Life in the Inner Solar System
Life in the Solar System

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

2. Life elsewhere in Solar System? \( (f_c) \)
Greenhouse effect
Planet Temperatures

Factors in Planet temperature:
Greenhouse gas?

- $N_2$, $O_2$: no
- $CO_2$, $H_2O$: yes
- $CH_4$, CFC’s: yes (Life)

Reflecting Light (Albedo)
Clouds, Rock, Ice, Snow

Two extremes:
Runaway Greenhouse
Runaway Glaciation
Terrestrial Planet Atmospheres

<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>
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<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>
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<tr>
<td>Pressure (bar)</td>
<td>90</td>
<td>60</td>
<td>0.0061</td>
<td>1.0</td>
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<tr>
<td>T avg (℃)</td>
<td>477</td>
<td>290</td>
<td>~ –50</td>
<td>15</td>
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<tr>
<td>T avg (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

Venus
\[
\begin{align*}
&d = 0.72 \text{ AU} \\
&A = 0.80 (!) \\
&T_{\text{avg}} = 220 \text{ (no greenhouse)}
\end{align*}
\]

Mars
\[
\begin{align*}
&d = 1.52 \text{ AU} \\
&A = 0.215 \\
&T_{\text{avg}} = 213 \text{ (actual)}
\end{align*}
\]
Venus: Basic Facts

Sister Planet: \[ R_{\oplus} = 0.95 \ R_{\odot} \]
\[ d_{\oplus} = 0.72 \ d_{\odot} \]

BUT HOT!

Clouds: Sulfuric Acid droplets

Radar “Active” surface

Age < Age of Planet

But no large-scale plates
Evolution of the Atmosphere

Ultraviolet \(\Rightarrow\) no oceans

\[d_\oplus < d_\odot \Rightarrow H_2O \text{ higher in atm}\]

\(\Rightarrow\) CO\(_2\) remained in atm

\(\Rightarrow\) no oceans

\(\Rightarrow\) Thick atm, Greenhouse

Hot! \(\Leftarrow\) Runaway Greenhouse

Example of positive feedback
Mars: Basic Facts

Smaller $R_\oplus = 0.53 \, R_⊕$
Less Massive $M_\oplus = 0.11 \, M_⊕$
Less Dense $\rho_\oplus = 0.71 \, \rho_⊕$

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

Seasons

2 small moons (captured asteroids)
Mars

Image from the Hubble Space Telescope during close approach of Earth and Mars. Shows polar ice caps.
Ancient Volcanoes

Olympus Mons
The largest volcano in the solar system
24 km high
Scarp is 550 km in diameter
Runaway Glaciation (also positive feedback)

Thin atmosphere led to Weak Greenhouse
Cold temperature led to freeze-out of greenhouse gases
Temperature range now: $T = 175 - 300$ K
Some places warm enough for liquid H$_2$O
but pressure is too low

Active in past, but not now: Fossil river beds

Liquid H$_2$O for $\sim 1 \times 10^9$ yr (and perhaps more recently)

Life?
Survive another $0.7 \times 10^9$ yr 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
Were there similar situations on Mars?
If life arose on Mars, it might have lasted $1 - 2 \times 10^9$ yr
Viking Mission

Two spacecraft, launched in 1976
1. Chryse Planitia 22º N. Lat
2. Utopia Planitia 48º N

Cameras, …

Organic Matter Analysis
3 life detection experiments
Sampler arm
View from Viking
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 $^{14}\text{C}$
Pyrolytic Release Experiment (PR)

- Assumed photosynthesizing autotrophs
  - Adapted to Mars
  - Supply light, Martian atmosphere
  - But label with $^{14}$CO$_2$ and $^{14}$CO
    - After incubation, remove gases
    - Burn up (pyrolyze)
    - Look for $^{14}$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: subsurface water
- Mars Express (ESA) 2003: evidence of past water
  - Beagle crashed (life detection)
- Mars Rovers 2004
  - Spirit and Opportunity
- Phoenix (NASA) landed in 2008
- Curiosity Rover landed in 2012
2001 Mars Odyssey Water Map
Mars Odyssey

Late Southern Summer

Epithermal Neutrons

H₂O-Rich to H₂O-Poor
Mars Express

- Walls of Candor Chasma
- Part of Valles Marineris
- Appears to be erosion
- Branching channels
- Signs of water
Mars Rovers

- Two Landers (Spirit and Opportunity)
- Can dust rock, drill into it, analyze dust, rock
- Spirit did not revive after Mars winter in 2010
- Opportunity still going in February 2015
  - (much longer than expected)
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.
Phoenix Lander

• Phoenix (NASA)
    • Winter, less sunlight, loss of solar power
    • Dug trenches, did chemical analysis
    • Some problems, soil was sticky
    • Clearly there was ice in the soil
Phoenix sees frost on Mars
Curiosity Rover

• Most ambitious yet (landed 2012)
  – In Gale Crater
  – Drill, sampling arm, many analysis tools
  – So far, has focused on drilling into rocks
  – Found location quite “habitable” in past
  – “Yellowknife Bay” in Gale crater
  – Dec. 2014 spike in methane
Artist’s Conception of Curiosity on Mars
Curiosity finds evidence of 20% clay material in mudstone in ancient stream bed: fresh water, not too acidic, suitable for origin of life
Organic Molecules in Mudstone

- Fairly complex organic (C-based) molecules found in mudstone samples
  - Some worries about contamination
  - Could show that conditions were suitable for life – or that these come from Mars life
- Also found “fixed” nitrogen (not in $N_2$)
  - Done by microbes on Earth
  - But could be asteroid impact on Mars
  - Habitability enhanced

Science, 347, 1402 (2015)
ExoMars

• ESA and Russia
• 2016 Launch
  – Orbiter to monitor atmospheric gases
    • Especially methane
  – Select landing site for Rover
  – Fixed lander
• 2018 Launch of Rover
  • http://exploration.esa.int/mars/48088-mission-overview/
Meteorites from Mars

- Easy way to get pieces of Mars to study
- Asteroid impact on Mars knocks off pieces
- Some land on Earth
- 132 known to be from Mars
- Antarctic ice is good place to find meteorites
- [http://www2.jpl.nasa.gov/snc/](http://www2.jpl.nasa.gov/snc/)
Martian meteorite found in LA county in 1999

245 gm
AIH 84001

1.9 kg (softball-sized) found in 1984 in Allan Hills Region (AIH)
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 $\sim 4.5 \times 10^9$ yr ago
Fractured by meteorite impact
Carbonate globules, … in cracks $\sim 3.6 \times 10^9$ 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
Signs of Life?


Found in fractures -  \( \sim 3.6 \times 10^9 \) 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
Martian Life in ALH84001?

- PAHs (break down from life or abiogenic?)
- Carbonate globules (form in liquid water)
- Magnetite grains (on Earth, associated with microbes)
- Structures that look like “nano-bacteria”
  - 10 to 100 times smaller than bacteria
- Nano-bacteria controversial even on Earth
- Hot springs deposits: life or minerals?
Carbonate globules

Evidence of liquid water formation temperature is disputed
Martians??
Water-rich Martian Meteorite

- NWA 7034 (Northwest Africa)
  - Bought in 2011 from Moroccan dealer
  - Unlike other Martian meteorites, but…
  - Very similar to rocks in Gusev crater
  - Where Curiosity is roving
  - From a pyroclastic (volcanic) flow
  - 0.6 percent water
  - May be sample of permafrost or early ocean
  - From 2 Gyr ago.
Summary

• Deeper understanding of greenhouse effects
• Venus too close to Sun to keep water
  – Runaway greenhouse
• Mars too far from Sun (and too small)
  – Lost too much gas, runaway glaciation
  – Still interesting, liquid water in past
  – Subsurface water now
  – No life found by Viking, but dig deeper…