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_ℓ)

Planet Temperatures

Factors in Planet temperature:

Greenhouse gas?

N_2, O_2	CO_2, H_2O	CH_4, CFC's
no	yes	yes (Life)

Reflecting Light (Albedo)

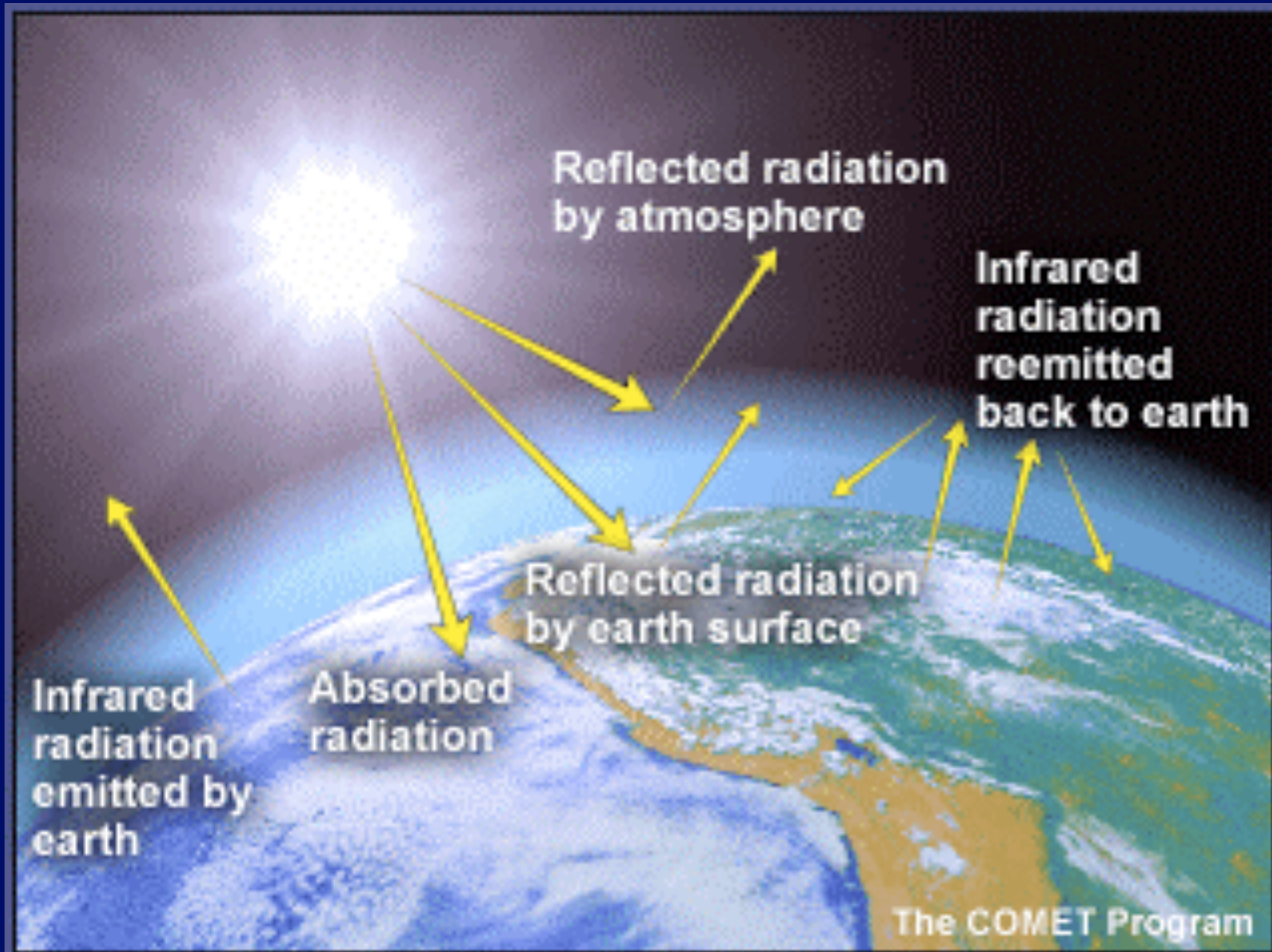
Clouds, Rock, Ice, Snow

Two extremes:

Runaway Greenhouse

Runaway Glaciation

Greenhouse effect



Terrestrial Planet Atmospheres

	Venus	Abiotic Earth	Mars	Biotic Earth
CO_2 (%)	96	96	95	0.03
N_2 (%)	~ 3	~ 3	2.7	79
O_2 (%)	trace	trace	0.16	21
H_2O (%)	< 0.1	?	--	
Pressure (bar)	90	60	0.0061	1.0
T_{avg} (ºC)	477	290	~ –50	15
T_{avg} (K)	750	563	~ 220	288

Recall from Chap. 3

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

Rapid Rotation, Albedo

Apply to Venus, Mars

	Venus	Mars
d	0.72 AU	1.52 AU
A	0.80 (!)	0.215
T_{avg} (no greenhouse)	220	213
T_{avg} (actual)	750	220

♀ Venus: Basic Facts

Sister Planet: $R_♀ = 0.95 \ R_⊕$

$d_♀ = 0.72 \ d_⊕$

BUT HOT!

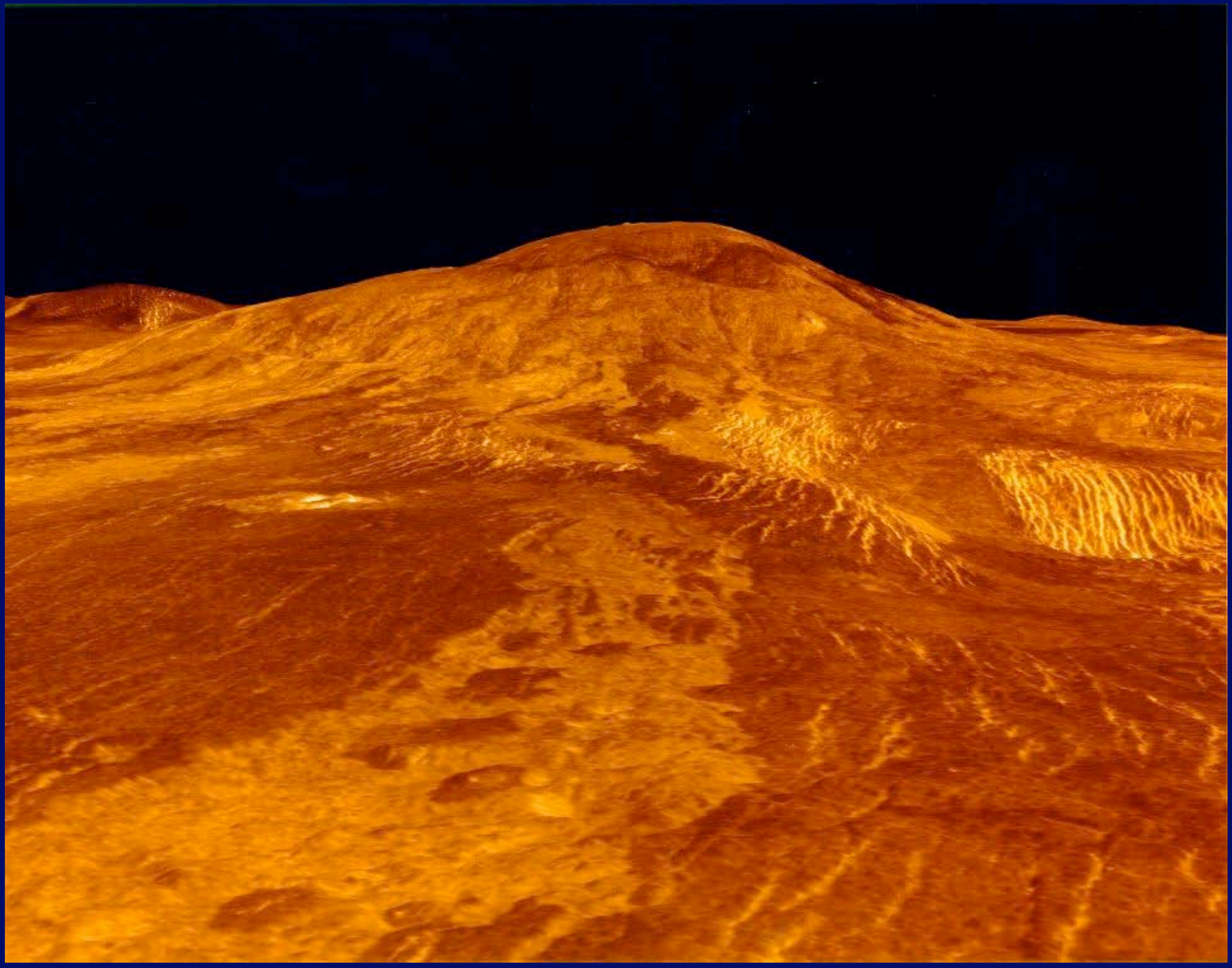
Clouds: Sulfuric Acid droplets

Radar "Active" surface

Age < Age of Planet

But no large-scale plates

View of Venus from Radar Mapping



Evolution of the Atmosphere

Escape

H

Ultraviolet

$\Rightarrow$ no oceans

O

H_2O

$\Downarrow$

CO_2 remained in atm

$d_{♀} < d_{\oplus} \Rightarrow H_2O$ higher in atm

$\Downarrow$

Hot! $\Leftarrow$ Thick atm, Greenhouse

Runaway Greenhouse

Example of positive feedback

Mars: Basic Facts

Smaller $R_{♂} = 0.53\ R_{\oplus}$

Less Massive $M_{♂} = 0.11\ M_{\oplus}$

Less Dense $\rho_{♂} = 0.71\ \rho_{\oplus}$

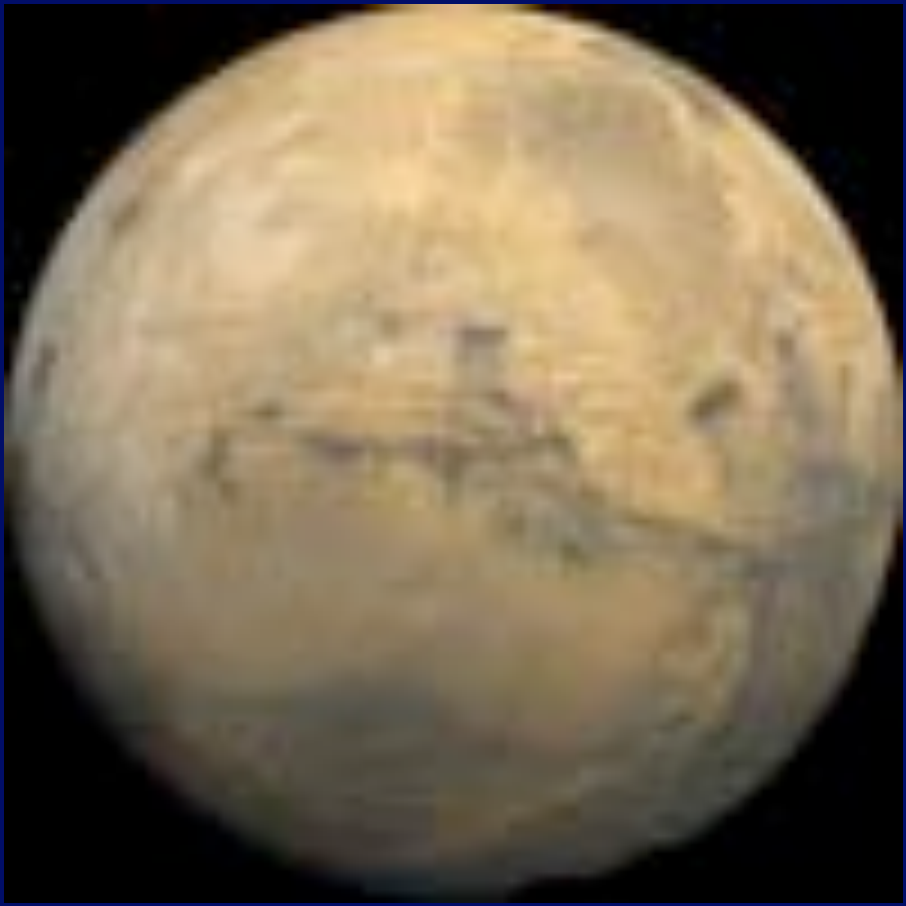
Mars year = 687 Earth days

Mars day = 24.5 Earth hours

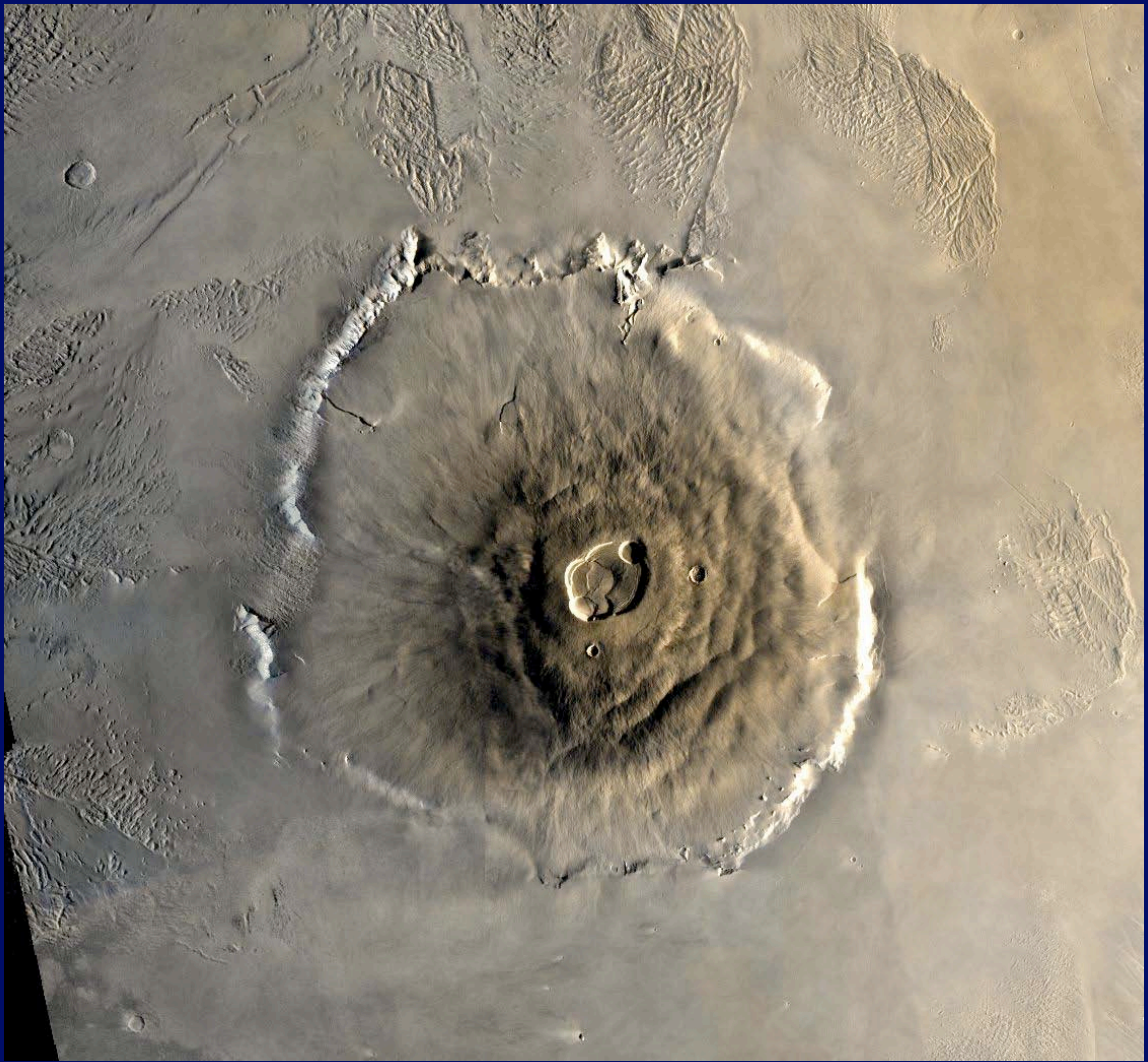
Seasons

2 small moons (captured asteroids)

Mars



Ancient Volcanoes



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

Polar Ice Caps

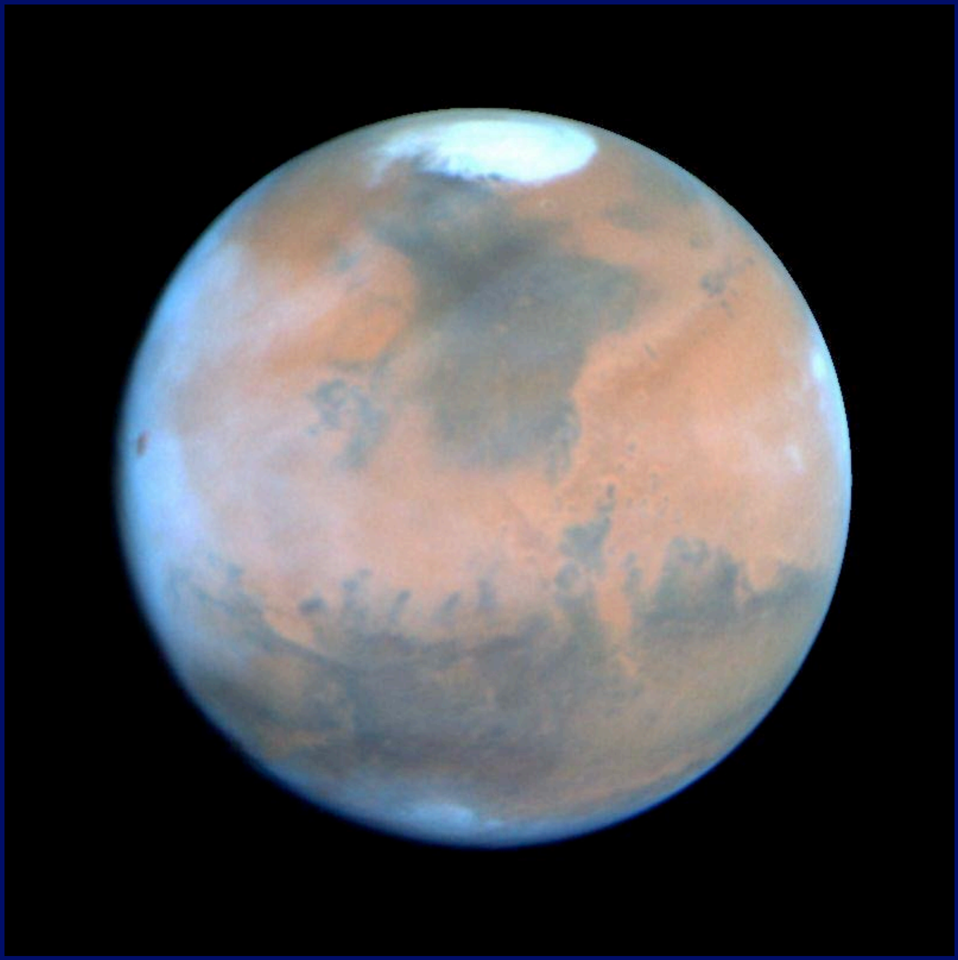


Image from the Hubble Space Telescope during close approach of Earth and Mars.

Runaway Glaciation (also positive feedback)

Thin atmosphere led to Weak Greenhouse

Cold temperature led to freeze-out of greenhouse gases: 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 0.7×10^9 y in frozen lakes?

Analogy to antarctic lakes

Antarctica as a model for early Mars

Dry valleys: Mean T = -20 ºC

Annual precipitation ~ 2 cm

But T > 0ºC for a few days in summer.

$\Rightarrow$ 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 $\times$ 10^9 yr

Recently, a large (140 mile $\times$ 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 22º N. Lat
2. Utopia Planitia 48º 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

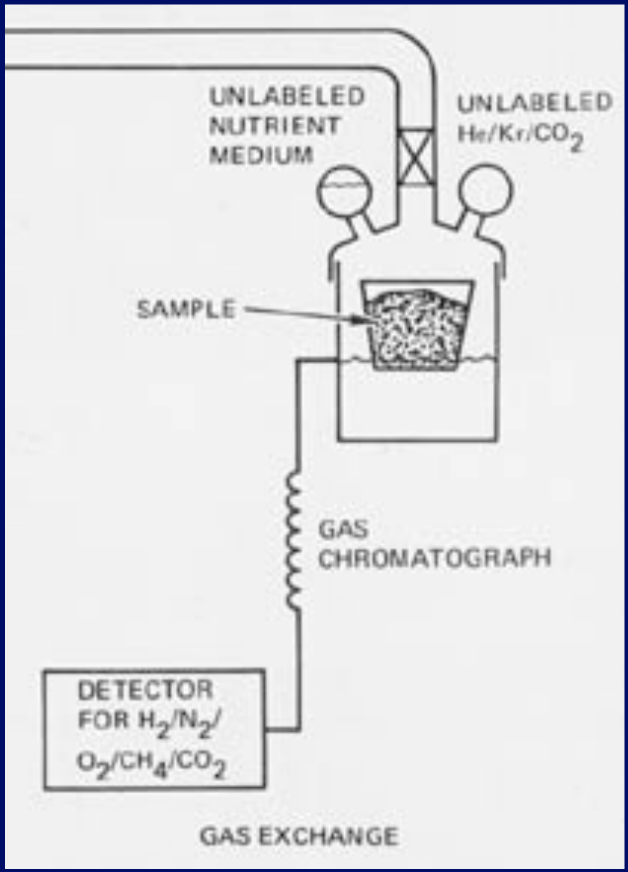
Life Detection Experiments

- 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

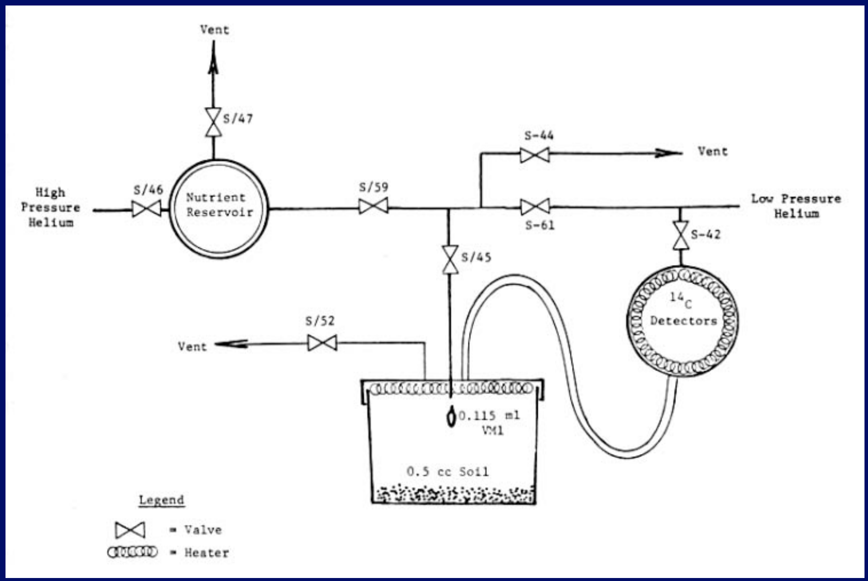


- Looks for metabolism
- Detects gaseous products
- Using gas chromatograph

Labeled Release Experiment

- Assumed metabolizing Martians
  - But less Earth like
  - Simpler mix of nutrients, labeled with ^{14}C
  - Metabolizing organisms produce $^{14}CO_2$
  - Very sensitive to small amounts
- Results: immediate release of $^{14}CO_2$
  - No further release when more added
- Chemical, not biological, reaction suspected

Labeled Release

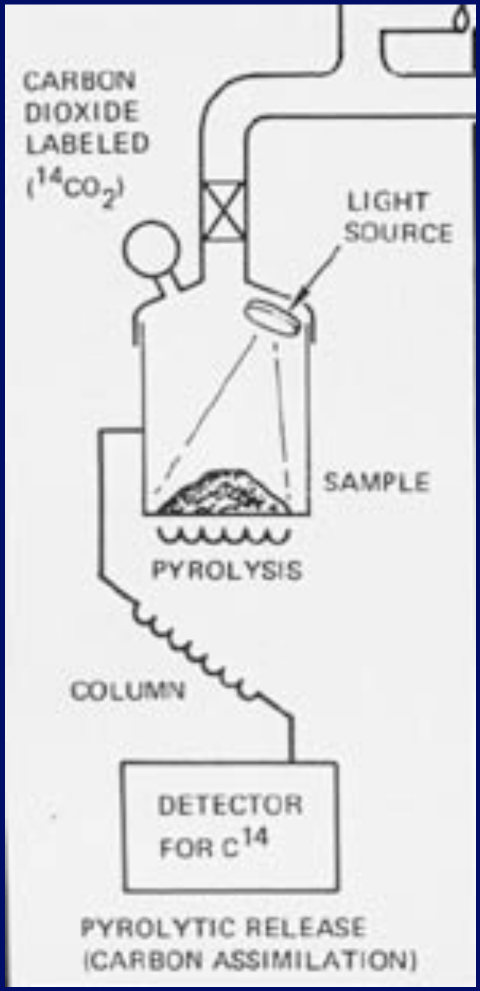


- Looks for metabolism
- Nutrients labeled with ^{14}C

Pyrolytic Release Experiment (PR)

- Assumed photosynthesizing autotrophs
  - Adapted to Mars
  - Supply light, Martian atmosphere
  - But label with $^{14}CO_2$ and ^{14}CO
    - After incubation, remove gases
    - Burn up (pyrolize)
    - Look for $^{14}CO_2$ from burned-up Martians
  - Interesting Results

Pyrolytic Release



- Looks for autotrophs
- Supplies gases
- Labeled with $^{14}CO_2$

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
$\Rightarrow$ 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…

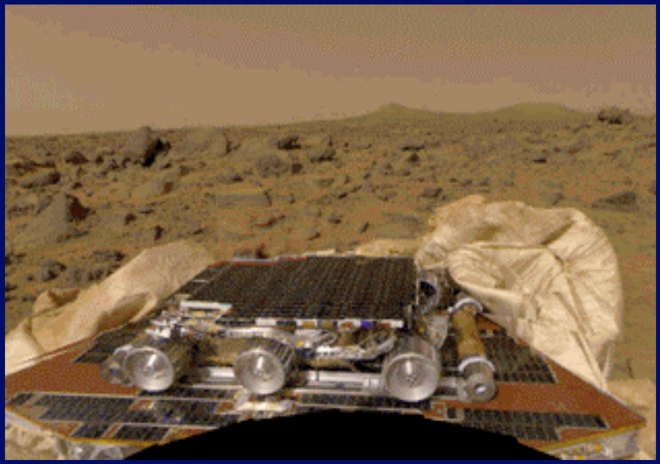
More Recent Mars Missions

- 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



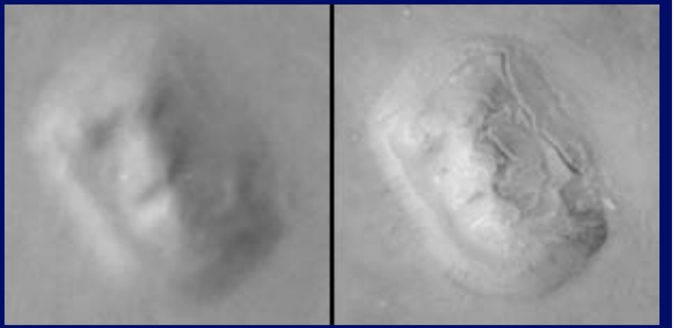
Global Surveyor

Mars Global Surveyor

http://mars.sdsc.edu/mgs/index.html

1998 - in orbit around Mars

The “Face” on Mars gets erased



Viking Surveyor

And with Mars Odyssey

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

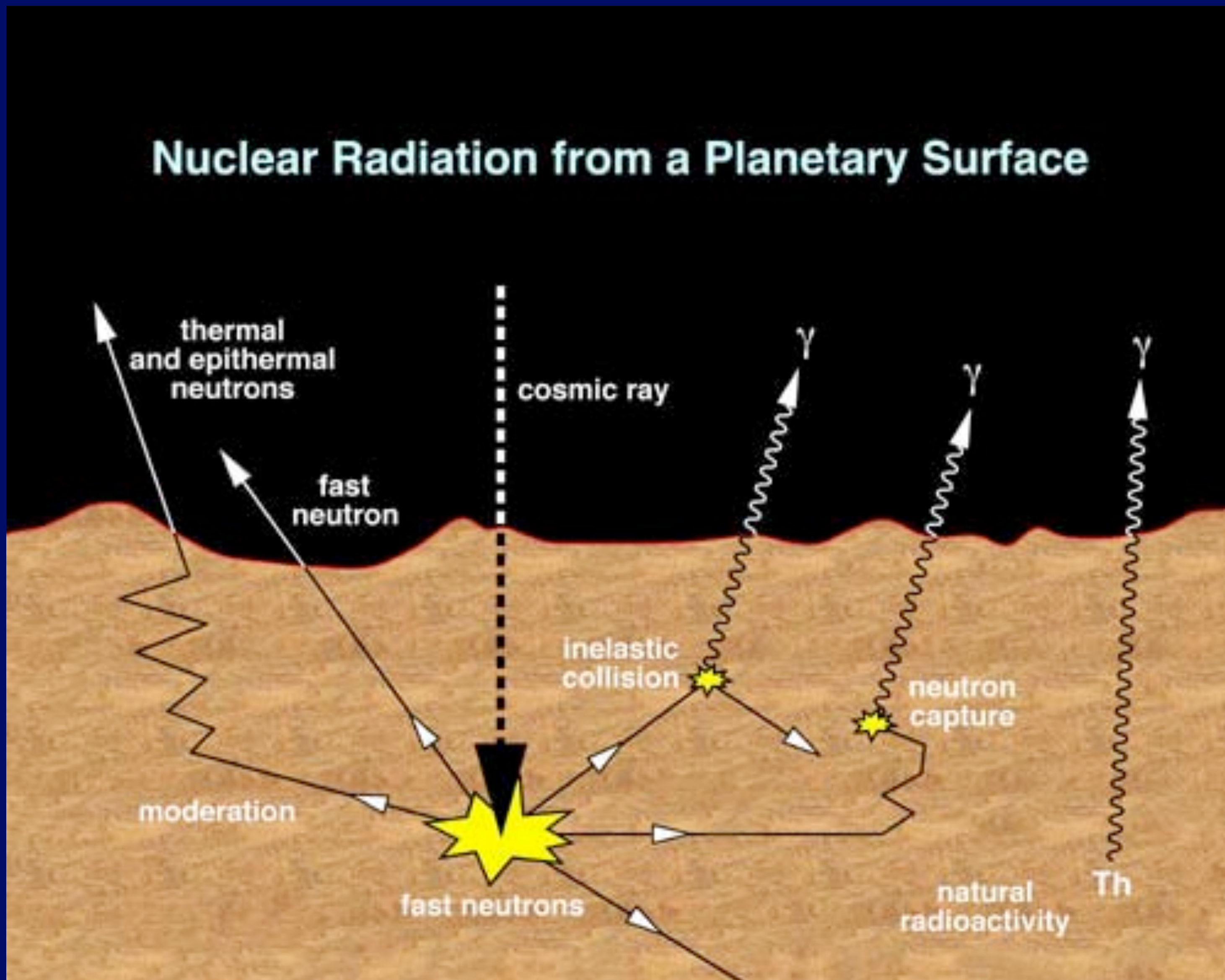
Mars Odyssey Results

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

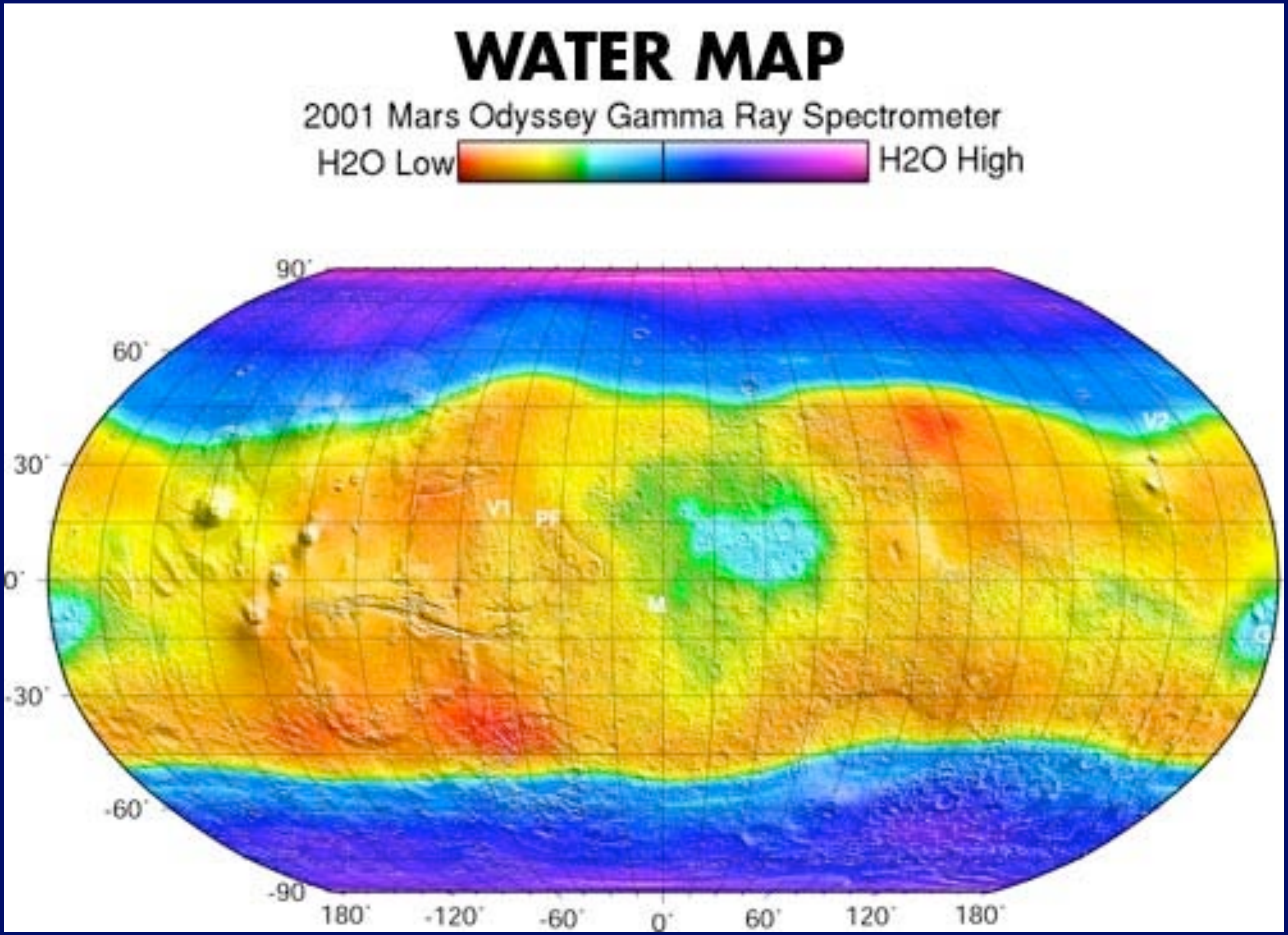
Wavelength of gamma rays characteristic of element

Also neutron detector
Can detect hydrogen (stand in for H_2O) in top meter
Evidence indicates substantial H_2O near south pole

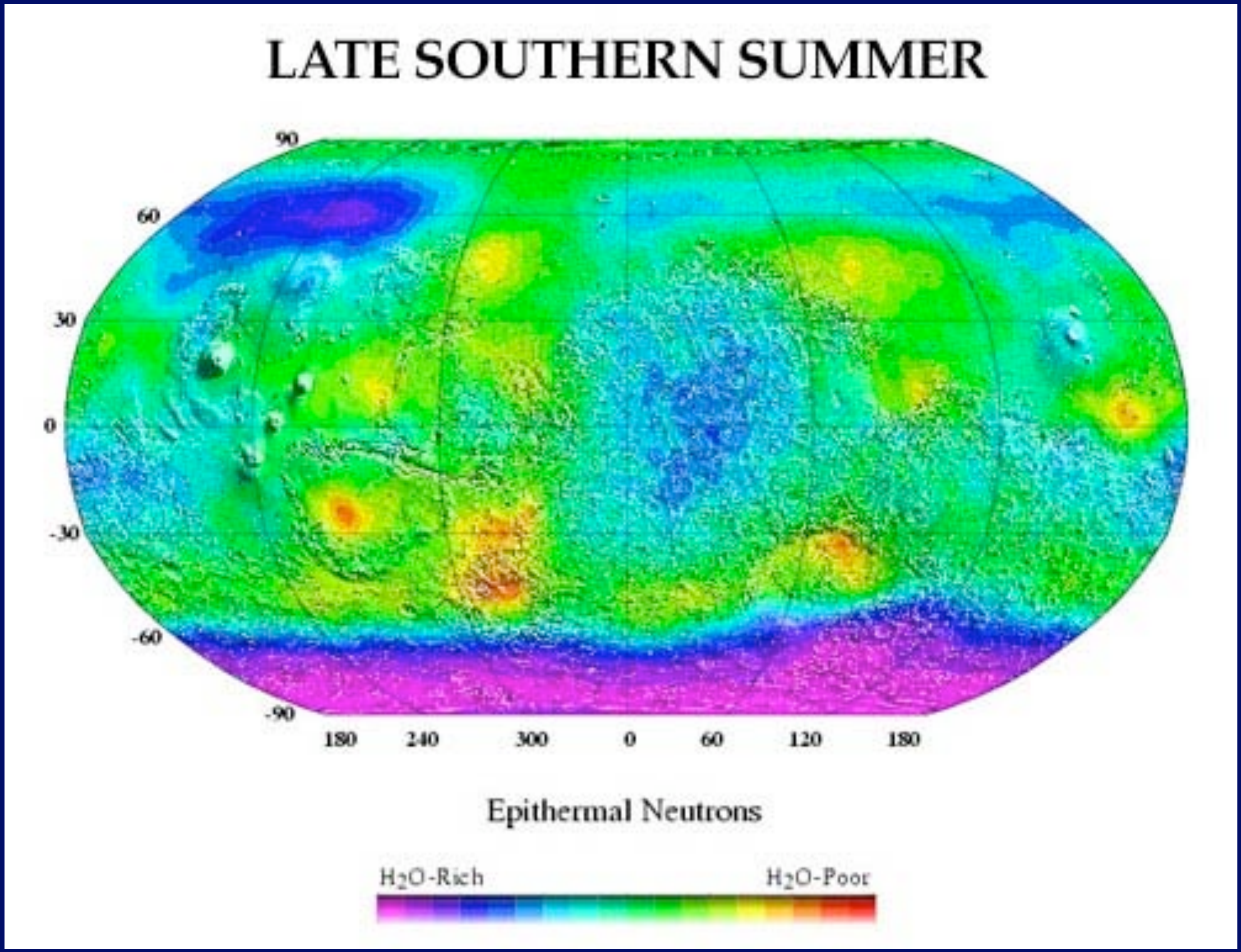
Mars Odyssey



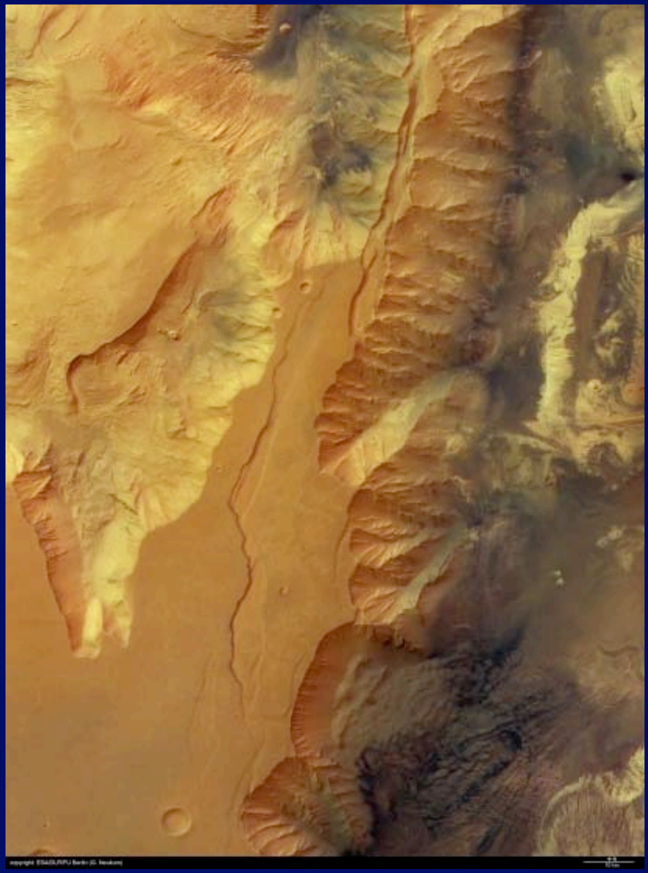
2001 Mars Odyssey Water Map



Mars Odyssey



Mars Express



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

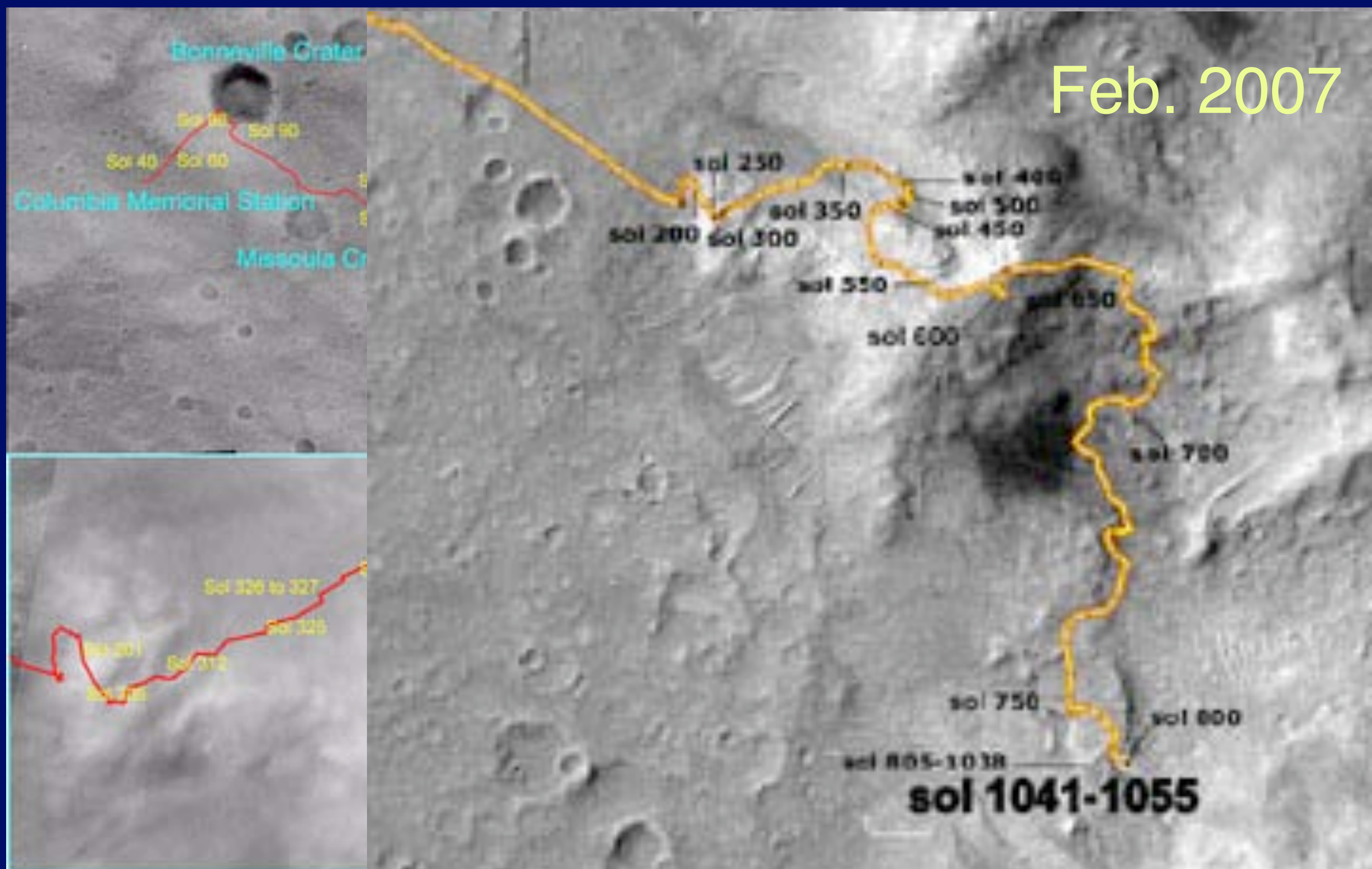
Mars Express

- Branching channels
- More evidence of water?

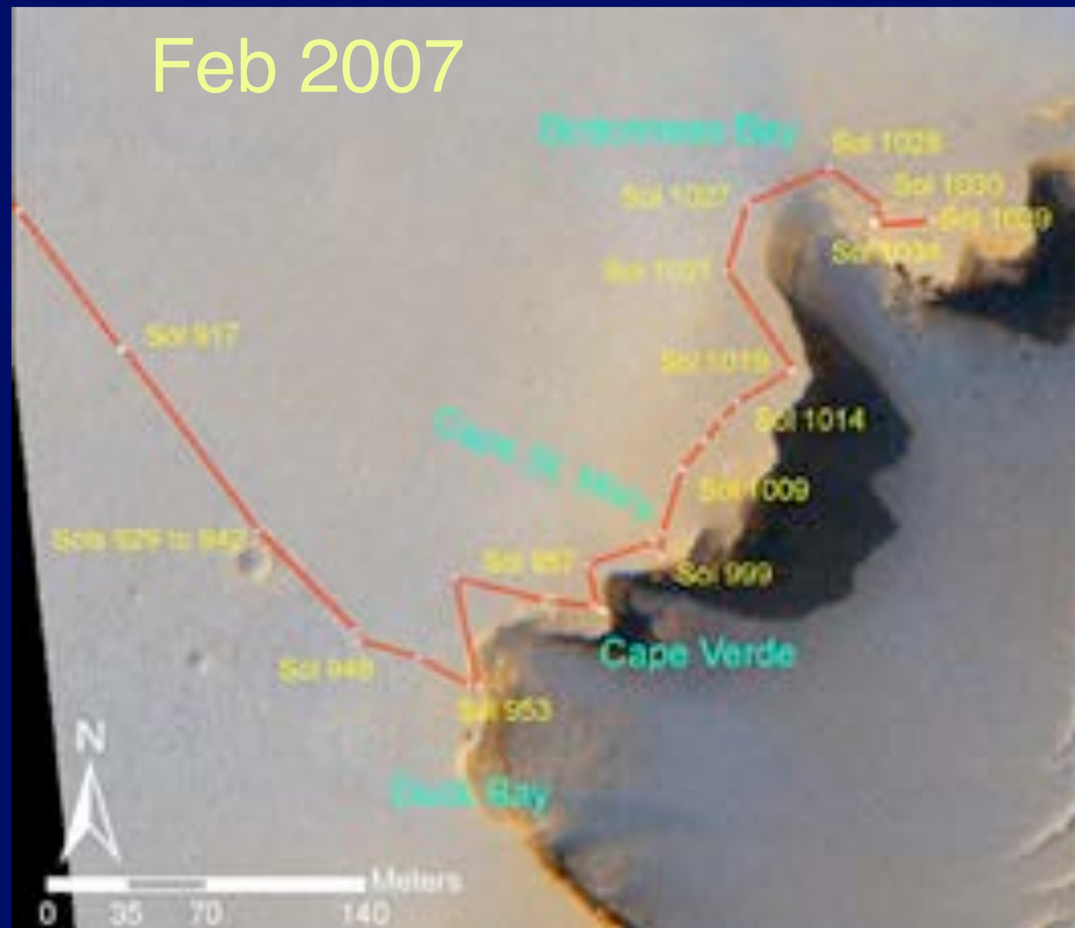
Mars Rovers

- Two Landers (Spirit and Opportunity)
- Both rovers that have explored 5 to 10 km
- Can dust rock, drill into it, analyze dust, rock
- Still going in February 2007
  - (**much** longer than expected)
- http://marsrovers.jpl.nasa.gov/home/index.html

Travels on Mars: Spirit



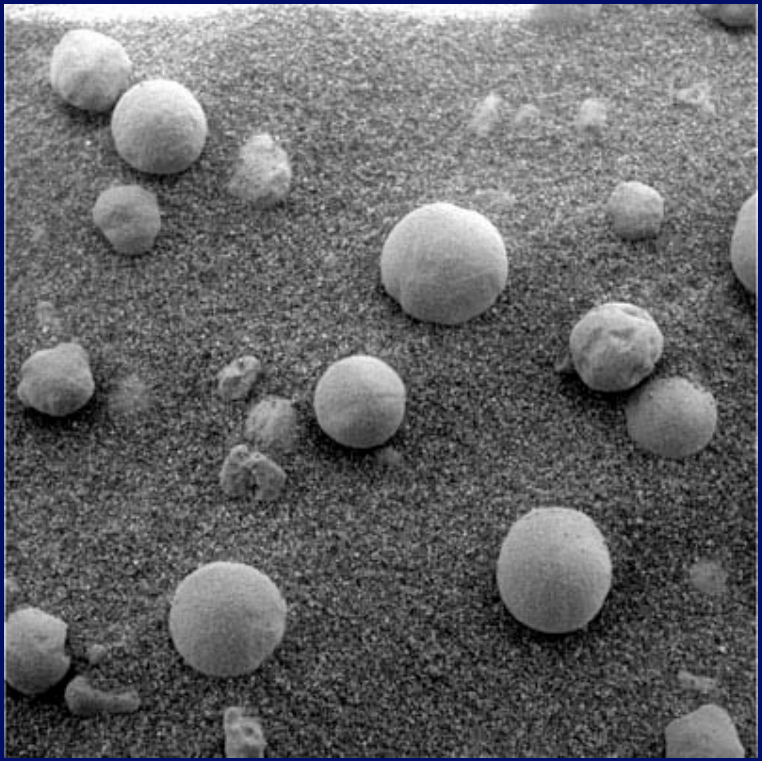
Travels on Mars: Opportunity



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/

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
[AlH 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 ~ 4.5×10^9 yr ago
Fractured by meteorite impact
Carbonate globules, … in cracks ~ 3.6×10^9 yr ago
Blasted off Mars by impact 17×10^6 yr ago
Fell to Earth 13×10^3 yr ago

So, known to be from Mars before issue of life arose

Los Angeles 2002

Martian meteorite found in LA county in 1999

245 gm

Signs of Life?

McKay et al., *Science*, **273**, 924 (Aug. 16, 1996)

Found in fractures - ~ 3.6×10^9 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

2. Carbonate Globules (50 μm across)

cores of manganese & rings of iron carbonate and iron sulfide

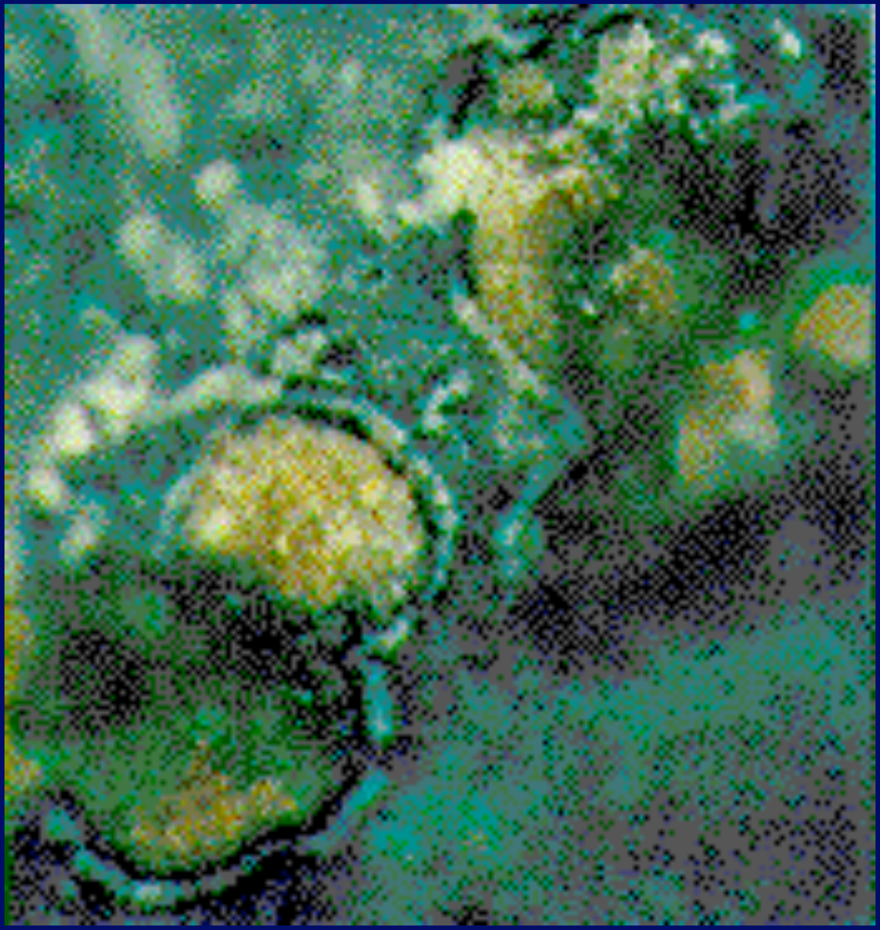
similar to globules associated with bacterial action in liquid on Earth

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)

(100×10^{-9} m = 0.1 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

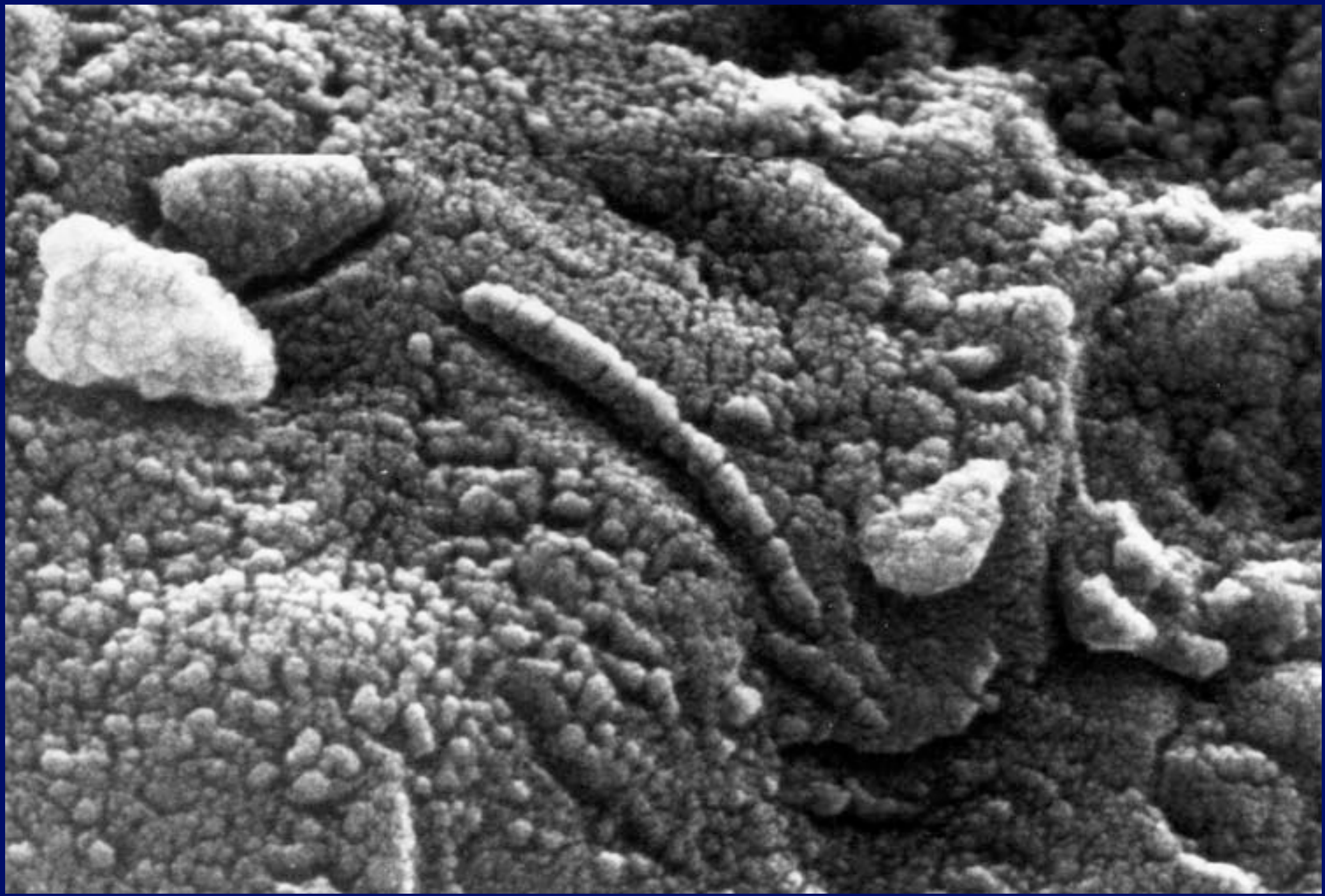
bacteria-like shapes (20 - 100 nm long) similar to those seen in Earth rocks near hot springs (R. Folk - UT Austin) ⟶ nanobacteria

~ 10 - 100 × smaller than normal bacteria

Are these artifacts of process used by microscope (gold coating)?

Need to section and look for membrane - very difficult

Martians??



Later Developments

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

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

3. Conference at Johnson Space Center in Houston
   4/24 - 4/27 1997 & March 1998

4. Bada et al., 1998, Science **279**, 362 Found amino acids, suggestive of terrestrial contamination
5. Many more meteorites from Mars being found.

Mars Reconnaissance Orbiter

- Orbiter with variety of instruments
  - Launched Aug. 2005, arrived Mar. 2006
  - http://mars.jpl.nasa.gov/mro/
  - Detailed minerals, subsurface water
  - Resolution down to 1 m
  - Evidence of fluid (gas or liquid) along cracks originally underground

Image of Cracks

Venus Express Orbiter

- Venus Express Orbiter, an ESA mission
  - Launched Nov. 2005, arrived Apr. 2006
  - Will study atmosphere, surface with radar
  - http://www.esa.int/SPECIALS/Venus_Express/SEMOD3808BE_0.html

Future Missions

- Phoenix (NASA)
  - Launch Aug. 2007, land near North pole
  - Dig trenches up to 0.5 m deep
  - Chemical analysis
- Planet-C (Japan) Venus Orbiter
  - Launch 2009
- Mars Scientific Laboratory (rover)
  - Launch 2009
  - Mineral and possible organic matter analysis