Life in the Solar System
Life in the Solar System

1. Study processes that produce current conditions on planets \( (n_e) \)

2. Life elsewhere in Solar System? \( (f_i) \)
## Planet Temperatures

### Factors in Planet temperature:

<table>
<thead>
<tr>
<th>Greenhouse gas?</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂, O₂</td>
</tr>
<tr>
<td>no</td>
</tr>
<tr>
<td>CO₂, H₂O</td>
</tr>
<tr>
<td>yes</td>
</tr>
<tr>
<td>CH₄, CFC’s’</td>
</tr>
<tr>
<td>yes (Life)</td>
</tr>
</tbody>
</table>

### Reflecting Light (Albedo)

- Clouds, Rock, Ice, Snow

### Two extremes:

- Runaway Greenhouse
- Runaway Glaciation
Greenhouse effect

[Diagram showing the greenhouse effect with labels for reflected radiation by atmosphere, infrared radiation reemitted back to earth, reflected radiation by earth surface, infrared radiation emitted by earth, and absorbed radiation.]
<table>
<thead>
<tr>
<th></th>
<th>Venus</th>
<th>Abiotic Earth</th>
<th>Mars</th>
<th>Biotic Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ (%)</td>
<td>96</td>
<td>96</td>
<td>95</td>
<td>0.03</td>
</tr>
<tr>
<td>N₂ (%)</td>
<td>~ 3</td>
<td>~ 3</td>
<td>2.7</td>
<td>79</td>
</tr>
<tr>
<td>O₂ (%)</td>
<td>trace</td>
<td>trace</td>
<td>0.16</td>
<td>21</td>
</tr>
<tr>
<td>H₂O (%)</td>
<td>&lt; 0.1</td>
<td>?</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Pressure (bar)</td>
<td>90</td>
<td>60</td>
<td>0.0061</td>
<td>1.0</td>
</tr>
<tr>
<td>T&lt;sub&gt;avg&lt;/sub&gt; (°C)</td>
<td>477</td>
<td>290 (&gt; 50)</td>
<td>~ –50</td>
<td>15</td>
</tr>
<tr>
<td>T&lt;sub&gt;avg&lt;/sub&gt; (K)</td>
<td>750</td>
<td>563</td>
<td>~ 220</td>
<td>288</td>
</tr>
</tbody>
</table>
Recall from Chap. 3

\[ T = 279K \left( \frac{(1 - A) L}{d^2} \right)^{1/4} \]

Rapid Rotation, Albedo

Apply to Venus, Mars

<table>
<thead>
<tr>
<th></th>
<th>Venus</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>( d )</td>
<td>0.72 AU</td>
<td>1.52 AU</td>
</tr>
<tr>
<td>( A )</td>
<td>0.80 (!)</td>
<td>0.215</td>
</tr>
<tr>
<td>( T_{avg} )</td>
<td>220 (no greenhouse)</td>
<td>213</td>
</tr>
<tr>
<td>( T_{avg} )</td>
<td>750 (actual)</td>
<td>220</td>
</tr>
</tbody>
</table>
Venus: Basic Facts

Sister Planet: $R_\oplus = 0.95 \, R_\oplus$

$\,d_\oplus = 0.72 \, d_\oplus$

BUT HOT!

Clouds: Sulfuric Acid droplets

Radar "Active" surface

Age $< \text{Age of Planet}$

But no large-scale plates
View of Venus from Radar Mapping
Evolution of the Atmosphere

Ultraviolet

H₂O

H

O

Escape

no oceans

CO₂ remained in atm

H₂O higher in atm

Hot!

Thick atm, Greenhouse

Runaway Greenhouse
Mars: Basic Facts

Smaller \( R = 0.53 \, R_\oplus \)
Less Massive \( M = 0.11 \, M_\oplus \)
Less Dense \( \rho = 0.71 \, \rho_\oplus \)

Mars year = 687 Earth days
Mars day = 24.5 Earth hours

Seasons

2 small moons (captured asteroids)
Ancient Volcanoes

Olympus Mons
The largest volcano in the solar system
24 km high
Scarp is 550 km in diameter
Polar Ice Caps

Image from the Hubble Space Telescope during close approach of Earth and Mars.
Thin atmosphere led to Weak Greenhouse

Cold temperature led to freeze-out of greenhouse gases: **Runaway Glaciation**

$T = 175 - 300$ K

Warm enough for liquid $H_2O$ but low pressure

Active in past, but not now: Fossil river beds

Liquid $H_2O$ for $\sim 1 \times 10^9$ y (and perhaps more recently)

Life?

Survive another $0.7 \times 10^9$ y in frozen lakes?

Analogy to antarctic lakes
Antarctica as a model for early Mars

Dry valleys: Mean T = -20 °C
Annual precipitation ~ 2 cm
But T > 0°C for a few days in summer.
Lakes are not frozen solid (though always ice-covered)
Algae & bacteria photosynthesize in lakes
Also lichens in rocks
If life arose on Mars, it might have lasted 1 - 2 ¥ 10⁹ yr
Recently, a large (140 mile ¥ 30 mile) lake
Found ~ 2.5 miles deep in ice near Vostok station
May have been under ice for 500,000 yr
Plans to drill into lake - look for bacteria (but contamination)
Viking Mission

2 spacecraft 1976
1. Chryse Planitia 22° N. Lat
2. Utopia Planitia 48° N

Cameras, ...

Organic Matter Analysis
3 life detection experiments
Sampler arm
Organic Matter Analysis

- Could detect carbon molecules
  - Few/billion if more than 2 Carbons
  - Few/million if 1 or 2
  - 100 to 1000 times less than desert soils
  - Could be left over, brought by asteroids, …

- No organic molecules found
Life Detection Experiments

- All assumed microscopic soil organisms
  - Fairly near surface (shallow trench)
  - Either heterotrophs
    - Feed and look for signs of metabolism
  - Or autotrophs
    - Look for signs of photosynthesis
  - If signs of life, do a control experiment
    - Sterilize first
Gas Exchange Experiment (GEX)

• Most earth-biased
  – Assumed Martians would like chicken soup
  – Pressurized, warmed to 10 C
  – First mode: humidify
    • N$_2$, Argon, CO$_2$, O$_2$ released
    • O$_2$ required chemical reaction
  – Second mode: wet, nutrients
    • Monitor for 6 months, no further activity
• No sign of metabolizing, earth-like life
Gas Exchange Experiment

-Looks for metabolism
-Detects gaseous products
-Using gas chromatograph
Labeled Release Experiment

• Assumed metabolizing Martians
  – But less Earth like
  – Simpler mix of nutrients, labeled with $^{14}\text{C}$
  – Metabolizing organisms produce $^{14}\text{CO}_2$
  – Very sensitive to small amounts
• Results: immediate release of $^{14}\text{CO}_2$
  – No further release when more added
• Chemical, not biological, reaction suspected
Labeled Release

- Looks for metabolism
- Nutrients labeled with $^{14}$C
Pyrolytic Release Experiment (PR)

- Assumed photosynthesizing autotrophs
  - Adapted to Mars
  - Supply light, Martian atmosphere
  - But label with $^{14}\text{CO}_2$ and $^{14}\text{CO}$
    - After incubation, remove gases
    - Burn up (pyrolyze)
    - Look for $^{14}\text{CO}_2$ from burned-up Martians
  - Interesting Results
Pyrolytic Release

- Looks for autotrophs
- Supplies gases
- Labeled with $^{14}\text{CO}_2$
Pyrolytic Release Results

• First experiment gave positive result
  – Could be about 100 to 1000 bacteria
    • Could have escaped detection with GCMS
  – Repeat with sterilized sample (175 C, 3 days)
    • Reaction reduced, but not eliminated
  – Further controls, lower T sterilization
    • Little change in results
• Conclusion: most likely a chemical reaction
Summary of Viking Results

No organic molecules found

Some apparent activity in pyrolytic release expt.

Could be photosynthesis by 100 - 1000 bacteria
They could have escaped detection by organic matter analysis
But, sterilized controls did same thing

chemical, not biological, reaction
Surface is strongly oxidizing (UV)

- Organic matter would be destroyed
- Experiments not designed for this
- Oxygen rich compounds on surface can react like life

To find current Martians (or fossil Martians)....

Dig Deeper!

And remember that your experiments determine what you can find...
More Recent Mars Missions

- Pathfinder/Sojourner  1997
- Global Surveyor 1998
- Mars Odyssey 2002
- Mars Express (ESA) 2003  
  - Beagle crashed (life detection)
- Mars Rovers 2004  
  - Spirit and Opportunity
Pathfinder & Sojourner

See
http://mars.sdsc.edu/index.html
http://mars.jpl.nasa.gov/default.html

Close up photos, analysis of rocks
More evidence of past water flow
Has “movies” of rover’s journey
Global Surveyor

Mars Global Surveyor
http://mars.sdsc.edu/mgs/index.html
1998 - in orbit around Mars
The “Face” on Mars gets erased

Viking  Surveyor
Global Surveyor

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And with Mars Odyssey

Viking
Surveyor
Global Surveyor Results

Located areas of floods within last few million years (few impact craters)

Apparently from underground
Out through volcanic fissures

Like a geyser - suspect large aquifer a couple of miles below surface

Or maybe snow

(Feb. 2003)
Mars Odyssey Website
Mars Odyssey Results

Mapping from Orbit
Gamma ray spectrometer
Cosmic rays excite nuclei on surface to emit Gamma rays

Wavelength of gamma rays characteristic of element

Also neutron detector
Can detect hydrogen (stand in for H$_2$O) in top meter
Evidence indicates substantial H$_2$O near south pole
Mars Odyssey

Nuclear Radiation from a Planetary Surface

- Thermal and epithermal neutrons
- Fast neutron
- Cosmic ray
- Inelastic collision
- Neutron capture
- Gamma (γ) rays
- Natural radioactivity
- Th (Thorium)
2001 Mars Odyssey Water Map
Mars Odyssey
Mars Express

- Walls of Candor Chasma
- Part of Valles Marineris
- Appears to be erosion
- Liquid water?
Mars Express

- Branching channels
- More evidence of water?
Mars Rovers

• Two Landers (Spirit and Opportunity)
• Both rovers that have explored 3 to 5 km
• Can dust rock, drill into it, analyze dust, rock
• Still going in March 2005
  – (longer than expected)
• http://marsrovers.jpl.nasa.gov/home/index.html
Travels on Mars: Spirit
Travels on Mars: Opportunity
Panorama from Spirit

Looking back at tracks. Taken May 2004
More evidence of water

Picture from Opportunity
Beads of hematite
Called “blueberries”
Eroding out of rock
Usually form in liquid water
This implies standing water at this site.
Meteorites from Mars

- Easy way to get pieces of Mars to study
- Asteroid impact on Mars knocks off pieces
- Some land on Earth
- Antarctic ice is good place to find meteorites
- [http://www2.jpl.nasa.gov/snc/](http://www2.jpl.nasa.gov/snc/)
- Evidence for Life?
Martian Meteorites

Antarctic ice fields are a good place to look for meteorites in general
e.g. Allan Hills Region (AH)

1.9 kg (softball-sized) found in 1984
[AIH 84001]

A few meteorites (~12) are so similar to Mars Minerals & isotope ratios, that they are assumed
to come from Mars
1994 AH84001 joined the Mars club

History: formed from magma ~ 4.5 \( \times \) 10^9 yr ago
Fractured by meteorite impact
Carbonate globules, … in cracks ~ 3.6 \( \times \) 10^9 yr ago
Blasted off Mars by impact \( 17 \ \times \) 10^6 yr ago
Fell to Earth \( 13 \ \times \) 10^3 yr ago

So, known to be from Mars before issue of life arose
Martian meteorite found in LA county in 1999
245 gm
Signs of Life?


Found in fractures - $\sim 3.6 \times 10^6$ yrs old 
When water existed

1. PAHs - can be produced by breakdown of biological tissues
   Contamination from Antarctic Ice?
   Different mixture of PAHs
   Not necessarily biological - also found in space, interplanetary dust, other meteorites, ...
   Associated with carbonate globules
2. Carbonate Globules (50 μm across)  
cores of manganese & rings of iron carbonate  
and iron sulfide  
similar to globules associated with bacterial  
action in liquid on Earth  
Can form without bacteria on Earth  
Associated with tiny magnetite grains  
(magnetic iron oxides)  
Dispute about temperature at which globules  
formed
Carbonate globules

Evidence of liquid water formation temperature is disputed
3. Magnetite Grains 100 nanometers (nm)  
   \((100 \times 10^{-9} \text{ m} = 0.1 \text{ µm})\)  
   Shapes similar to crystals produced by bacteria on Earth  
   Other shapes seen by other workers  
   Whisker shapes → formation in hot fumaroles  

4. Fossilized Bacteria?  
   With scanning electron microscope, see  
   bacteria-like shapes (20 - 100 nm long) similar to those seen in Earth rocks near hot springs (R. Folk - UT Austin) → nanobacteria  
   \(~10 - 100 \µ\text{m}\) smaller than normal bacteria  
   Are these artifacts of process used by microscope (gold coating)?  
   Need to section and look for membrane - very difficult
Martians??
Recent Developments

1. Several studies support lower temperature for carbonate globule formation - consistent with life

2. Folk finds similar shapes in Allende meteorite (not from Mars)

3. Conference at Johnson Space Center in Houston
4. Bada et al., 1998, Science 279, 362 Found amino acids, suggestive of terrestrial contamination
5. Many more meteorites from Mars being found.
Future Missions

• Mars Reconnaissance Orbiter
  – Launch Aug. 2005
• Venus Express Orbiter
  – Launch Nov. 2005
• Planet-C (Japan) Venus Orbiter
  – Launch 2007
• Mars Scientific Laboratory (rover)
  – Launch 2009