Robotic Lunar Ecopoiesis
Test Bed
NIAC

Presented by: Paul Todd
October 19, 2004
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),
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
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.

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$_2$O 0.03%
- Trace amounts of Ne, Kr, Xe, O$_3$
- No significant ozone layer
- Surface pressure 6-10 mbar
How Dry is Mars?

- Moisture mm/yr
- Life
- Mars-like soils
- Soil Bacteria
- Hypolithic algae
- Shrubs and insects
- Desert ecosystems

- Biology wins, reducing
- Photochemistry wins, oxidizing

- 0.2
- 1
- 5
- 25
- 125

- Gobi Desert
- Mojave Desert

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
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

![Diagram of Laboratory Chamber and Subsystems Design Drawings]

**SHOT**
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°C
- SHOT-designed computing hardware and software
- Thermoelectric cascade
- Solar spectrum simulator
- Classrooms and labs
- Patent applied for
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.).
- \( \text{CO}_2 \) 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)
## Candidate Extremophiles

<table>
<thead>
<tr>
<th>Environment</th>
<th>Bacteria/Microorganism</th>
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<tbody>
<tr>
<td>Radiation</td>
<td><em>Deinococcus radiodurans</em></td>
</tr>
<tr>
<td>Hyperbaric/Anaerobic</td>
<td><em>Bacillus infernus</em></td>
</tr>
<tr>
<td>High saline</td>
<td><em>Haloferax volcani</em> (Searles Lake)</td>
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<tr>
<td>Vacuum</td>
<td><em>Streptococcus mitis</em></td>
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<tr>
<td>Sulfurous environment</td>
<td><em>Thiobacillus sp.</em></td>
</tr>
<tr>
<td>Low temperature</td>
<td><em>Anabaena</em>, other cyanobacteria</td>
</tr>
<tr>
<td>Spore dormancy</td>
<td><em>Bacillus subtilis</em></td>
</tr>
<tr>
<td>High temperature</td>
<td>Not relevant</td>
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</tbody>
</table>
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

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

- **E. coli:** 10% survival at 0.1 kGy
- **Deinococcus:** 100% survival at 5 kGy
## Halobacterium and Mars

<table>
<thead>
<tr>
<th>Advantages:</th>
<th>Challenges:</th>
<th>Possible Uses:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistant to extremes in cold, desiccation, vacuum, gamma and UV radiation</td>
<td>Nutrient source?</td>
<td>Genetic engineering</td>
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<tr>
<td>Facultative anaerobe</td>
<td>Liquid water?</td>
<td>E.g. Genes for resistances into a primary producer</td>
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<td>Model System</td>
<td>Halophilic autotrophs?</td>
<td>Problem of acidic residues in proteins</td>
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<td></td>
<td></td>
<td>Secondary colonizer</td>
</tr>
</tbody>
</table>
Permafrost

Ice Caves

Cryoconites

Basal melt springs

Icy Habitats
Lava Habitats

Lavatubes

Alba Patera

Arsta Mons

Elysium Mons

Olympus Mons

Bubbles

Squeeze-ups

Palagonitization

Dr. Penny Boston
What do microbes do to rocks and minerals?

Transformation....

Dissolution
active mining
metabolic byproducts

Corrosion
bedrock
minerals
metals

Nucleation
alive
dead

Precipitation
passive
active

Ferromanganese Biodeposit in Lechuguilla Cave, NM
Image by Val Hildreth-Werker
Microbial "Cave Corrosion" (Speleosols)

Microbial oxidation
$\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$
$\text{Mn}^{2+} \rightarrow \text{Mn}^{4+}$

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

Carbonate dissolution by organic acids

Cave

Air/Rock Interface

microbes

chelating ligand

Organic Acids

(Ca,Mg,Mn$^{2+}$,Fe$^{2+}$)CO$_3$

Wall rock
Anabaena species

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

Dr. David Thomas
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.).
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 Advisory Committee established
- First bimonthly report submitted
- Phase II presentation
The Ecopoiesis Team

- 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