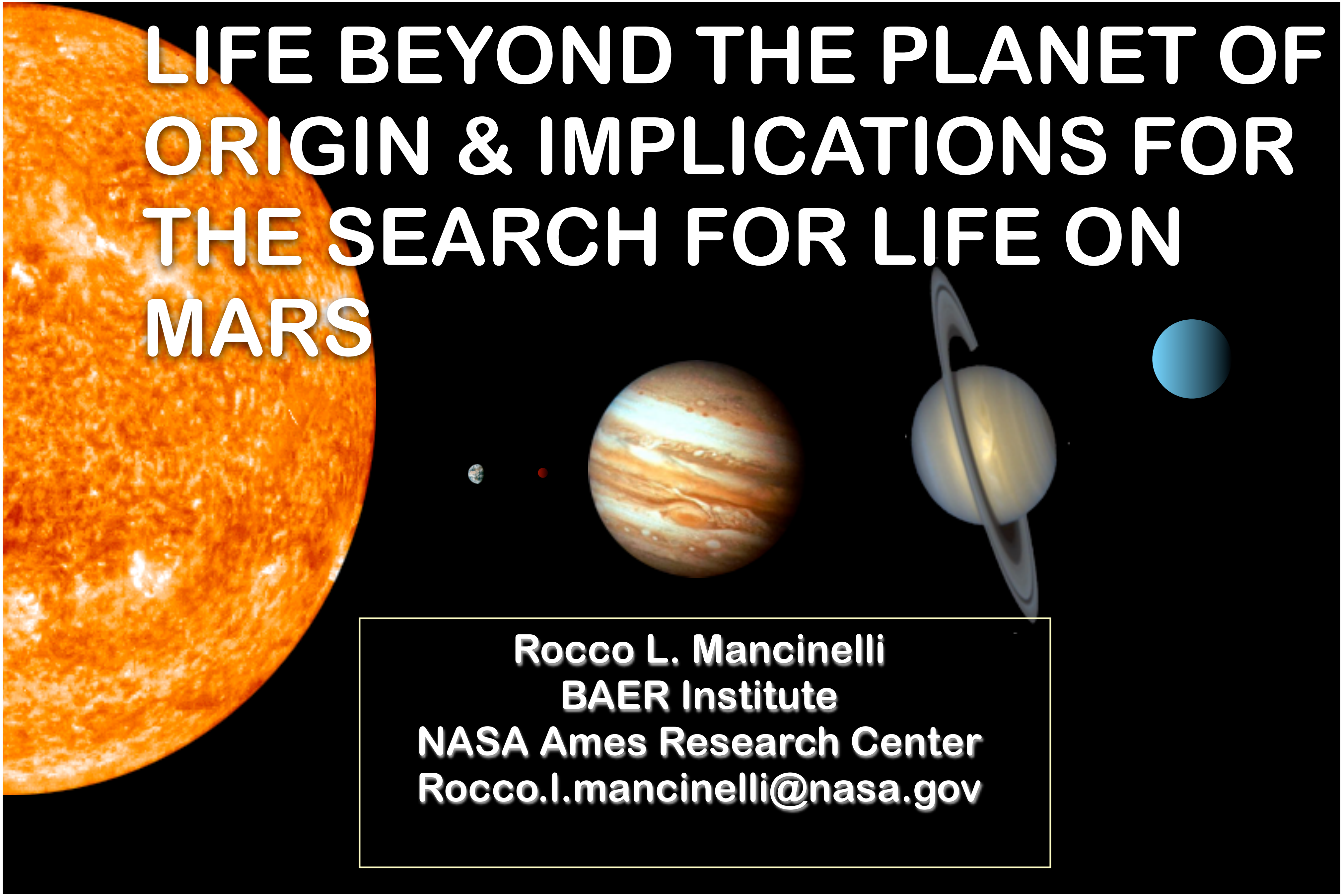
LIFE BEYOND THE PLANET OF ORIGIN & IMPLICATIONS FOR THE SEARCH FOR LIFE ON MARS



Rocco L. Mancinelli
BAER Institute
NASA Ames Research Center
Rocco.l.mancinelli@nasa.gov

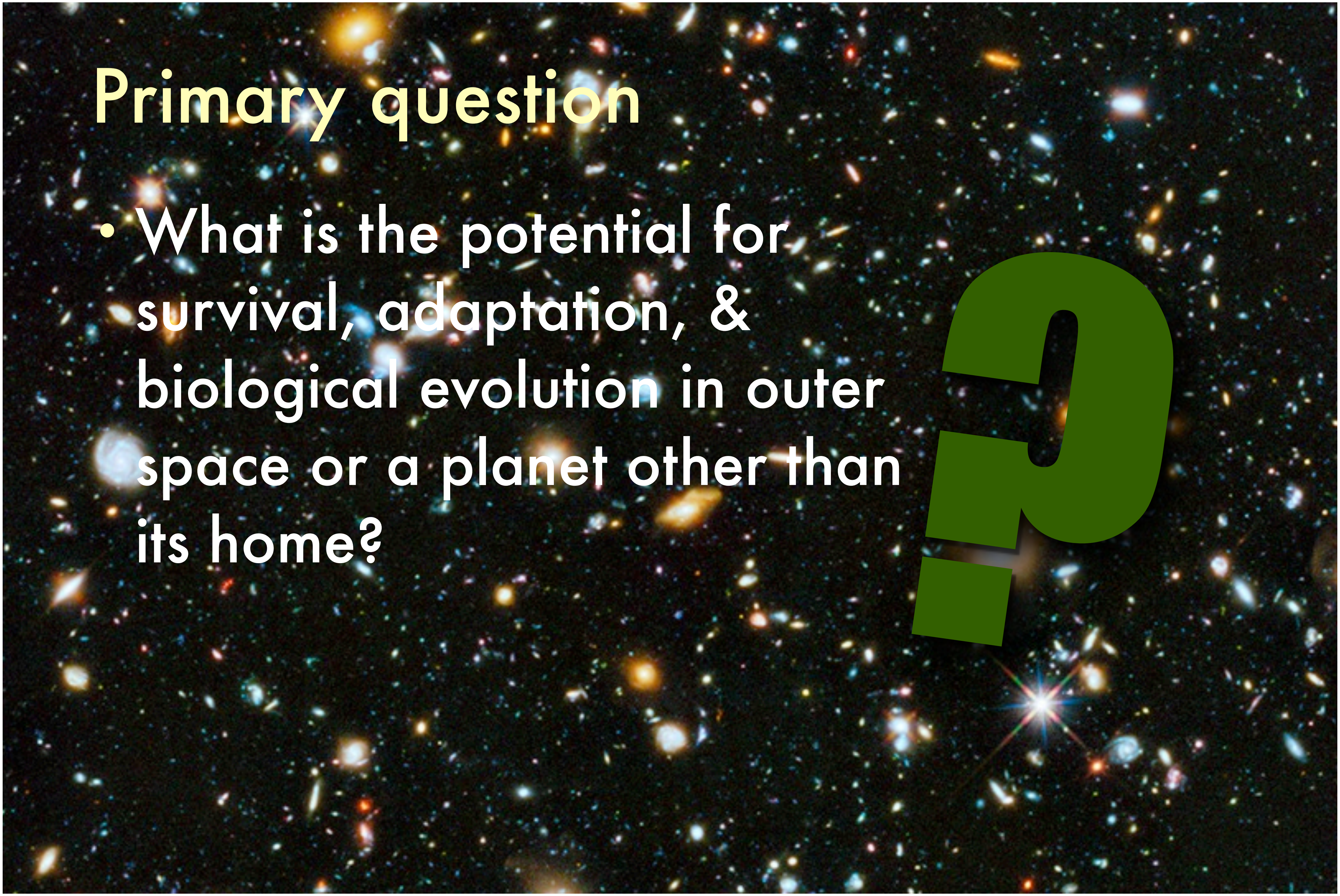
Our Journey Today

- Historical - From the past to the present
- Space - as an environment for life
- Venture to “Mars on Earth” simulation experiments
- Implications for the search for Martians

Our only planet with life so far

What is Panspermia?

- Life beyond the planet of origin
- Living organisms travel throughout the universe and develop wherever and whenever the environment is favorable (Richter, Lord Kelvin,and Arrhenius).
- Criticisms:
  - It *does not* answer the question of the origin of life. It sidesteps the issue.
  - Life will not survive long exposure to the hostile environment of intergalactic space.

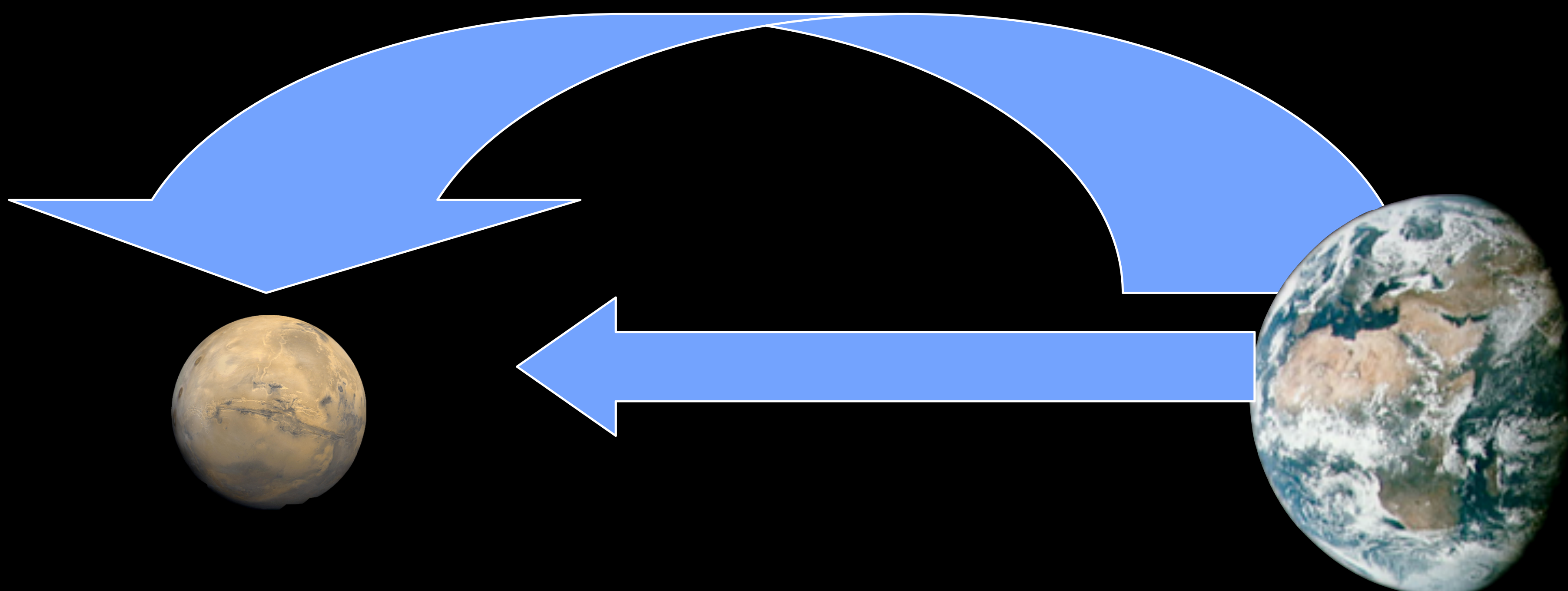


Primary question

- What is the potential for survival, adaptation, & biological evolution in outer space or a planet other than its home?

First step is to...

- Determine if terrestrial life can survive and live away from earth's surface. Atmosphere? Space Environment? Another planet (e.g., Mars)?

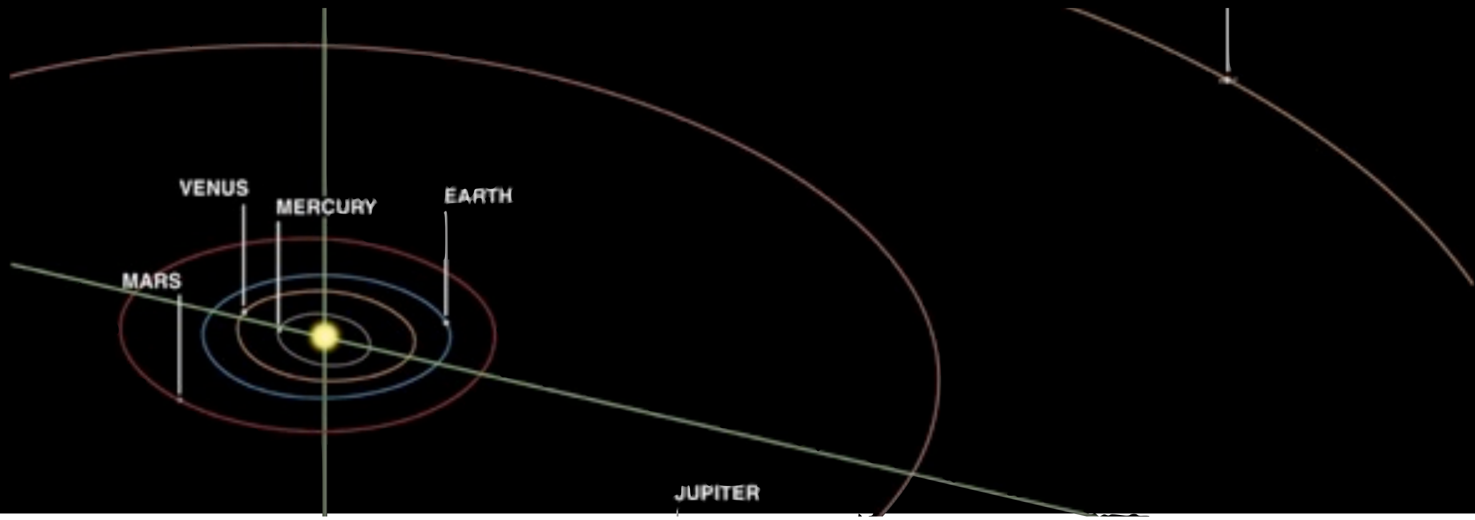


Why bother with this issue?

- Evolutionary questions: Origin of life on Earth; panspermia, or "Are we really Martians?"
- Planetary protection: How should we protect other planets?

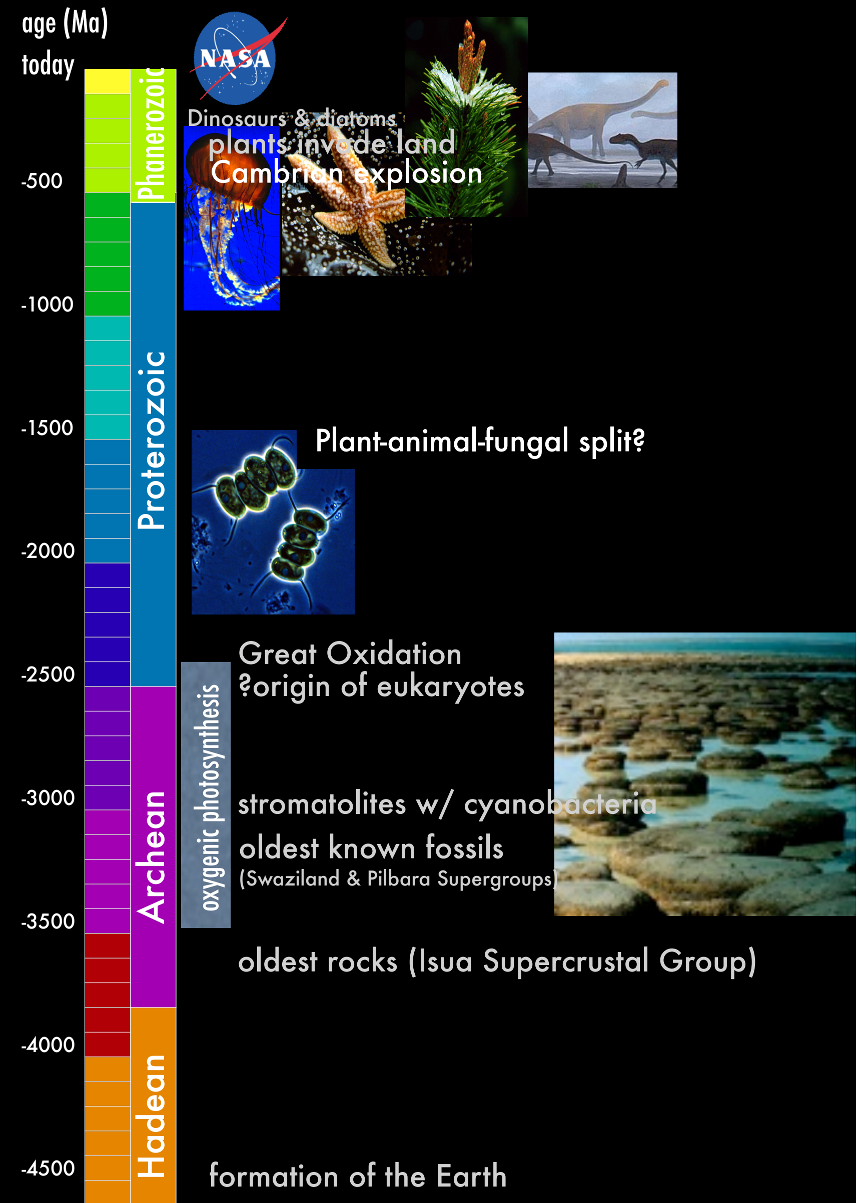
Contemporary Panspermia

- The transport of life from one planet to another.
- Problem
  - Need to travel from the surface through the atmosphere and into space.



Early Bombardment

- Late Heavy Bombardment occurred ~ 3.9-4.2 billion years ago.
- Mars and Earth exchanged rocks.
- Microbes will survive the ejection and landing process.
- Lithopanspermia (transfer of microbes between solar system bodies via meteors)



Interplanetary space travel

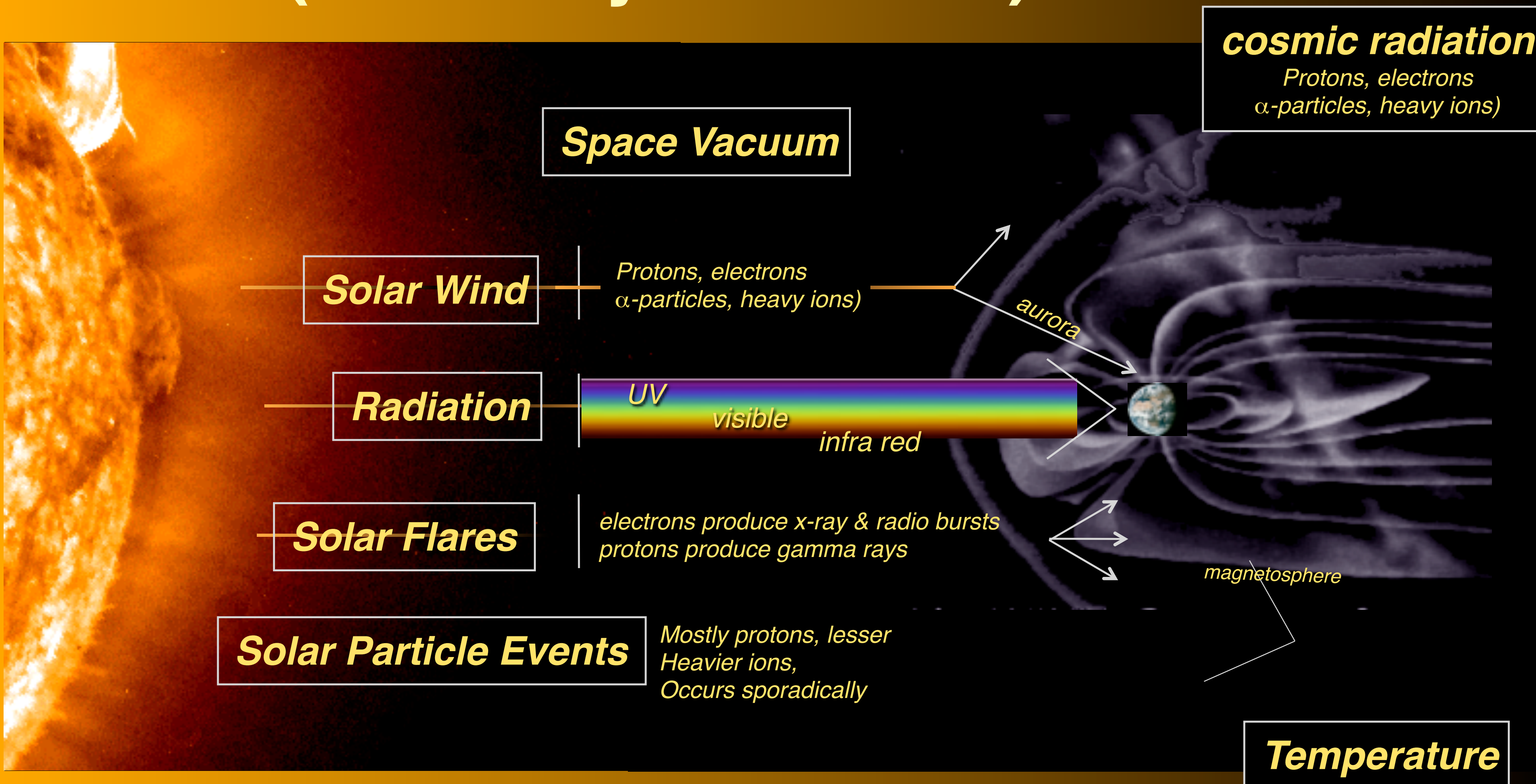
- Meteorites (natural) = Lithopanspermia

- Spacecraft (artificial)

Early History

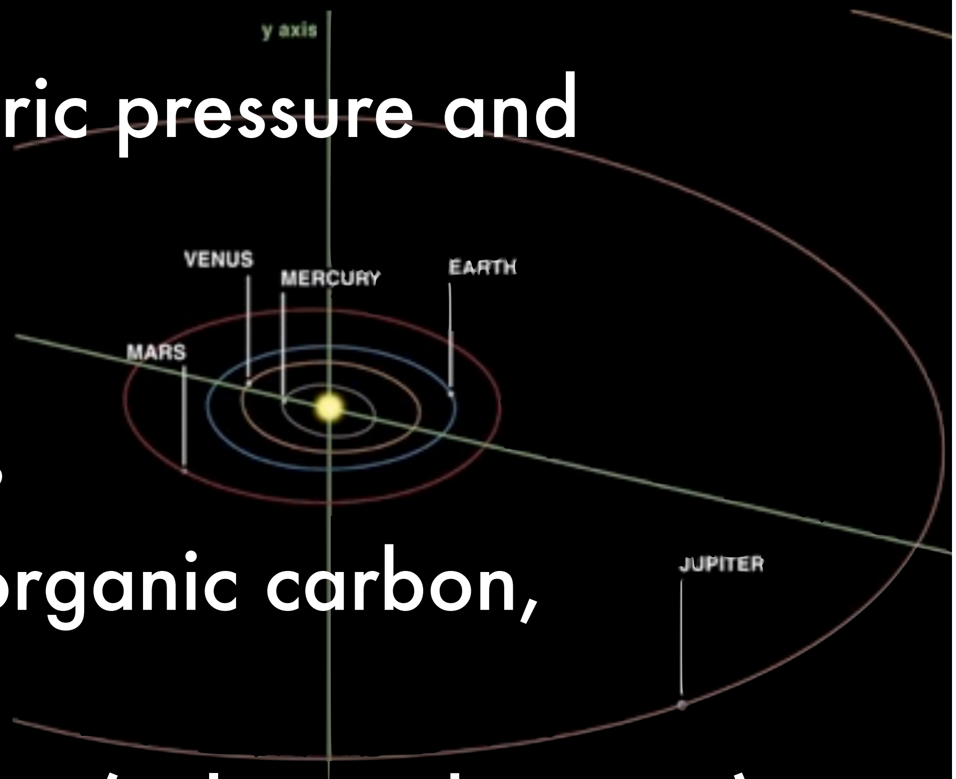
- Microbes (viruses, vegetative bacteria, *D. radiodurans, B. subtilis* spores) have been flown and exposed to space environment since the 1960's. All died instantly except *B. subtilis* spores
- LDEF 1984-90 – Survival of *B. subtilis* spores only in multi-layer or overlain with a substance.

Why is the space environment difficult for life (it's nasty out there)



Why is life beyond the home planet difficult?

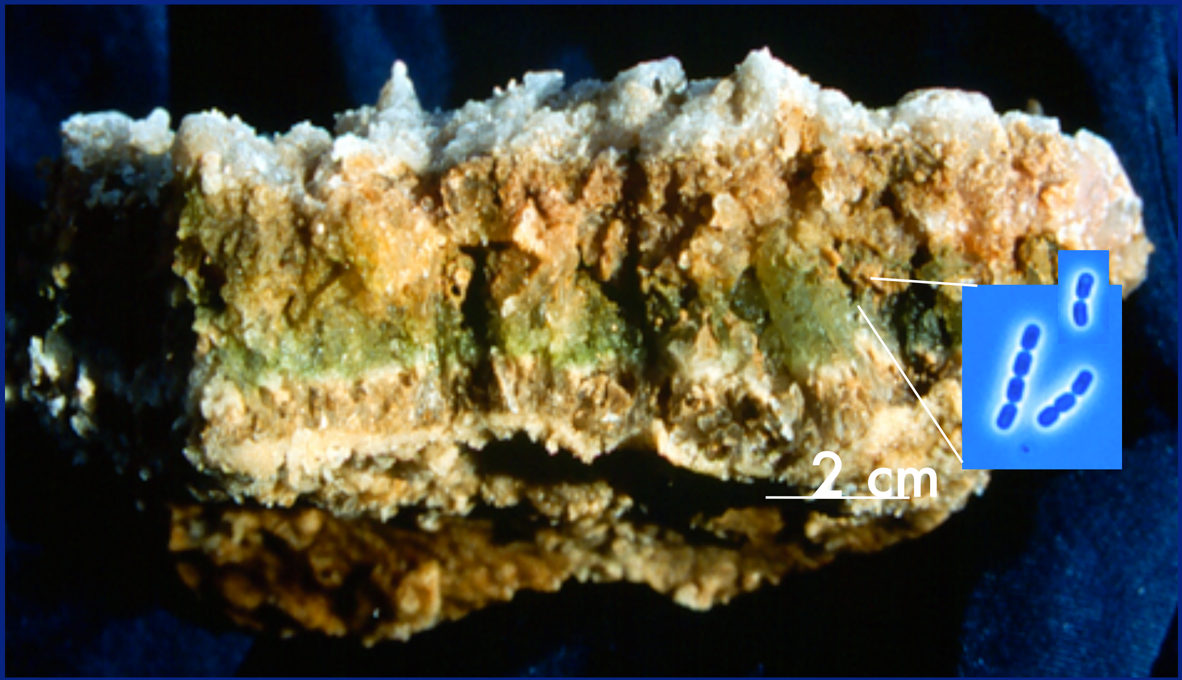
- Differences in atmospheric pressure and composition
- Altered gravity
- Temperature differences
- Nutrient sources (e.g., organic carbon, nitrogen)
- Different radiation regime (solar and cosmic)
- Life on Earth evolved to live on Earth not elsewhere




Life in Space

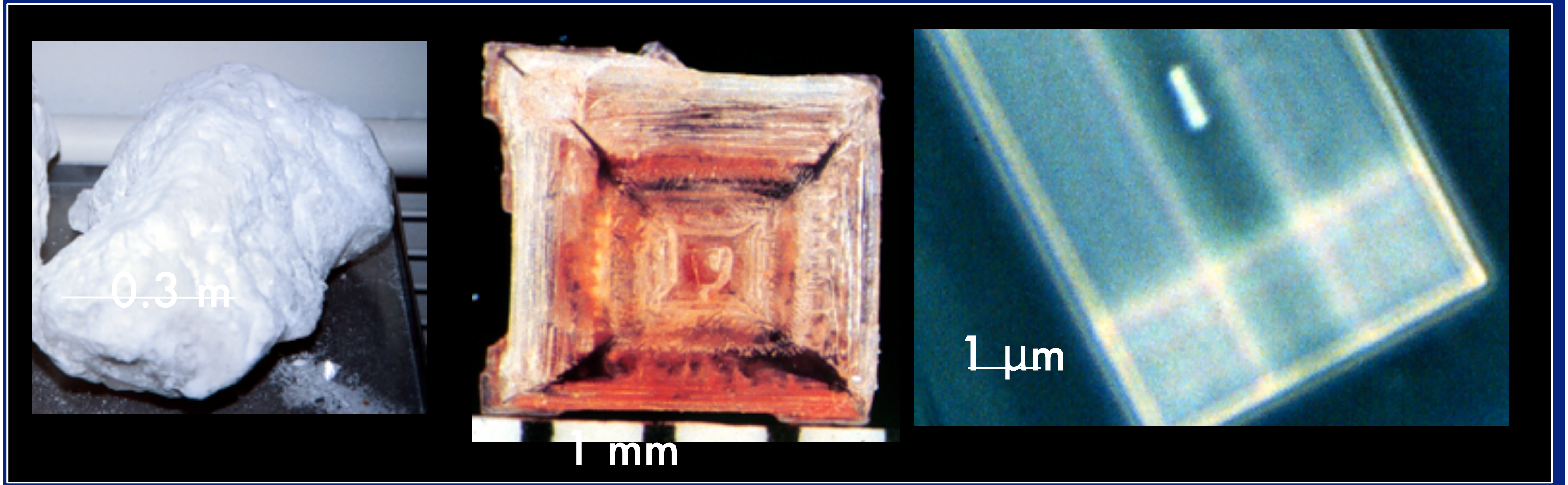
Gypsum-Halite crusts

Guerrero Negro, Baja California, Mexico



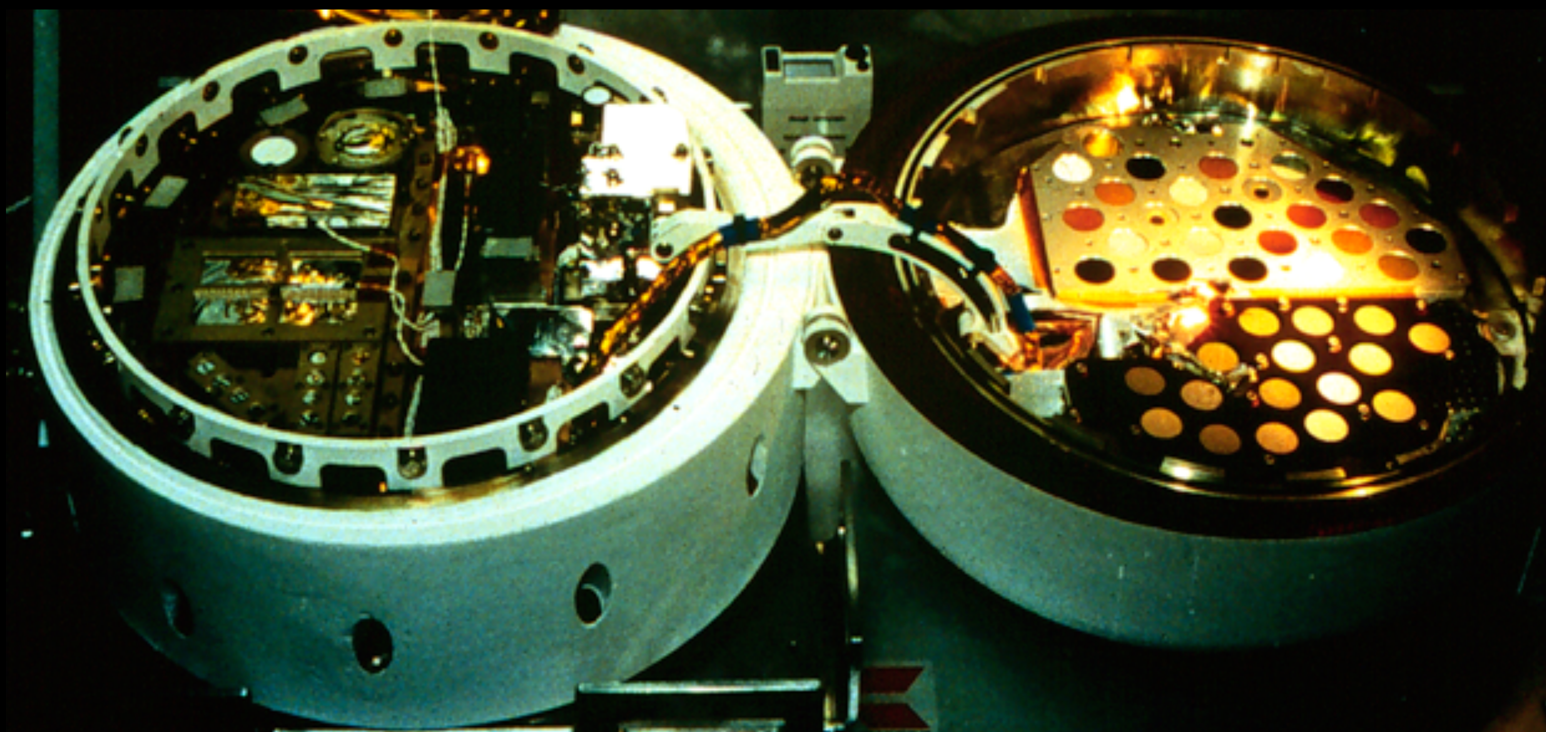
Synechoccocus

Halophiles in NaCl crystals



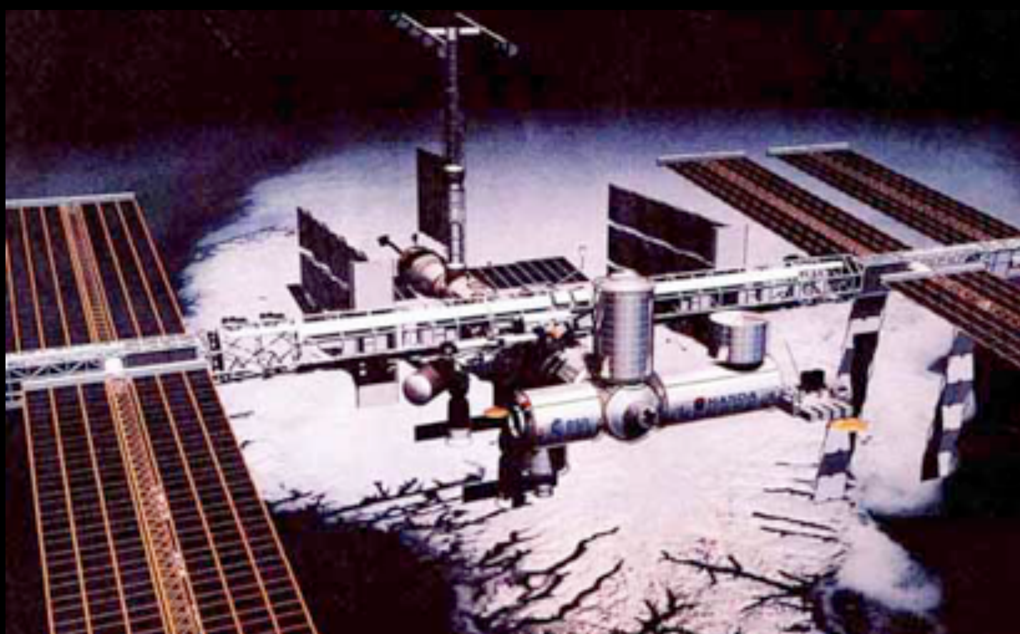
- Archaea

Biopan - ESA's pan shaped biological space exposure facility designed to fly in earth orbit aboard the Russian Foton rocket.



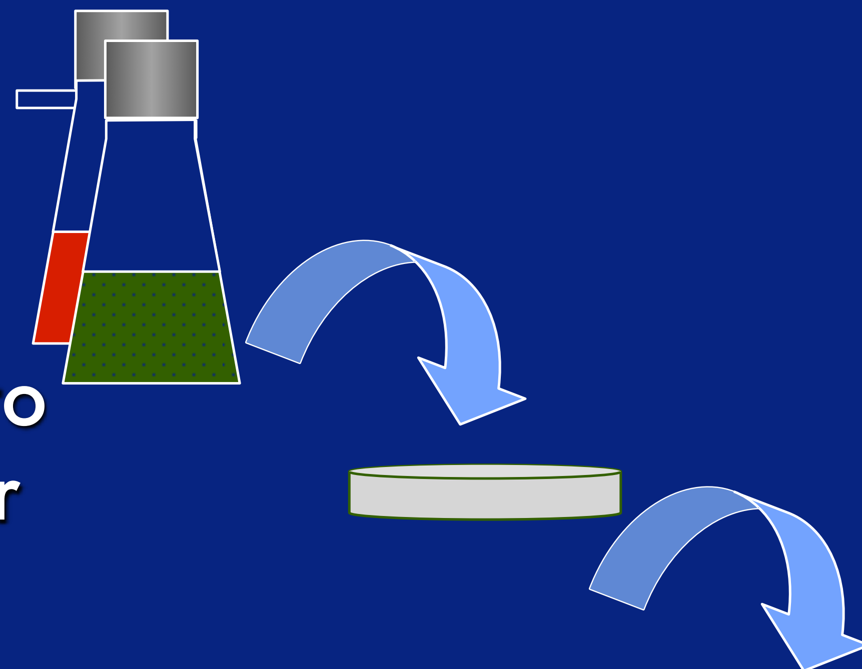
Question

Can Halophiles survive in space as well as bacterial endospores?



Experimental protocol: pre-flight

- Washed mid-log phase organisms diluted to 10^7 microbes μL^{-1}.
- 40 µL aliquots placed onto 7 mm quartz discs and air dried overnight.
- 2 sets of discs prepared for flight (UV & dark), 1 set remains in lab (control).

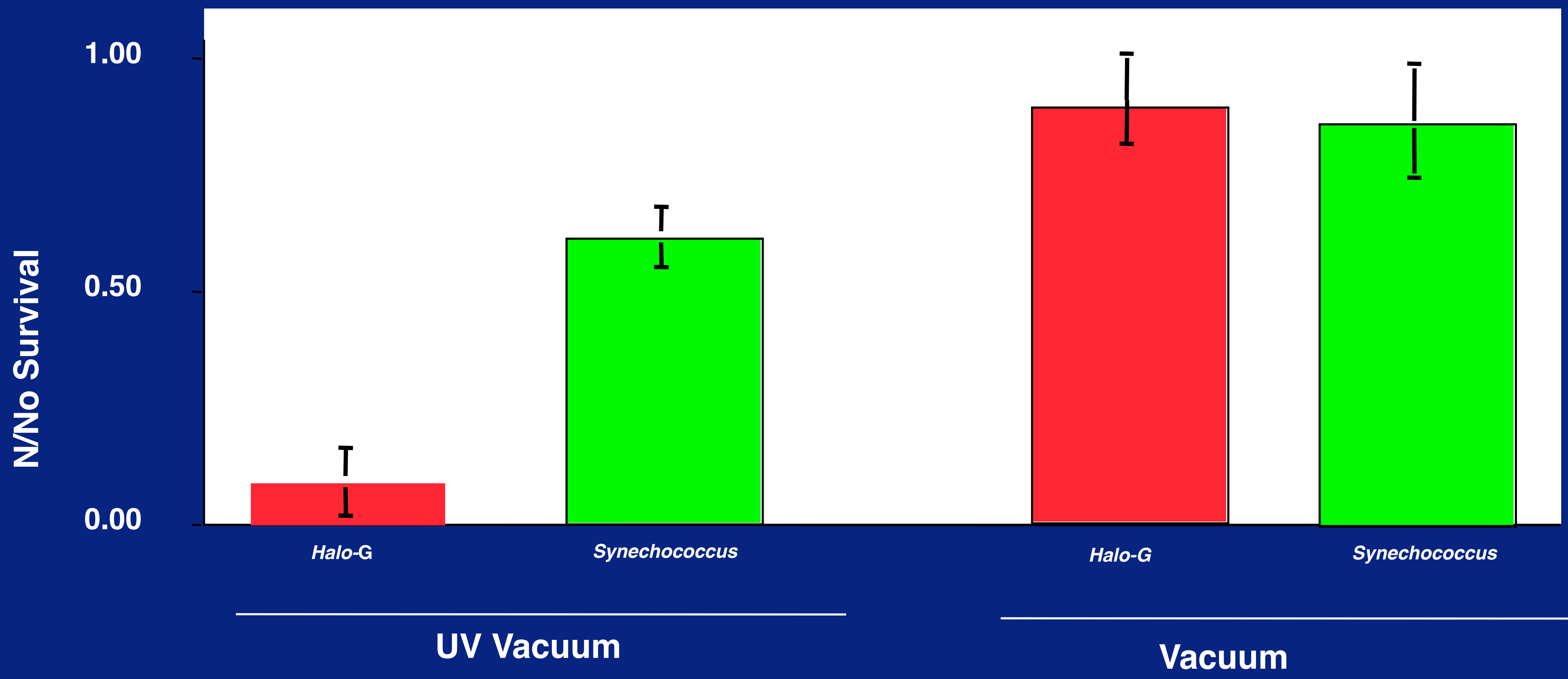


Biopan Mounted to Satellite

Three Biopan missions launched

- Organisms exposed to the space environment for 15 days
- Total UV dose = 10,000 KJ m^{-2} (~ 6,000 KJ m^{-2} UVA 4,000 UVB-C)
- Earth surface dose ≈ 6,000 KJ m^{-2} (UVA)
- Temperature +25 to – 14 °C

BIOPAN 3


N/No Survival
1.00
0.50
0.00
Halo-G
Synechococcus
Halo-G
Synechococcus
UV Vacuum
Vacuum

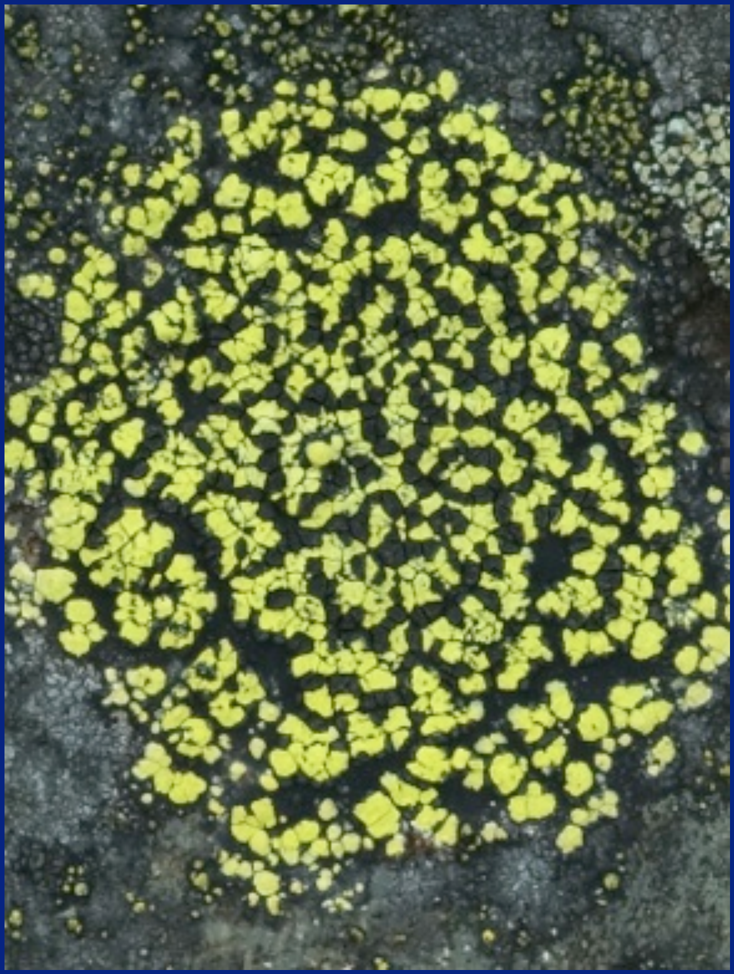
Results

- Hypothesis true: *Synechococcus* (Nägeli) inhabiting gypsum-halite crusts and *Halo*-*G* survive exposure to the space environment.
- DNA damage correlated negatively with survival.

First non-sporeformers to survive space

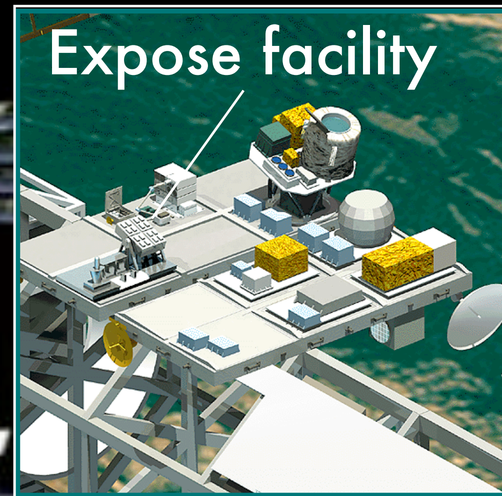
Biopan 6

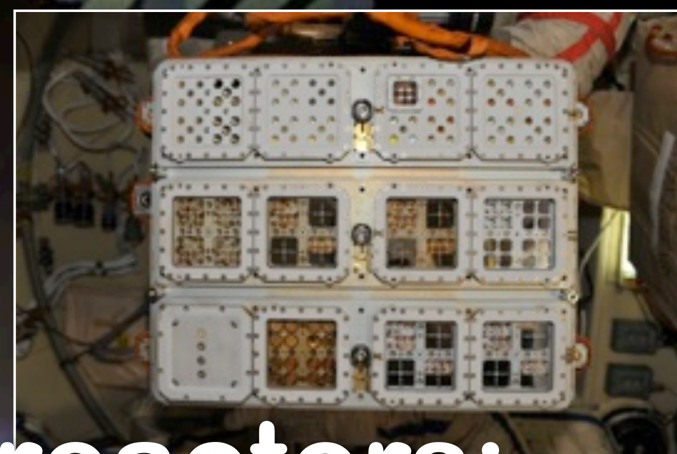
- *Rhizocarpon geographicum* a bipolar epilithic lichen colony was flown on Biopan in 2005 and some members of the colony survived.



External Space Bioreactors: Expose Facility (ESA)

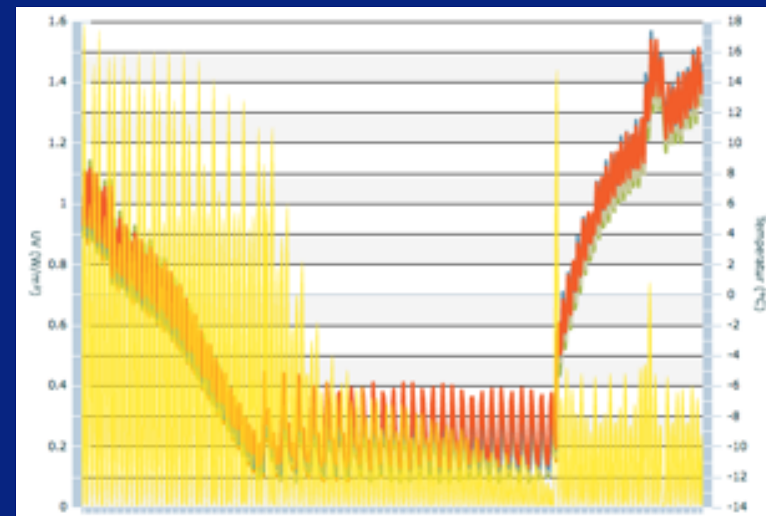
- *Halorubrum chaoviator Synechococcus Nägli*
- Exposed for 2 years March 2009- Feb. 2011
- Fully exposed samples appear bleached.



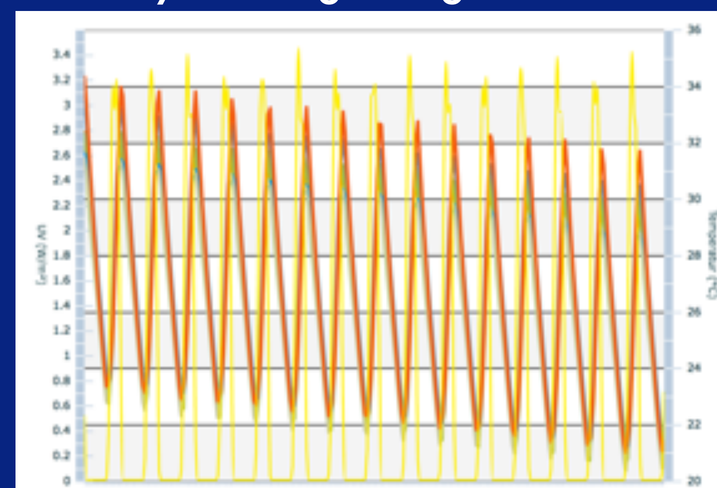


Temperature/UV

- Measured at six sites
- T Fluctuated between +49.47 and −24.65 °C due to the oscillation of the orbital plane of the ISS w.r.t. the Sun and from the day/night oscillations during each orbital loop

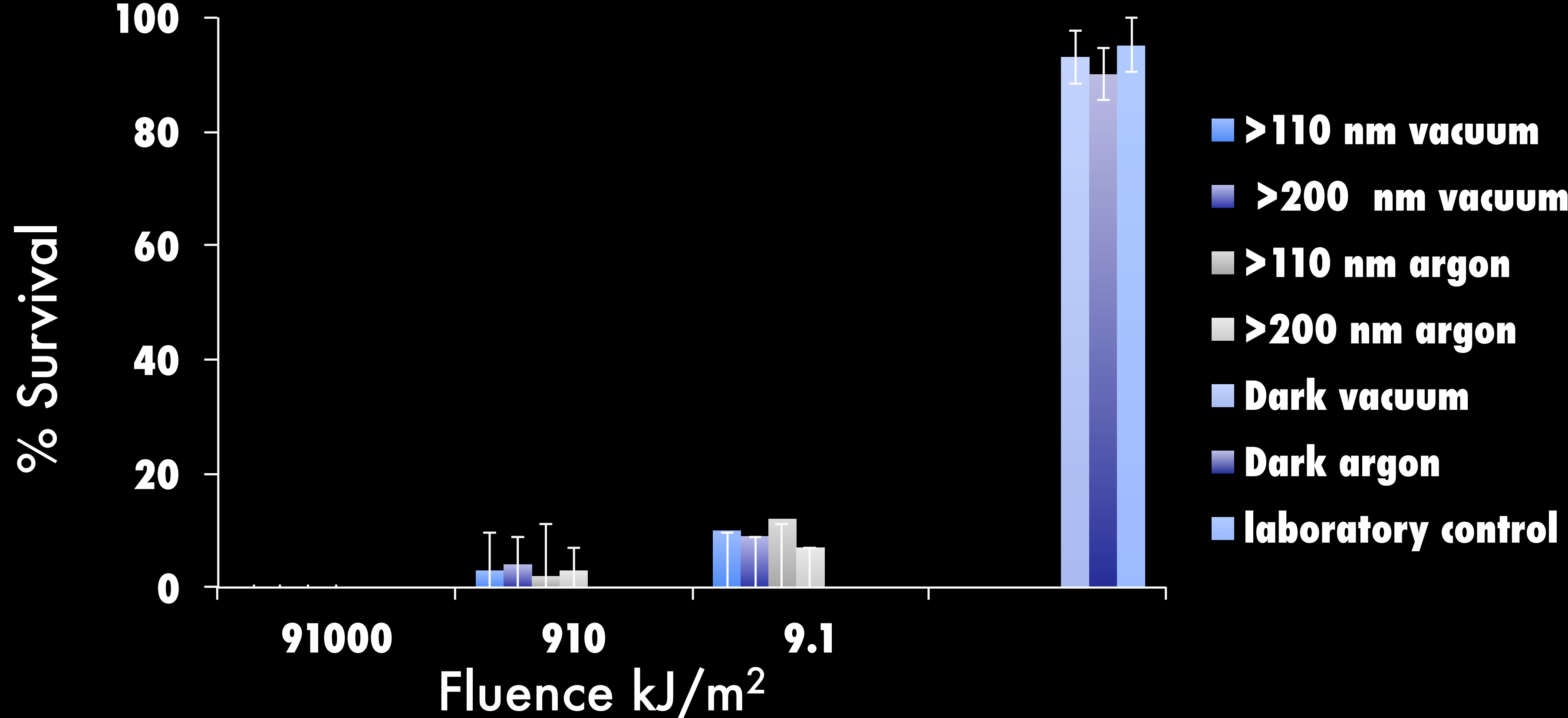


Daily Average August 2009



Hourly Average 9 August 2009

Results



Flight samples *Halorubrum Chaoviator*

Mancinelli, 2015

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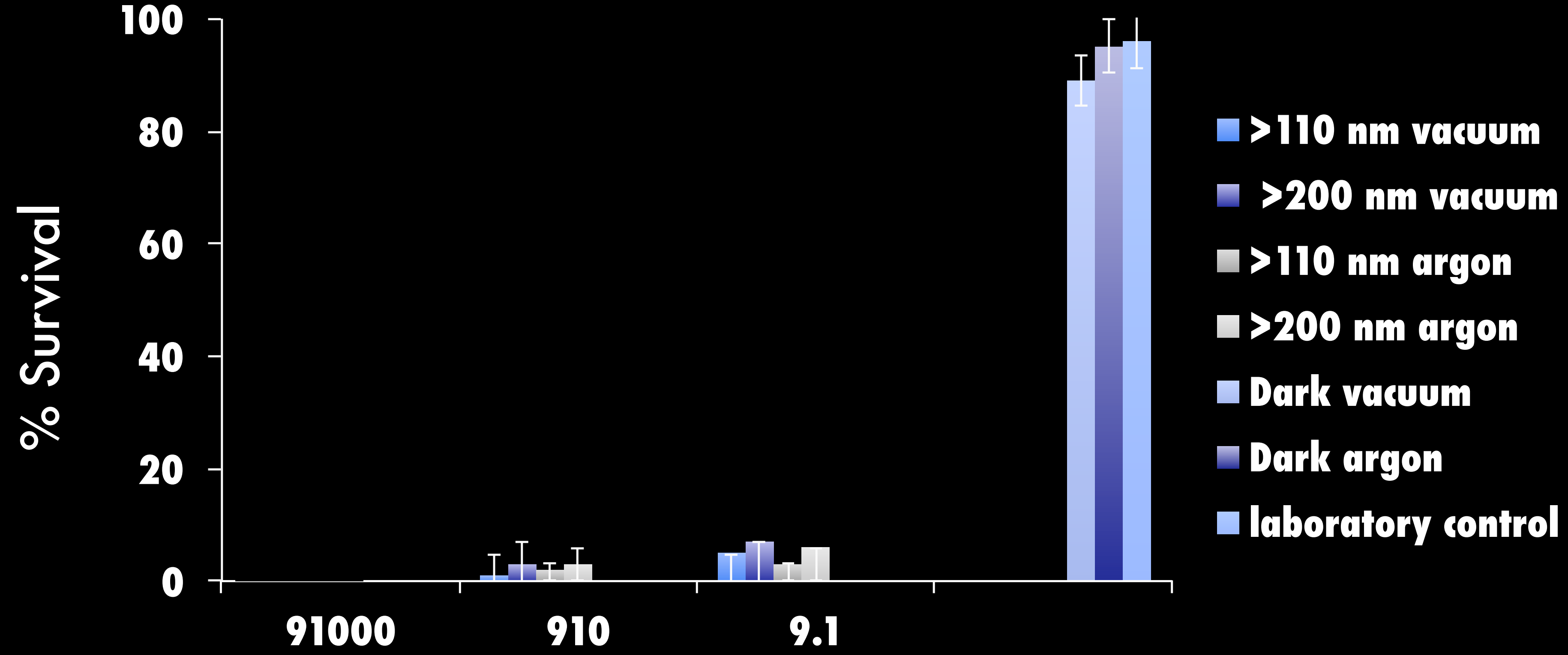
Results



Fluence kJ/m²

Flight samples *Synechococcus* (Nägli)

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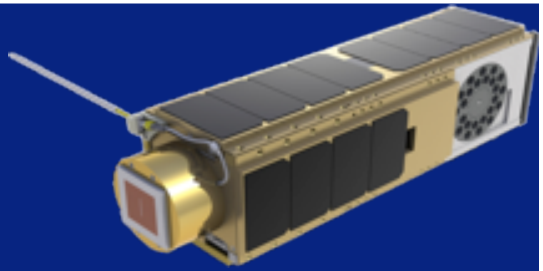
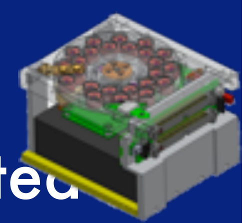
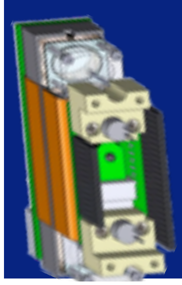
O/OREOS-Sat



- O/OREOS demonstrates the viability of low-cost spaceflight science experiments on miniaturized satellites for astrobiology
- O/OREOS studied microbial survival and growth as a function of microgravity and hard radiation utilizing in-situ detection (optical measurements), in micro-well plates.



- O/OREOS was launched in spring 2010 and conducted experiments over a period of 6 months while orbiting at an altitude of 650 km

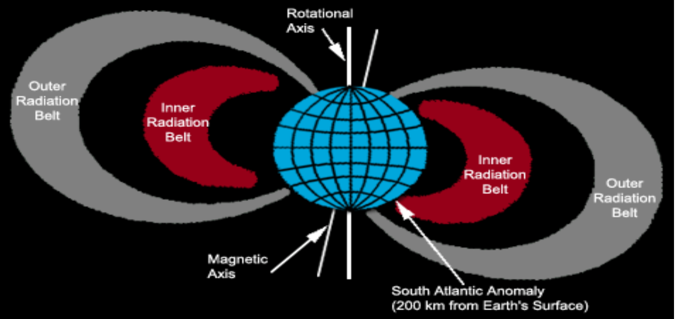


Kodiak lift off

- Launch: November 2010
- Launch Vehicle: Minotaur IV
- Launch Site: Kodiak, Alaska

Kodiak Launch Complex, AK
57° 25′ N, 152° 21′ W

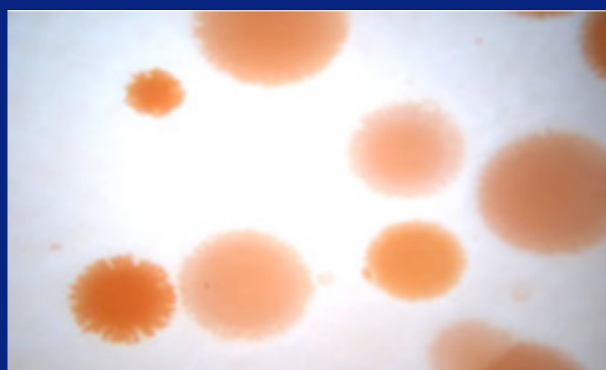
Space conditions



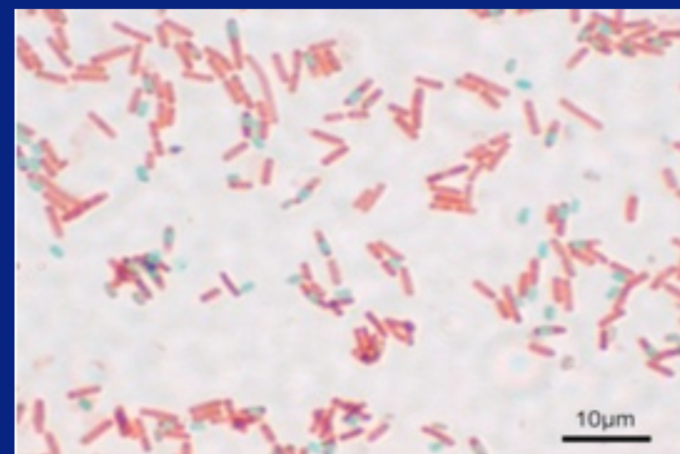
- Biology: Particle radiation and microgravity
  - < 10^{-3} g
  - 2 – 20 Gy total dose over 6 mo (0.1 Gy is GCR)

Space Environment Survivability of Live Organisms (SESLO)

- *Halorubrum chaoviator & Bacillus Subtilis* spores (each as wild-type and mutant) were launched in a dry state



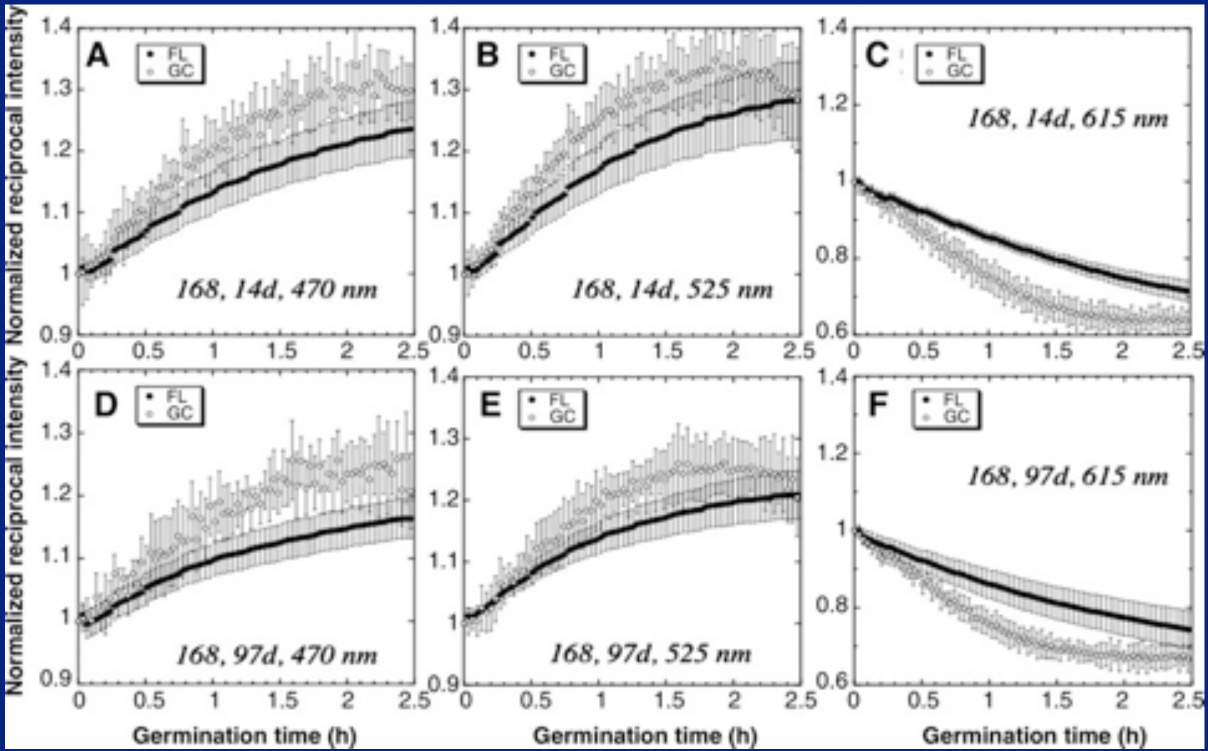
Halorubrum chaoviatoris



Bacillus subtilis

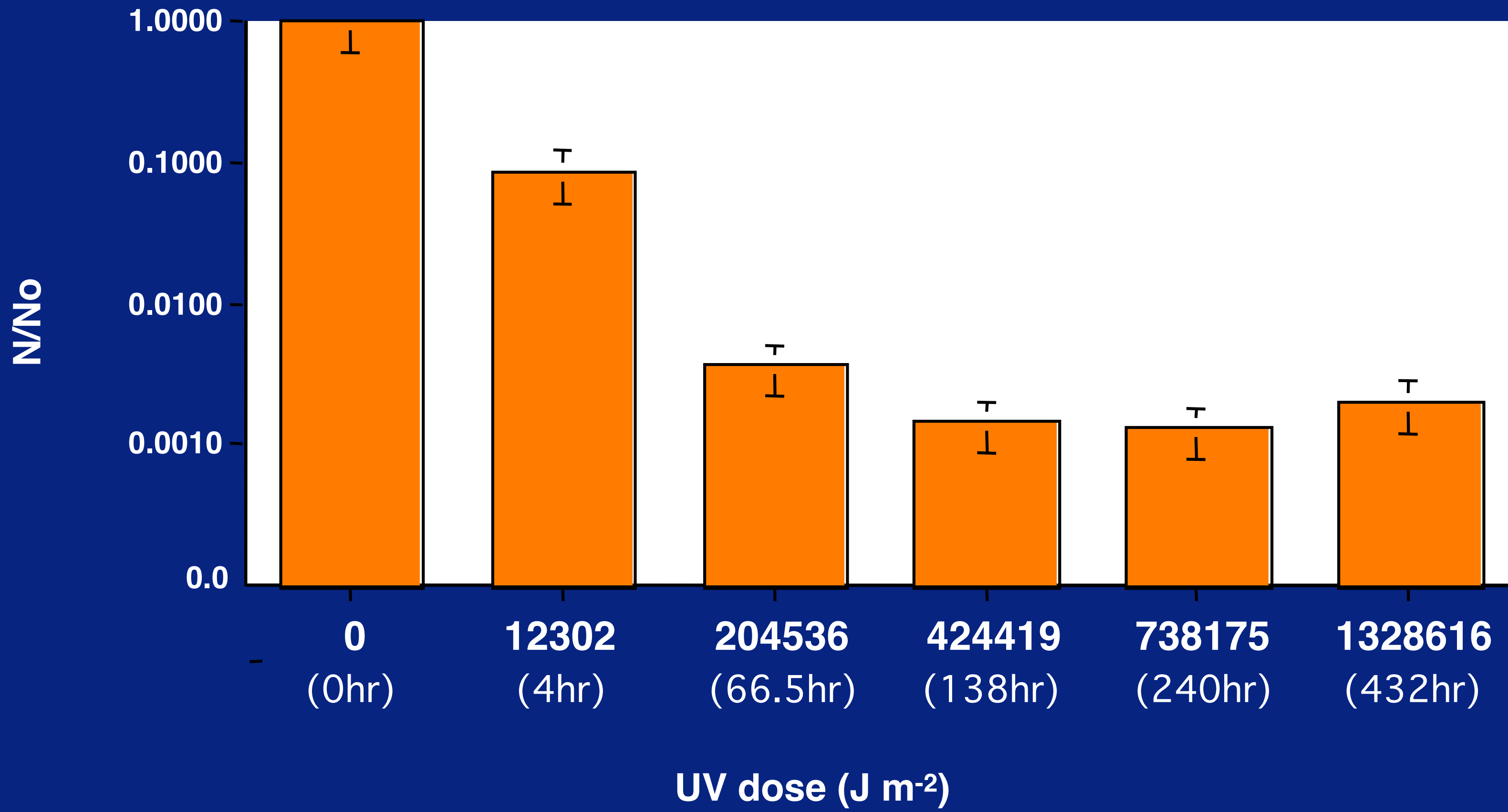
- Fluids were added to sub-groups of organism-containing microwells at three time points over the 6-month course of the mission

Results



Wild-type *B. subtilis* strain 168 spores. Flight (FL; filled circles) and ground control (GC; open circles) data for SESLO bioblock module 1, activated at Day 14 post-launch (top row A–C) and bioblock module 2, activated at Day 97 post-launch (bottom row D–F). Data were taken at 470 nm (A, D), 525nm (B, E), and 615 nm (C, F). Data points are averages – standard deviations (n = 4 for D/FL; n = 5 for B/FL and E/FL; n = 6 for all others).

Potential Survival on Mars

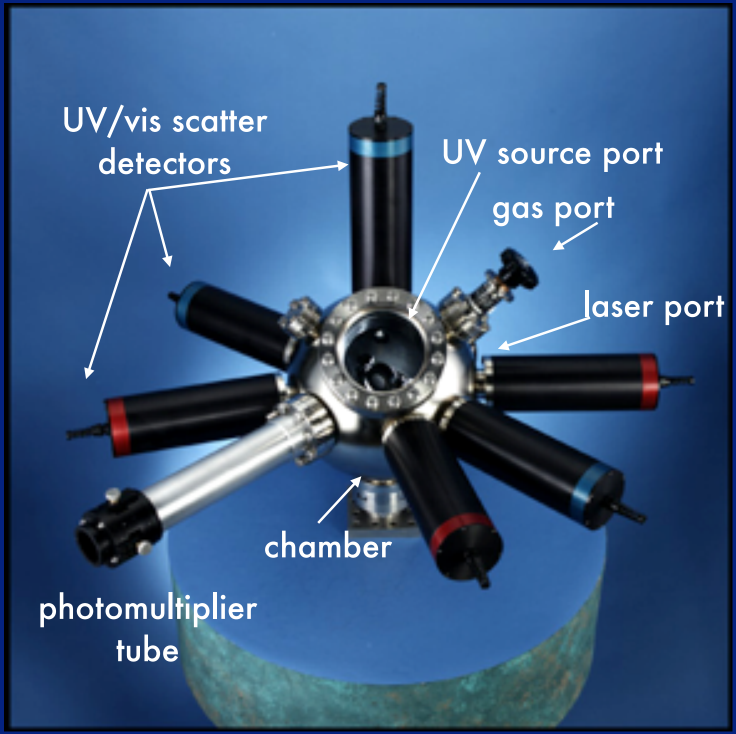


Survival of spores in a monolayer (1.7 x 10^6 spores/ml) under a 12 µm layer of sterile sieved Mars analog soil exposed to increasing doses of UV radiation.

Mars windblown dust

- **Mars has global dust storms (~ 25% of yr.)** *Microbes are easily picked up in dust storms*
- **Dust decreases the UV flux**
- **On Earth survival of airborne microbes enhanced by dust in the atmosphere.** *Dust protects microbes from UV*.

AEROSOL SPECTROMETER

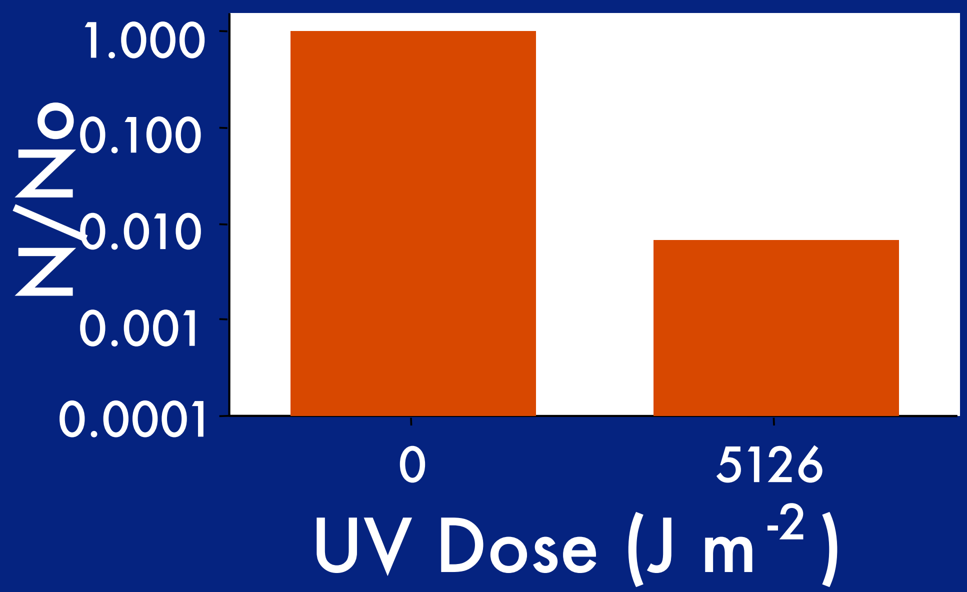


- The spectrometer consists of an 8L SS gas tight chamber with variable speed rotor, gas/evacuation ports, Ar-laser (particle concentration/ size), UV/vis source & detectors.
- Keeps the dust in motion & determines velocity, size & number of particles suspended in the chamber to determine the average UV exposure rate per particle.

Approach

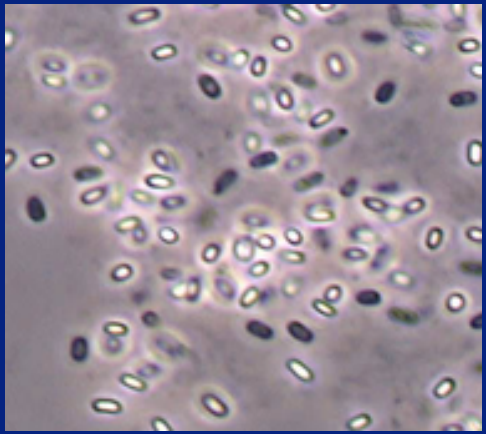
- Microbes (*B. subtilis spores* & *E. coli*) were mixed with Mars Analog soil and dried (~5 X 10^6 cells g^{-1} dry wt soil).
- Soil/microbe mixture sieved & placed into chamber
- Suspend & expose soil/microbe mixture to UV (190-400 nm) at 10 mbar Mars simulated atmosphere for various periods of time
- Collect soil from chamber and determine number of survivors using MPN method.
- Controls not exposed to UV treated similarly

Survival in Mars dust

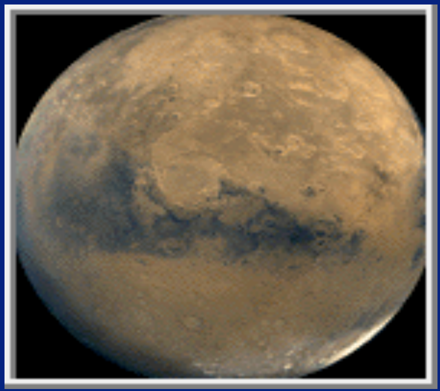


Bacillus subtilis spores survive exposure to UV radiation in Mars wind blown dust (OD = 0.75 @ 660 nm) in a Mars atmosphere,. *E. coli* killed by drying

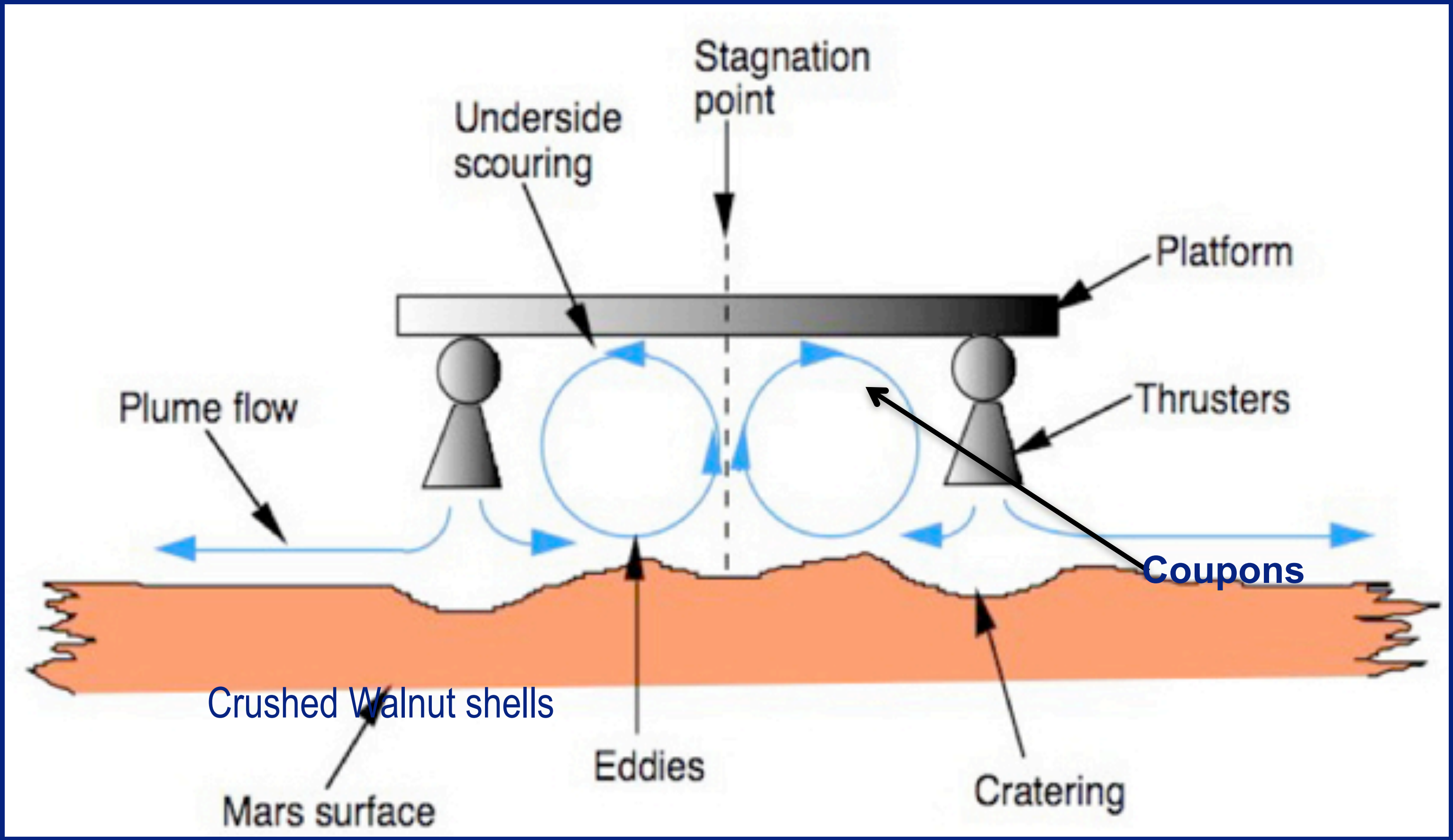
SIGNIFICANCE



- The ability of *B. subtilis* spores to survive in windblown dust on Mars raises the potential for global contamination.



Mars Phoenix landing simulation

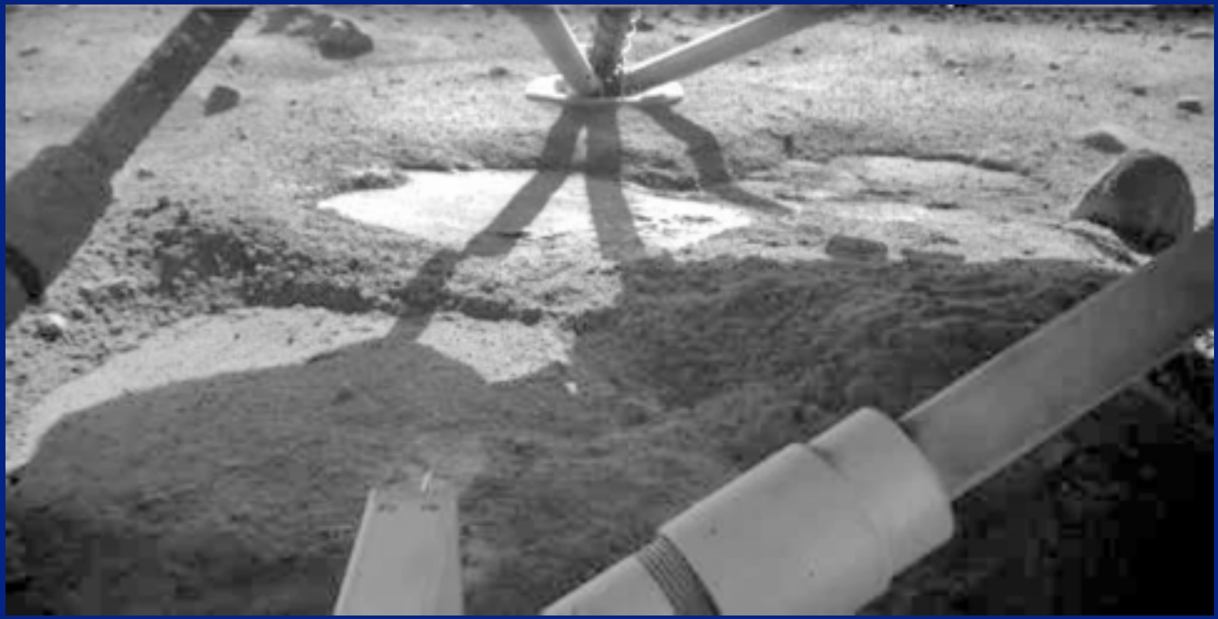


Lander engine arrangement with thrusters positioned on platform perimeter. This leads to captured reverse flow eddies impinging on the spacecraft underside (highly simplified). Tested at 10 mbar.

Test matrix for PP experiments

	Test 1	Test 2	Test 3
Test bed material	Crushed Walnut	Crushed Walnut	Crushed Walnut
Test bed grain size	180 microns	180 microns	30 microns
Thruster height	0.5 m	0.5 m	0.5 m
Thrust duration	1.5 s	1.5 s	1.5 s
Engine mode	pulsed	Steady state	pulsed

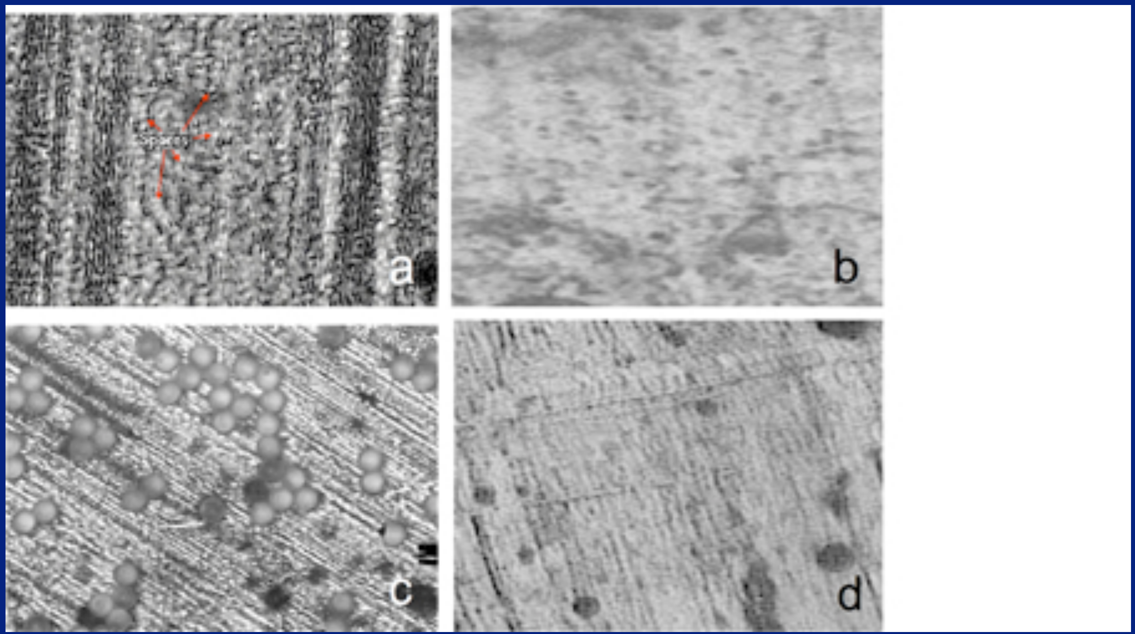
Phoenix lander image



Robot Arm Camera image of cratering under the Phoenix lander. Soil has been completely stripped down to the ice table. The right side of the image shows piling up of soil under the center of the lander where the plume eddies converge

Results

99.99999 % of spores and beads removed

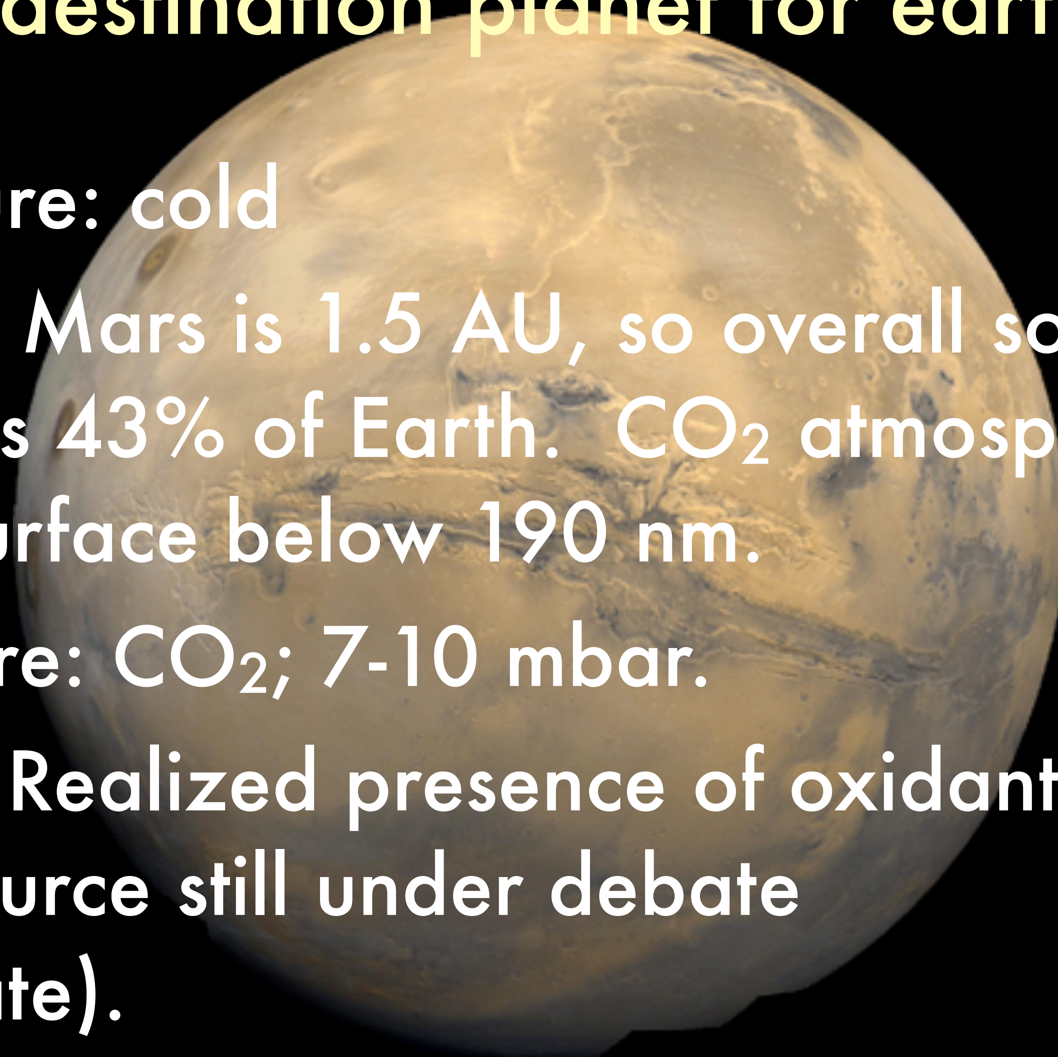


Photomicrograph of spores and beads on coupons before and after test. a: Bacillus subtilis spores on control coupon. b: Coupon after test. c: 6 um microspheres on control coupon. d: Bead coupon after test. Width of image fields =100 um.

Summary

- *Different planetary protection cleanliness levels for different parts of a spacecraft do not necessarily prevent soil contamination because these cleaning strategies evolved without consideration of the effects of the descent engine plumes.*

Mars as a destination planet for earth life



- Temperature: cold
- Radiation: Mars is 1.5 AU, so overall solar radiation is 43% of Earth. CO_2 atmosphere protects surface below 190 nm.
- Atmosphere: CO_2; 7-10 mbar.
- Oxidants: Realized presence of oxidants after Viking. Source still under debate (perchlorate).

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Mars potential for anthropogenic contamination

- Probability of microbial growth on Mars is low.
  - Cold (~ –60 °C)
  - Dry (Atm. vapor=100 ppt H_2O max, N-pole),
  - P=7-10 mbar (95.3% CO_2, 2.7% N_2, 1.6% Ar)
  - oxidizing, UV flux (10^4 erg cm^{-2} sec^{-1})
  - Microbes can survive cold, dry, oxidizing conditions, and some UV exposure.
- Probability of microbial *survival* on Mars possible.
- Finite probability of global contamination by dust storms.
- If we find life on Mars we must take exta care to make sure that it is NOT something brought from Earth.

Conclusions

- Terrestrial life can *survive* away from earth
  - Space environment
  - Simulated Mars environment
- We have just taken the first step in understanding the process of life beyond the home planet.