Robotic Lunar Ecopoiesis Test Bed NIAC

Presented by: Paul Todd
October 19, 2004

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Four Levels of Inquiry Concerning Biology and Mars

1. **Planetary protection, contamination and quarantine issues (NRC, 1992),**
2. **The search for life on Mars (Banin, 1989; Banin and Mancinelli, 1995; Ivanov, 1995; Koike et al., 1995; Biemann et al., 1977),**
3. **Human expeditions to Mars and ecosynthesis (Meyer & McKay, 1984, 1989, 1995)**
4. **The terraforming of Mars, ecopoiesis (Haynes, 1990; McKay, 1990; Haynes and McKay, 1992; McKay et al., 1991, 1994; Hiscox, 1993, 1995, 1998).**

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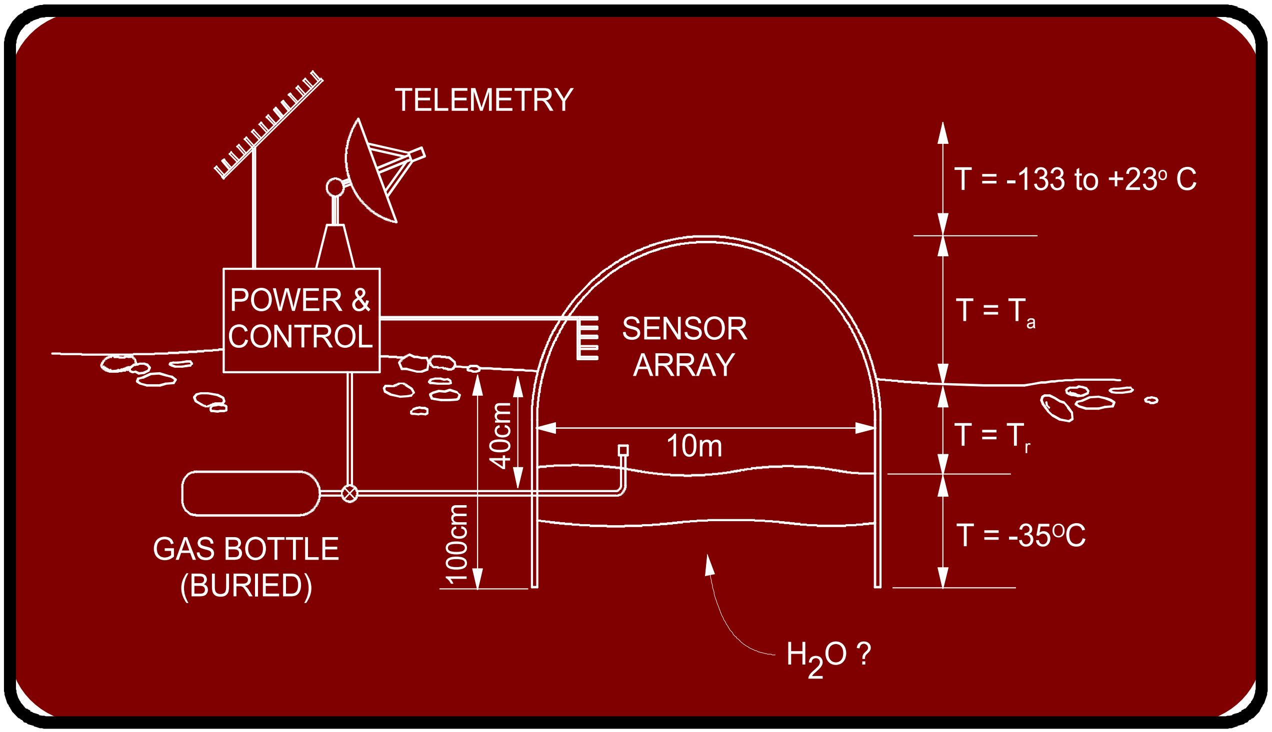
ECOPOIESIS

- Term introduced by Haynes and McKay
- Terraforming = making another planet or object in the solar system like Earth
- Heating: (1) Greenhouse gases, (2) Mirrors and smoke, (3) Ecopoiesis
- Ecopoiesis = emergence of a living, eventually self-sustaining ecosystem
- Precedes terraforming
- Required step: experimental ecopoiesis

Starting Position: Robotic Lunar Ecopoiesis Test Bed

- Trenched, depressed site
- Sealed in all dimensions
- Inflatable dome solidifies
- Sealed interior controlled to Mars atmosphere
- Organisms & chemicals added to artificial regolith
- Control and data telemetry to earth



Robotic Lunar Ecopoiesis Test Bed: an Architecture

1. *Identify community of organisms.* A symposium will be held to develop a consensus concerning organisms to be utilized in early experiments.
2. *Develop preliminary chamber design.* A detailed set of drawings, with critical parts identified will constitute the principal engineering activity of Phase I.
3. *Identify partial-gravity venues and requirements.* Develop top-level logistics for accessing low-gravity venues (on ISS) that are compatible with partial-gravity, low-pressure hardware required for the on-orbit experiments.
4. *Develop scaling rules for test beds.* Derive scaling rules for gas concentrations, heat capacities, heat transfer, light and radiation intensities, biomass and mechanical properties

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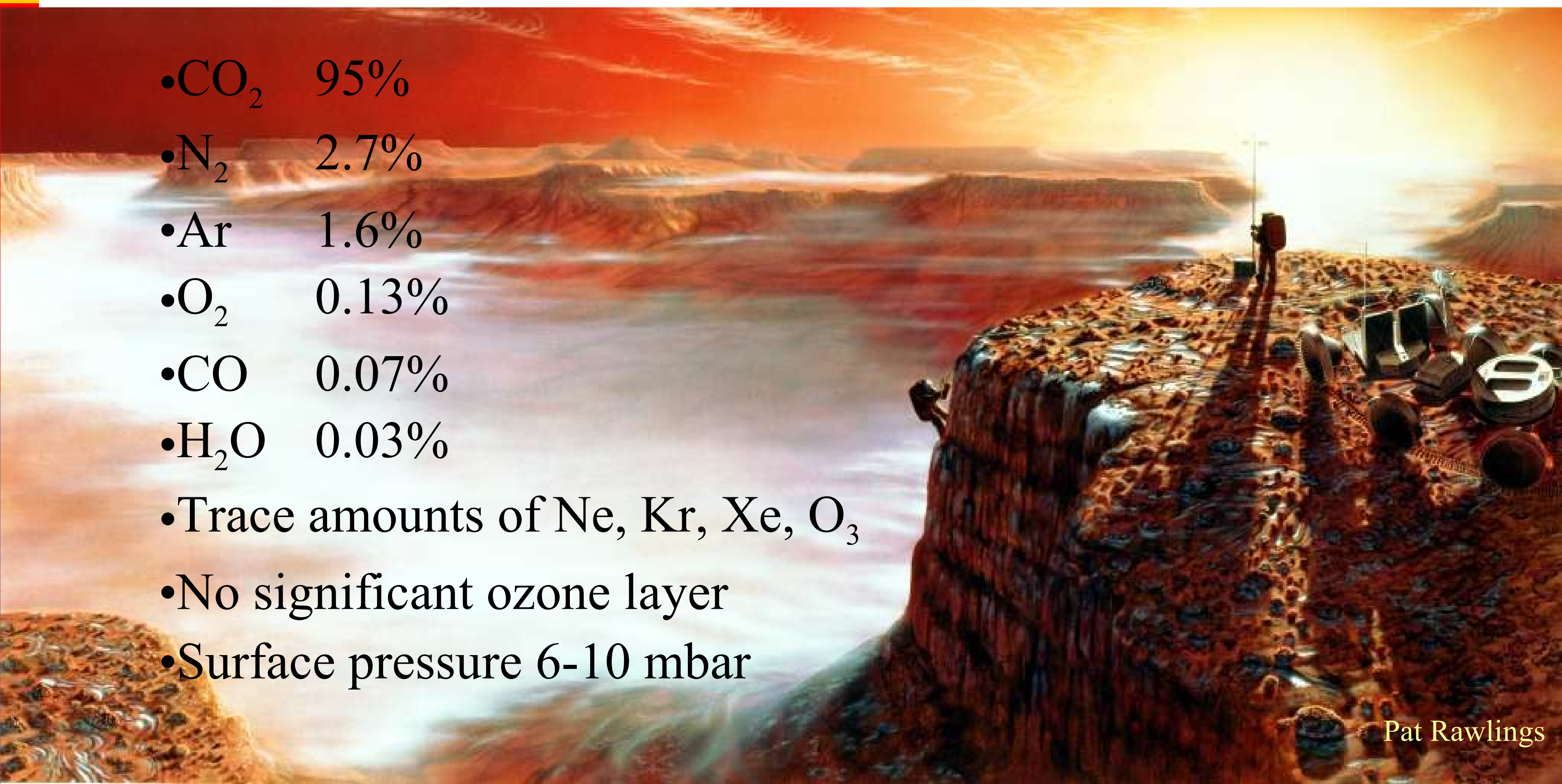
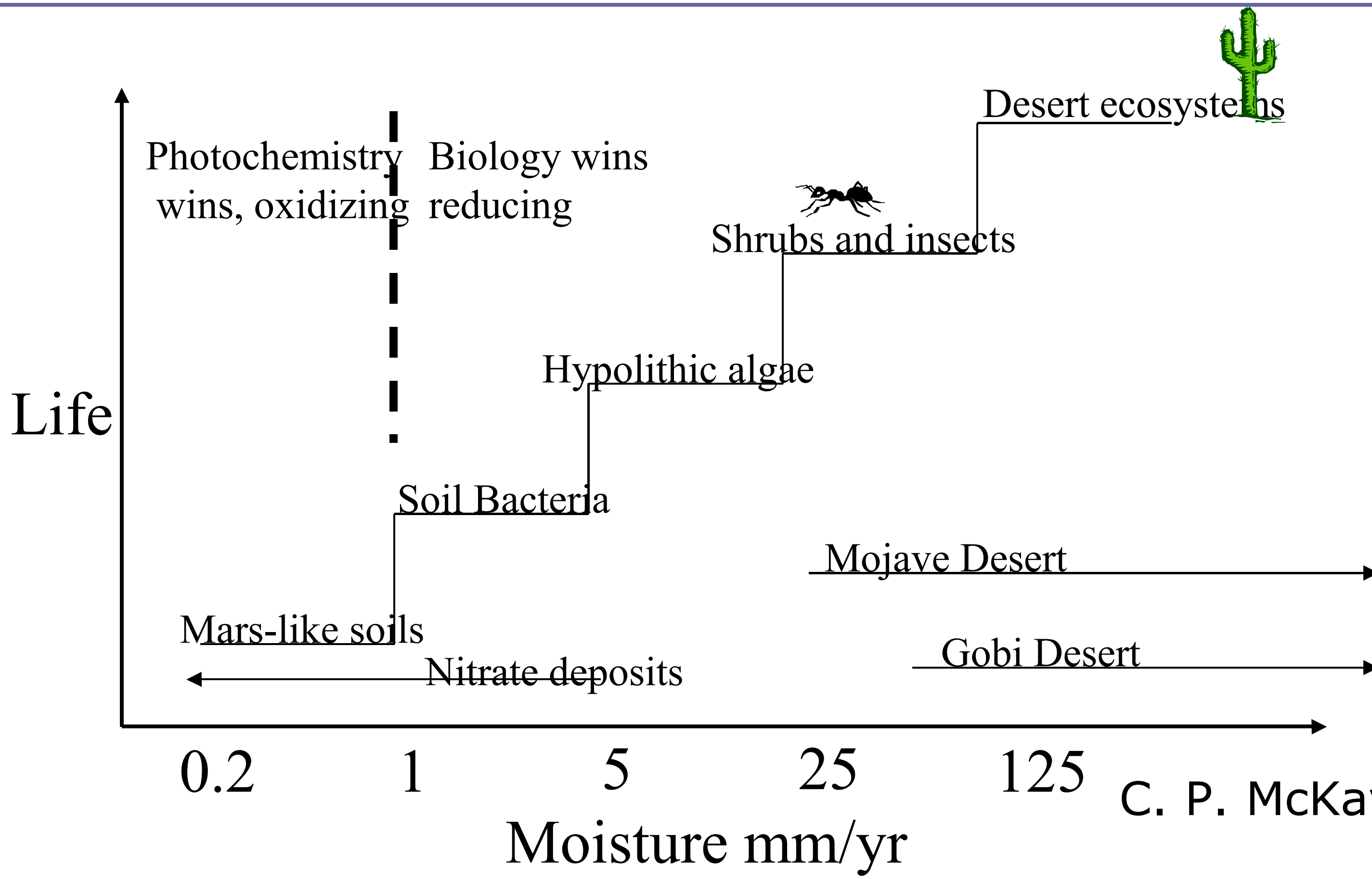
Mars' atmosphere today:

Assume that initial engineering efforts will increase atmospheric pressure and maintain the same relative abundances of gases.



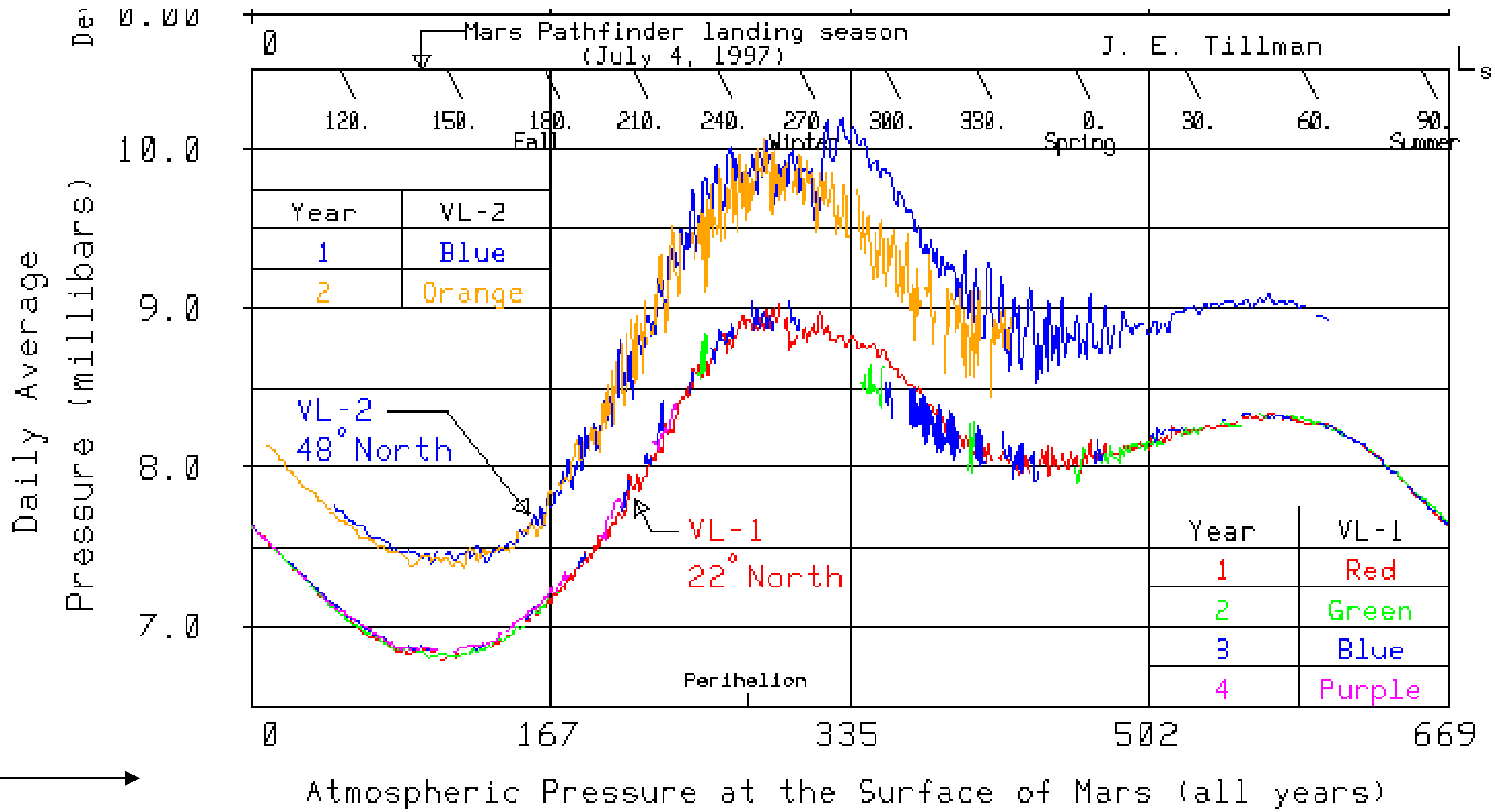
- CO_2 95%
- N_2 2.7%
- Ar 1.6%
- O_2 0.13%
- CO 0.07%
- H_2O 0.03%
- Trace amounts of Ne, Kr, Xe, O_3
- No significant ozone layer
- Surface pressure 6-10 mbar

How Dry is Mars?



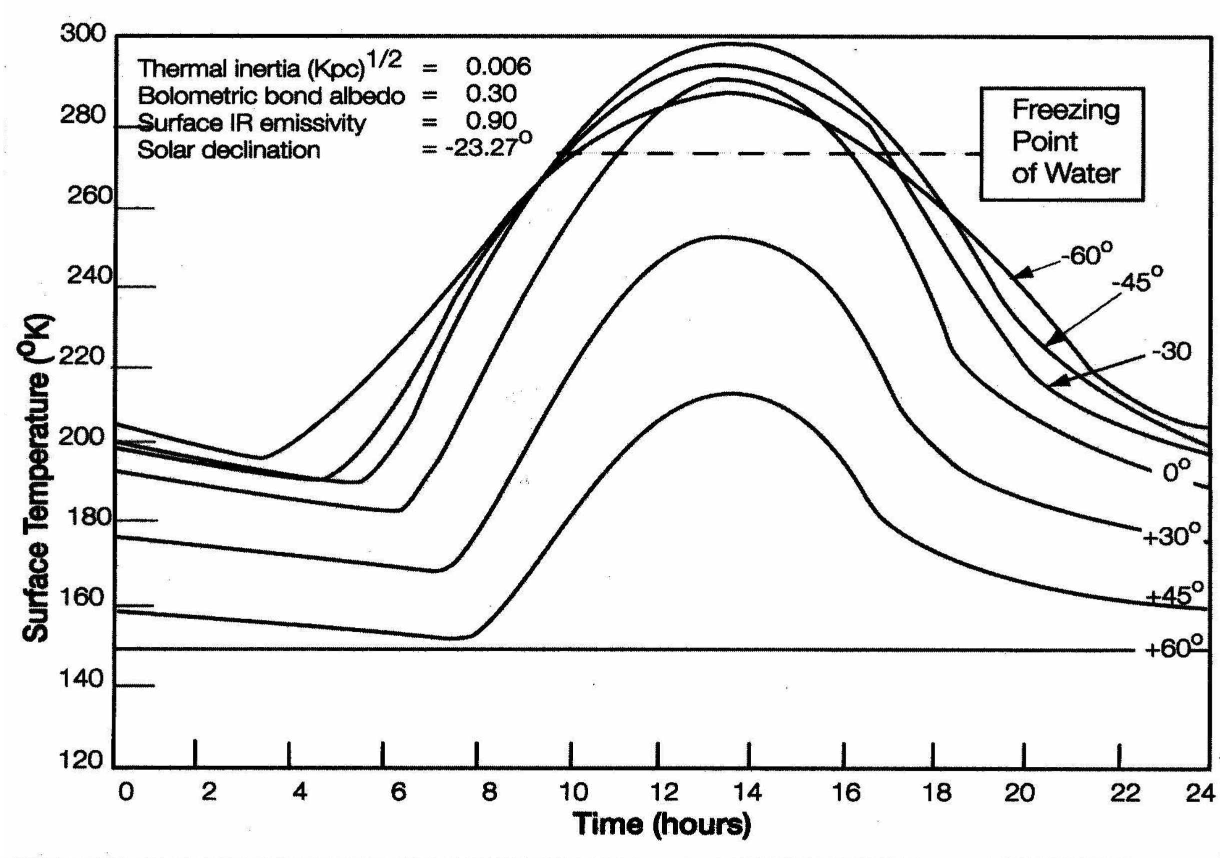
C. P. McKay, 2004

Pressure on the Mars Surface



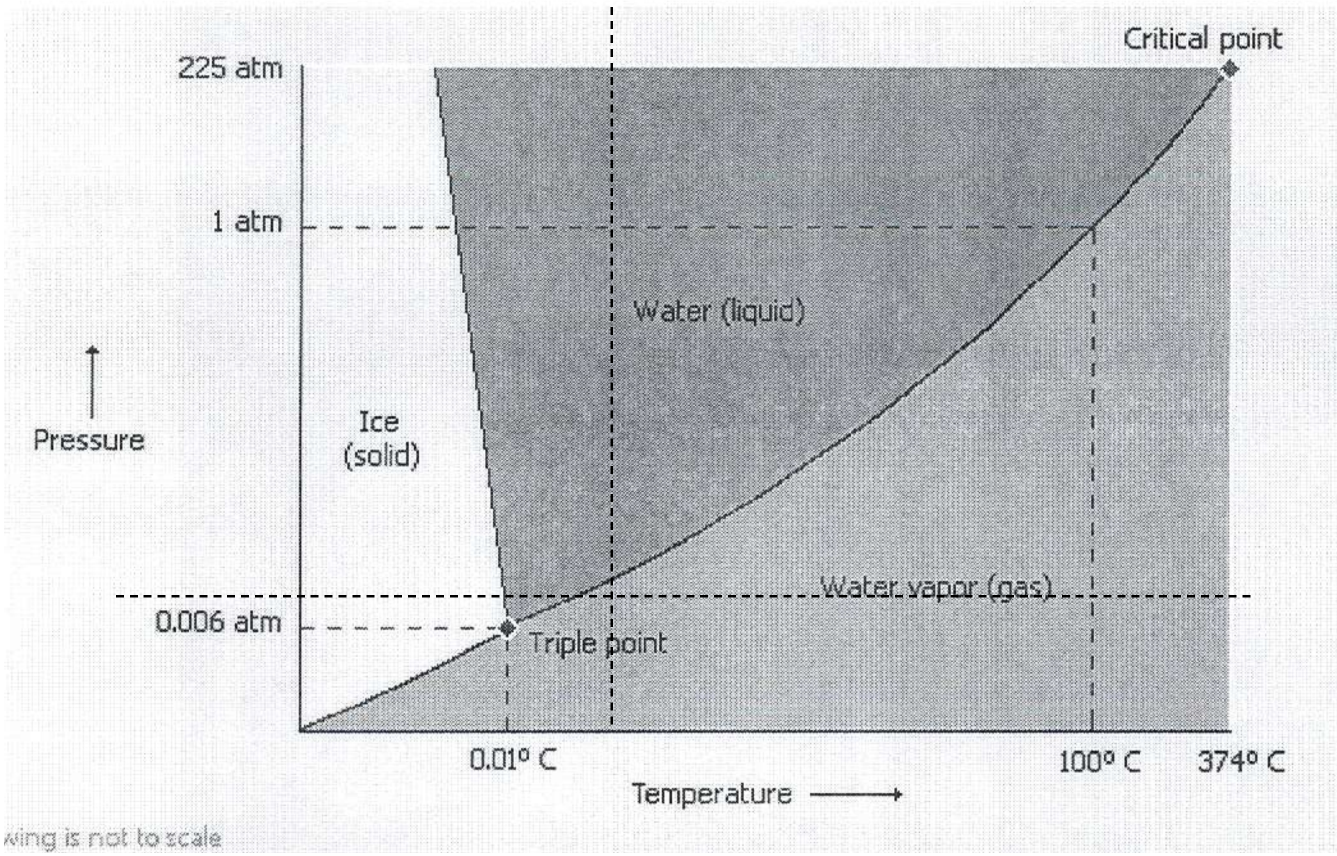
→ triple point of H_2O

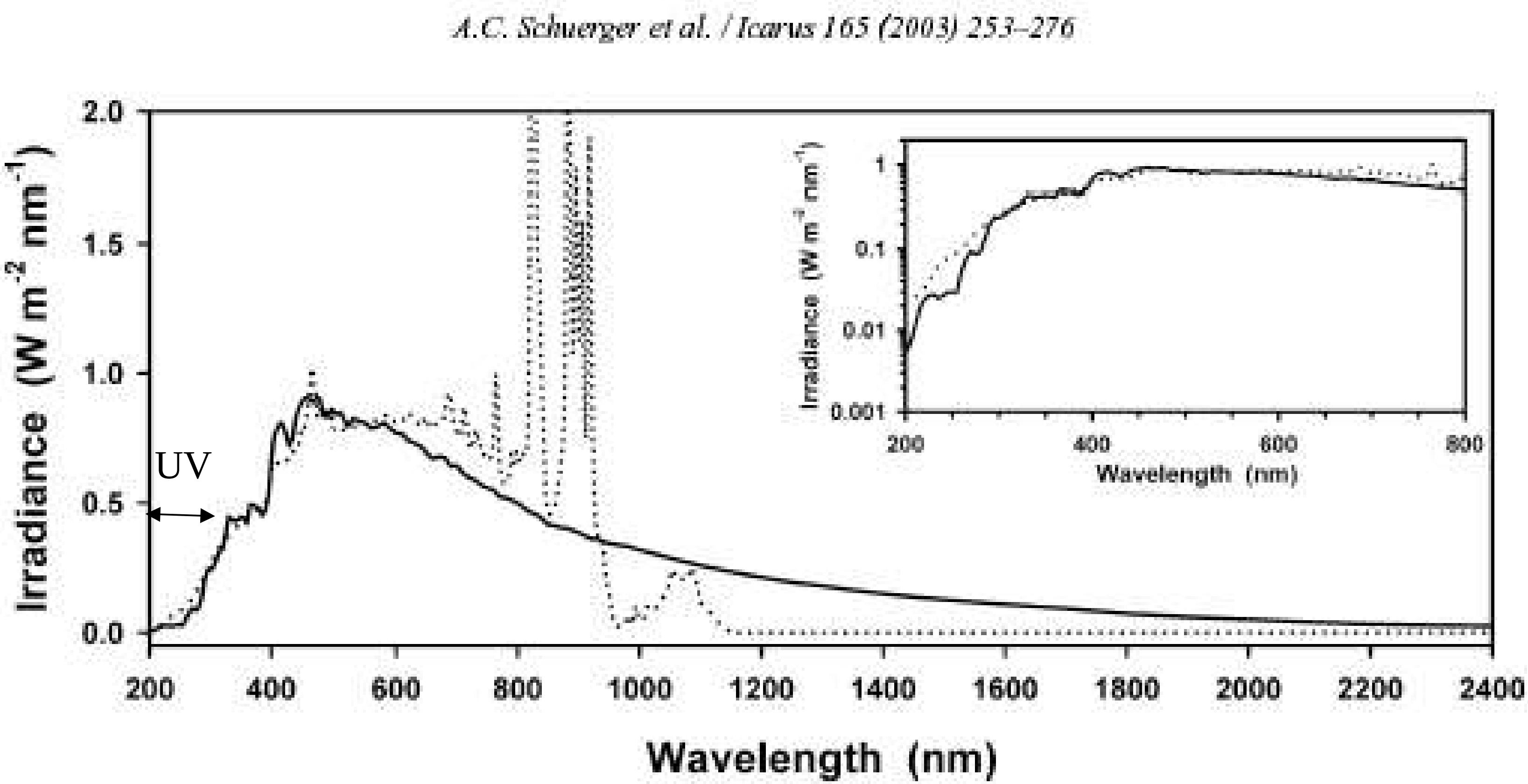
Temperature Cycles on Mars Surface



M. H. Carr, 1981

Liquid Water on Mars (Sometimes)?

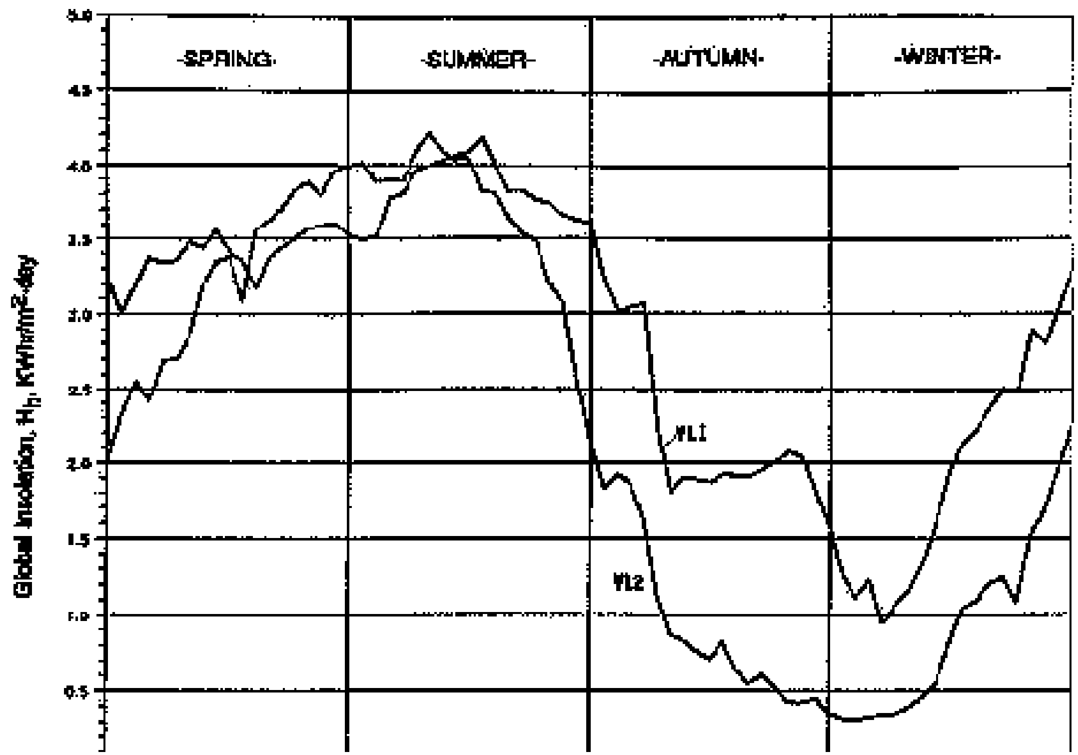




The main challenge for survival on the surface of Mars is the UV radiation between 200 and 300 nm.

Lighting: Temporal Simulation

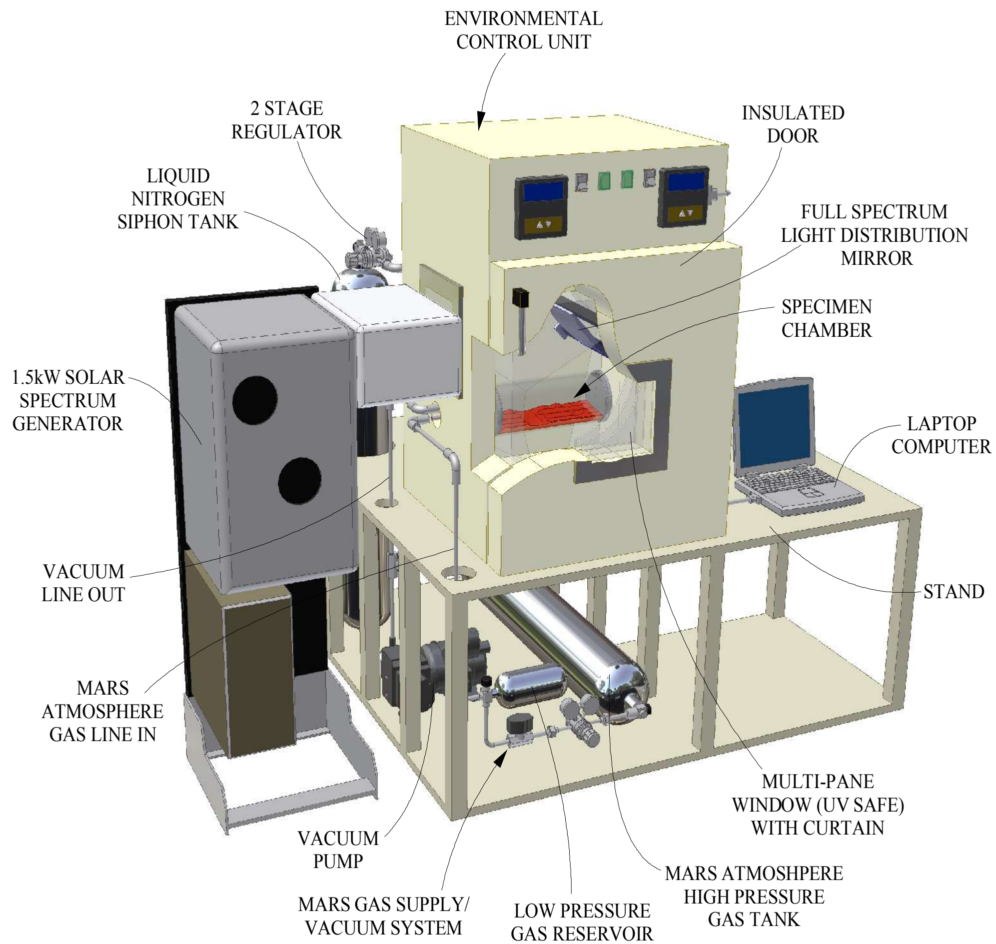
Integral at mid-day is about 590 W/m²



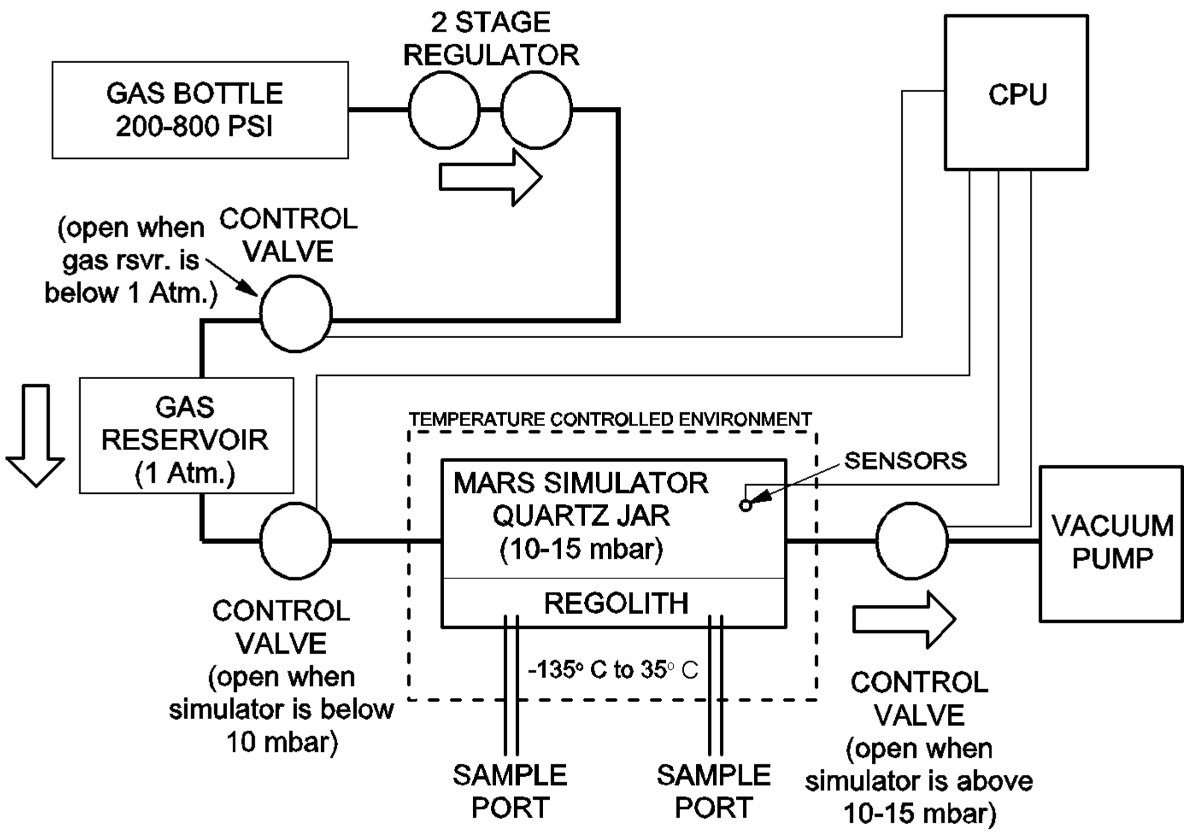
BY SEASON AT EQUATOR

Laboratory Chamber and Subsystems Design Drawings

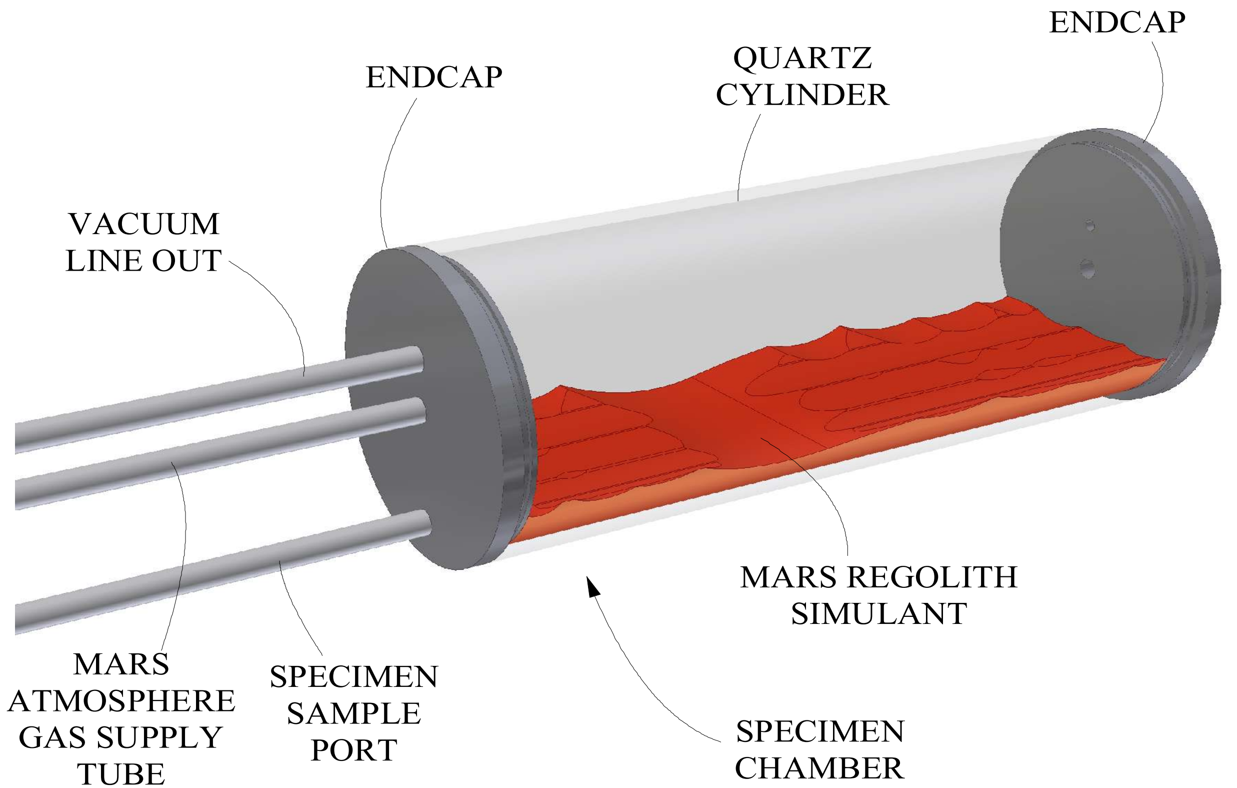
- Outer housing controls temperature -130 to +26°C (dry nitrogen cryogenic)
- Sealed illuminator with housing & cooling vents
- Low-pressure “Mars Jar” held at 7 --10 mbar
- Atmosphere composition analysis and control
- Regolith simulant and regolith sampling
- Affordable product for research laboratories



Laboratory Simulator Schematic



MARS-LTB Specimen Chamber
“Mars Jars”



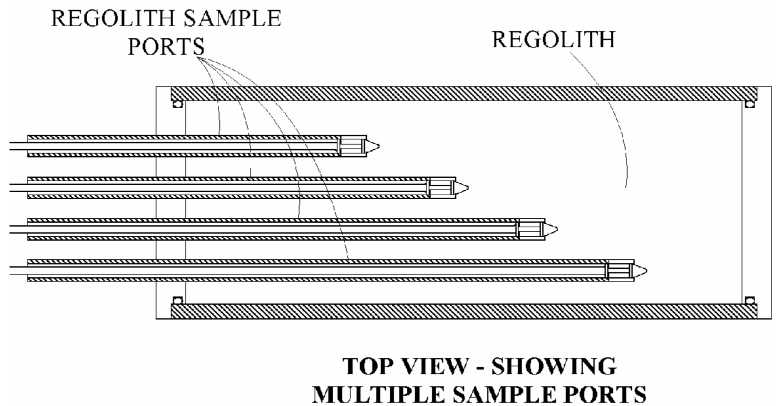
Mars Regolith Simulant

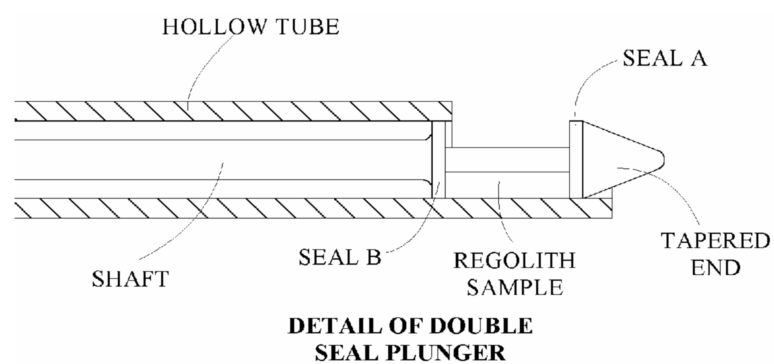
- Mars regolith simulants available commercially

Santiam Mars-2 Soil Sim	**Santiam Sim Sifting System**	

MARS-LTB
Regolith Sampling System

- A double seal plunger inside a hollow tube.
- Regolith sample is pulled from the specimen chamber by inserting the tapered tip of the plunger into the regolith.
- One seal remains inside the hollow tube.
- Plunger is retracted with both seals inside the hollow tube.
- The regolith sample is translated inside the hollow tube until the first seal exits the hollow tube.
- Regolith sample is deposited into the airlock area, ready for further study.





Modular Ecopoiesis Test Bed

- Controlled volume = 80 cc
- Several simulators per recharge station
- Temperature -80 -- +26^{o}C
- SHOT-designed computing hardware and software
- Thermoelectric cascade
- Solar spectrum simulator
- Classrooms and labs
- Patent applied for

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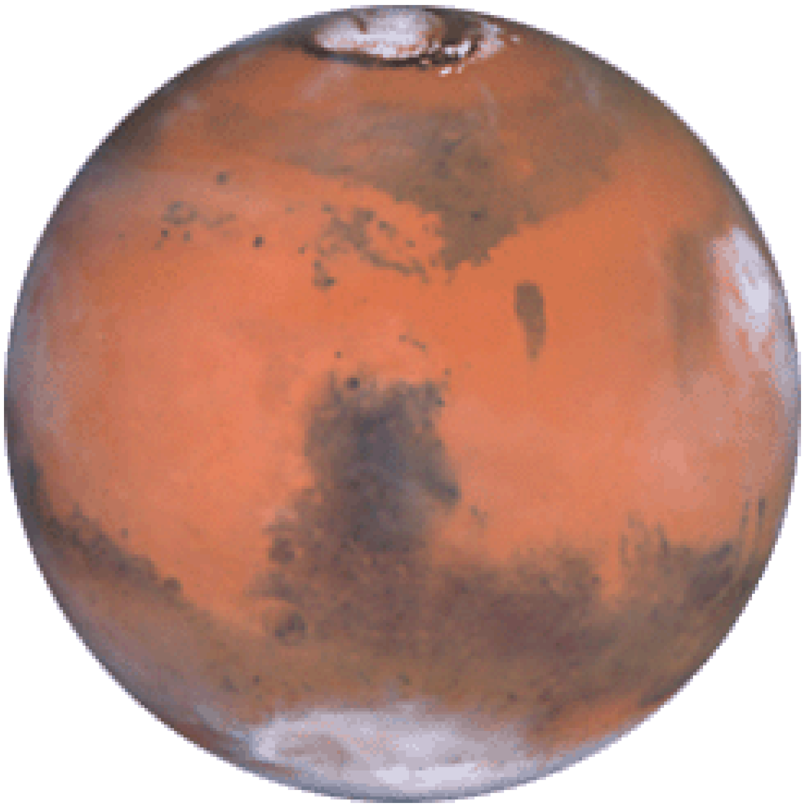
Summary of Requirements for Pioneer Martians

- Anaerobic
- UV resistant
- Low pressure
- Drought resistant
- Freeze resistant
- Phototroph
- Nitrogen fixing

C. McKay, 2004



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Physiological traits of engineered martian organisms (“Marsbugs”):

- Reactive oxygen tolerance (superoxides, peroxides, ozone, etc.).
- CO_2 tolerance.
- Intracellular acidification tolerance.
- Carbonate dissolution.
- Osmotic tolerance and adaptation.
- Ultraviolet radiation resistance and repair.
- “Switchable” genes for nutrient cycling (e.g., N-fixation, denitrification).

(Hiscox and Thomas, 1995)

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Candidate Extremophiles

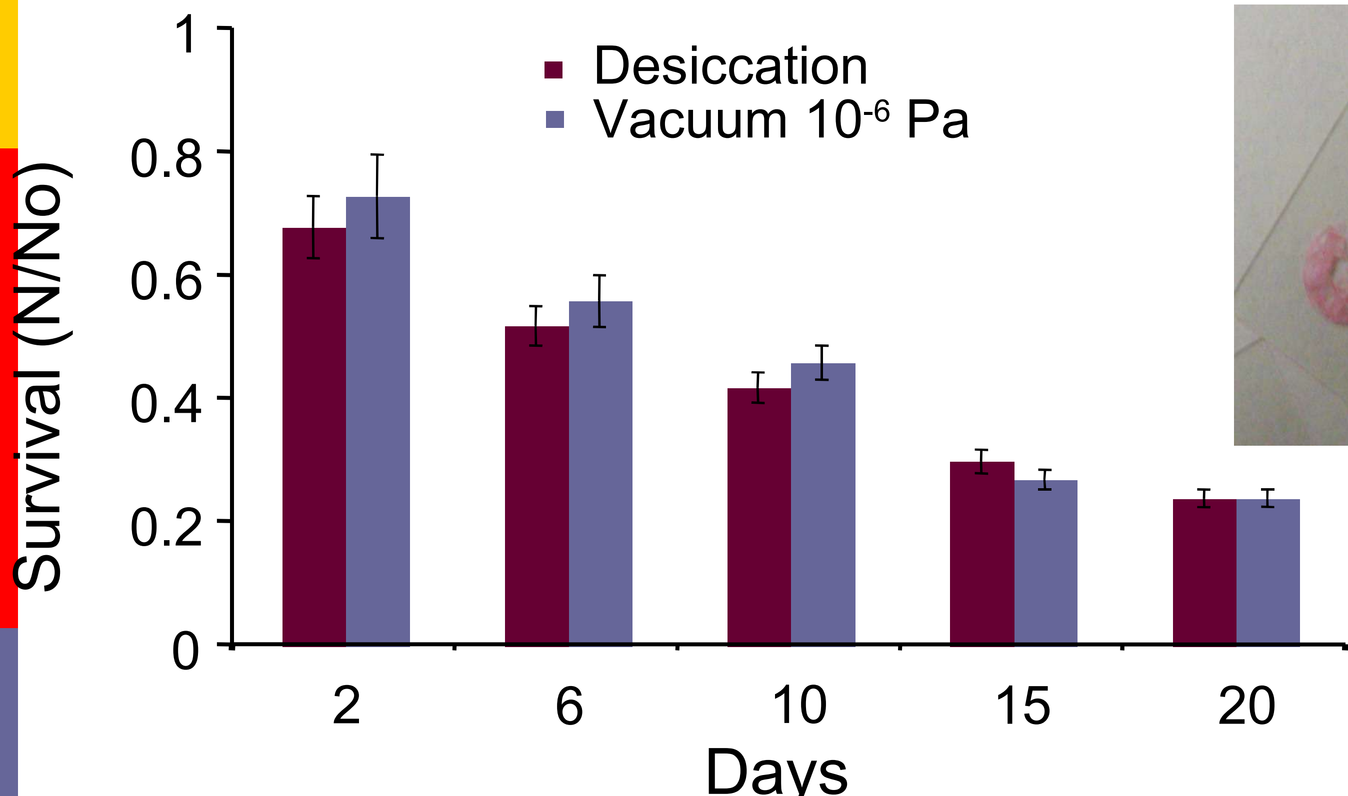
- Radiation *Deinococcus radiodurans*
- Hyperbaric/Anaerobic *Bacillus infernus*
- High saline *Haloferax volcani* (Searles Lake)
- Vacuum *Streptococcus mitis*
- Sulfurous environment *Thiobacillus sp.*
- Low temperature *Anabaena*,other cyanobacteria
- Spore dormancy *Bacillus subtilis*
- High temperature not relevant

Halobacterium Adaptation to DNA-Damaging Conditions

- Avoidance
  - Phototaxis using buoyant gas vessicles (from blue light towards orange light)
- Protection
  - UV shielding: salt crystals, pigments (rhodopsins, carotenoids)?
  - Adaptation
  - Internal salt equilibrium, acidic proteins, scavenger molecules for reactive oxygen species
- Repair
  - All known and conserved DNA repair systems
  - Prokaryotic-type SOS repair system? Other novel systems?

Prof. Jocelyn DiRuggerio

Halobacterium is Highly Resistant to Desiccation and High Vacuum



N=number of viable cells in challenged sample; No = number of viable cells in control; Error bars represent standard deviation for 3 replicates.

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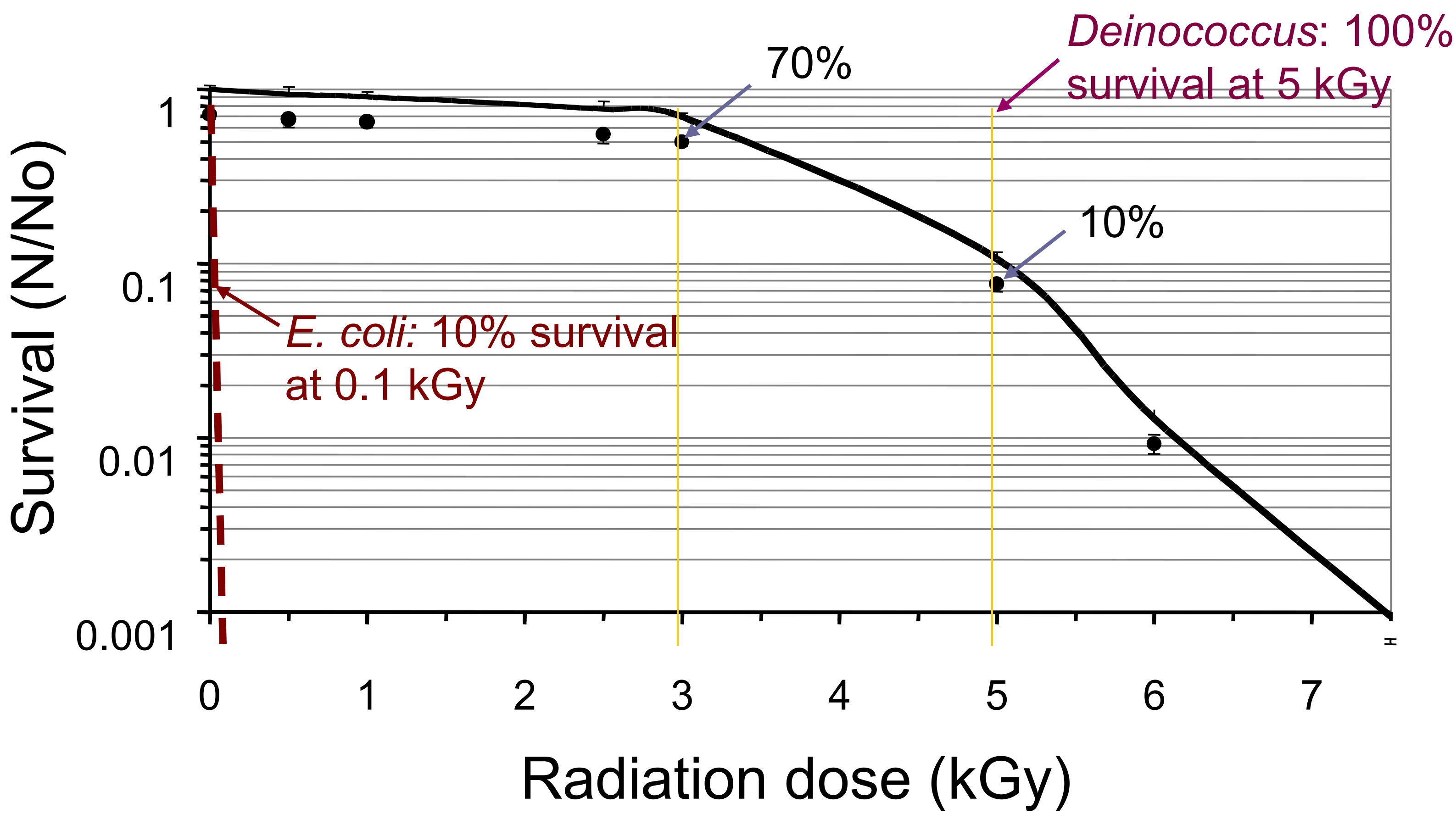
Halobacterium is Highly Resistant to ^{60}Co Gamma Irradiation



Halobacterium and Mars

Advantages:	Challenges:	Possible Uses:

➢Resistant to extremes in cold, desiccation, vacuum, gamma and UV radiation
 	
➢Facultative anaerobe
 	
➢Model System
	➢Nutrient source?
	
	➢Liquid water?
	
	➢Halophilic autotrophs?
		➢Genetic engineering
		  ➢E.g. Genes for resistances into a primary producer
		  ➢Problem of acidic residues in proteins
		
		➢Secondary colonizer

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Icy Habitats

Permafrost

Ice Caves

Cryoconites

Basal melt springs

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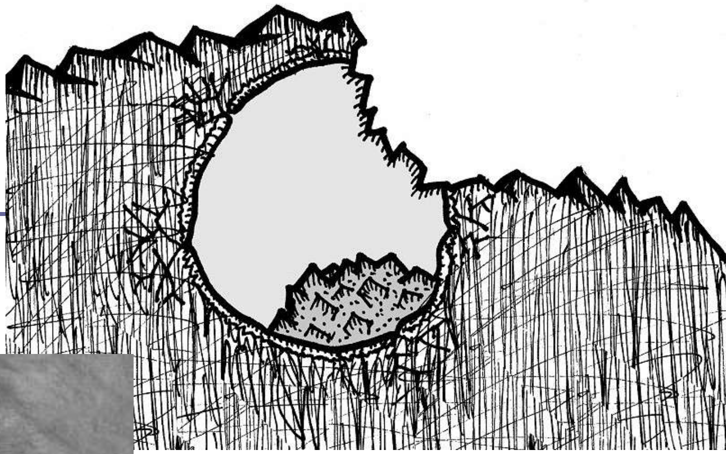
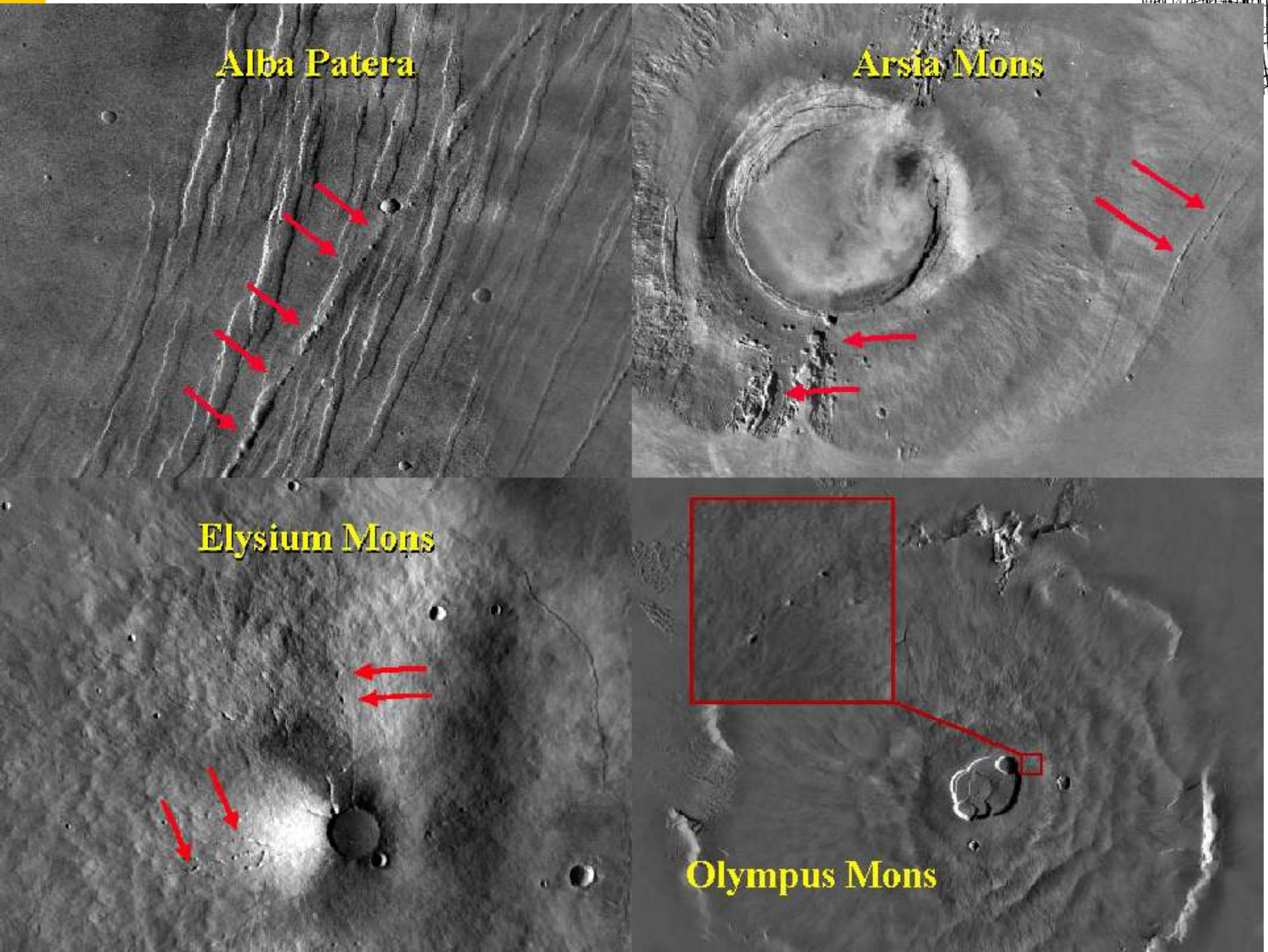
Lava Habitats

Lavatubes





Bubbles

Squeeze-ups

Palagonitization

Dr. Penny Boston

What do microbes do to rocks and minerals?

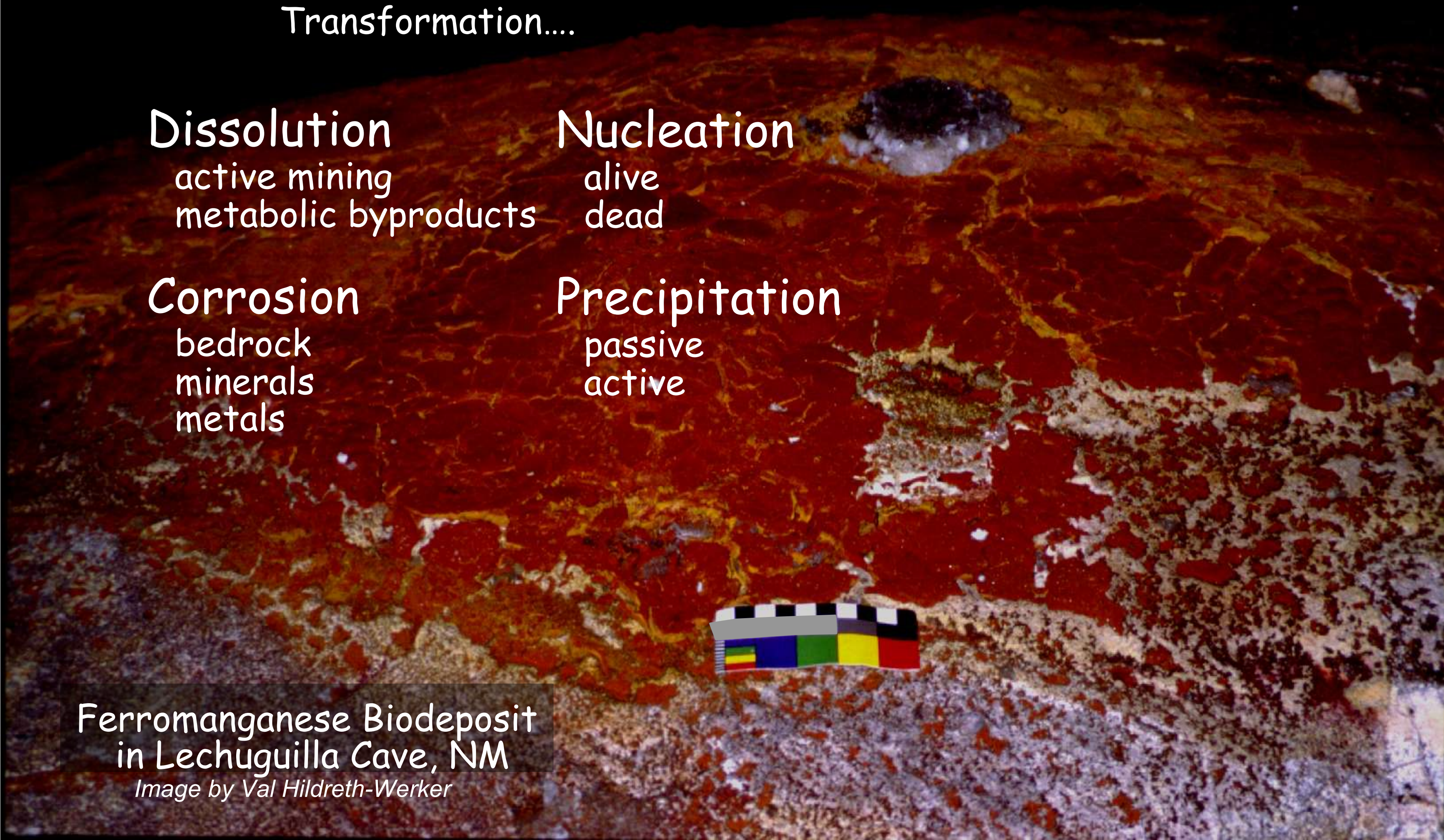
Transformation….

Dissolution
- active mining
- metabolic byproducts

Nucleation
- alive
- dead

Corrosion
- bedrock
- minerals
- metals

Precipitation
- passive
- active



Ferromanganese Biodeposit in Lechuguilla Cave, NM

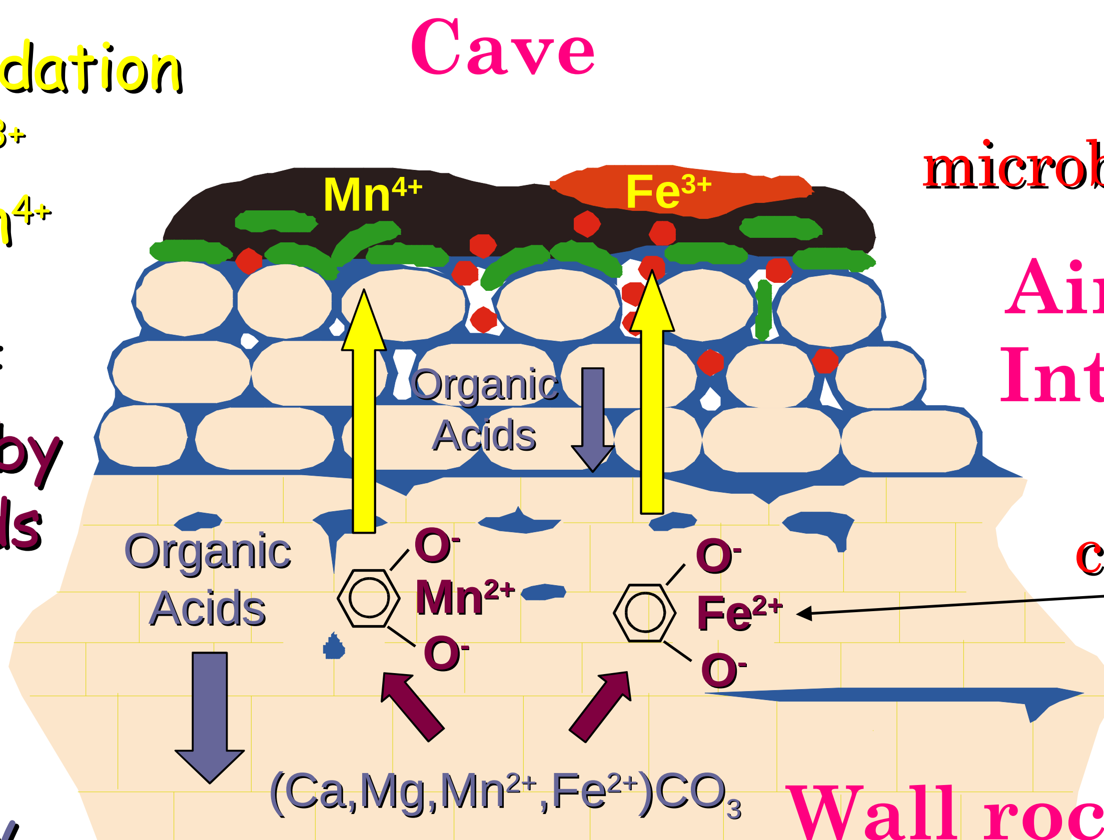
Image by Val Hildreth-Werker

Microbial "Cave Corrosion" (Speleosols)

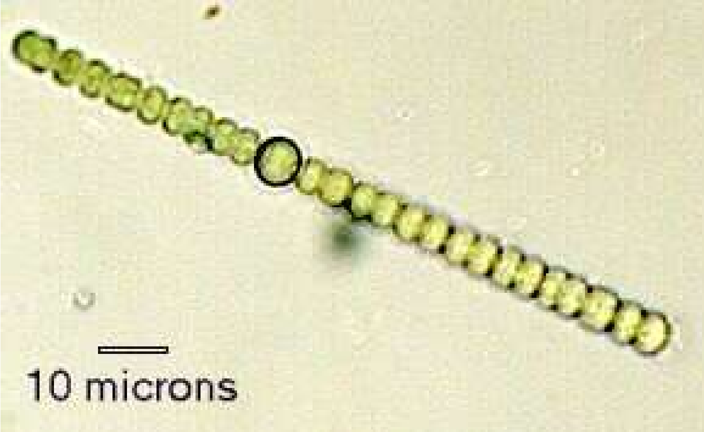
Microbial oxidation
Fe^{2+}->Fe^{3+}
Mn^{2+}->Mn^{4+}

Chelation of Fe^{2+} and Mn^{2+} by organic ligands

Carbonate dissolution by organic acids



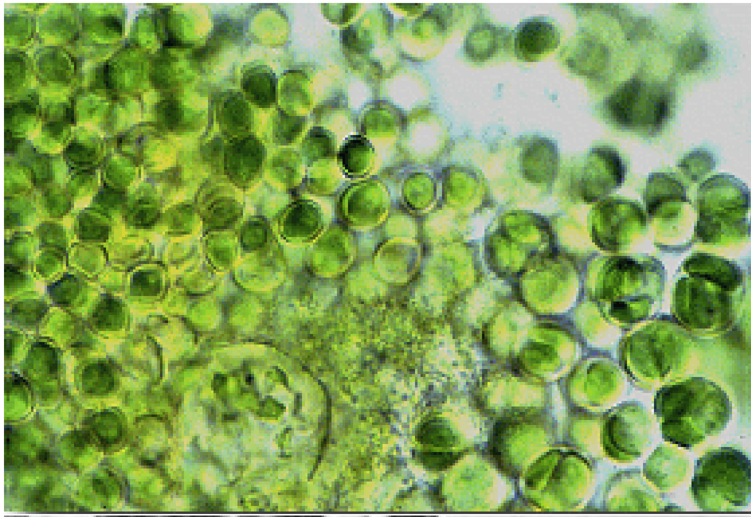
Anabaena species

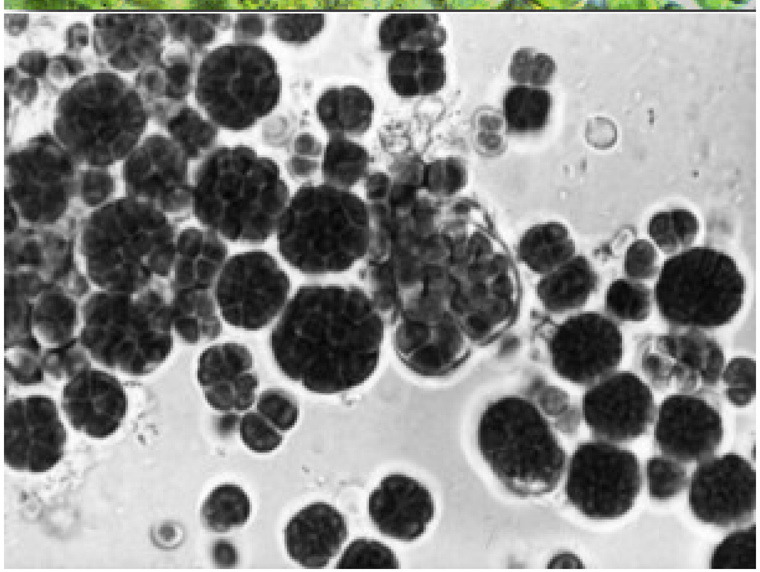


- Common freshwater and marine genus.
- Filamentous.
- Mesotrophic.
- Well-studied genetics and physiology.
- Nitrogen fixation in heterocysts.

Dr. DavidThomas

Chroococcidiopsis





- Primitive cyanobacterial genus.
- Unicellular, multicellular.
- Capable of surviving in a large variety of extreme conditions: aridity, salinity, high and low temperature.
- Sole surviving organism in hostile environments.
- Often endolithic.

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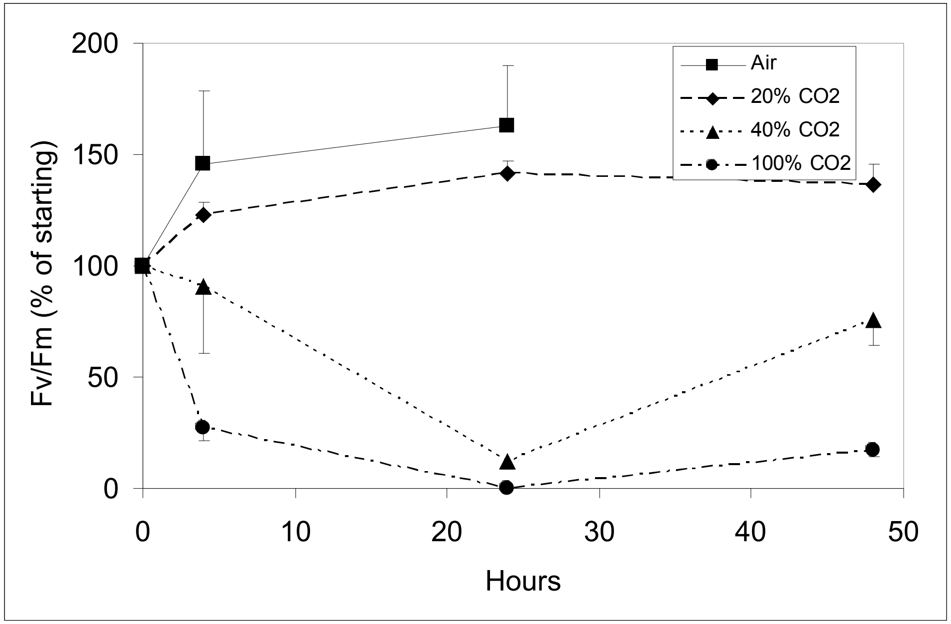
High % CO_2 tolerance



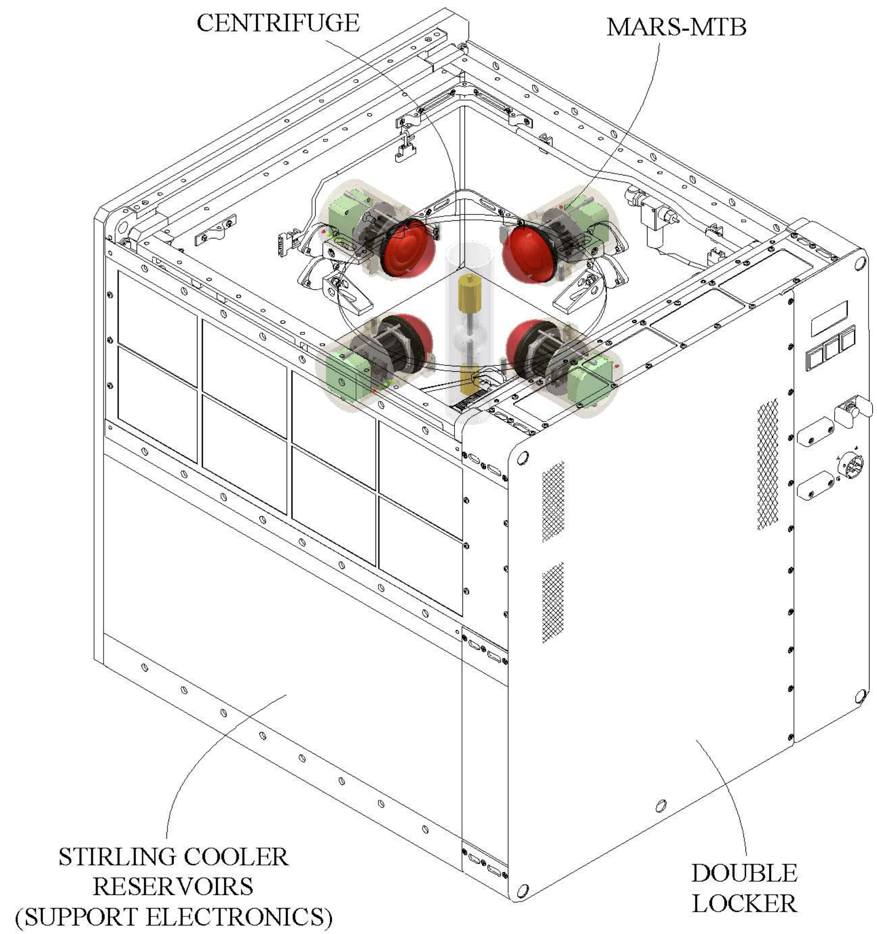
CO_2 effects on *Synechococcus*. *Synechococcus* responds to high CO_2 similarly to *Anabaena*. PS-II activity increases at 20% CO_2, but is inhibited at 40-100% CO_2. At 100%, the photosystems do not recover after 24 hours in air (n = 4, bars = s.d.).

Phase III

- Build 0.08 liter chambers for ADF centrifuge & perform physical tests
- Build Modified Avian Development Facility (ADF) to include cryogenics and up to 4 low-pressure jars
- Install Modified ADF on ISS and operate rotors at 0.38 g with analytical capability
- Test pioneer communities in MARS MTB chamber, 0.38 g

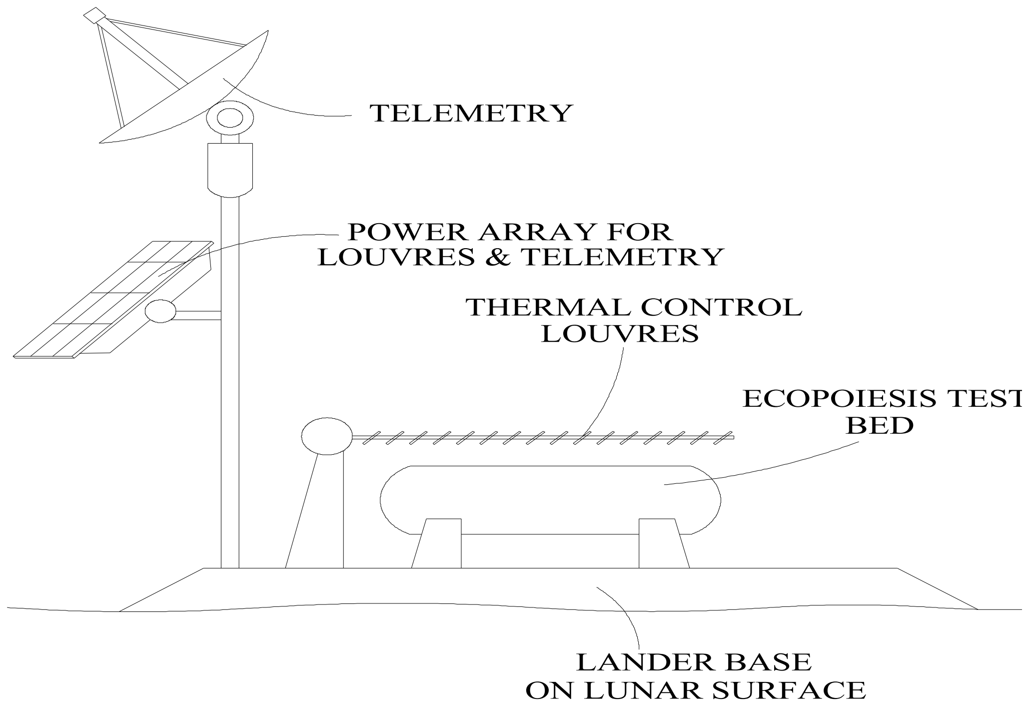
Potential Low-g Simulator on ISS

- Built on SHOT Avian Development Facility Foundation
- Double mid-deck locker
- Houses one or more modular test bed



Concept Proposed for RLEP

- Test chamber same as laboratory test bed
- Mars gas pressure reservoir at 10 atmospheres
- Louvres for light and temperature control



PROGRESS ON MILESTONES

- Phase I completed; laboratory test bed design, extremophile selection initiated
- Phase I articles for publication
- Laboratory test bed purchases, venue
- Modular portable test bed proposed
- Low-volume lunar test bed proposed
- Science AdvisoryCommittee established
- First bimonthly report submitted
- Phase II presentation

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The EcopoiesisTeam

- Paul Todd, Principal Investigator
- Penny Boston, Co-Investigator (lithotrophs)
- David Thomas, Co-Investigator (cyanobacteria)
- Nathan Thomas, EE, Project Manager
- Bill Metz, MET, Mechanical design
- John Phelps, EET
- Bill Johnson, Software Engineer
- Alan Constance, ME, Thermal Engineer
- Lara Deuser, ChE, Lab Scientist
- Heidi Platt, ChE