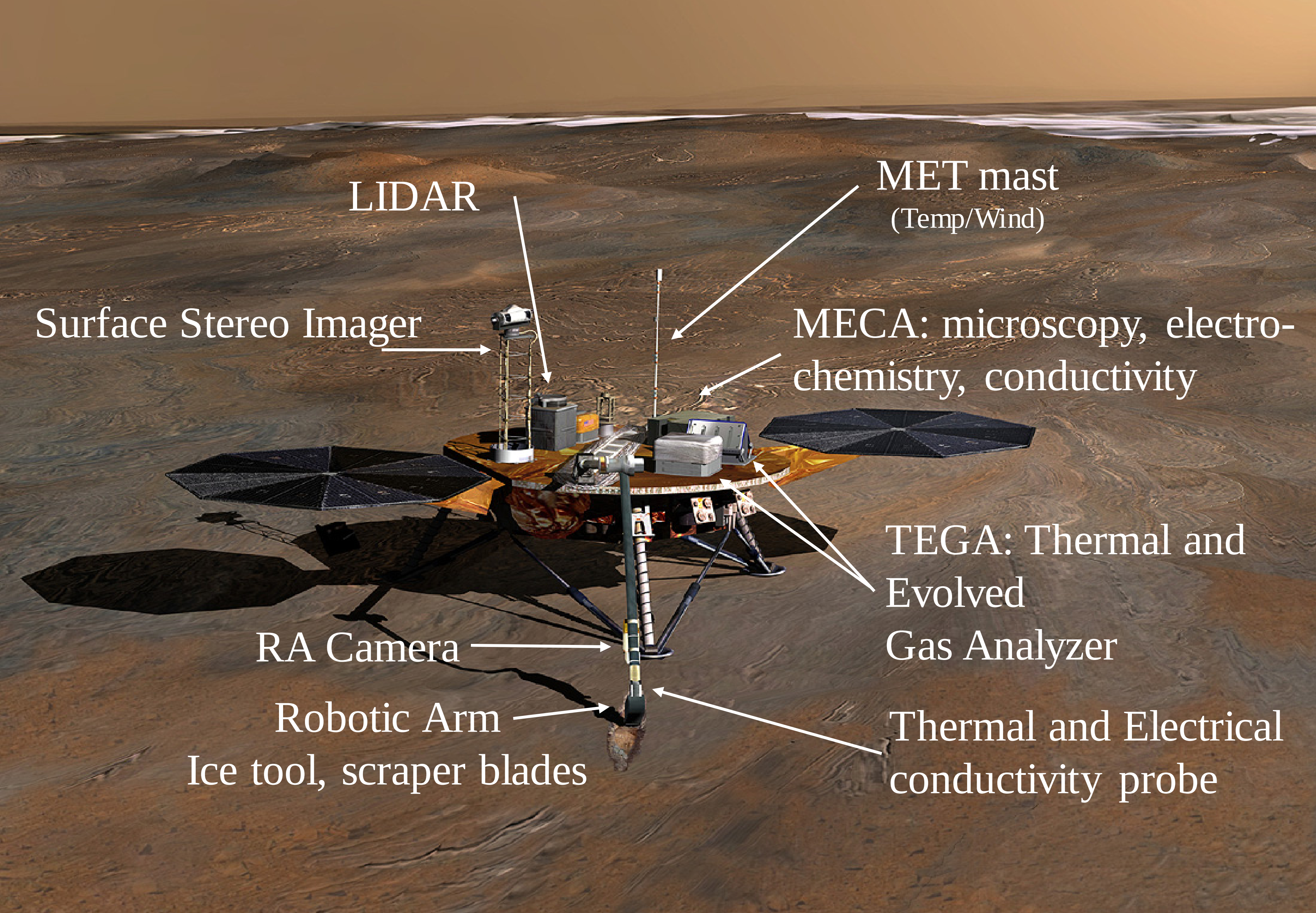
- From the MSP 2001 Announcement of Opportunity

The Microscopy, Electrochemistry, and Conductivity Analyzer



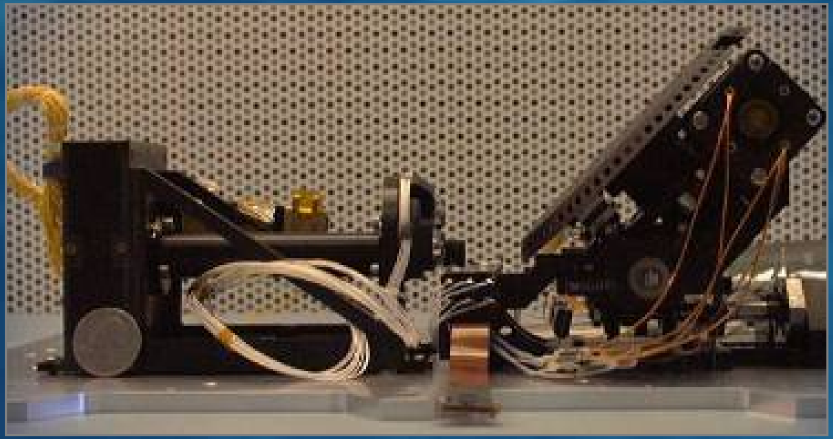


The Phoenix Mission

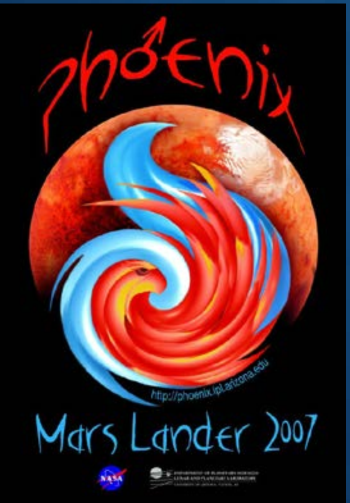


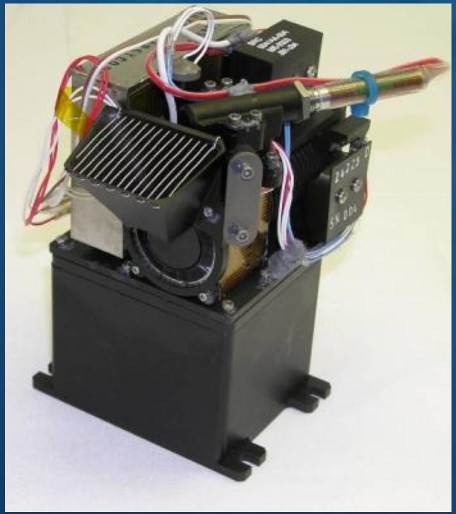
The Microscopy, Electrochemistry, and Conductivity Analyzer (MECA)

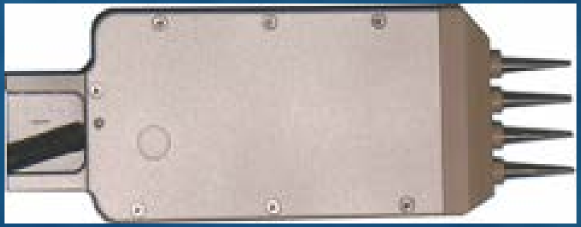
Originally the Mars Environmental Compatibility Assessment for the 2001 Mars Surveyor Lander



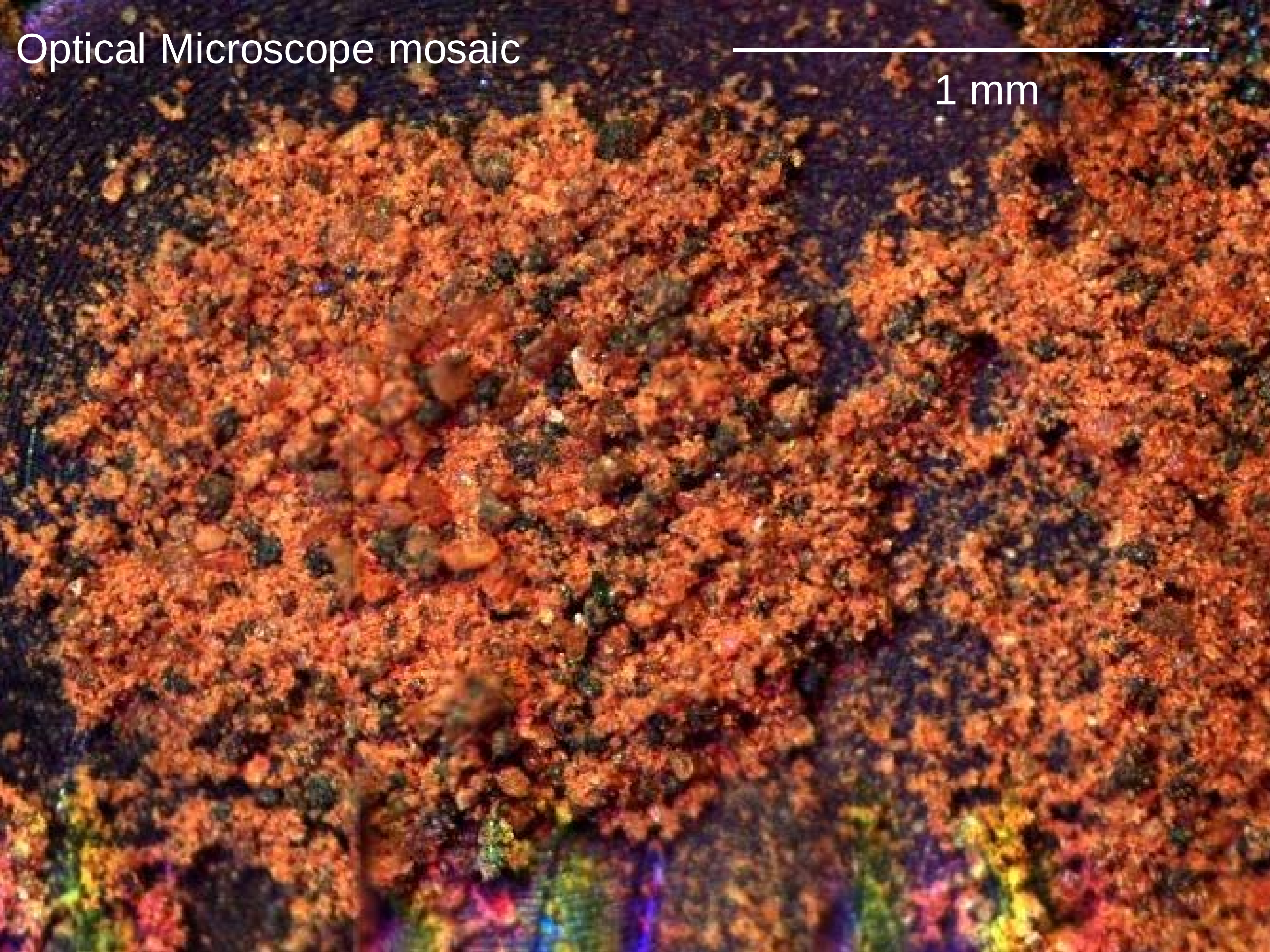
30 cm

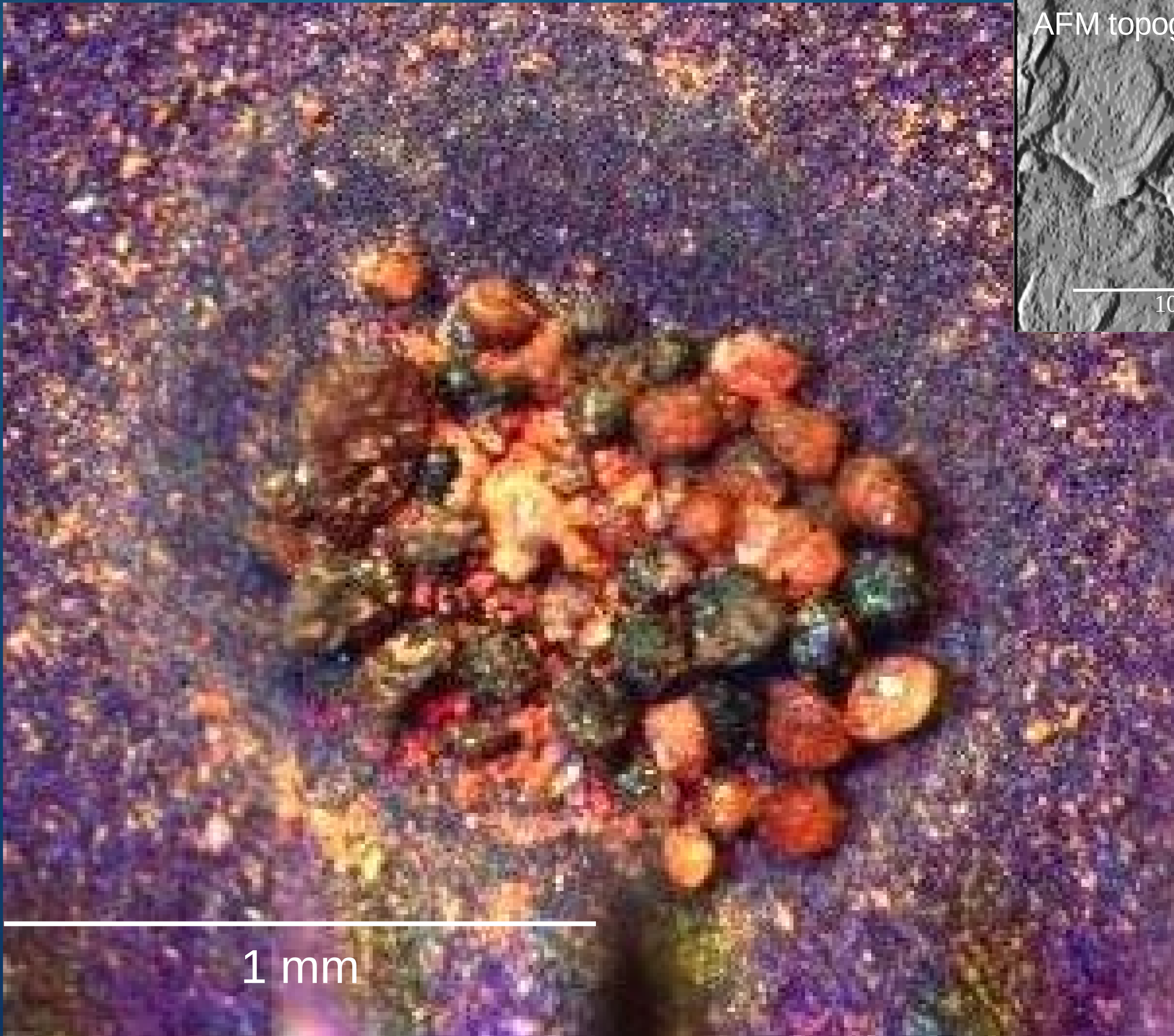


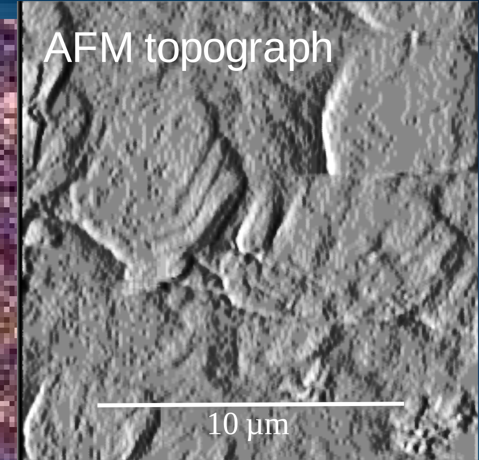




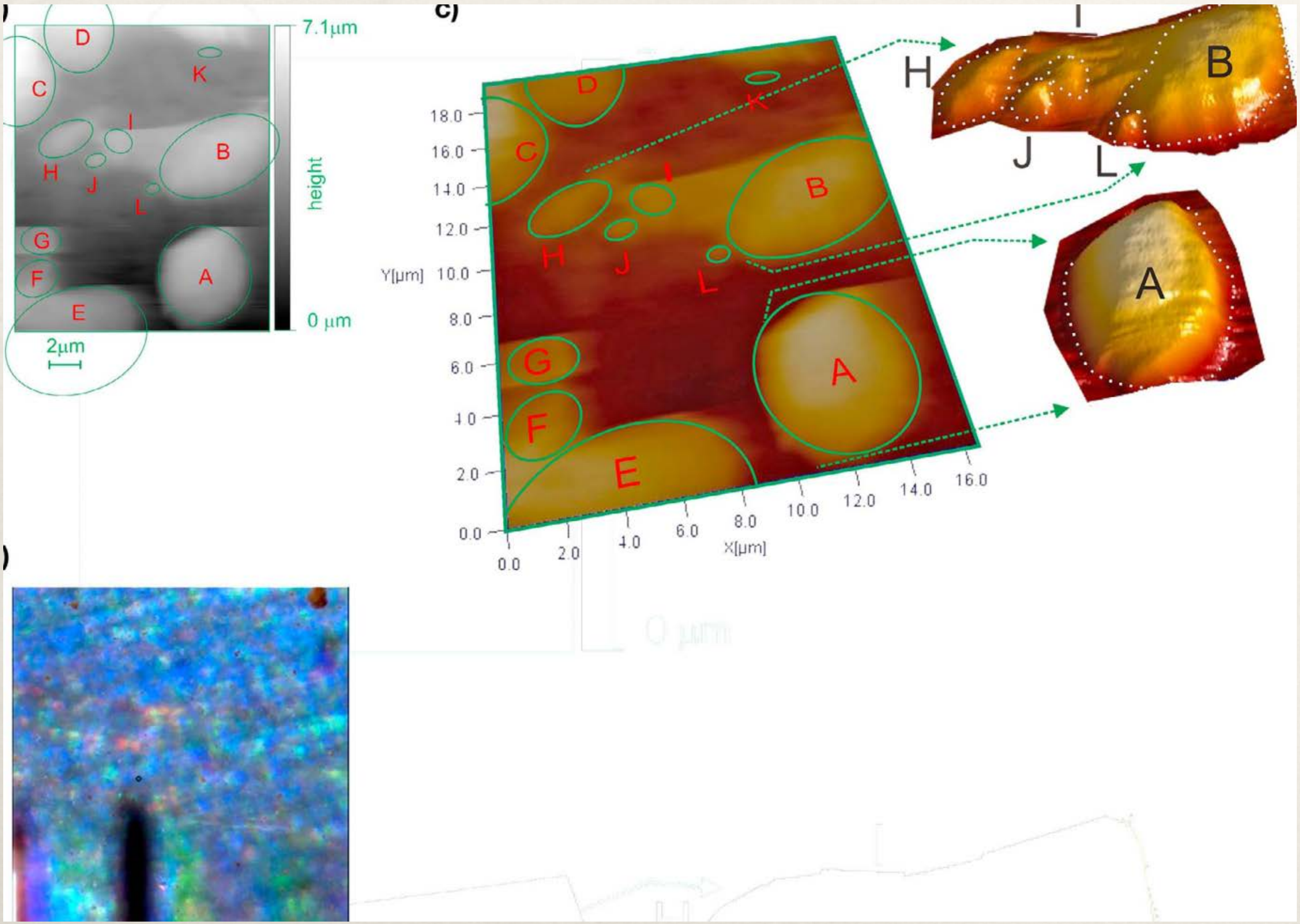
12 cm


Optical Microscope mosaic
1 mm


1 mm

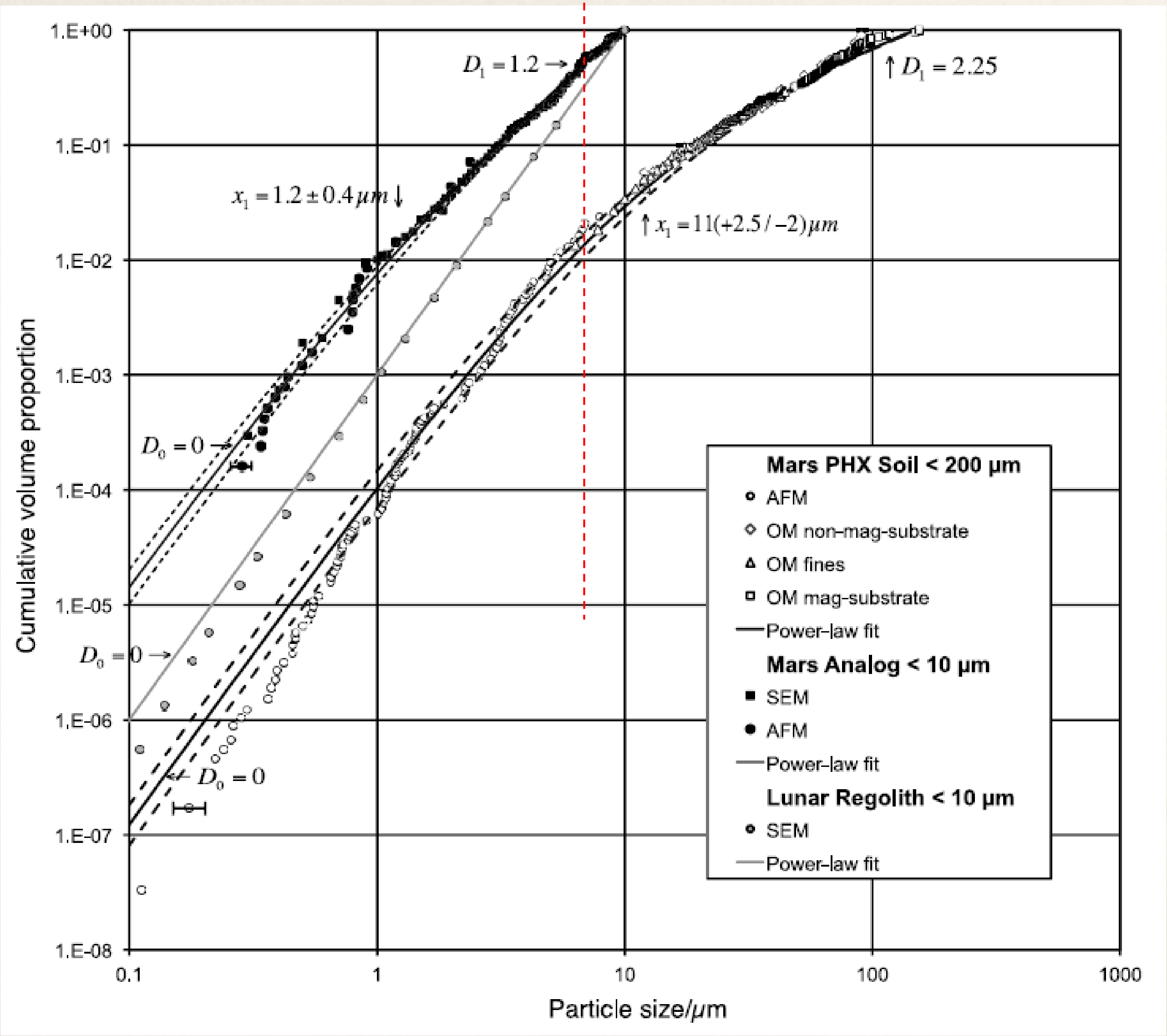

AFM topograph
10 µm

AFM Data



c)
7.1µm
0 µm
height
2µm
A
B
C
D
E
F
G
H
I
J
K
L
Y[µm]
X[µm]
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0

PSD

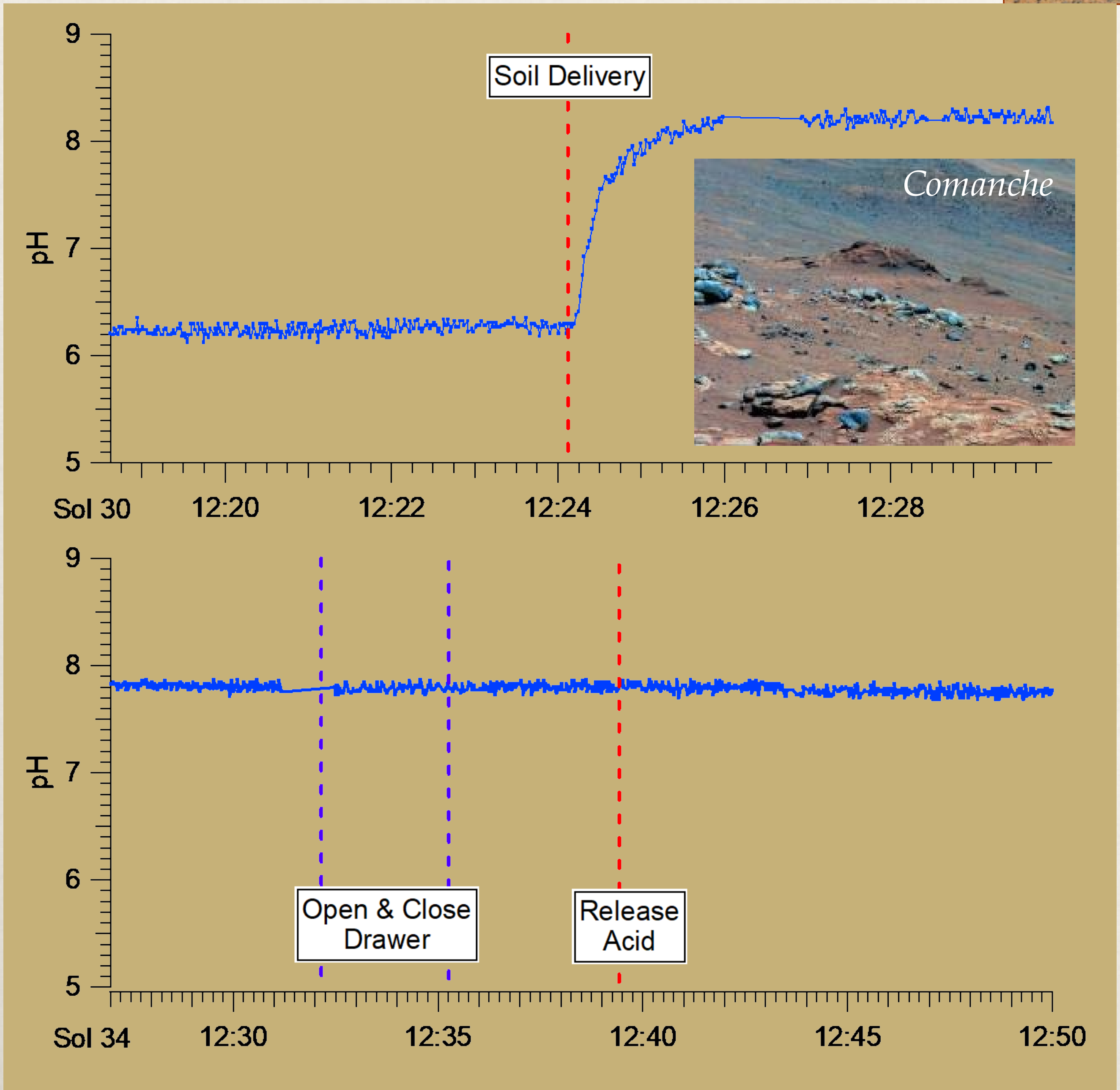


Cumulative volume proportion
Particle size/μm
$D_1 = 1.2$
$D_1 = 2.25$
$x_1 = 1.2 \pm 0.4 \mu m$
$x_1 = 11(+2.5/-2) \mu m$
$D_0 = 0$
$D_0 = 0$
$D_0 = 0$
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
0.1
1
10
100
1000
Mars PHX Soil < 200 μm
AFM
OM non-mag-substrate
OM fines
OM mag-substrate
Power-law fit
Mars Analog < 10 μm
SEM
AFM
Power-law fit
Lunar Regolith < 10 μm
SEM
Power-law fit

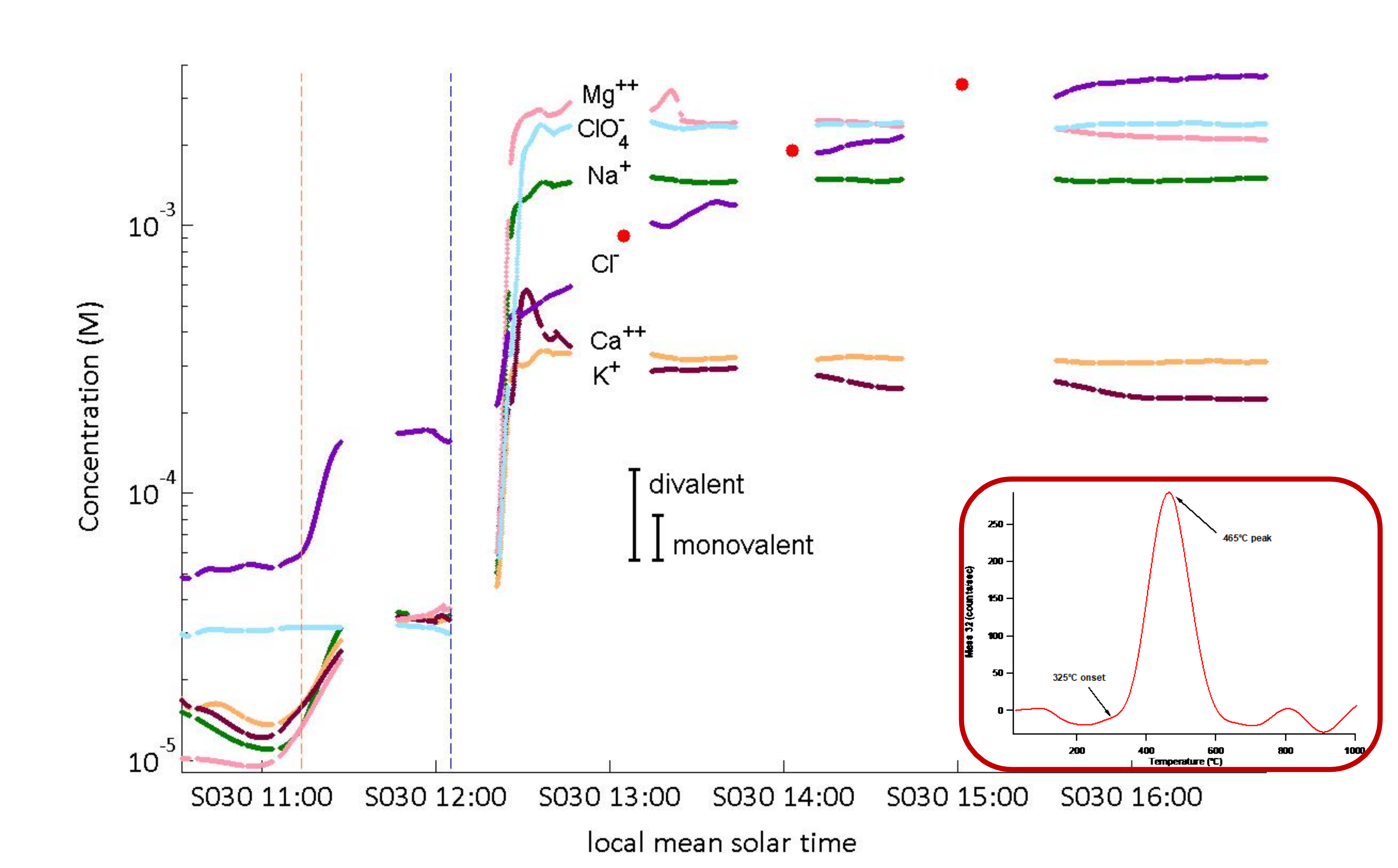
What does it mean?

- Single formation process from smallest to 11μm, (Earth is typically <1μm). <0.05% by volume is phyllosilicate size (<2μm)
- → Aeolian, not chemical weathering
- → < 5000 years cumulative exposure to water if fines are phyllosilicates
- More analogous to lunar regolith than terrestrial
- Some similarity to authigenic clays in Beacon Valley (Marchant et al 1996)

pH Measurement



Dissolved ions

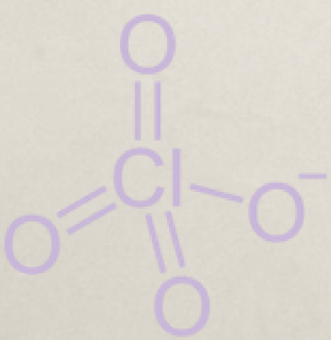


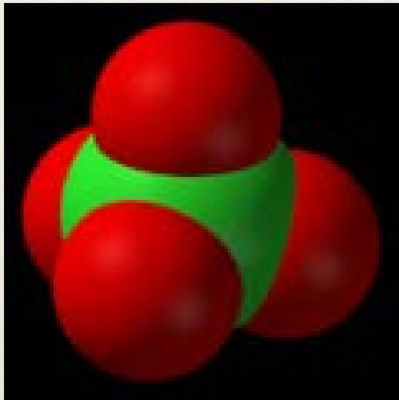
What's in the soil?

- Various soluble salts, ~2%
  - Cations: Calcium, Magnesium, Potassium, Sodium
  - Anions: Chloride, **Perchlorate**
- Less soluble anions
  - Carbonate, a few %
  - Sulfate, soluble component ~2%
- pH is ~7.7

Characteristics of Perchlorate (ClO4$^-$)

- Highly soluble, exothermic reaction in water.
- Chemically inert at room temperature, doesn’t adsorb onto mineral surfaces
- Unstable at elevated temperature, generates oxygen and heat (fireworks, rocket fuel, oxygen candles)
- Salts are deliquescent, form brines: Eutectics of Mg and Ca freeze at ~-70°C.
- **Mildly toxic (reversible thyroid function suppression)**





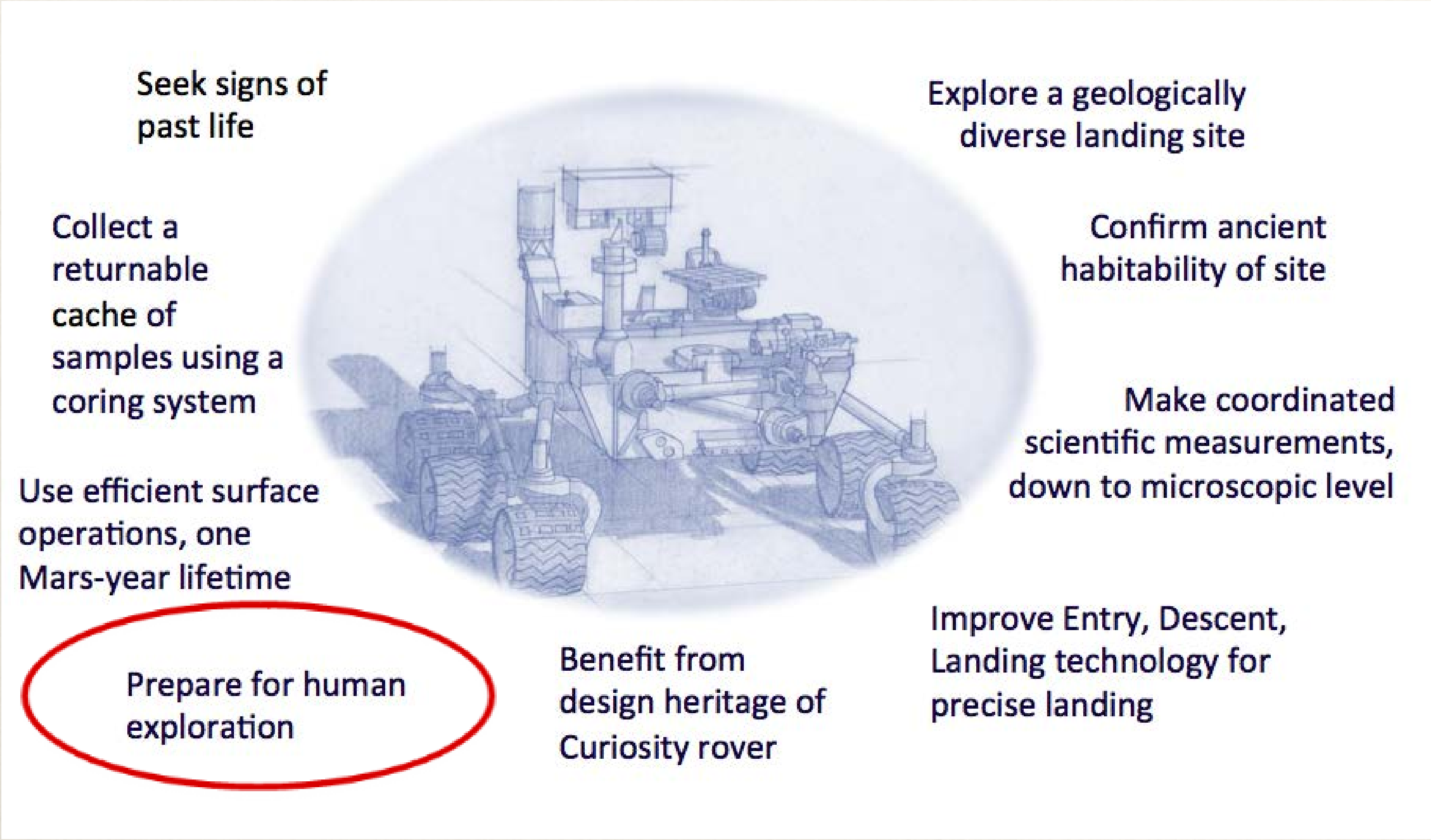
Lessons from Phoenix: Regolith and human exploration

- Particle size distribution
  - Measured over 4 orders of magnitude (from 0.1μ)
  - Martian soil is highly deficient in clay-sized fines (i.e. coarse) compared to terrestrial or lunar soils
  - Presumably this is due to lack of aqueous chemical alteration (dominant on Earth) or impact gardening (dominant on moon)
  - → Modest inhalation hazards
- Bulk soil properties
  - Soil is highly cohesive and competent
  - Dust is readily removed by vortices (dust devils)
- Toxicity and corrosion
  - Soil is near-neutral pH due to ~3% calcium carbonate (as in most of Earth's water)
  - Most chlorine is in the form of perchlorate rather than chloride (perchlorate salts are nearly 1% of soil). On Earth, biology reduces most perchlorate.
  - Perchlorate is highly soluble, hence readily removed with water.
  - Water ice is plentiful at Phoenix latitudes.
  - Perchlorate can suppress thyroid function, but effect is reversible.
- Findings pertain primarily to high-latitude soils in icy regions

Lessons from Phoenix: ISRU

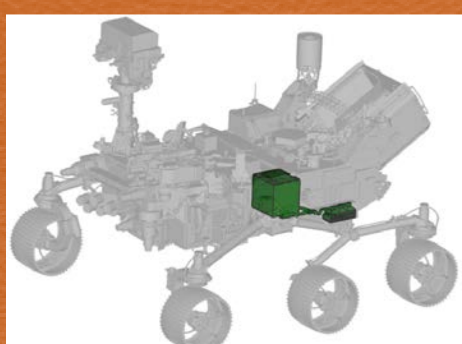
- Soil is ~1% perchlorate, uniformly mixed, which is readily extracted from the soil with water.
  - A primary component of rocket propellant (need to provide fuel, e.g. aluminum, and binder)
  - Can be used in biological fuel cells to generate electricity
- As predicted, water (ice) is everywhere within centimeters of the surface in the northern plains
- Atmospheric water vapor is in equilibrium with the coldest part of the soil (the surface at night, the ice table by day)

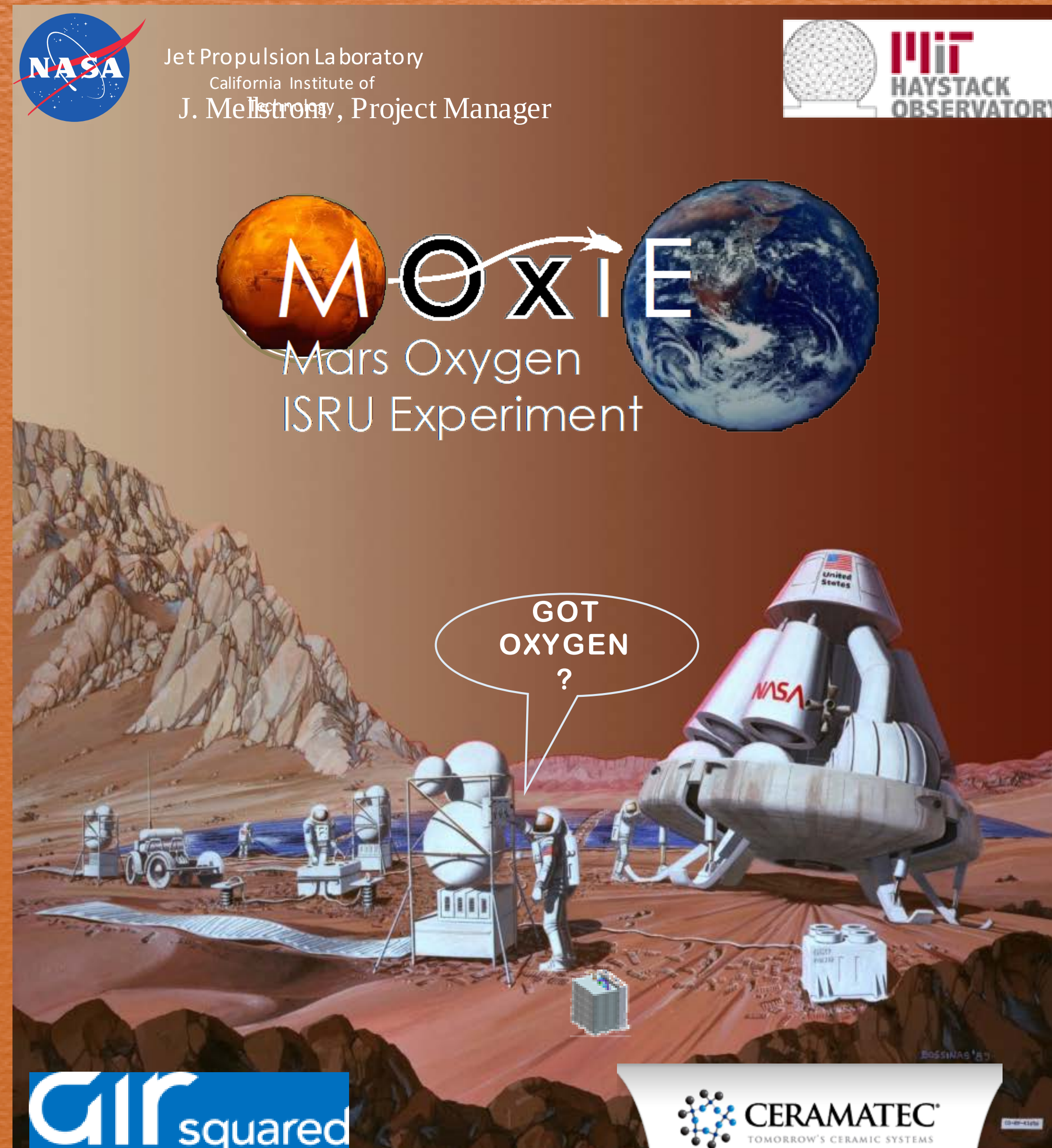
Perseverance



NASA invests in sending ISRU to Mars!

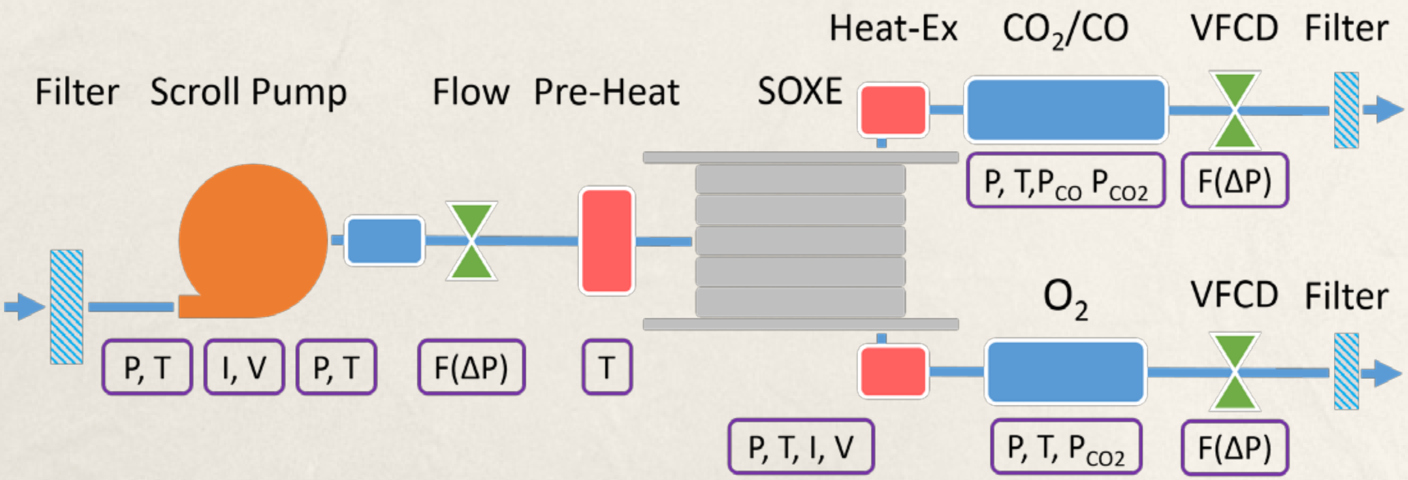
* MOXIE is a 1:200 scale model of an ISRU plant for a human mission.
* MOXIE will make 6-10 g of propellant-grade O_2 per hour
  * Like a smallish tree, or ~50% of what a person breathes
* O_2 purity will be >99.6%.



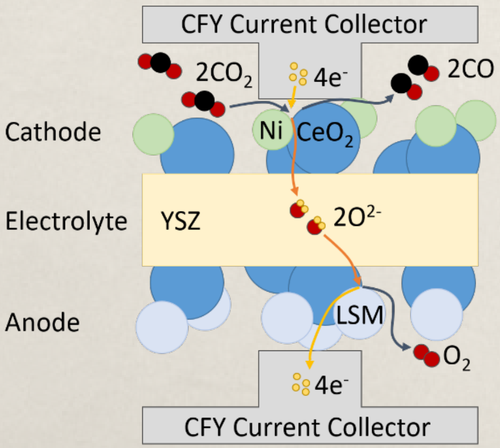


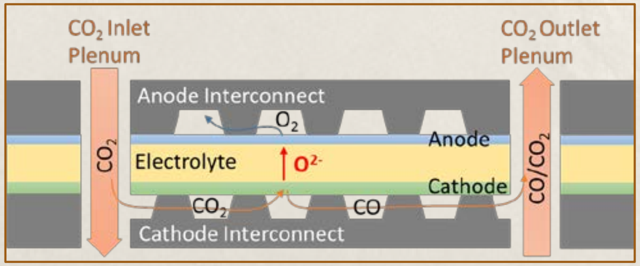
How does it work?

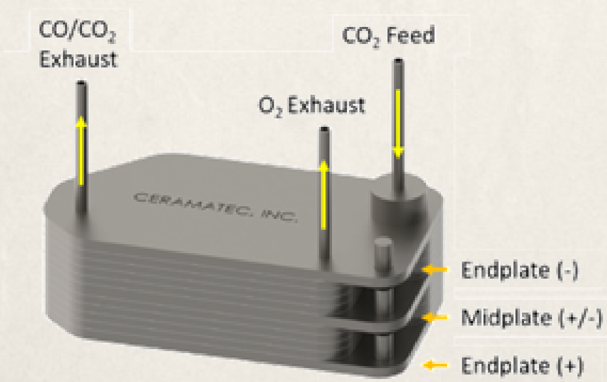
MOXIE
Mars Oxygen
ISRU Experiment



Meyen (2015)







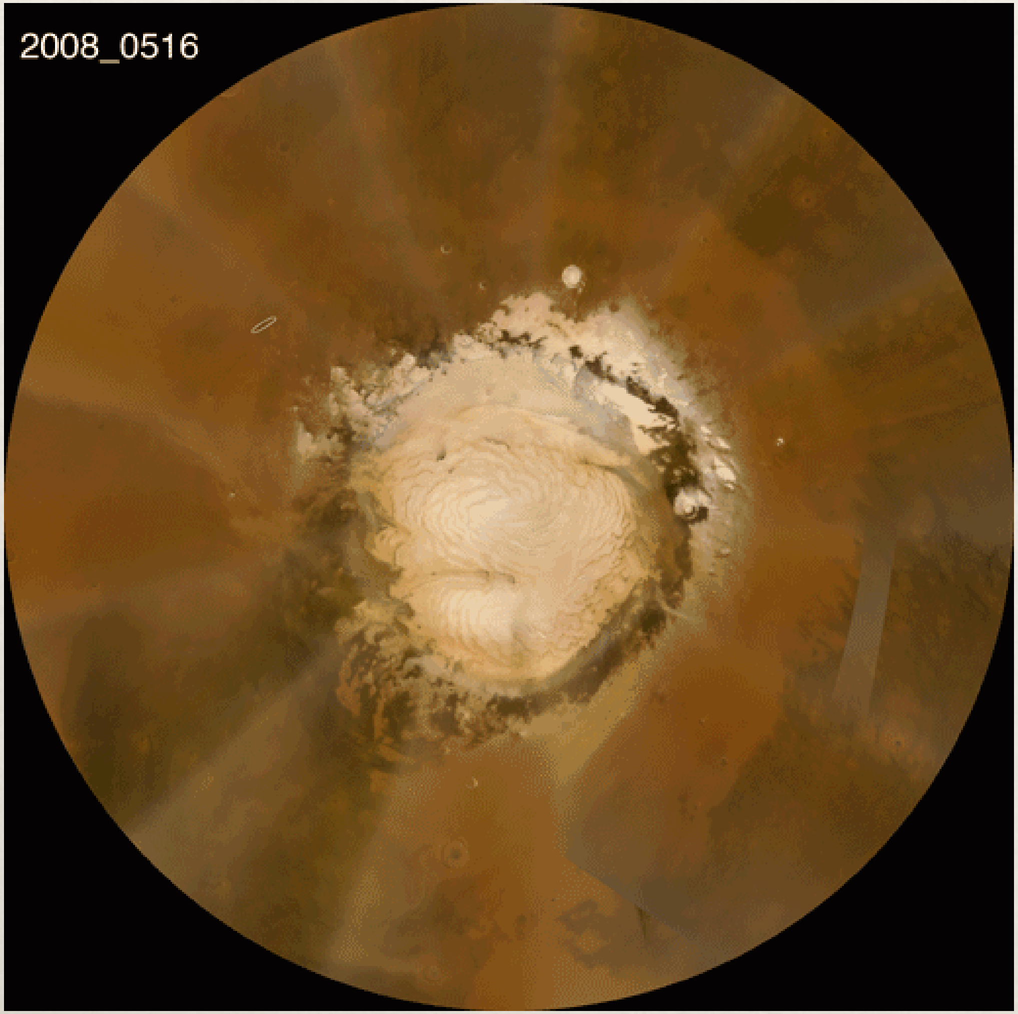
Final assembly

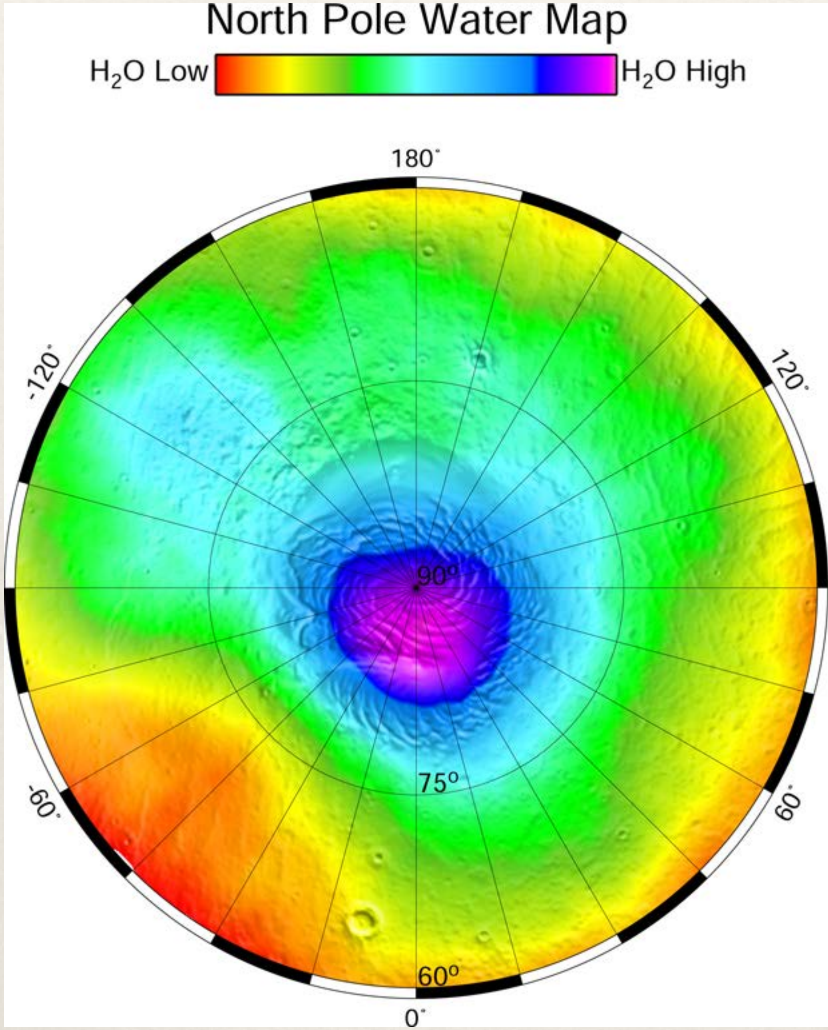
Perseverance launched on July 31, 2020 and will land on February18, 2021.

A final thought experiment

Going to the North Pole – a thought experiment

The North Pole as a destination?





The north pole: Paradise on Mars?

- Advantages
  - Benign thermal environment, contrary to popular belief (1 cycle per year at pole!)
  - Plentiful ice for consumption (water) and structures (including radiation shielding)
  - Interesting science (stratigraphic historical record)
  - Good communications via DTE or polar orbital relay
  - Good landing sites
- The thought experiment
  - Whether or not you're convinced that this is of value, how would it impact technology development?
  - For example, aerocapture would look very different if it involved latitude shifting.

Backup

Opposition class mission references
Radiation
Going to the North Pole

Opposition mission references

* Bridenstine tweet:
  https://twitter.com/JimBridenstine/status/1285277135712780290

  Blog post:
  https://blogs.nasa.gov/bridenstine/2020/07/20/human-exploration-of-mars-is-on-the-horizon/

  Mars lite doc:
  https://www.nasa.gov/sites/default/files/atoms/files/moon-investments-prepare-us-for-mars.pdf

  YouTube video:
  https://youtu.be/N0f-QkEVU7U

  Tech Feature:
  https://www.nasa.gov/directorates/spacetech/6_Technologies_NASA_is_Advancing_to_Send_Humans_to_Mars/

Radiation

- Solar protons: Largest dosage from storms, warning is available, and water provides shielding
- Energetic ions from Galactic Cosmic Rays: Essentially unshieldable in space. Protection offered by atmosphere, magnetic fields, or massive rock and ice
- Potentially harmful, not fatal, comparable to risks from other sources.
- Extensively studied on and around Mars (MARIE)

MOXIE
Mars Oxygen
ISRU Experiment

MARIE, designed to measure radiation, started malfunctioning shortly after a series of strong solar flares occurred in Autumn of 2003