Lunar Ecopoiesis Test Bed Research Team

- Penelope Boston, Ph.D., Director, Karst and Cave Research Institute, New Mexico Institute of Mining and Technology and Complex Systems Research, Inc.
- Heidi Platt, Chemical Engineer
- Lara Deuser, Chemical Engineer
- Bill Metz, Mechanical Designer
- Extremophile workshop group
- Paul Todd, Principal Investigator

ECOPOIESIS

- 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

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) and**
4. **The terraforming of Mars or ecopoiesis (Haynes, 1990; McKay, 1990; Haynes and**

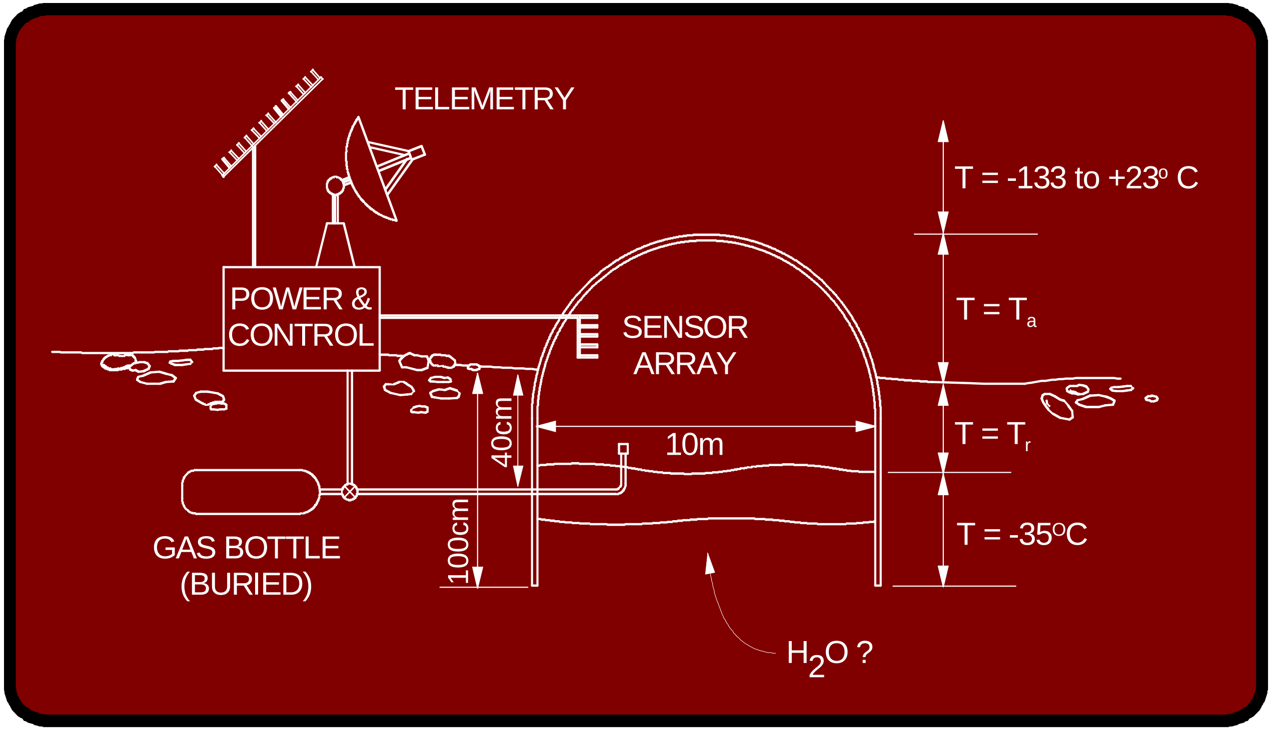
   McKay, 1992; McKay et al., 1991, 1994; Hiscox, 1993, 1995, 1998).

Ecce Ecopoiesis: Playing God on Mars

“ . . if it is decided to implement such a program of planetary engineering, a slow and conservative approach is essential. Sufficient time must be allowed for a wide range of studies of Mars as it exists at present, and for careful planning, modeling and ‘pilot-plant’ trials (where possible) of all successive steps in the enterprise.” (Haynes & McKay, 1995).

Starting Position: Robotic Lunar Ecopoiesis Test Bed

- Trenched, depressed site
- Inflatable dome solidifies
- Interior controlled to Mars atmosphere and day length
- Organisms & chemicals added to regolith
- Control and data telemetry to earth



Robotic Lunar Ecopoiesis Test Bed: an Architecture

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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 3 L, 0.15 L, and 500 m3.* Derive scaling rules for gas concentrations, heat capacities, heat transfer, light and radiation intensities, biomass and mechanical properties

Objective 1. Symposium on Pioneer Organisms and Succession

- What known organisms thrive and grow most rapidly in terrestrial polar environments?
- What known organisms will metabolize and proliferate in minimal water and pressure?
- What organisms are most appropriate to start a community using mineral energy?
- What conditions must humans create in the atmosphere to encourage cell proliferation?
- What conditions must humans create in the regolith to encourage proliferation?
- What should be the expected succession of organisms in an ecopoietic environment?
- What time scales are appropriate for experiments in model architectures?
- What are the appropriate analytical methods for detecting growth, metabolism and environmental modification and succession?

Extremophile Selection for Ecopoiesis 30-31 Jan, 2004 Objectives of the Workshop

From the proposal: "A symposium will be held for the tentative identification of ecopoietic **communities of organisms**, recommendation of **experiment parameters** including duration and size of inoculum, and appropriate **analytical methods**. An interesting problem, for example, is how to compress to a period **within a human lifetime** the progressive transitions that may require incredibly slow organisms and lengthy physical processes."

Procedure

Agenda, sessions including discussions

- Session I: Mars Simulation Testbeds
- Session II: Planetary environments
- Session III: Pioneer organisms I
- Session IV: Pioneer organisms II
- Session V:Laboratory, ISS and lunar test-bed scenarios
- Session VI: Recommendations
  - Meeting of three working subgroups (70 min)
  - Subgroup reports, written recommendations (60 min)
  - Wrap-up discussion (Additional writing assignments?)

Seven Identified Principles

- Problem to be addressed: terraforming of the surface of Mars.
- Starting conditions: those expected to exist at the best possible Mars location
- Regolith to be heated to accommodate most robust terrestrial life
- Pioneer organisms derive energy from mineral content and/or sunlight
- Pioneer organisms capable of withstanding or protected from radiations
- Organisms early in succession should produce significant amounts of O_2.
- Heterotrophic aerobes needed after dangerous levels of O_2 emerge.

Candidate Extremophiles

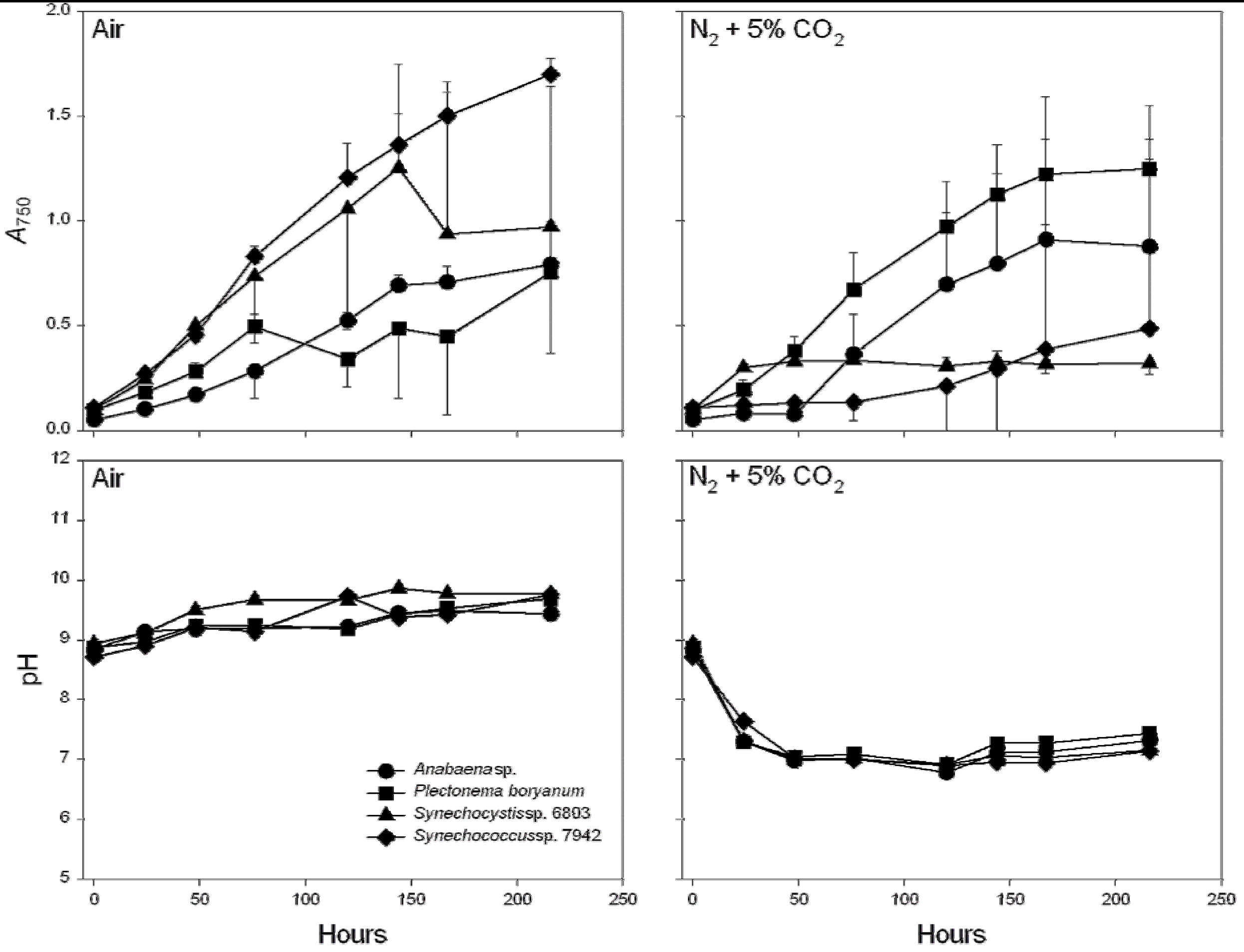
- Radiation *Deinococcus radiodurans*
- Hyperbaric/Anaerobic *Bacillus infernus*
- High saline *Haloferax volcani* (Searles Lake)
- Vacuum *Streptococcus mitis*
- Sulfurous environment *Thiobacillus sp.*
- Low temperature *Anabaena*,other cyanobacteria
- Spore dormancy *Bacillus subtilis*
- High temperature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

Cyanobacteria: Anabaena

David Thomas, Lyon College

- Common freshwater and marine genus.
- Filamentous.
- Tolerates high CO_2
- Well-studied genetics and physiology.
- Nitrogen fixation in heterocysts.

Cyanobacteria that tolerate high CO_2 also tolerate low O_2.



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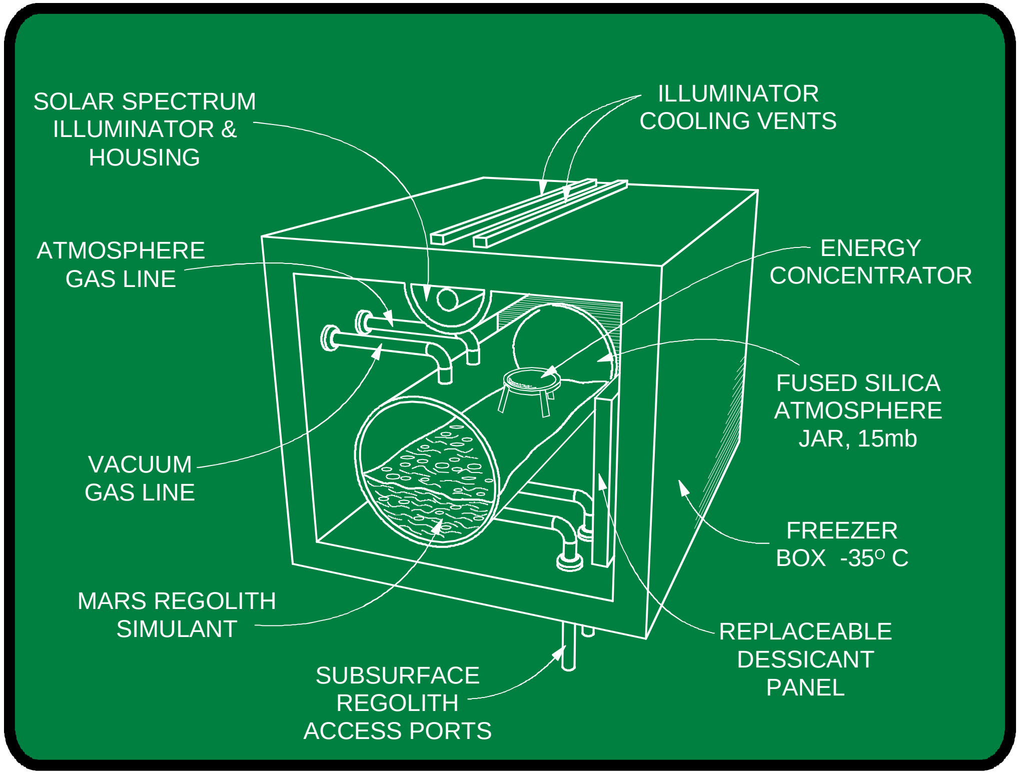
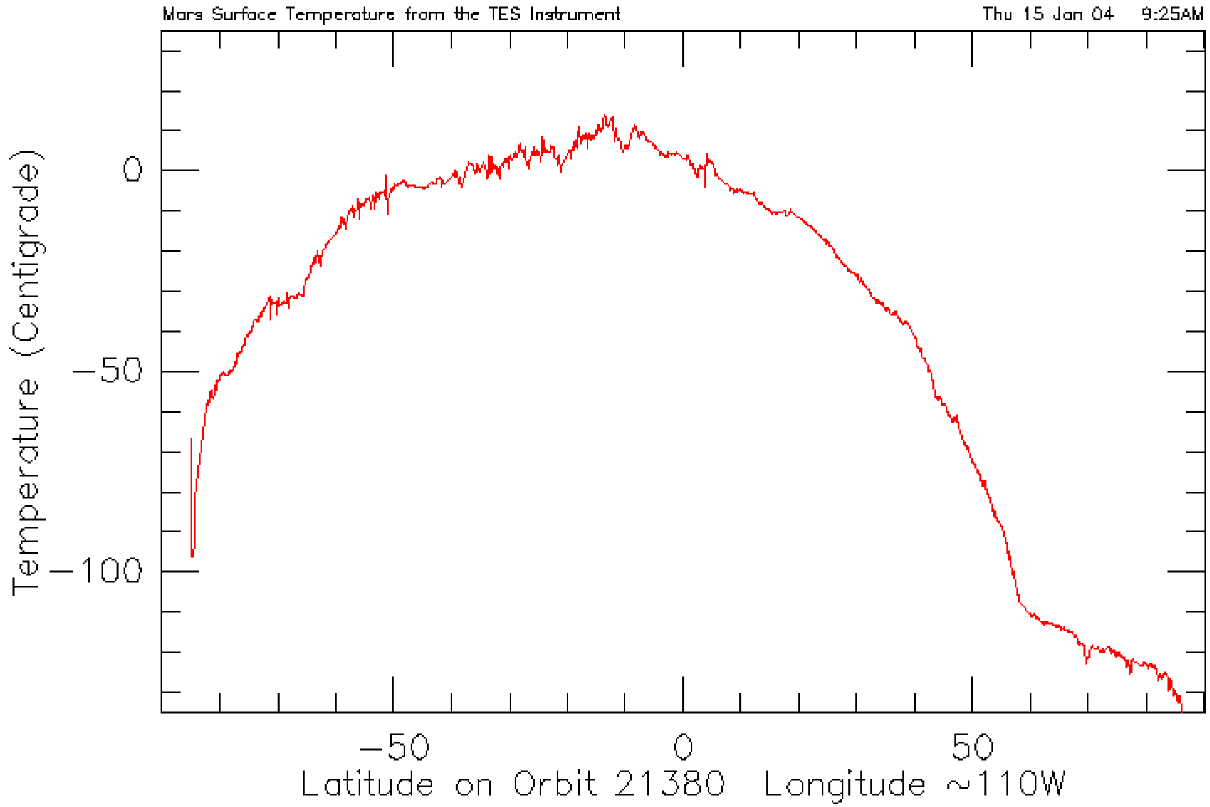
Objective 2. Phase II Laboratory Test Bed (MARS-LTB)

- Quartz jar with Mars regolith simulant & atmosphere (10 mbar)
- Mars surface solar spectrum
- Mars T cycle
- Organisms in regolith
- Sampling and analysis



The Latest Data From the Thermal Emission Spectrometer

Daily Martian Temperature Profiles and Global Temperature Images



http://emma.la.asu.edu/daily.html

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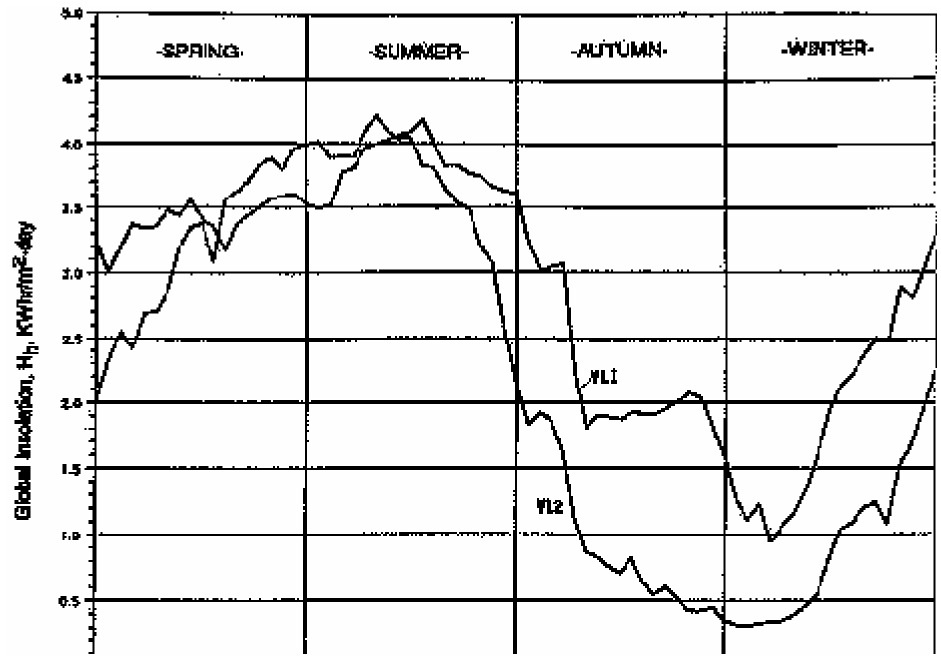
Lighting: Temporal Simulation



BY SEASON AT EQUATOR

the 1.5kW arc lamp is 135 W at output. With a total surface area of 256 in2, the spectral output of the simulator is 817 W/m2. This is more than adequate for simulation of the solar intensity on Mars (590 W/m2), but not enough for simulation on the moon (1370 W/m2).

Mars Pathfinder

Analysis of Martian Samples by the Alpha Proton X-Ray Spectrometer: Preliminary Results

Comparison with SNCs and the Earth

	Mars			Earth		
	A-3, Rock "Barnacle Bill"	A-5, Soil	SNCs (Mars Meteorites)	Continental Average	Crust Sediments	Oceanic Crust
	weight %	weight %	weight %	weight %	weight %	weight %
MgO	3.1	8.6	9.3-31.6	3.1	3.1	7.7
Al_2O_3	12.4	10.1	0.7-12.0	15.2	13.0	15.6
SiO_2	55.0	43.8	38.2-52.7	60.2	50.0	50.7
K_2O*	1.4	0.7	0.022-0.19	2.9	2.0	0.17
CaO	4.6	5.3	0.6-15.8	5.5	8.4	11.4
TiO_2	0.7	0.7	0.1-1.8	0.7	0.7	1.5
MnO*	0.9	0.6	0.44-0.55	0.1	0.1	0.16
FeO	12.7	17.5	17.6-27.1	6.05	5.5	9.9
FeO/MnO	14.1	29.2	37.0-51.5	-	-	-

*Values for potassium (K) and manganese (Mn) are probably too high and subject to revision after further analysis.

http://science.ksc.nasa.gov/mars/science/apxs_comparison.html

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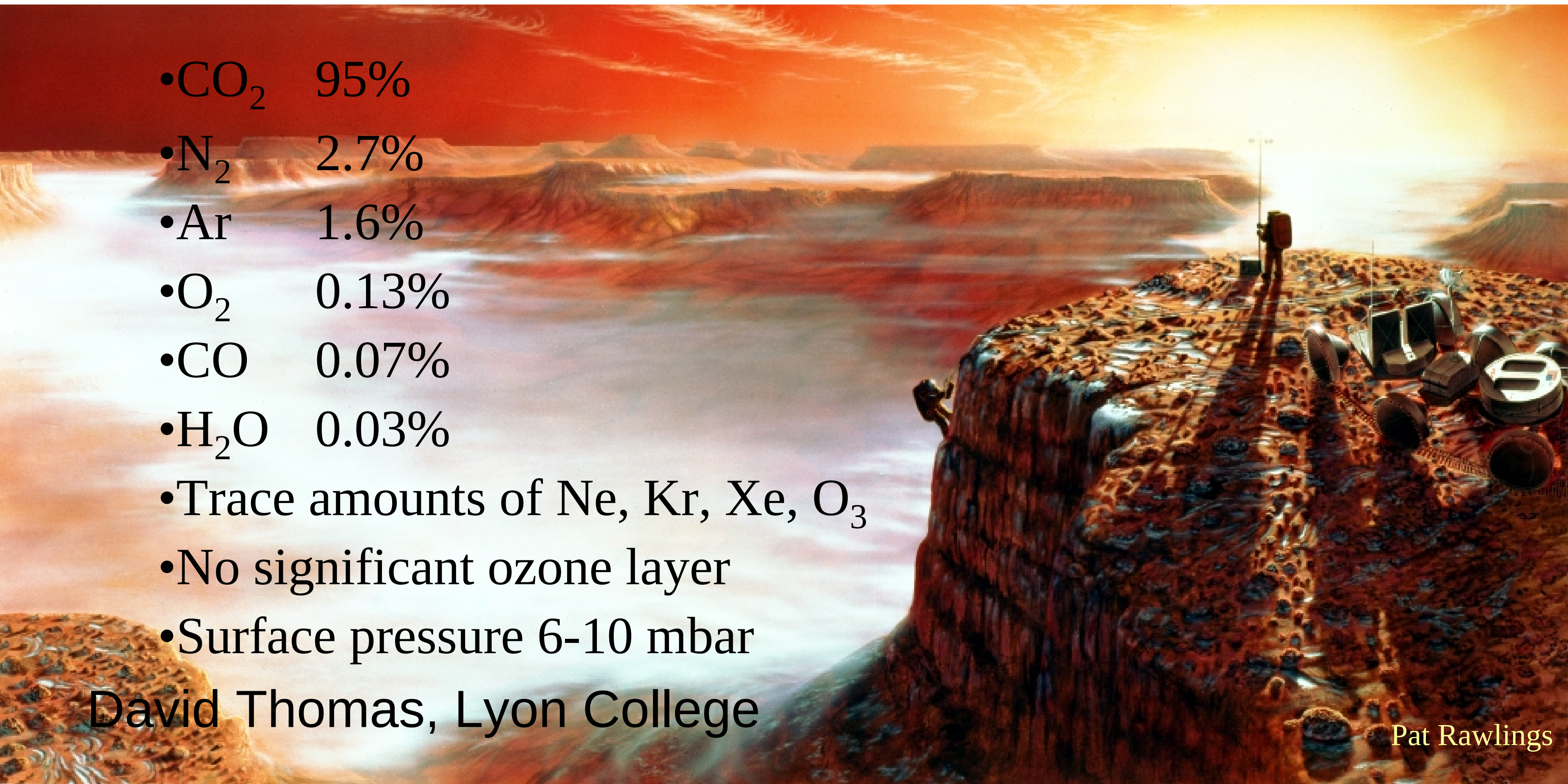
Mars' atmosphere today:

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



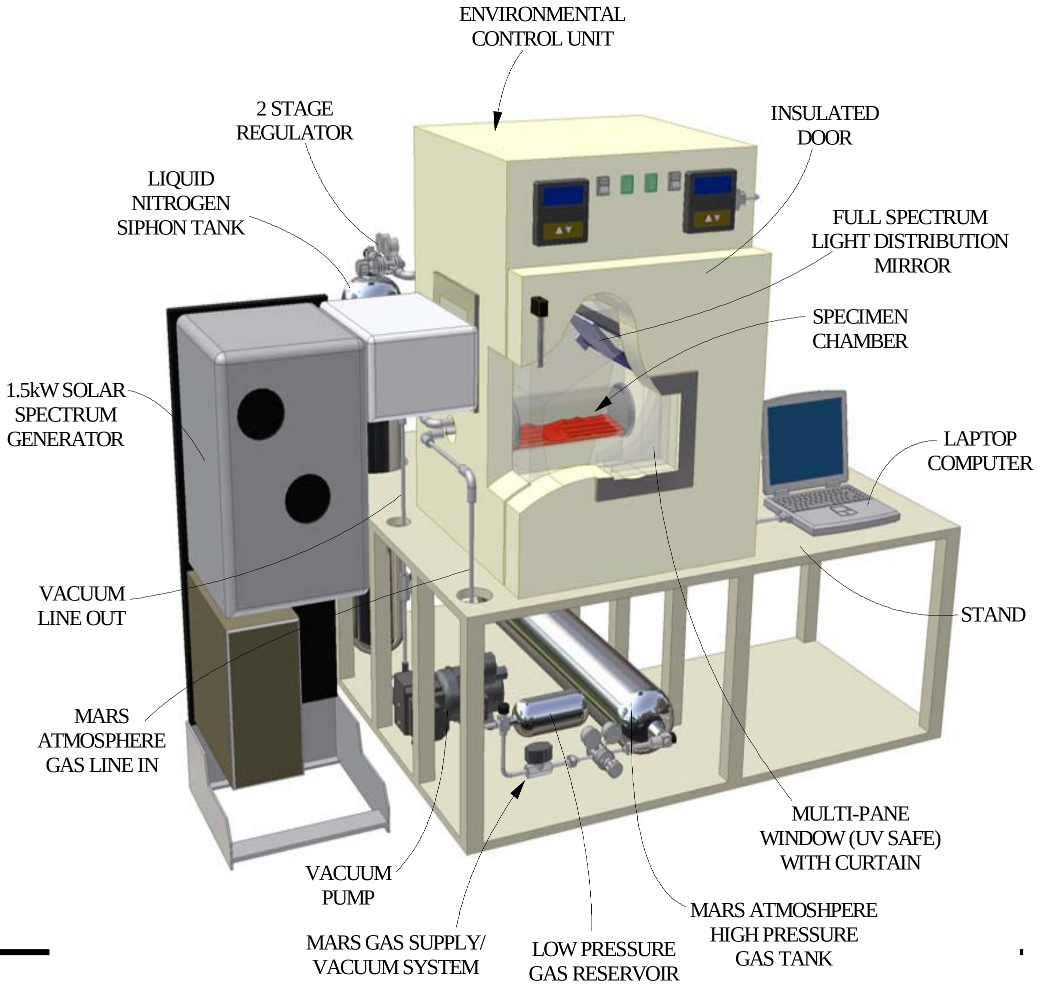
- CO_2 95%
- N_2 2.7%
- Ar 1.6%
- O_2 0.13%
- CO 0.07%
- H_2O 0.03%
- Trace amounts of Ne, Kr, Xe, O_3
- No significant ozone layer
- Surface pressure 6-10 mbar

David Thomas, Lyon College

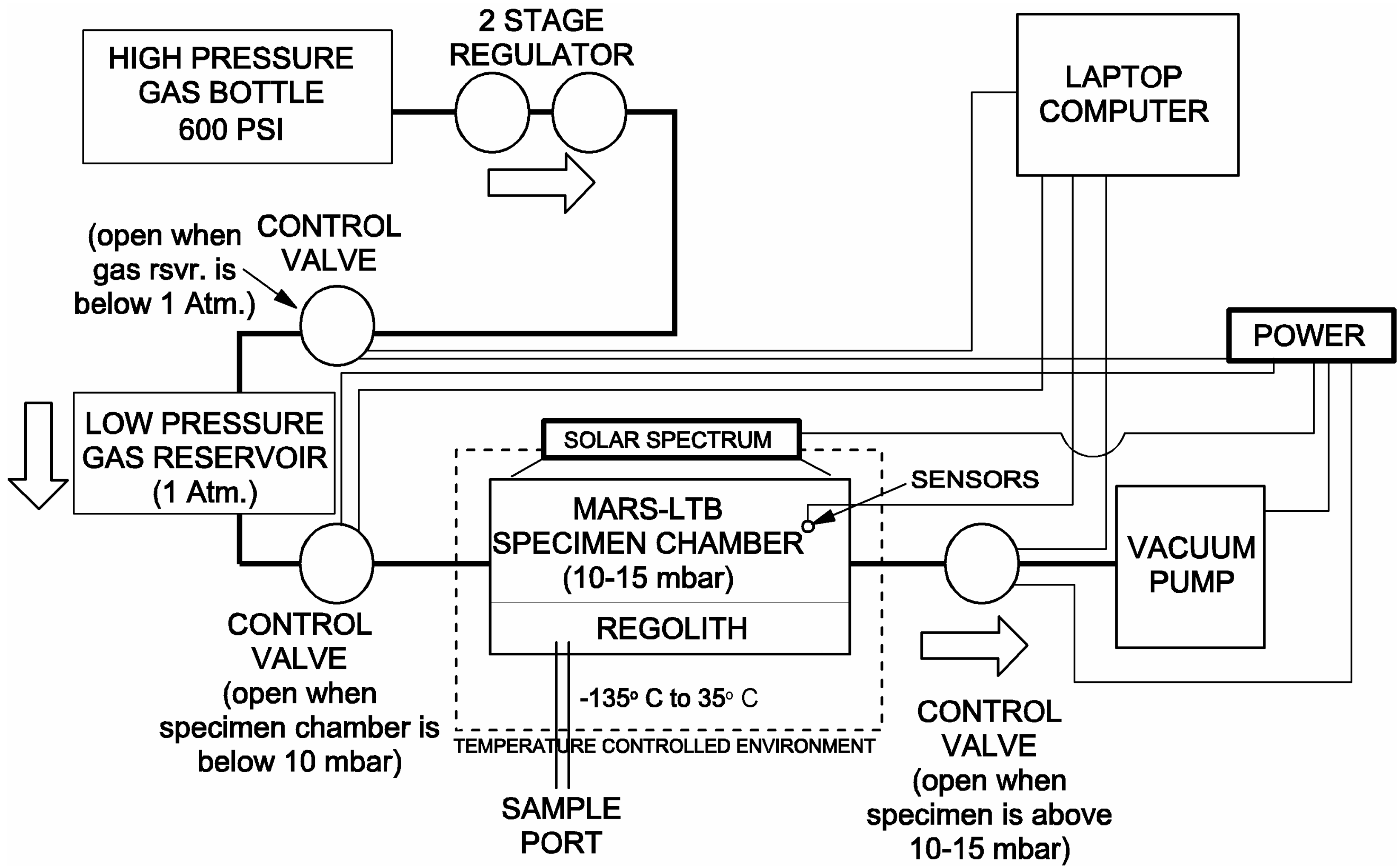
Pat Rawlings

Laboratory Chamber and Subsystems Design Drawings

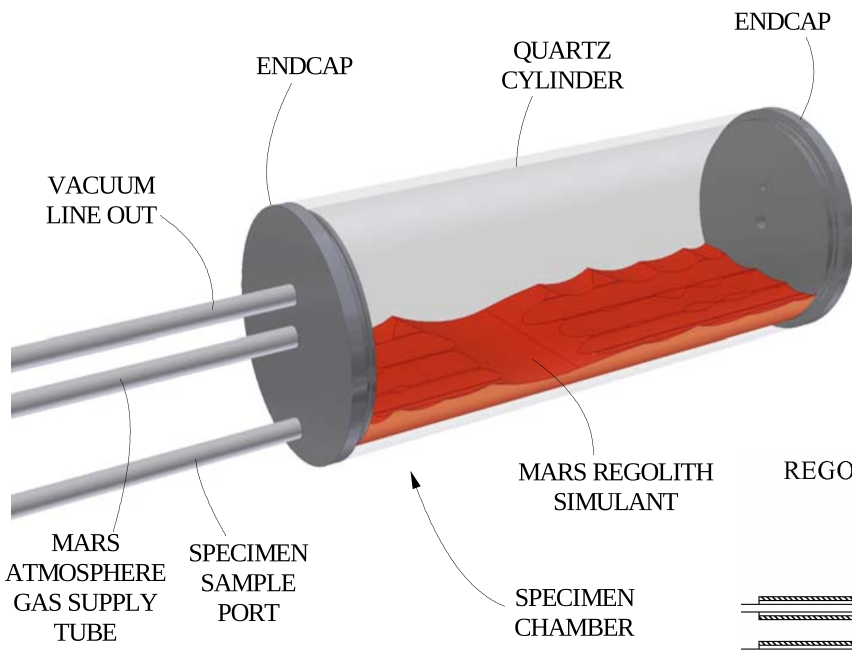
- Mars Atmosphere and Regolith Simulator-Lab Test Bed (MARS-LTB)
- Outer housing controls temperature -130 to +23°C (dry nitrogen cryogenic + compressor)
- Sealed illuminator with housing & cooling vents
- Low-pressure “Mars Jar” held at 10 – 15 mbar
- Atmosphere composition analysis and control
- Regolith simulant and regolith sampling

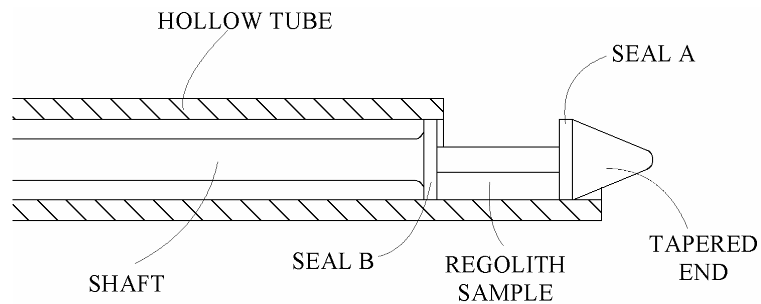


Laboratory Simulator Schematic

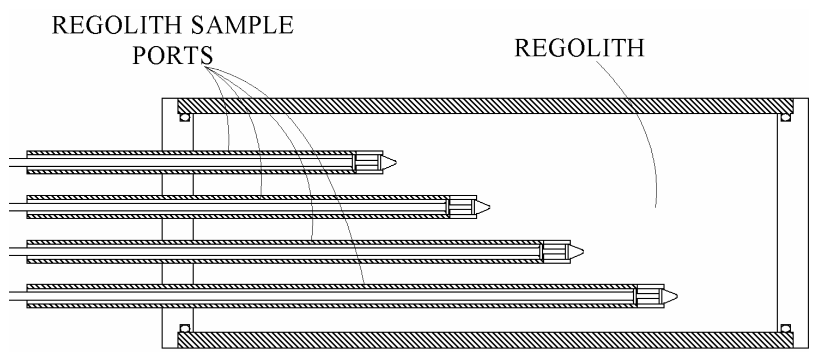


MARS-LTB Specimen Chamber "Mars Jars"





DETAIL OF DOUBLE SEAL PLUNGER



TOP VIEW - SHOWING MULTIPLE SAMPLE PORTS

MARS-LTB
Regolith Sampling System

•Double seal plunger inside a hollow tube.

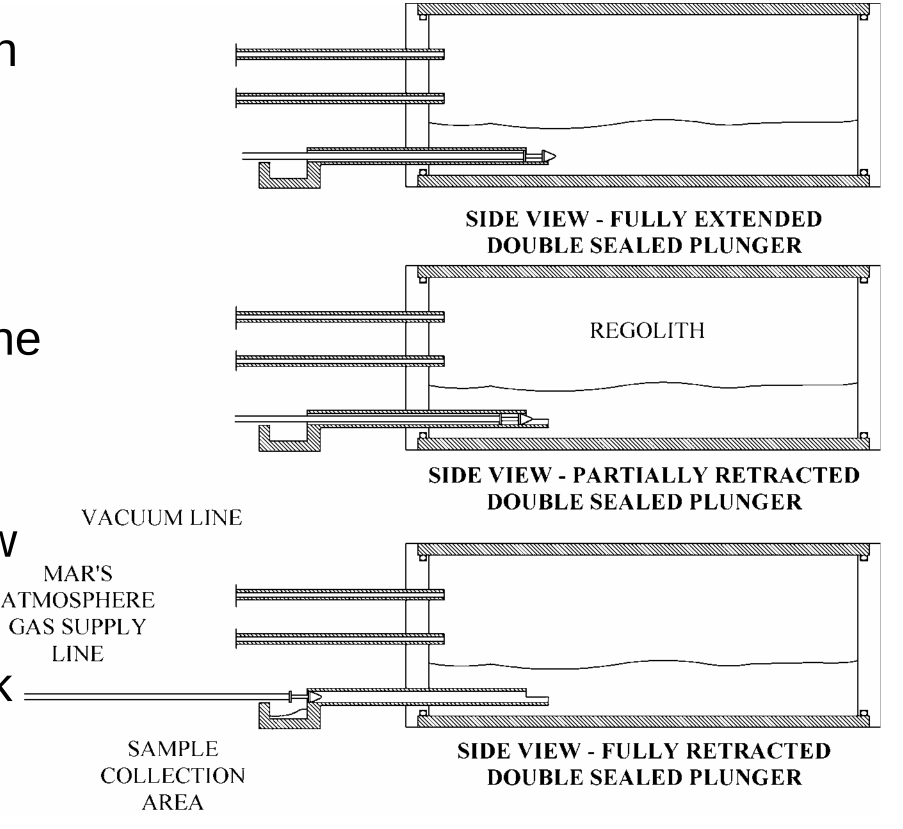
•Regolith sample is pulled from the specimen chamber by inserting the tapered tip of the plunger into the regolith.

•One seal remains inside the hollow tube.

•Plunger is retracted with both seals inside the hollow tube.

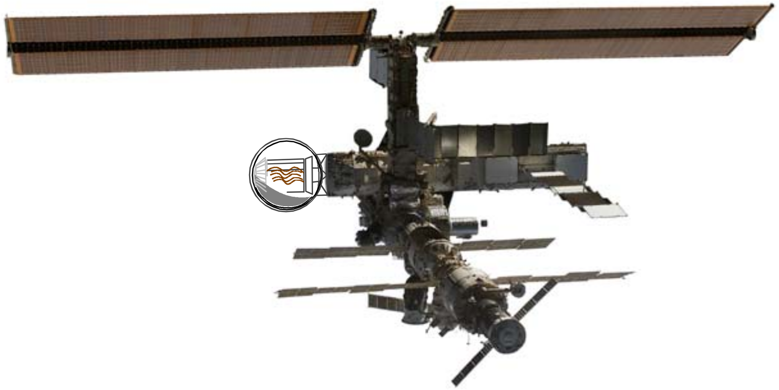
•The regolith sample is translated inside the hollow tube until the first seal exits the hollow tube.

•Regolith sample is deposited into the airlock area, ready for further study.



Objective 3: Identify Partial-Gravity Venues

- **Modified Avian Development Locker on International Space Station**
- **Single Locker on ISS**
- **External Pallet on ISS**
- **Dome on Moon**
- **How important is partial gravity?**

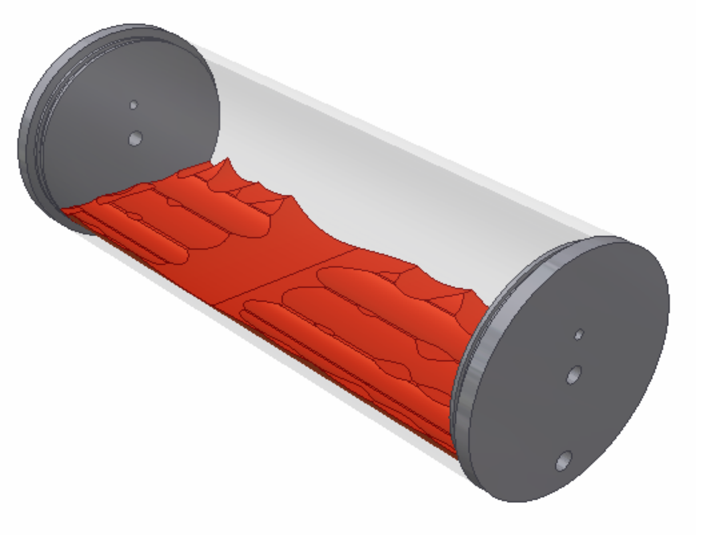


Comparison of Venues

	Multiple species	Atmosphere comp.	regolith	Light spectrum	accessibility	Ionizing radiation	gravity	complexity	Day length	integration	temperature	cost	pressure	season
Lab chamber	4	4	4	4	4	2	1	3	4	4	4	3	4	4
Miniature lab chamber														
single	2	4	3	4	3	0	1	4	4	4	3	4	4	4
multiple	4	4	4	4	4	3	3	4	4	4	4	4	4	4
Miniature ISS chamber	3	4	4	2	2	0	4	2	4	2	3	2	4	1
External ISS chamber	3	4	4	3	2	2	1	1	0	1	2	2	4	0
Earth test bed	4	4	3	2	4	1	1	2	4	2	3	3	2	1
NASA Simulation facility	4	4	4	4	3	1	1	2	4	2	4	2	4	2
Lunar test bed														
3. Lander + dome	4	4	1	4	4	4	3	1	0	1	3	1	4	2
2. Lander + container	3	4	4	4	2	4	3	2	3	2	4	1	4	2
1. Miniature	2	4	4	4	1	4	3	4	0	3	3	3	4	2
Mars test bed														
3. Lander + dome														
2. Lander + container														
1. Piggy-back	2	4	4	4	1	4	4	4	4	3	4	3	4	4

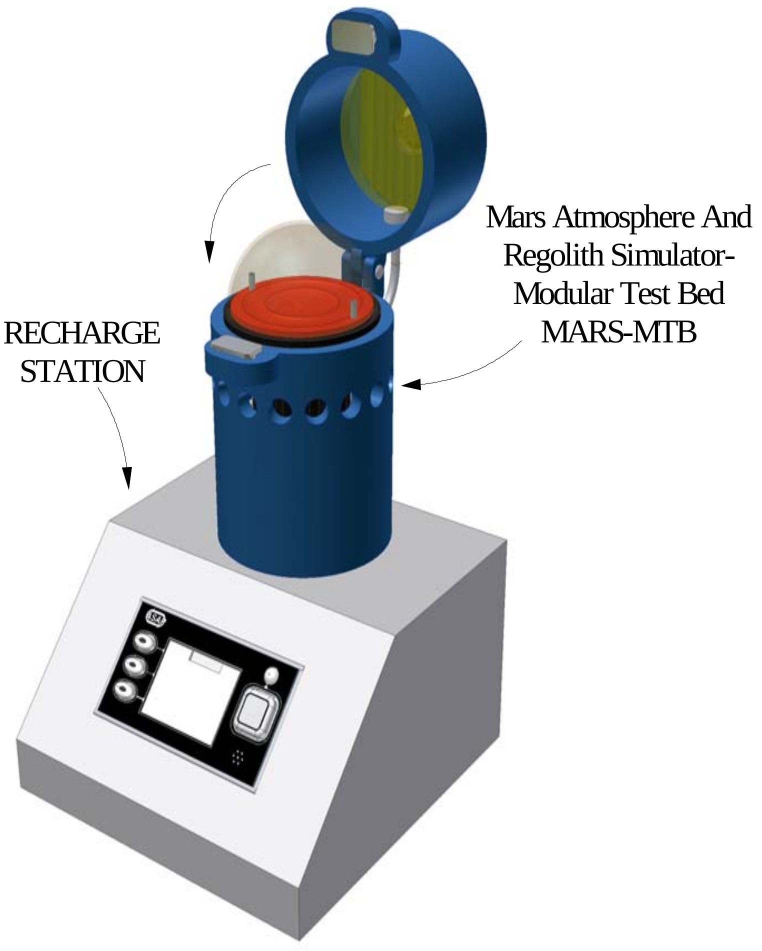
Objective 4. Scaling Rules for Atmosphere and Lighting

- Short optical path in jar atmosphere will not absorb IR radiation when greenhouse gases appear
- Monitor greenhouse gases and scale temperature for Martian field
- Use heat (energy) concentrator to create warm zone in regolith simulant using incoming "insolation"
- Scale pioneer biomass to feasible mass per unit regolith area but sufficient for analysis
- Write algorithms for scaling rules
- Scale down to modular test bed (MARS-MTB)

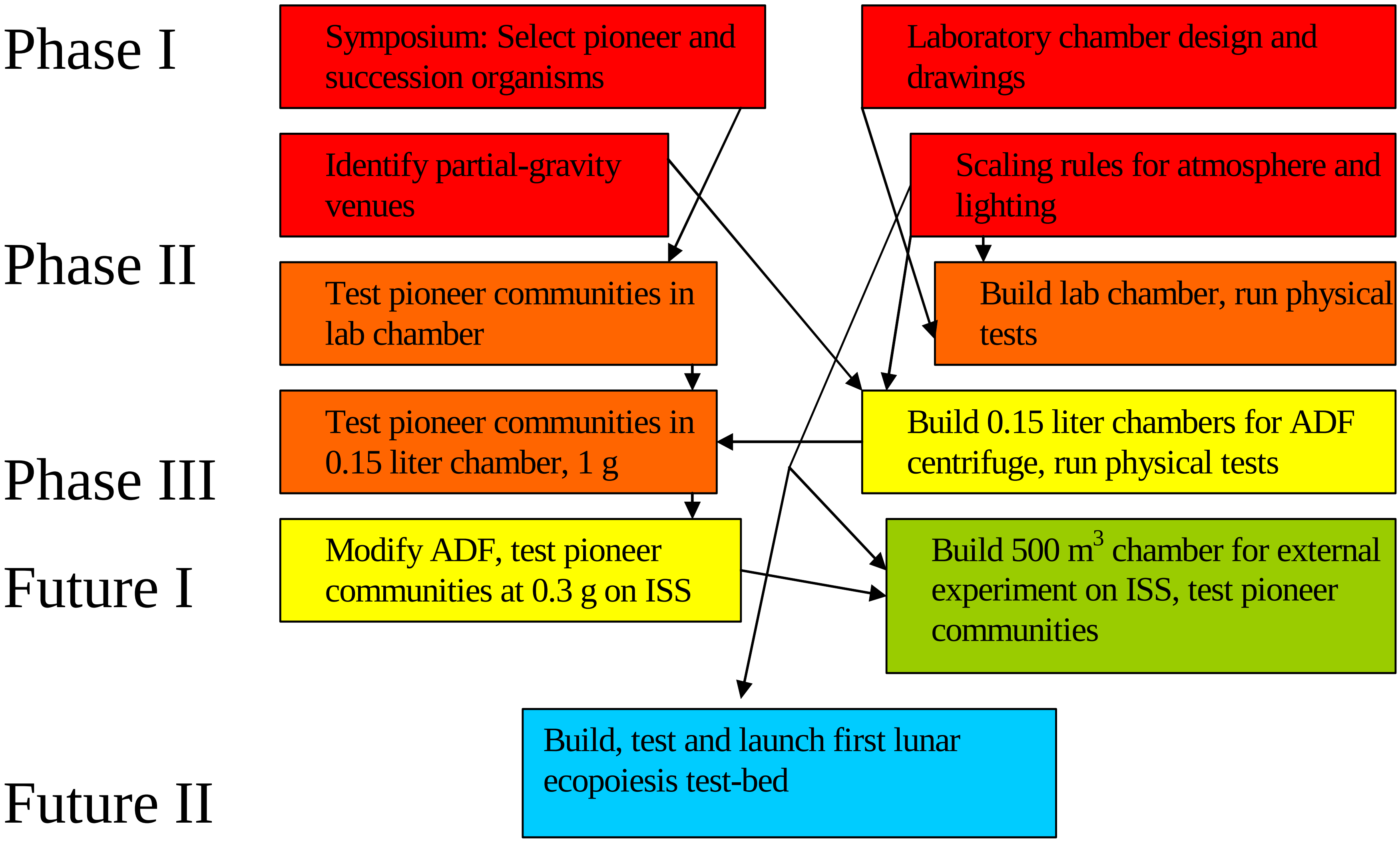


Scale down to modular test bed (MARS-MTB)

- Mars Atmosphere and Regolith Simulator Modular Test Bed (MARS-MTB)
- Scaled to bench top for schools and labs
- Multiple test beds for each recharge station, maximize data acquisition
- Includes sampling ability
- Simulated light spectrum



Flow Chart of Phases



Phase II

- Build lab chamber & perform physical tests
- Test pioneer communities in lab chamber
- Build 0.15 liter chamber and perform physical tests
- Test pioneer communities in 0.15 liter chamber, 1 g
- Plan Phase III design and controls for multiple 0.15 liter chambers at 0.3 g

Phase II Stated Objectives

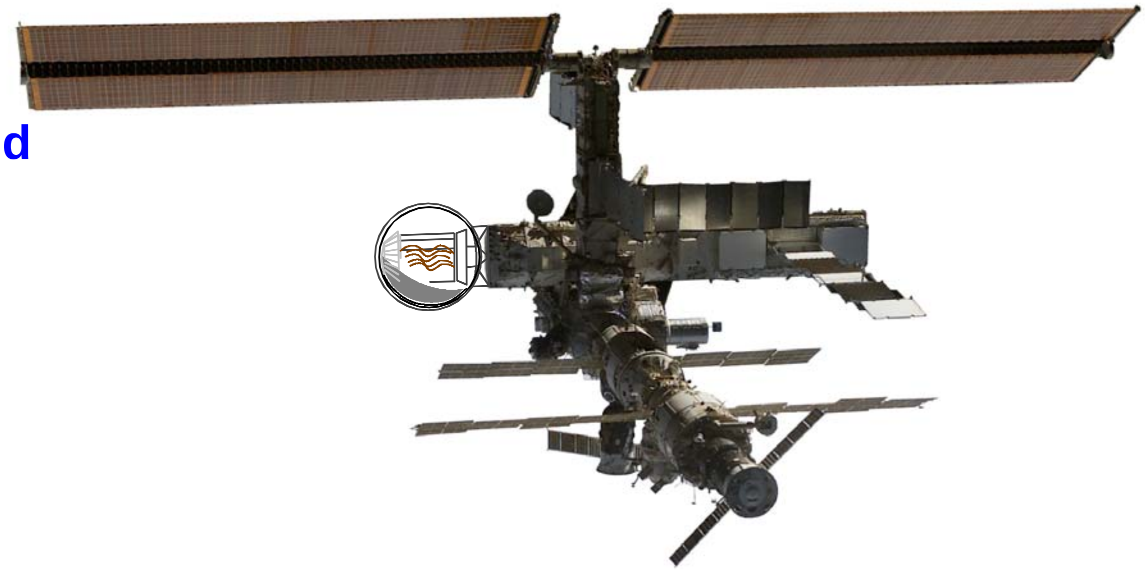
- *Objective 1. Build ecopoiesis chamber for experiments at 1 g, 3 L.*A low-temperature freezer at 1 atm will be built or acquired, and it will contain a transparent low-pressure 10-L chamber based on the design derived from Phase I, objective 2 .
- *Objective 2. Run tests using communities selected in Phase I.* A multi-institutional biological research team will be assembled for the acquisition and preparation of a test community of organisms for inoculation into the "regolith" component of the ecopoiesis chamber built under Phase II objective1.
- *Objective 3. Build ecopoiesis chambers for experiments on ISS, 0.15 L.* Using SHOT's existing variable-gravity space centrifuge technology an array of experiments based on the results of objective 2 will be accommodated in 0.15 L chambers.
- *Objective 4. Run tests at 1 g.* An array of experiments based on the results of Phase II objective 2 will be accommodated on SHOT's test centrifuge in low-volume ecopoiesis chambers built under objective 3 for pre-flight tests.

Phase III

- **Build 0.15 liter chambers for ADF centrifuge & perform physical tests**
- **Build Modified Avian Development Facility (ADF) t include cryogenics and 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**

Future I

- Design and build 500 m^3 inflatable spherical enclosure for external installation on ISS
- Install enclosure on ISS and make physical measurements of light and temperature
- Install Mars/ecopoietic atmosphere and pioneer communities
- Operate for maximum duration in orbit



Future II

- Design and build robotically assembled lunar ecopoiesis test bed
- Perform physical tests at Earth venue
- Perform biological tests with pioneer communities at Earth venue
- Launch to moon and install robotically near lunar south polar cap
- Monitor vapor phase and regolith for several decades, attend as needed

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