Robotic Lunar Ecopoiesis Test Bed. Phase II NIAC

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Presented by Paul Todd
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Four Levels of Inquiry Concerning Biology and Mars

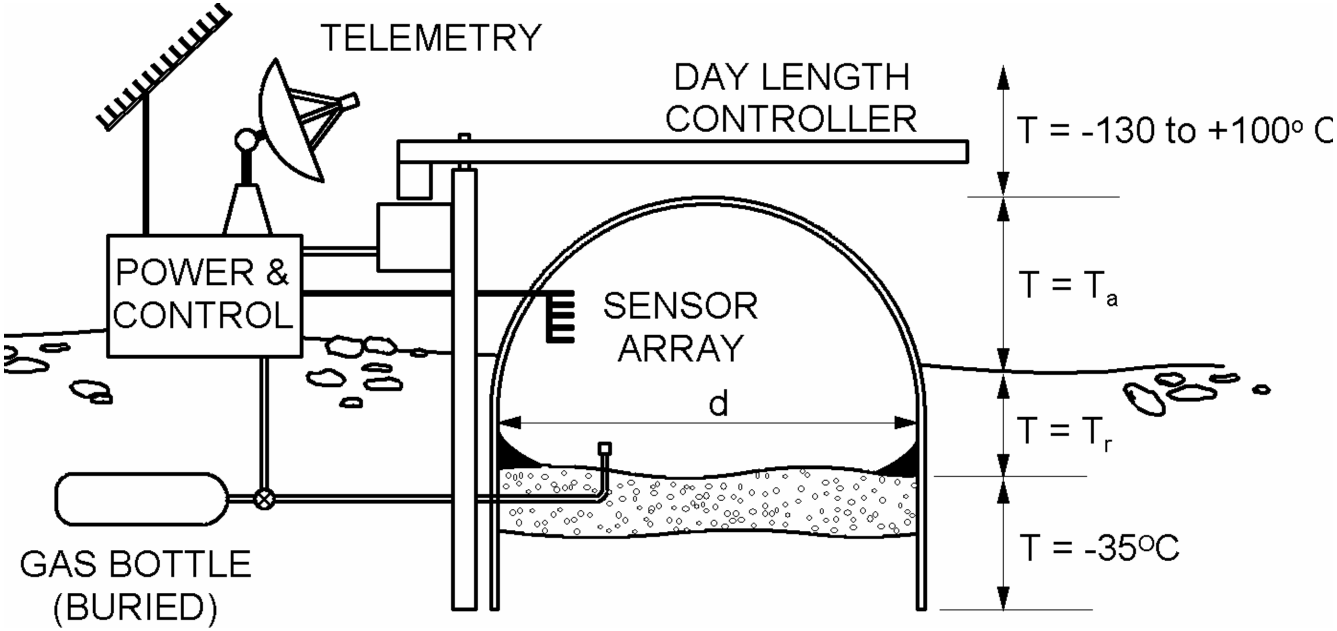
1. **Planetary protection, contamination and quarantine issues (NRC, 1992),**
2. **The search for life on Mars (Banin, 1989; Banin and Mancinelli, 1995; Ivanov, 1995; Koike et al., 1995; Biemann et al., 1977),**
3. **Human expeditions to Mars and ecosynthesis (Meyer & McKay, 1984, 1989, 1995)**
4. **The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

ECOPOIESIS

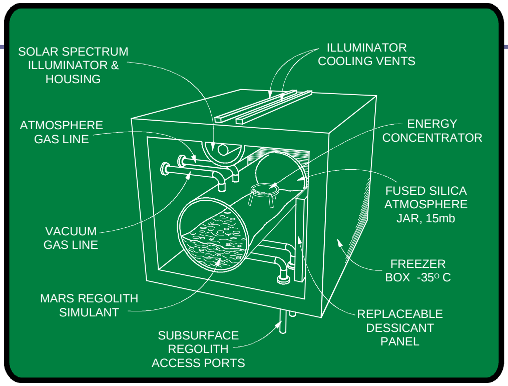
- Term introduced by Haynes and McKay
- Terraforming = making another planet or object in the solar system like Earth
- Heating: (1) Greenhouse gases, (2) Mirrors and smoke, (3) Ecopoiesis
- Ecopoiesis = emergence of a living, eventually self-sustaining ecosystem
- Precedes terraforming
- Required step: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

Starting Position: Robotic Lunar Ecopoiesis Test Bed

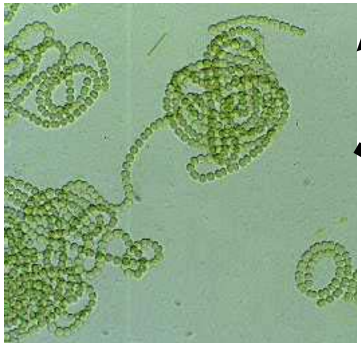
- Trenched, depressed site
- Sealed in all dimensions
- Inflatable dome solidifies
- Sealed interior controlled to Mars atmosphere
- Organisms & chemicals added to artificial regolith
- Control and data telemetry to earth

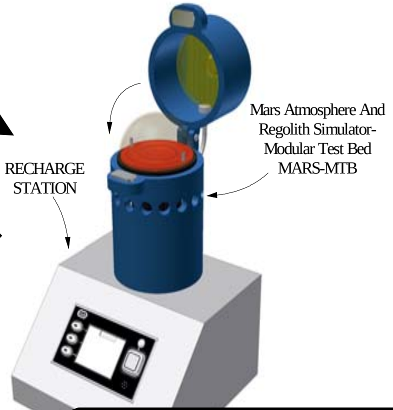


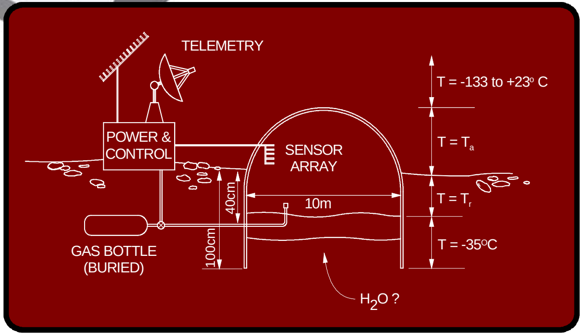
Project Architecture: Roadmap



- Science base
- Laboratory test bed
- Basic research
- Distributed test beds
- Low-gravity venues
- Lunar test bed
- Mars experiments







Robotic Lunar Ecopoiesis Test Bed: Phase II Goals

1.*Build and demonstrate Laboratory Test Bed.* Use preliminary chamber design from Phase I, purchase and assemble components, demonstrate operation.

2. *Evaluate pioneer organisms using Laboratory Test Bed.* Subject organisms identified in Phase I to various Mars-like ecopoietic conditions, test activity and viability.

3. *Develop ecopoiesis research community.* Design modular test beds for lab and classroom use. Develop user community.

4. *Refine requirements for extraterrestrial test beds.* Pursue opportunities within NASA programs such as ISS and RLEP.

Robotic Lunar Ecopoiesis Test Bed: Science Advisory Committee

Penelope Boston. New Mexico Institute of Mining and Technology; Complex Systems Research, Inc.

Lawrence Kuznetz, NASA Space Biomedical Research Institute

Christopher McKay, NASA Ames Research Center

Lynn Rothschild, NASA Ames Research Center

Andrew Schuerger, University of Florida

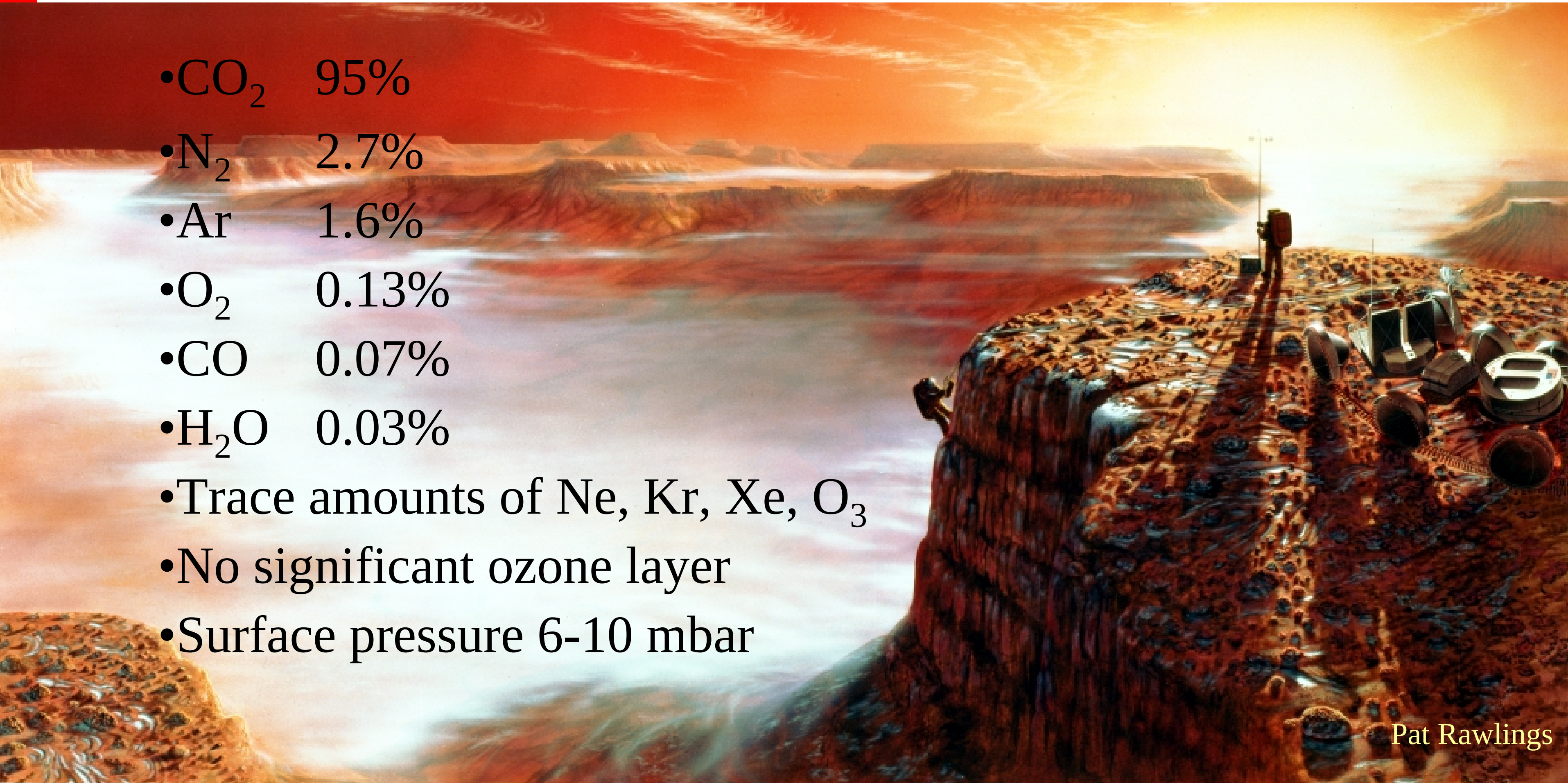
David Thomas, Lyon College

Objective 1: Laboratory Test Bed

- Requirements
- Design and Construction
- Performance

Mars’ atmosphere today:

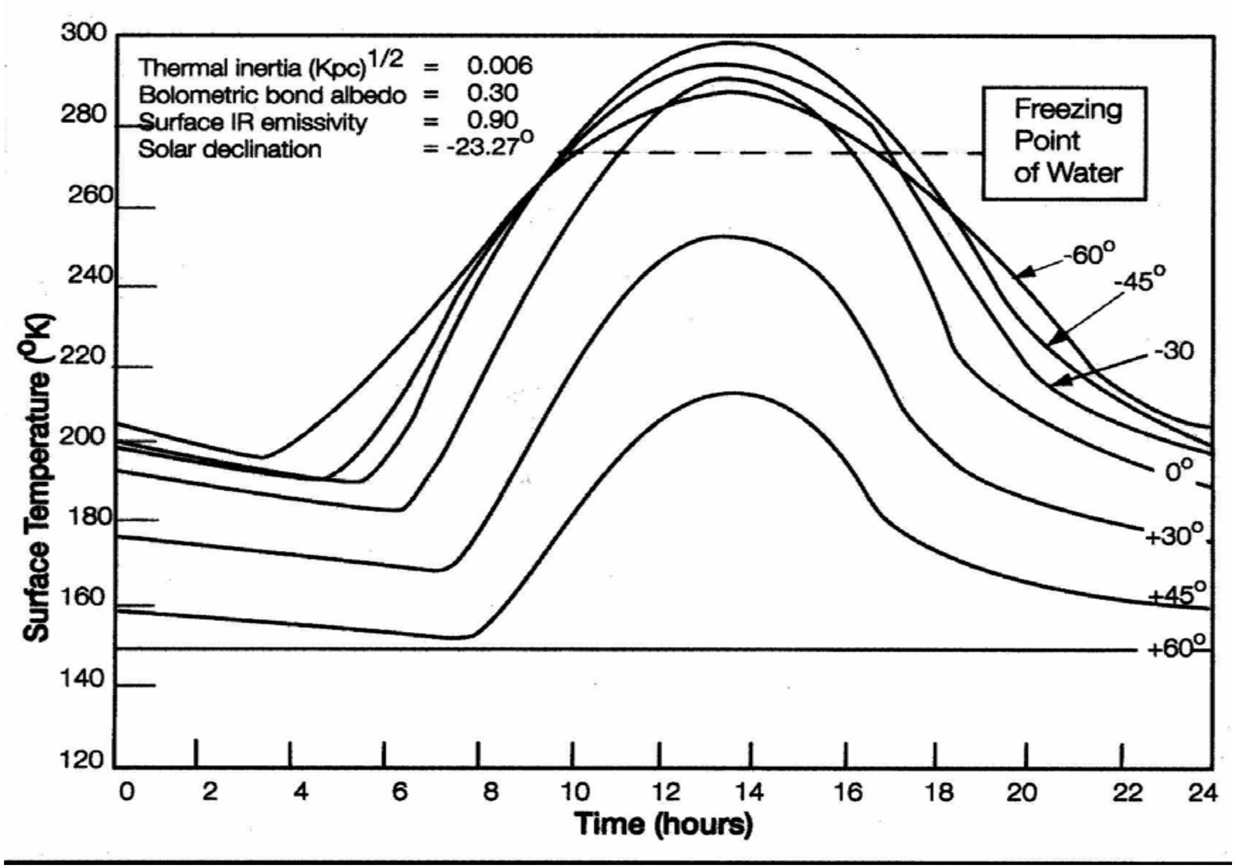
Assume that initial engineering efforts will increase atmospheric pressure and maintain the same relative abundances of gases or raise only CO_2.



- 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

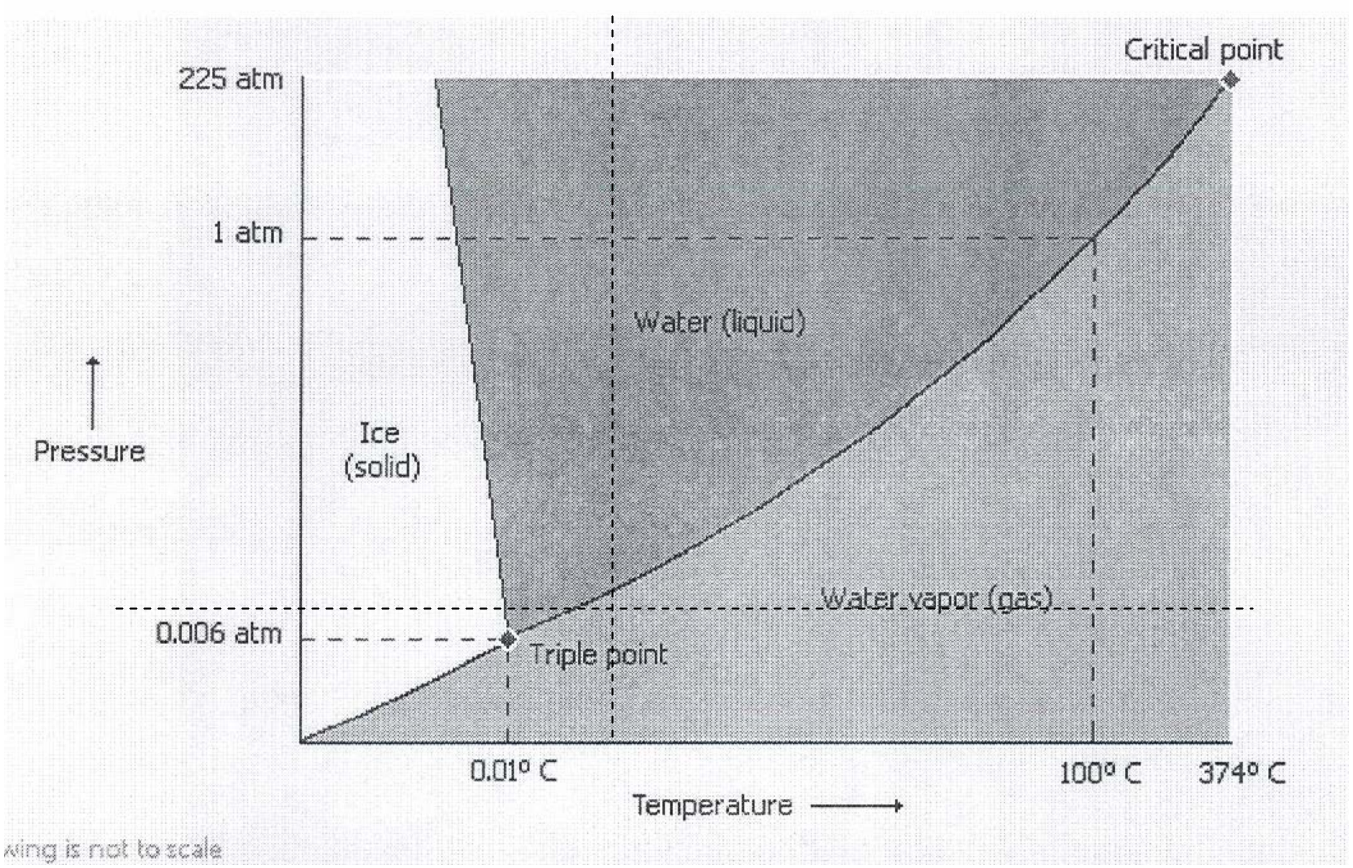
Pat Rawlings

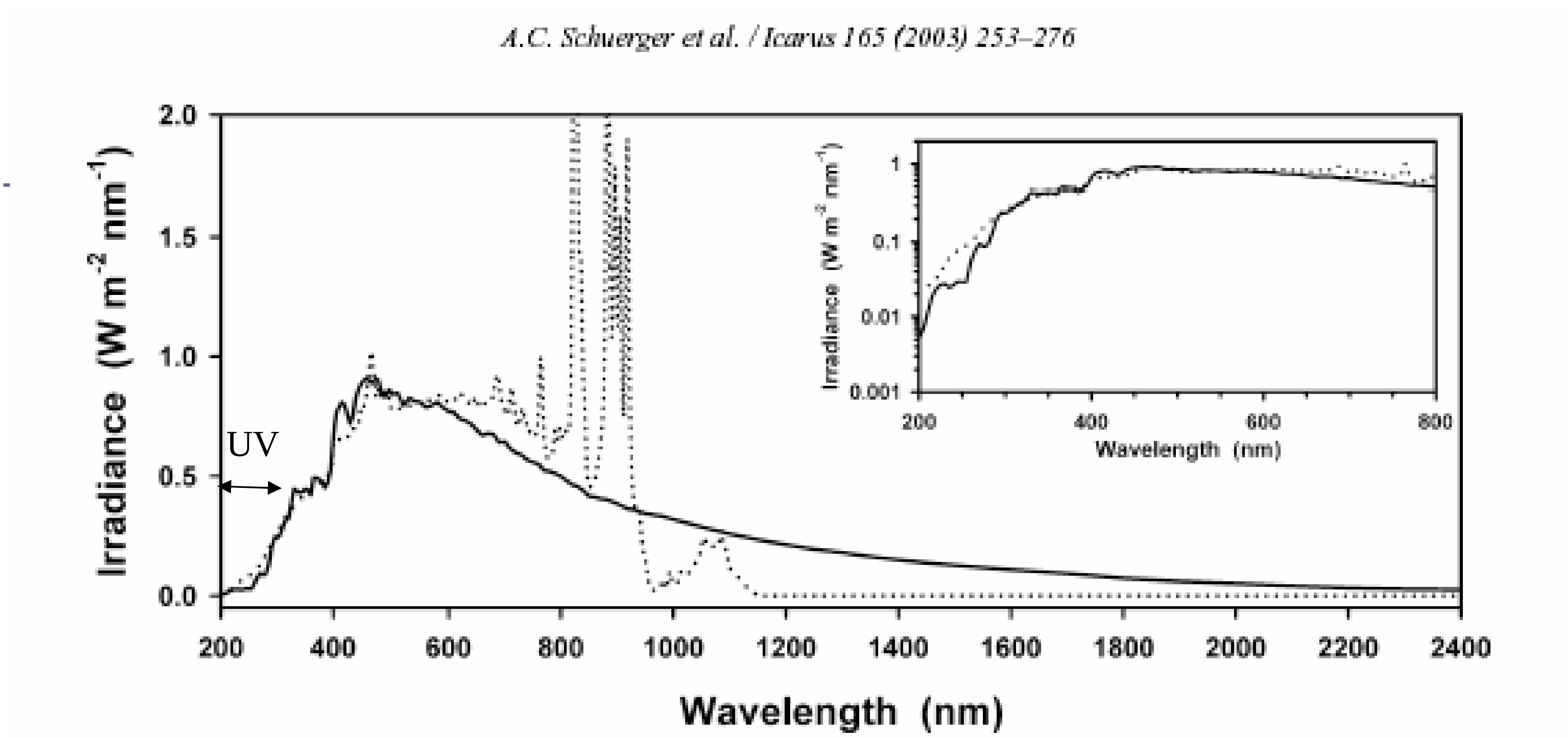
Temperature Cycles on Mars Surface



M. H. Carr, 1996

Liquid Water on Mars (Sometimes)?



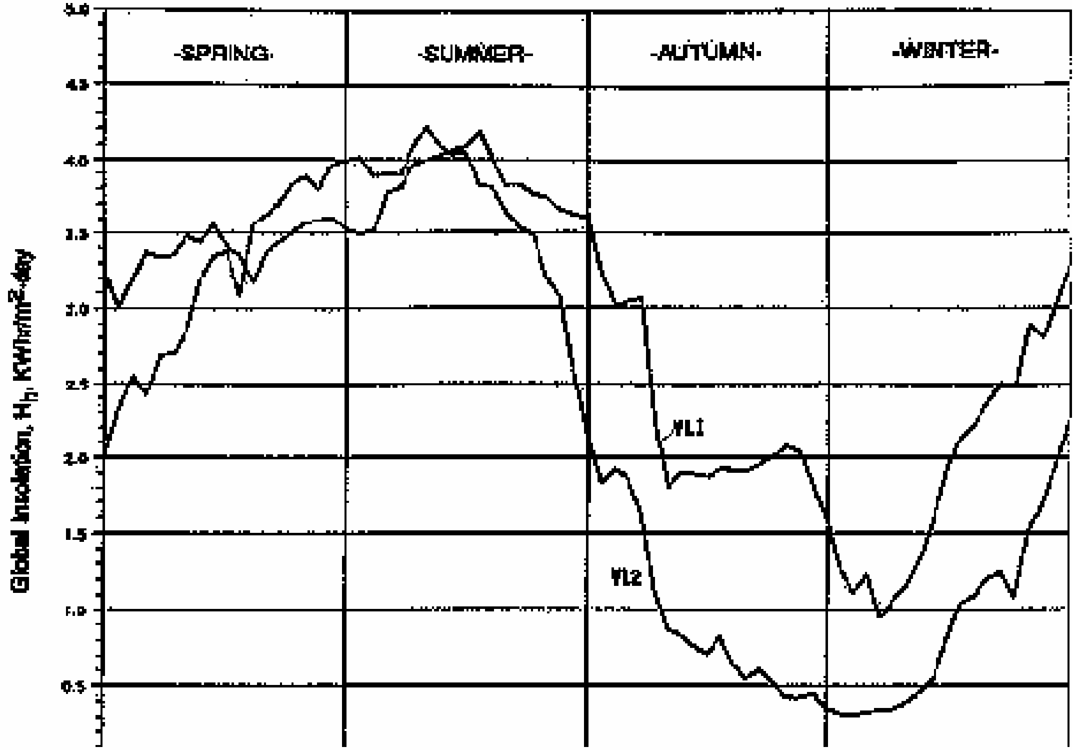


A.C. Schuerger et al. / Icarus 165 (2003) 253–276

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

Lighting: Temporal Simulation

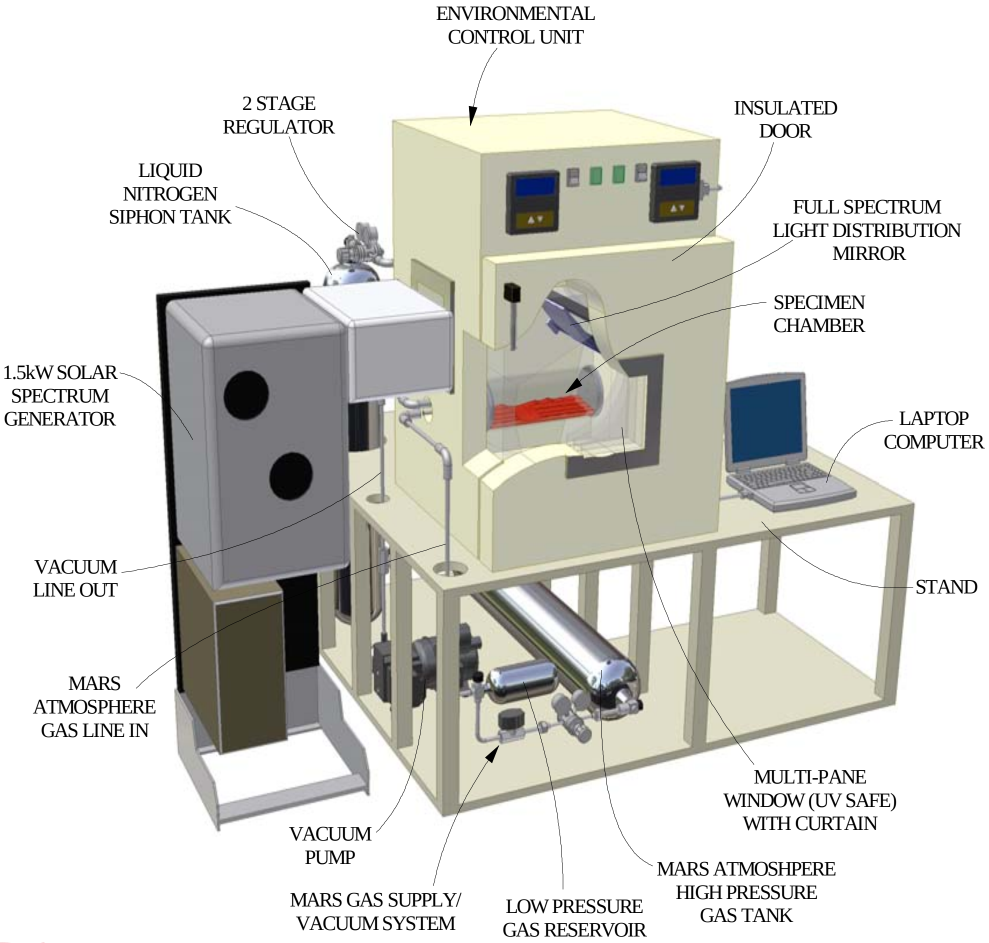
Integral at mid-day is about 590 W/m^2



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 mbar
- Atmosphere composition analysis and control
- Regolith simulant
- Automated operation and data logging
- Affordable product for research laboratories



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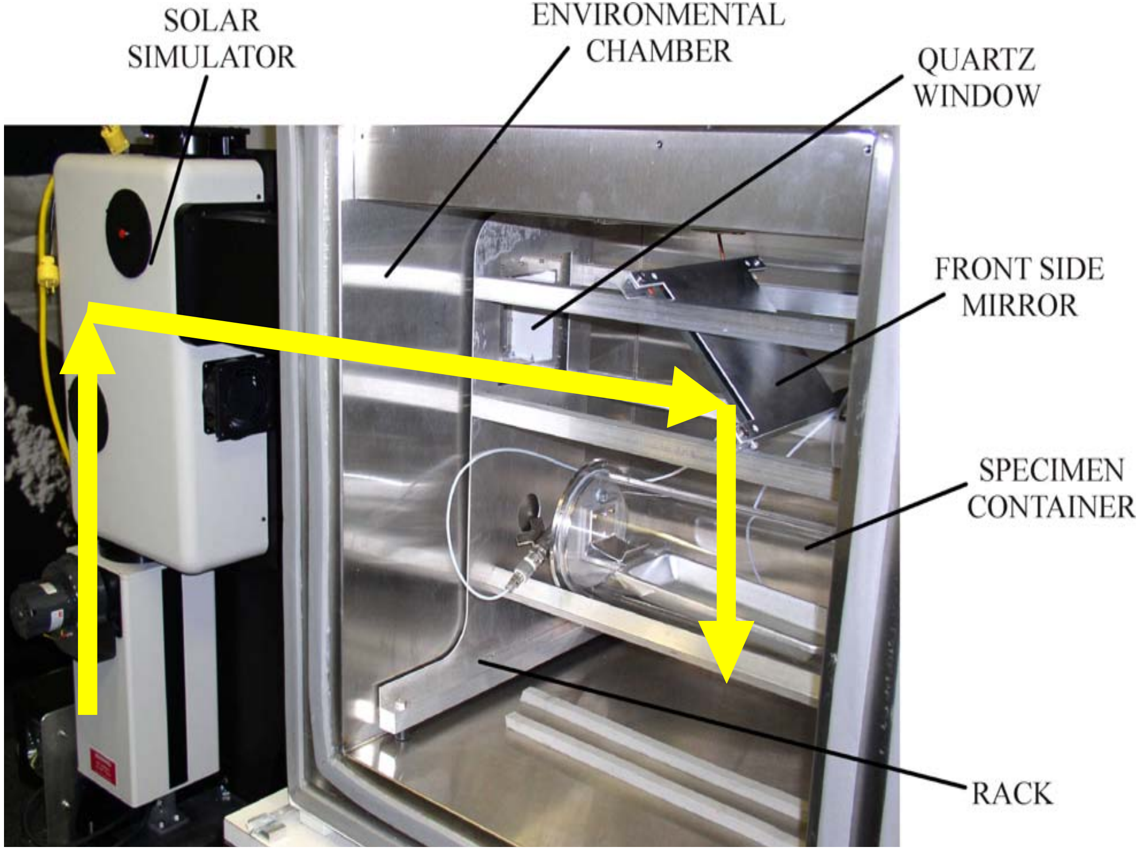
Laboratory Test Bed Thermal Control

Continuous operation on Mars sol program (-80°C night; +26°C day) consumes >200 gal LN_2 /wk. A 500-gal supply tank was installed behind a locked safety fence. During dawn and evening, set-point is reset every 10 min to reproduce thermal profile on Mars at low latitude.

Laboratory Test Bed Optical Path

- 1000W Xenon arc
- Automated arc striking
- 8” x 8” lighted area
- Fused quartz container
- Photosynthetically active radiation (PAR) = 1100 µmoles/m²-s = 237 W/m² (vs. 242)
- Translates closely to 590 W/m²



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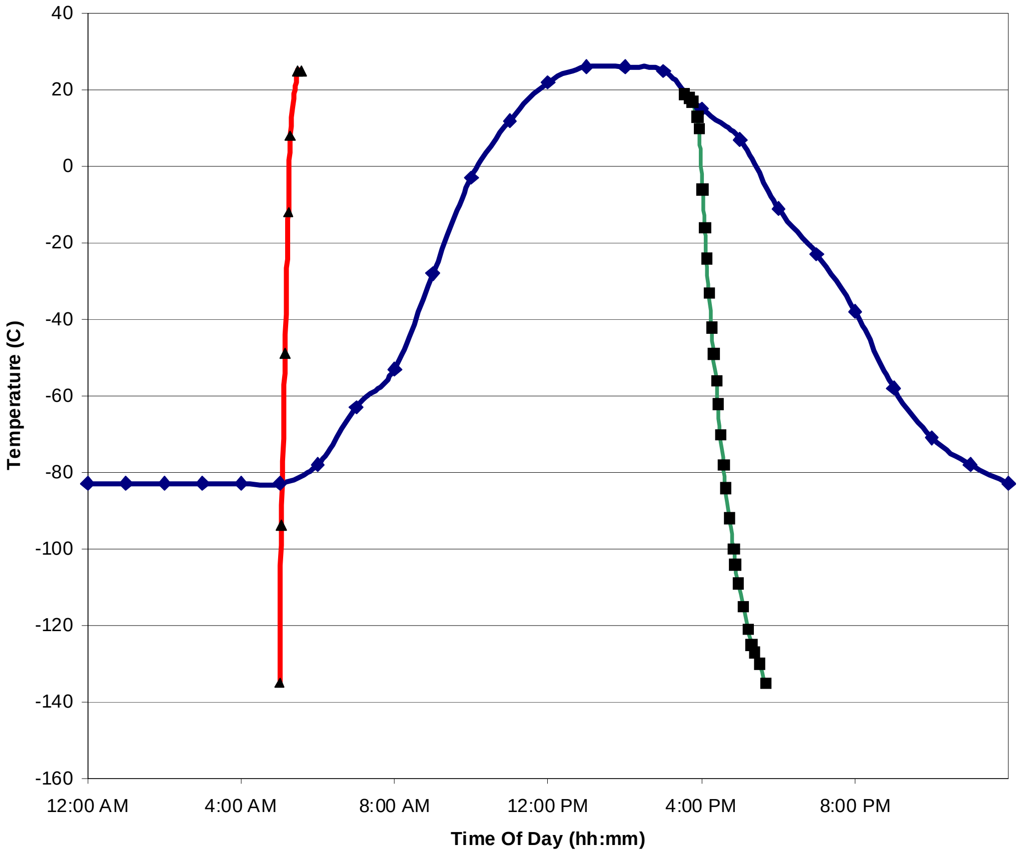
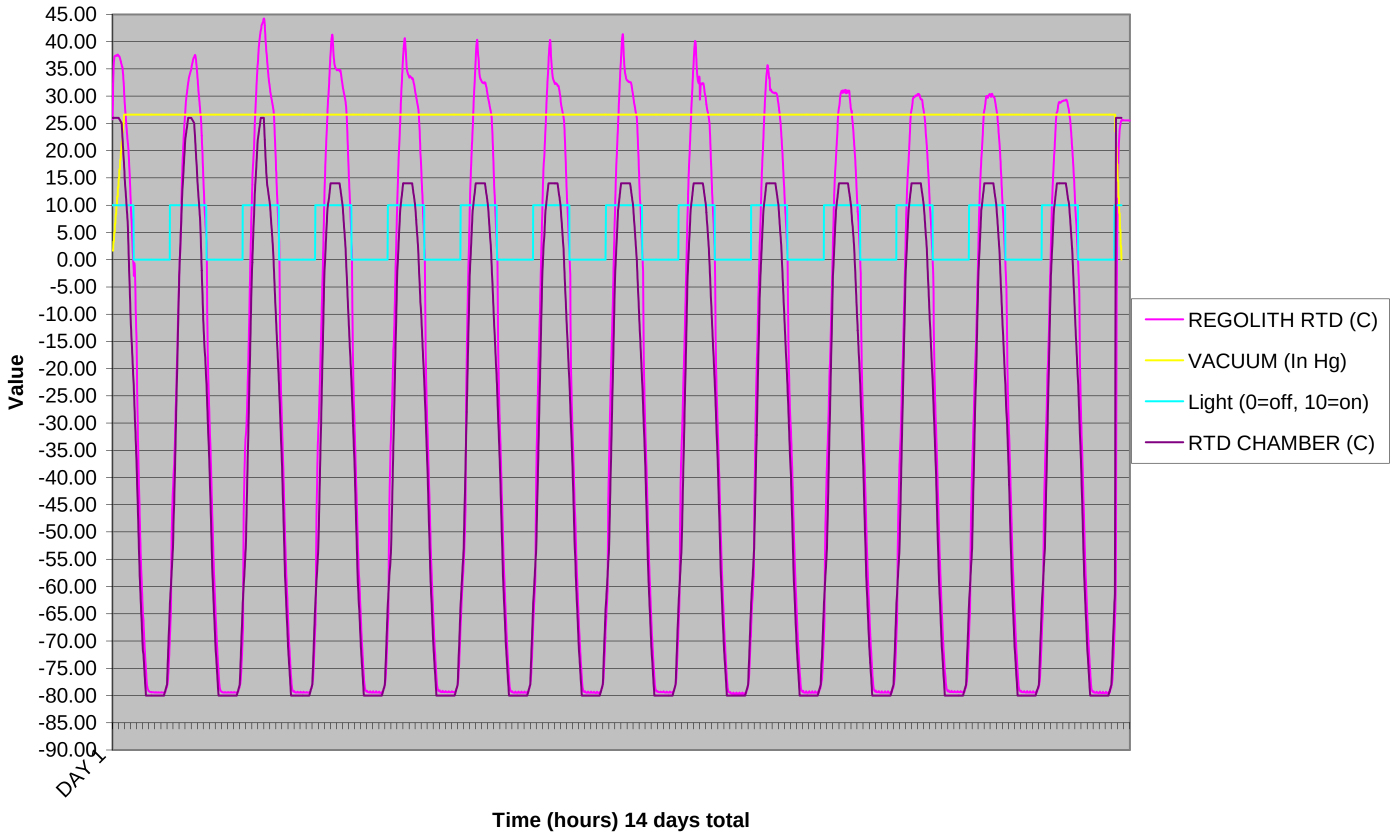
Laboratory Test Bed
Regolith Temperature Control

- **Rise rate (triangles) exceeds requirements**
- **Cooling rate (squares) exceeds requirements**
- **Watlow controller programmed to new set point every hour**
- **Simulates daily temperature profile at low latitude at vernal equinox**
- **Controlling sensor submerged in regolith simulant**



Laboratory Test Bed Performance Data

Mars Environmental Conditions (14 day test) 6/1/05 - 6/15/05



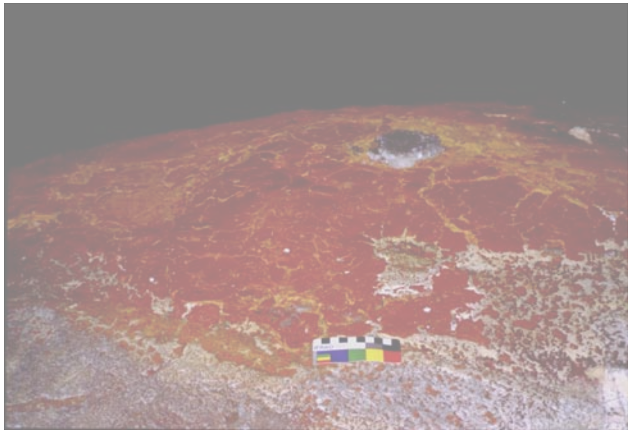
Objective 2
Evaluate Pioneer Organisms

- Selection of organisms based on Phase I results
- Performance of experiments in test bed
- Preliminary results

Summary of Requirements for Pioneer Martians

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

C. McKay, 2004



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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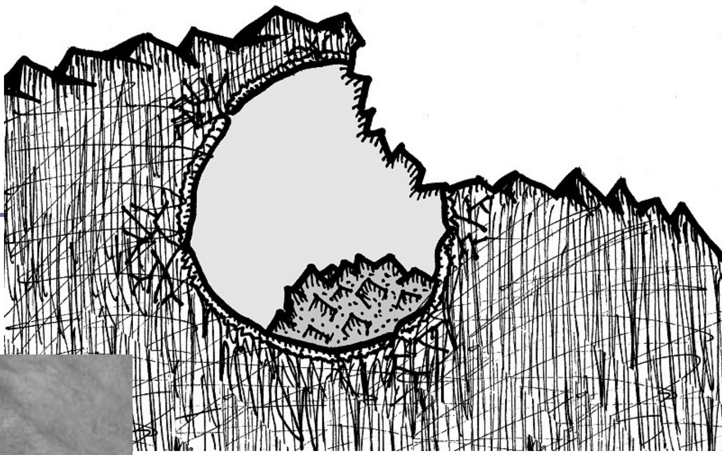
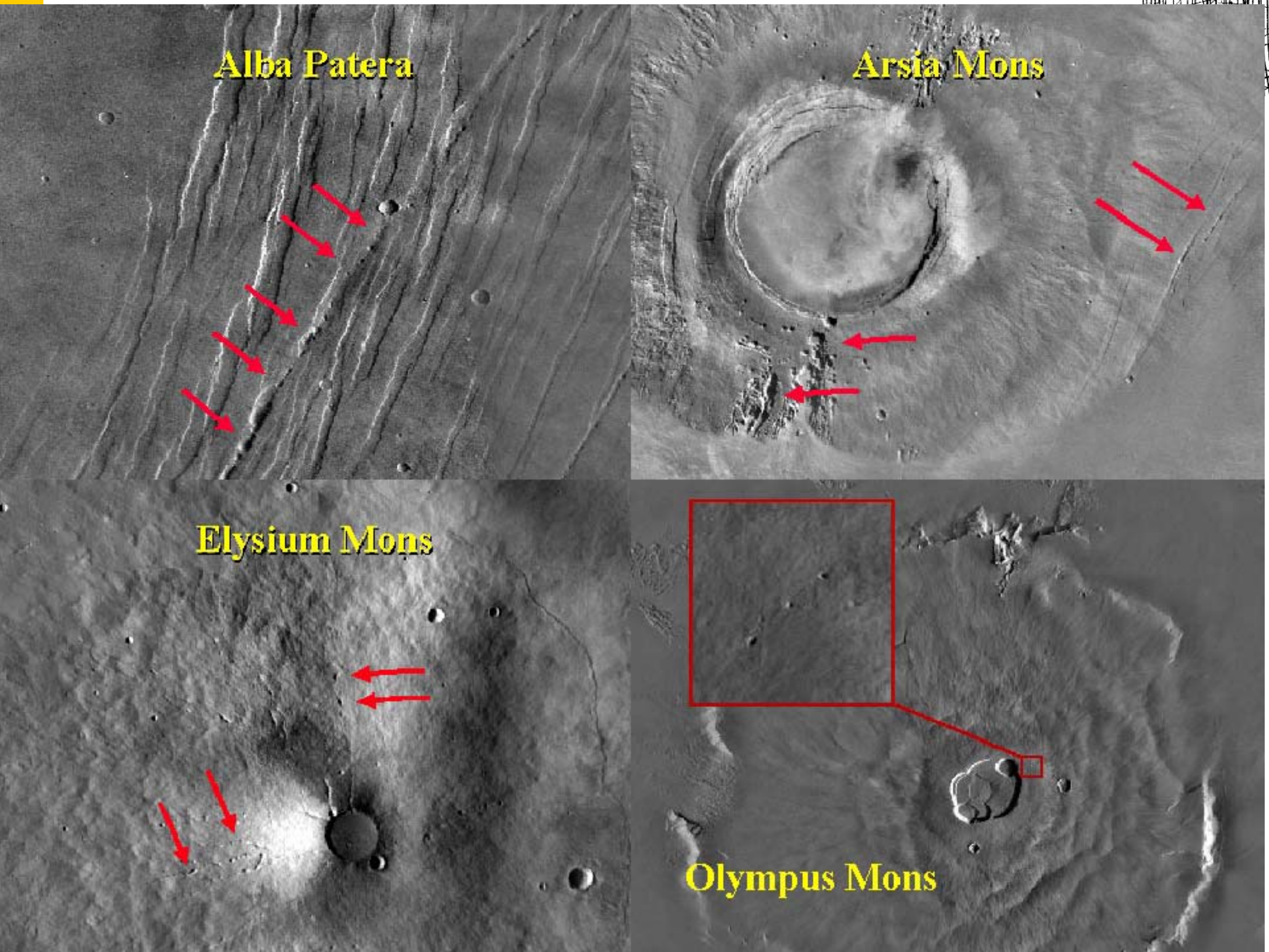
Lava Habitats



Lavatubes



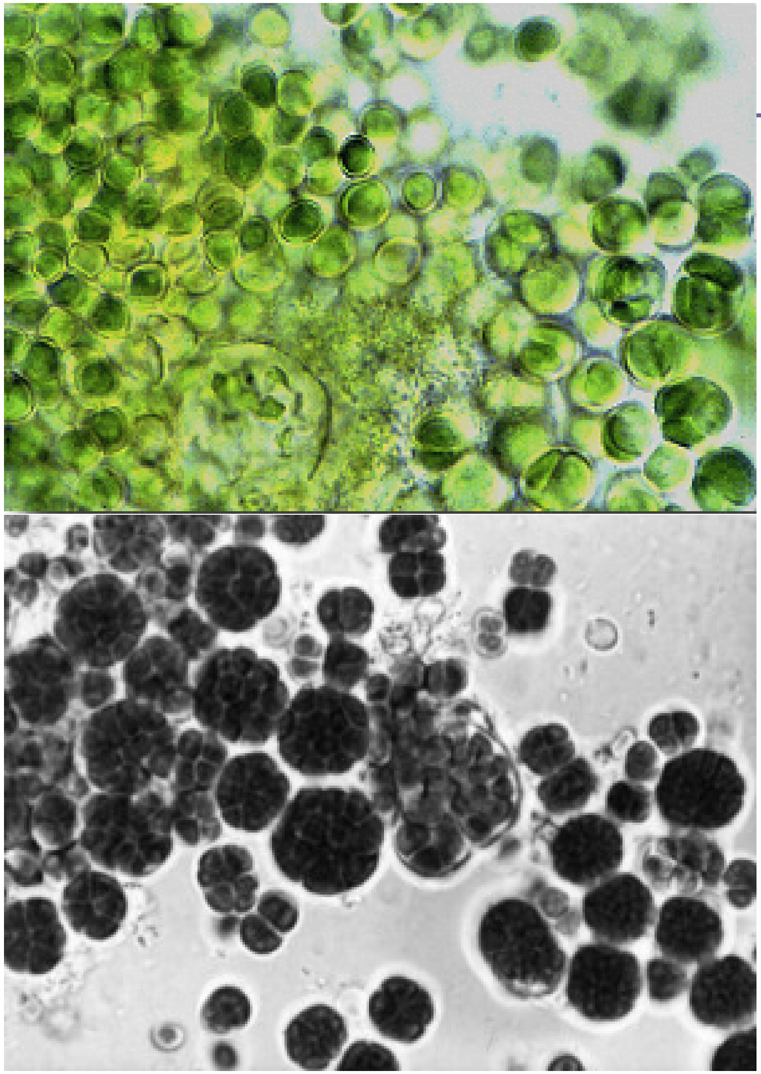
Bubbles

Squeeze-ups

Palagonitization

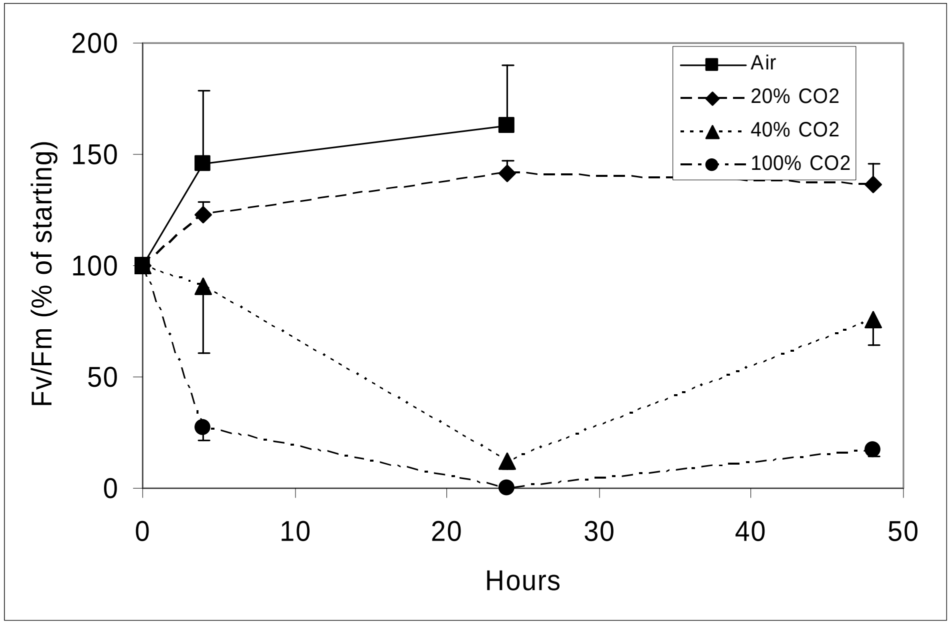
Dr. Penny Boston

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.

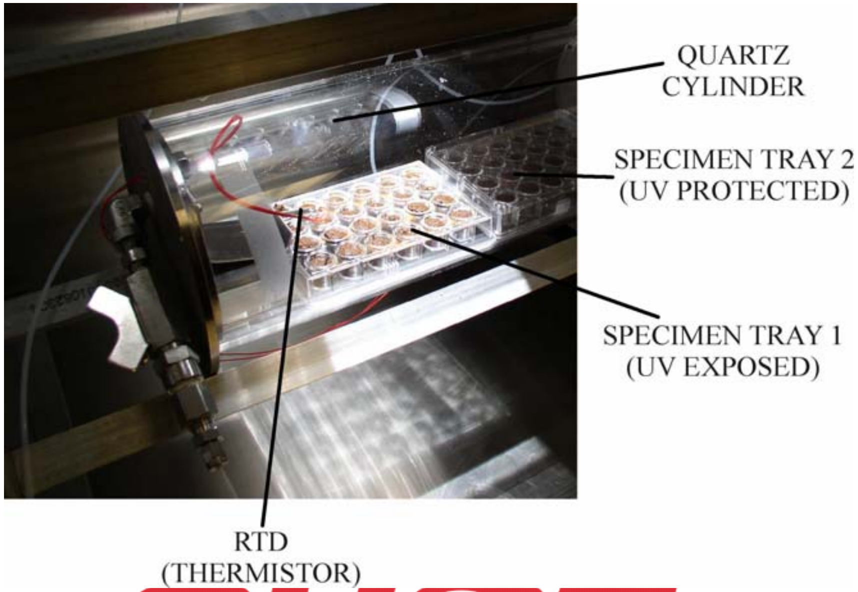
High % CO_2 tolerance



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.). Dr. David Thomas.

Experiments with Microbial Specimens to Date

EXPERIMENT	DATE	DURATION	SPECIMENS
1	May 31	23 hours	Dr. Thomas’
2	June 1	14 days	Dr. Thomas’
3	June 18	8 days	Dr. Thomas’
4	June 23	22 hours	Dr. Boston’s
5	June 25	5 weeks	Dr. Boston’s Dr. Thomas’



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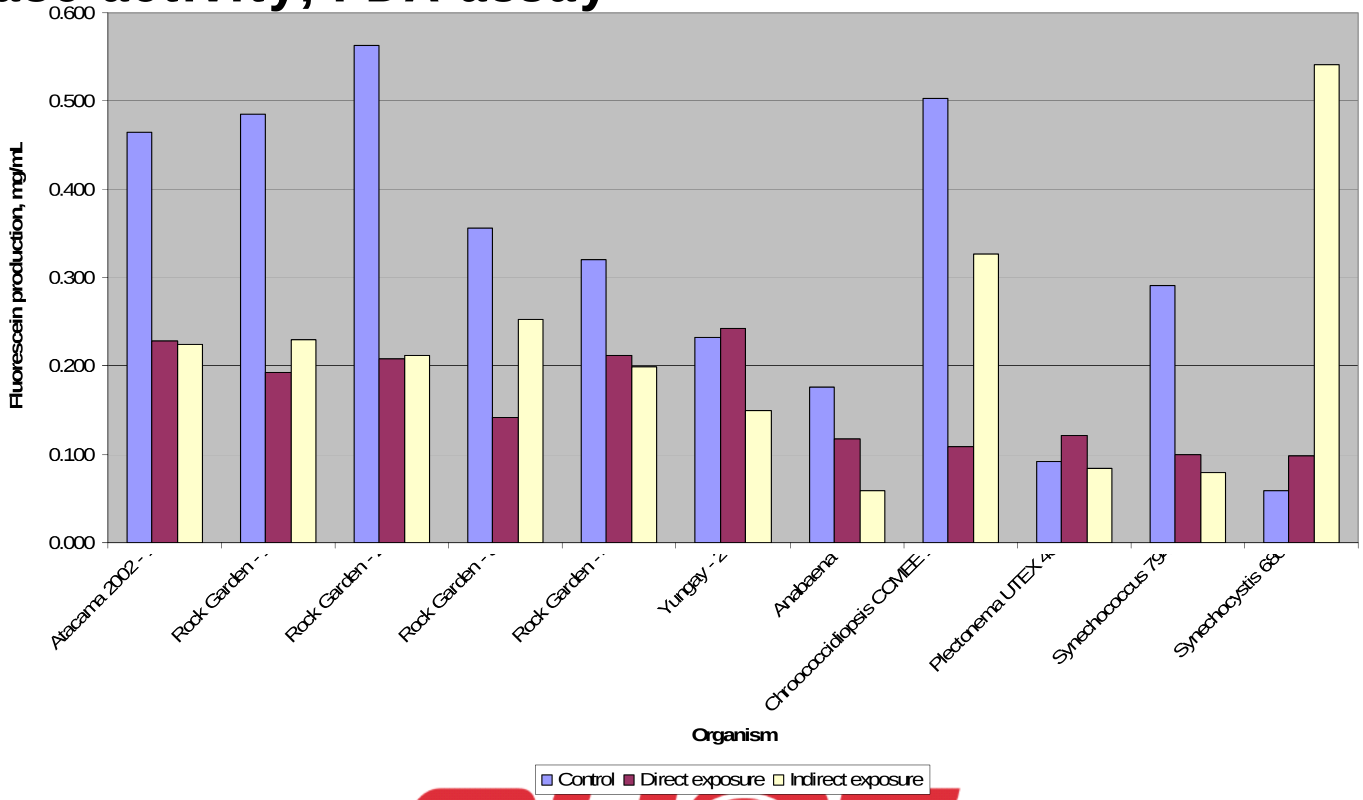
Preliminary Results of Microbial Experiments

- 14 days at 100mbar, water saturaturation
- Cyanobacteria (5 strains), Atacama desert bacteria (6 isolates)
- Esterase activity, FDA assay

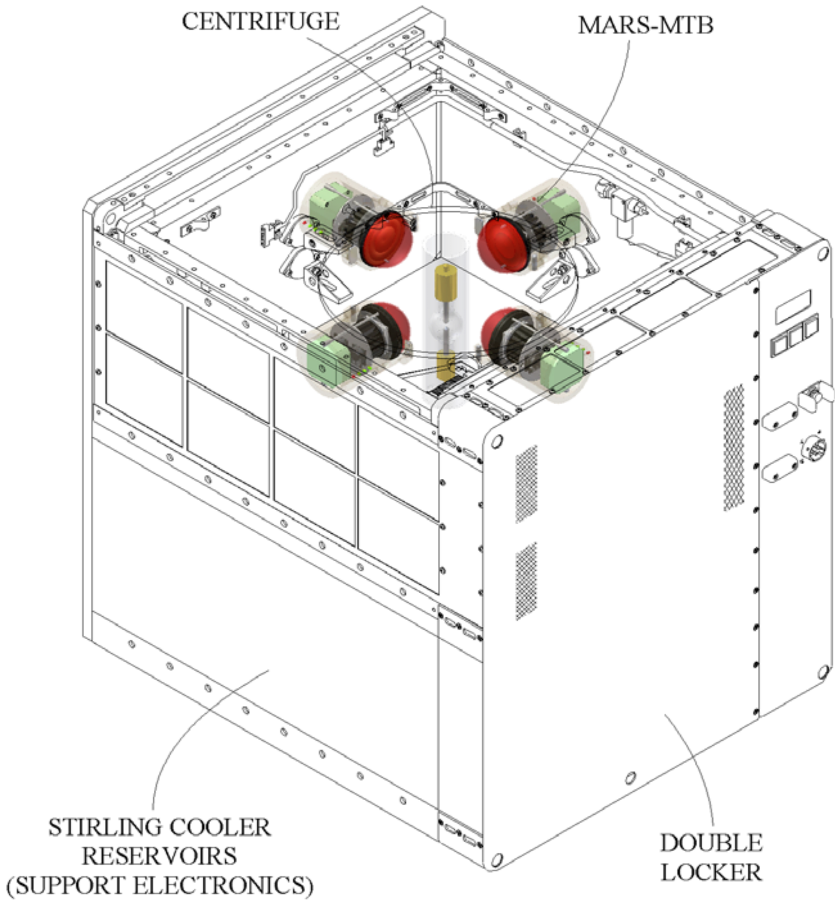


Objective 3.
Modular Ecopoiesis Test Bed

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

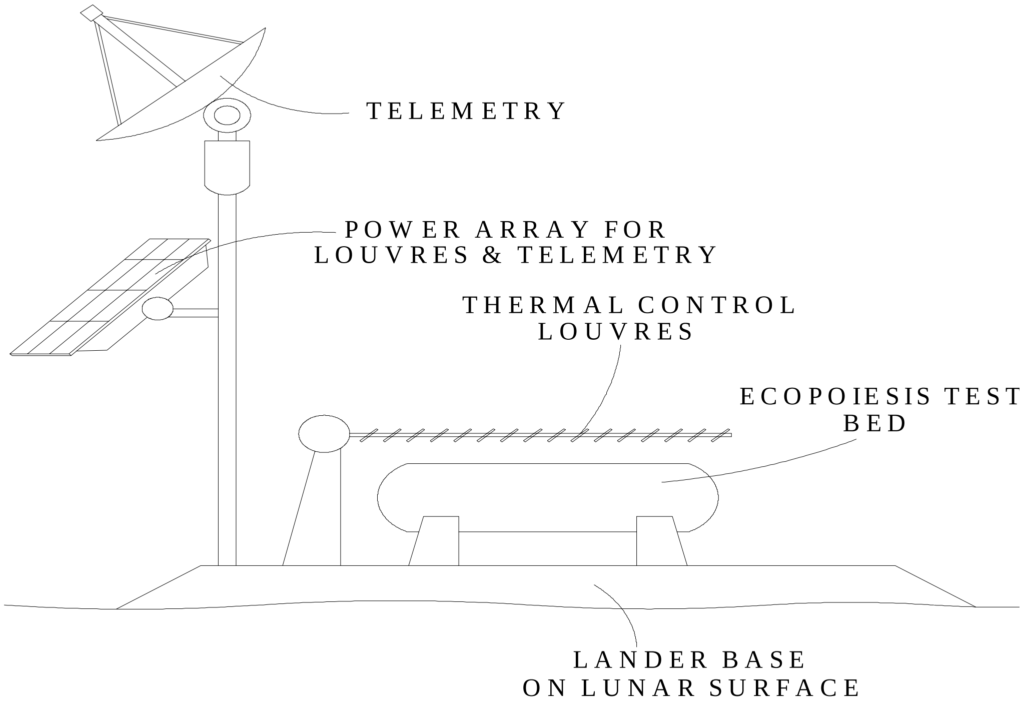
Objective 4
Extraterrestrial Test Bed Opportunities (Phase III)

- **Partial gravity on Shuttle or ISS?**
- **Modified Avian Development Facility and up to 4 low-pressure jars**
- **Test pioneer communities in MARS-chamber, 0.38 g**



Concept Proposed for RLEP

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



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PROGRESS ON MILESTONES

- Phase I completed; laboratory test bed design, extremophile selection initiated
- Phase I articles for publication
- Laboratory test bed completed, operated
- Modular portable test bed proposed
- Low-volume lunar test bed proposed
- Science Advisory Committee met twice
- Annual First report submitted
- Phase II presentations at conferences

Year 2 Tasks

- Perform 4 additional 5-week biological experiments
- Create community of ecopoiesis and astrobiology simulation scientists
- Obtain funding for modular test beds
- Report biological results
- Stay connected to RLEP

Thanks to HIAC and the SHOT 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
- Darrell Masden, ME, Thermal Engineer
- Lara Deuser, ChE, Lab Scientist
- Heidi Platt, ChE