

# 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? ( $f_\ell$ )

# 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)

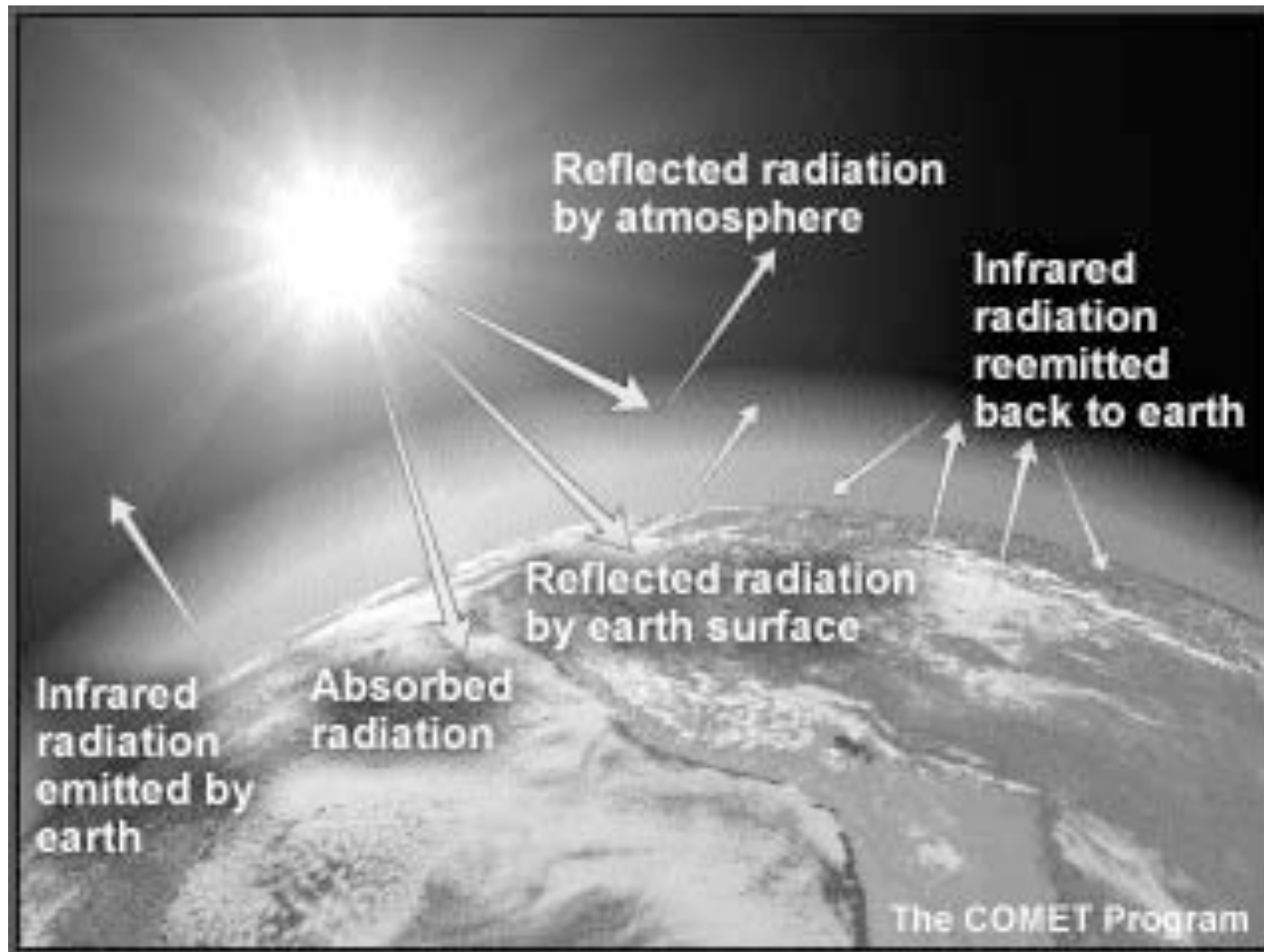
Clouds, Rock, Ice, Snow

Two extremes:

Runaway Greenhouse

Runaway Glaciation

# Greenhouse effect



# Terrestrial Planet Atmospheres

	Venus	Abiotic Earth	Mars	Biotic Earth
CO <sub>2</sub> (%)	96	96	95	0.03
N <sub>2</sub> (%)	~ 3	~ 3	2.7	79
O <sub>2</sub> (%)	trace	trace	0.16	21
H <sub>2</sub> O (%)	< 0.1	?	--	
Pressure (bar)	90	60	0.0061	1.0
T <sub>avg</sub> (°C)	477	290 (> 50)	~ -50	15
T <sub>avg</sub> (K)	750	563	~ 220	288

## Recall from Chap. 3

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

Rapid Rotation, Albedo

Apply to Venus, Mars

Venus

d      0.72 AU

A      0.80 (!)

T<sub>avg</sub>    220  
(no greenhouse)

T<sub>avg</sub>    750  
(actual)

Mars

1.52 AU

0.215

213

220



## Venus: Basic Facts

Sister Planet:  $R = 0.95 R_{\oplus}$   $\oplus$   
 $d_{\oplus} = 0.72 d_{\oplus}$   $\oplus$

BUT HOT!

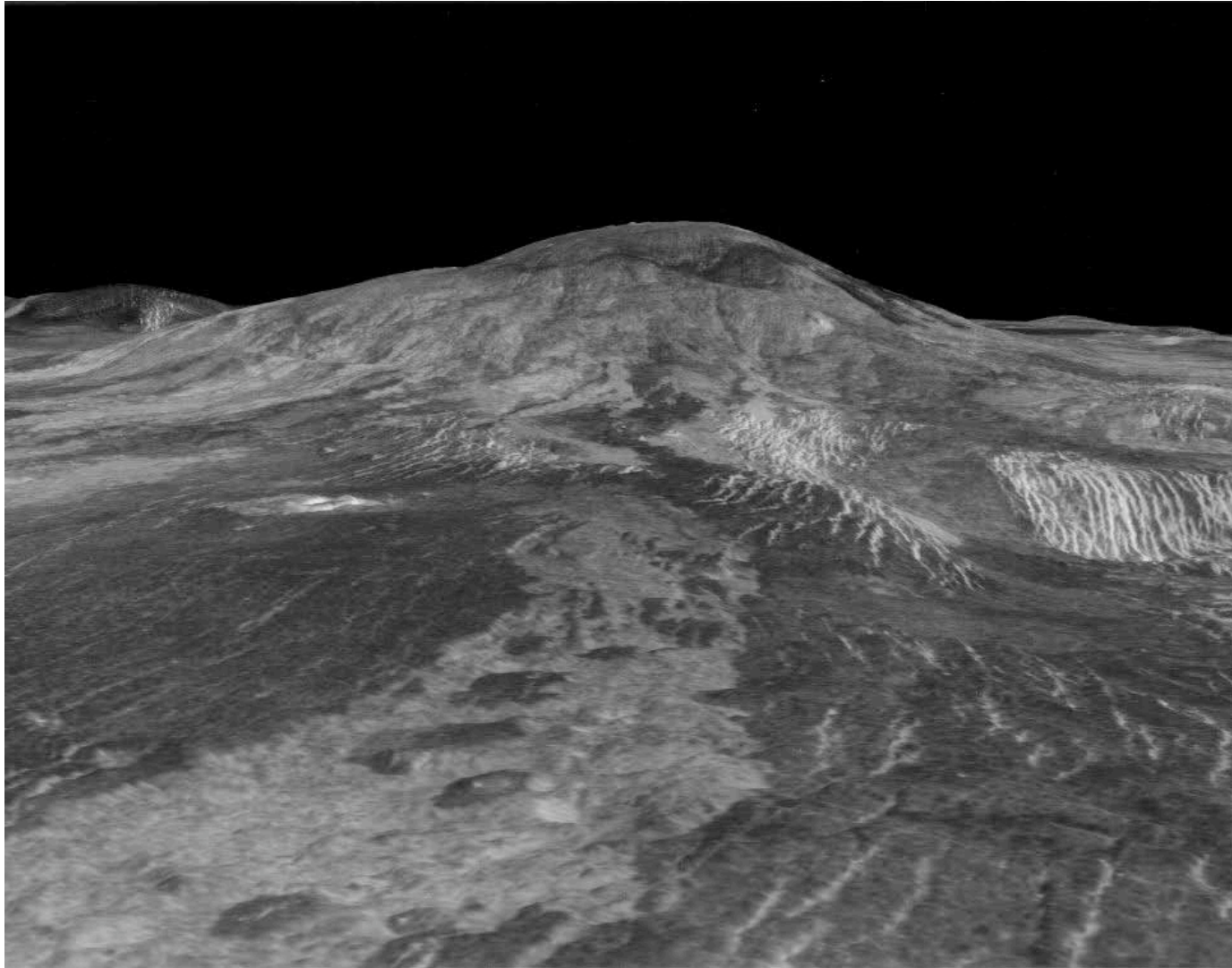
Clouds: Sulfuric Acid droplets

Radar “Active” surface

Age < Age of Planet

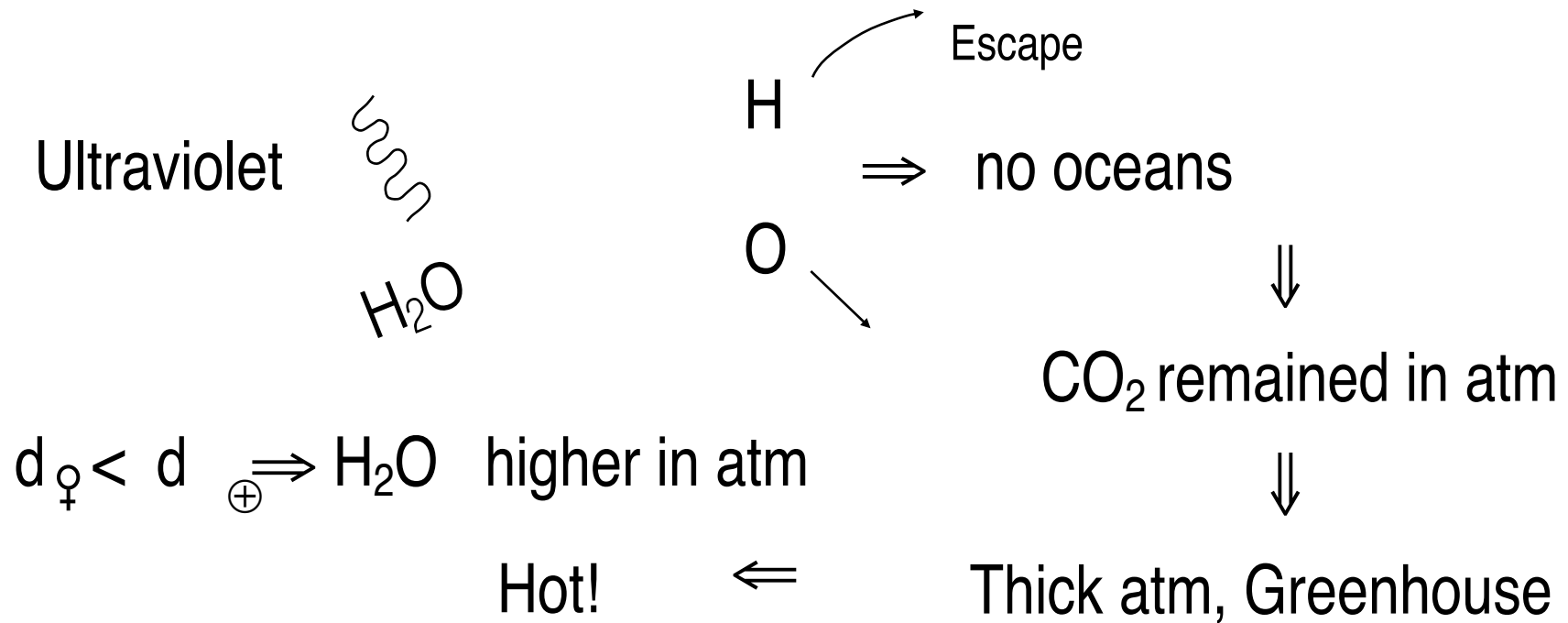
But no large-scale plates

## View of Venus from Radar Mapping





# Evolution of the Atmosphere



Runaway Greenhouse

Example of positive feedback



## Mars: Basic Facts

Smaller  $R_{\text{M}} = 0.53 R_{\oplus}$   $\oplus$   
Less Massive  $M = 0.11 M_{\oplus}$   $\oplus$   
Less Dense  $\rho = 0.71 \rho_{\oplus}$   $\oplus$

Mars year = 687 Earth days

Mars day = 24.5 Earth hours

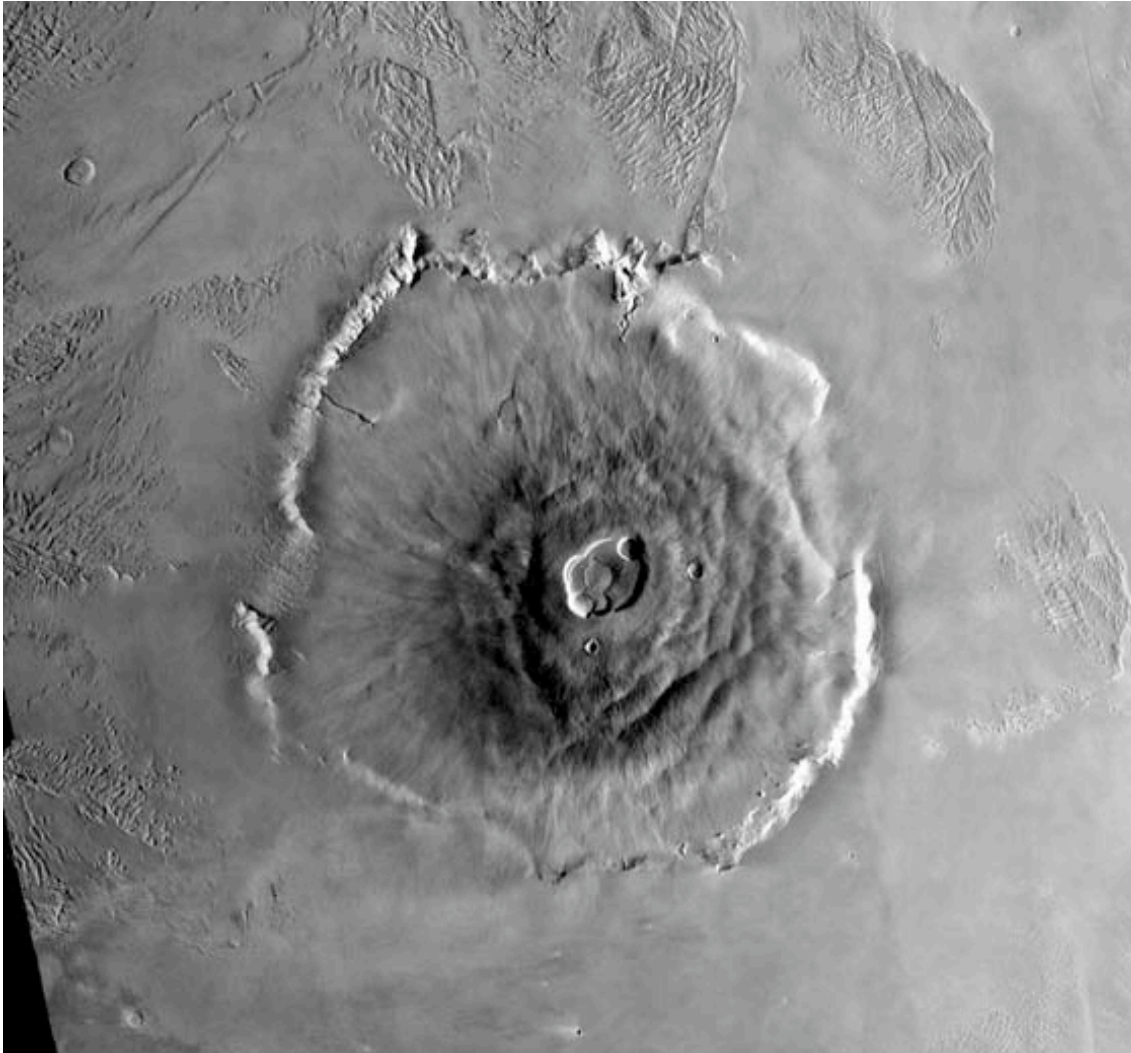
Seasons

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

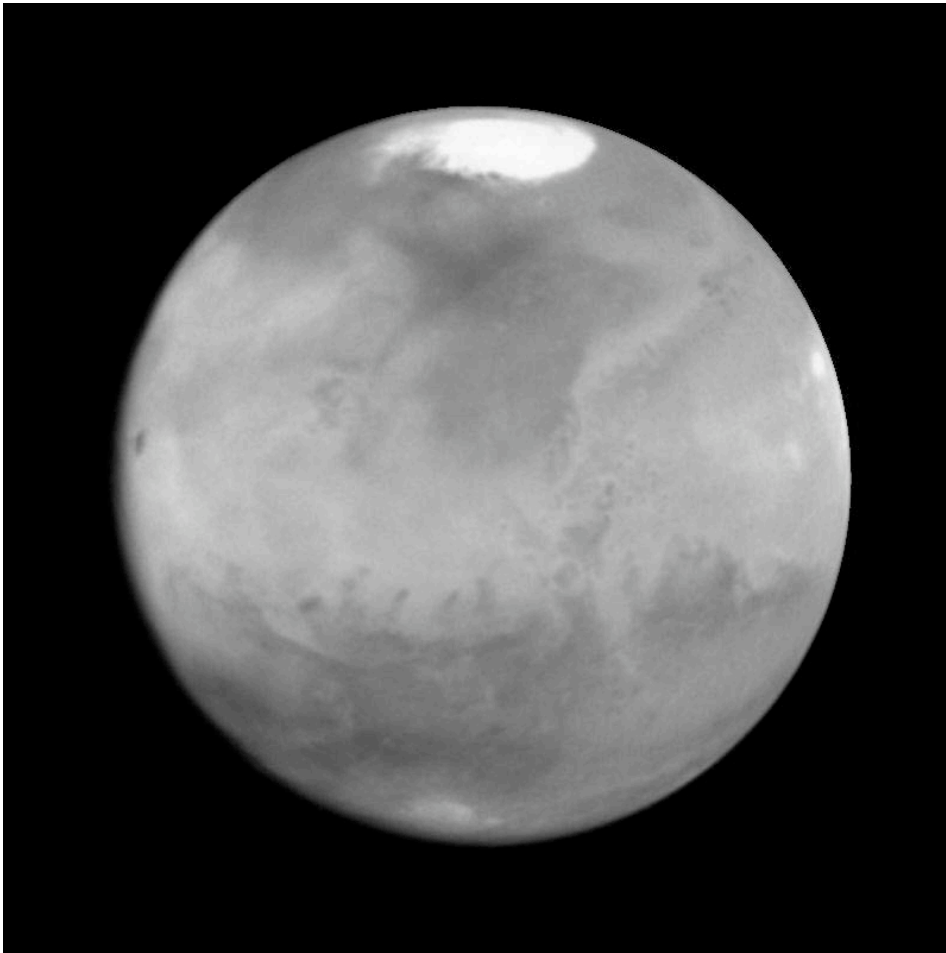


Image from the Hubble Space Telescope during close approach of Earth and Mars.

# Runaway Glaciation (also positive feedback)

Thin atmosphere led to Weak Greenhouse

Cold temperature led to freeze-out of greenhouse gases:  $T = 175 - 300 \text{ K}$

Warm enough for liquid  $\text{H}_2\text{O}$  but low pressure

Active in past, but not now: Fossil river beds

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

Life?

Survive another  $0.7 \times 10^9 \text{ yr}$  in frozen lakes?

Analogy to Antarctic lakes

# Antarctica as a model for early Mars

Dry valleys: Mean  $T = -20\text{ }^{\circ}\text{C}$

Annual precipitation  $\sim 2\text{ cm}$

But  $T > 0^{\circ}\text{C}$  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  $1 - 2 \times 10^9\text{ yr}$

A large (140 mile  $\times$  30 mile) lake

exists  $\sim 2.5$  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

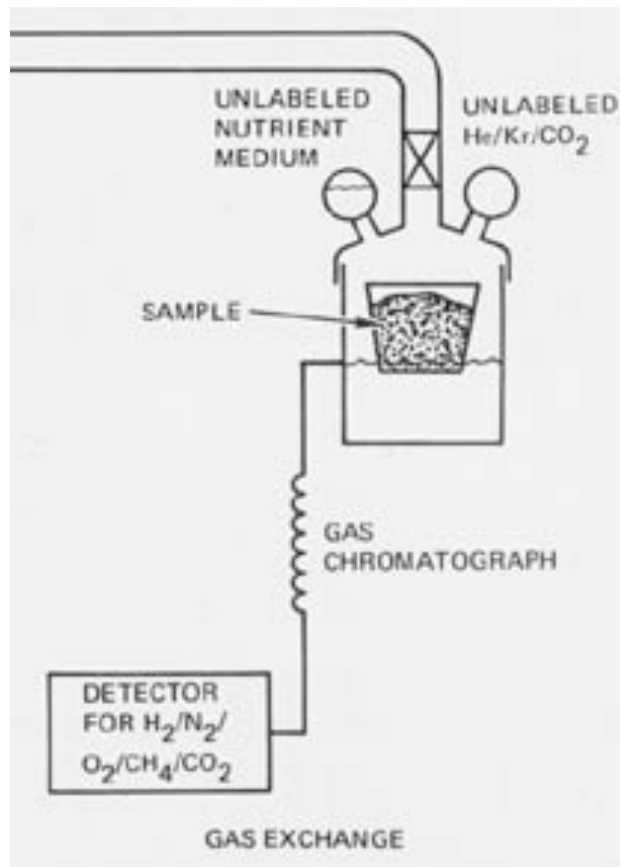
# Life Detection Experiments

- 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<sub>2</sub>, Argon, CO<sub>2</sub>, O<sub>2</sub> released
    - O<sub>2</sub> required chemical reaction
  - Second mode: wet, nutrients
    - Monitor for 6 months, no further activity
- No sign of metabolizing, earth-like life

# Gas Exchange Experiment



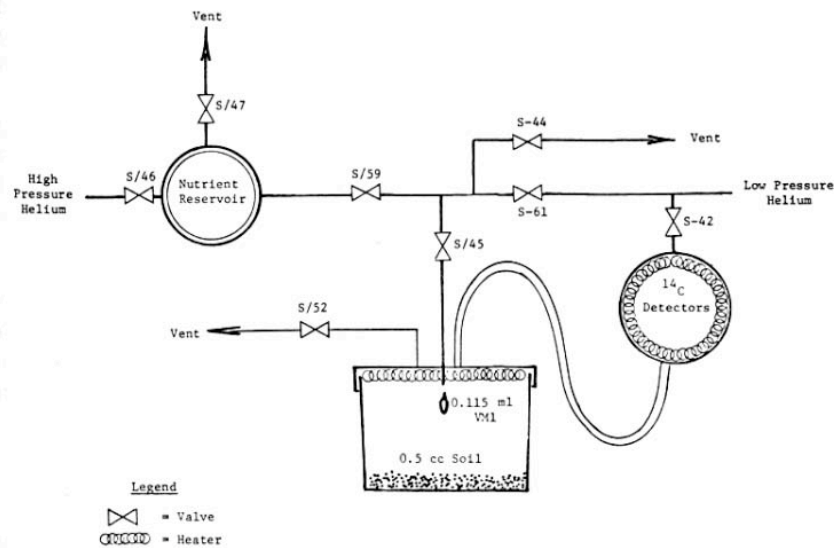
- Looks for metabolism
- Detects gaseous products
- Using gas chromatograph

# 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

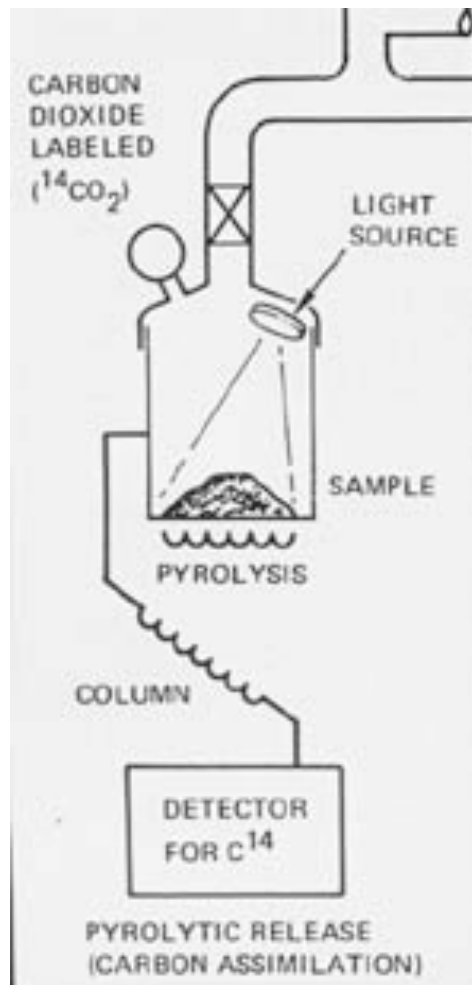
- Looks for metabolism
- Nutrients labeled with  $^{14}\text{C}$



# Pyrolytic Release Experiment (PR)

- Assumed photosynthesizing autotrophs
  - Adapted to Mars
  - Supply light, Martian atmosphere
  - But label with  $^{14}\text{CO}_2$  and  $^{14}\text{CO}$ 
    - After incubation, remove gases
    - Burn up (pyrolize)
    - 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
- Phoenix (NASA) landed in 2008

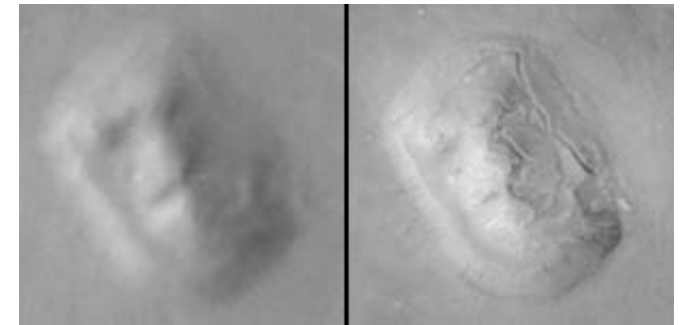
# Global Surveyor

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)

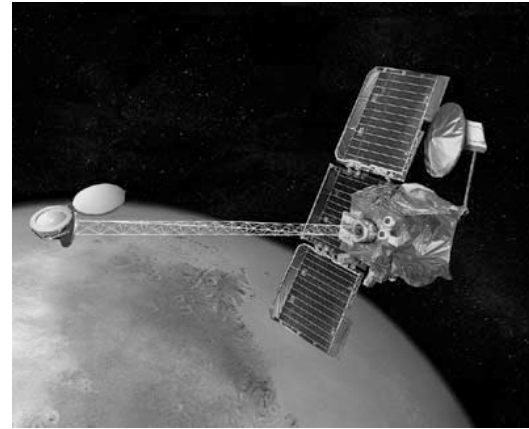
Mars Odyssey Website

# Mars Odyssey Results

Mapping from Orbit

Gamma ray spectrometer

Cosmic rays excite nuclei on surface  
to emit Gamma rays



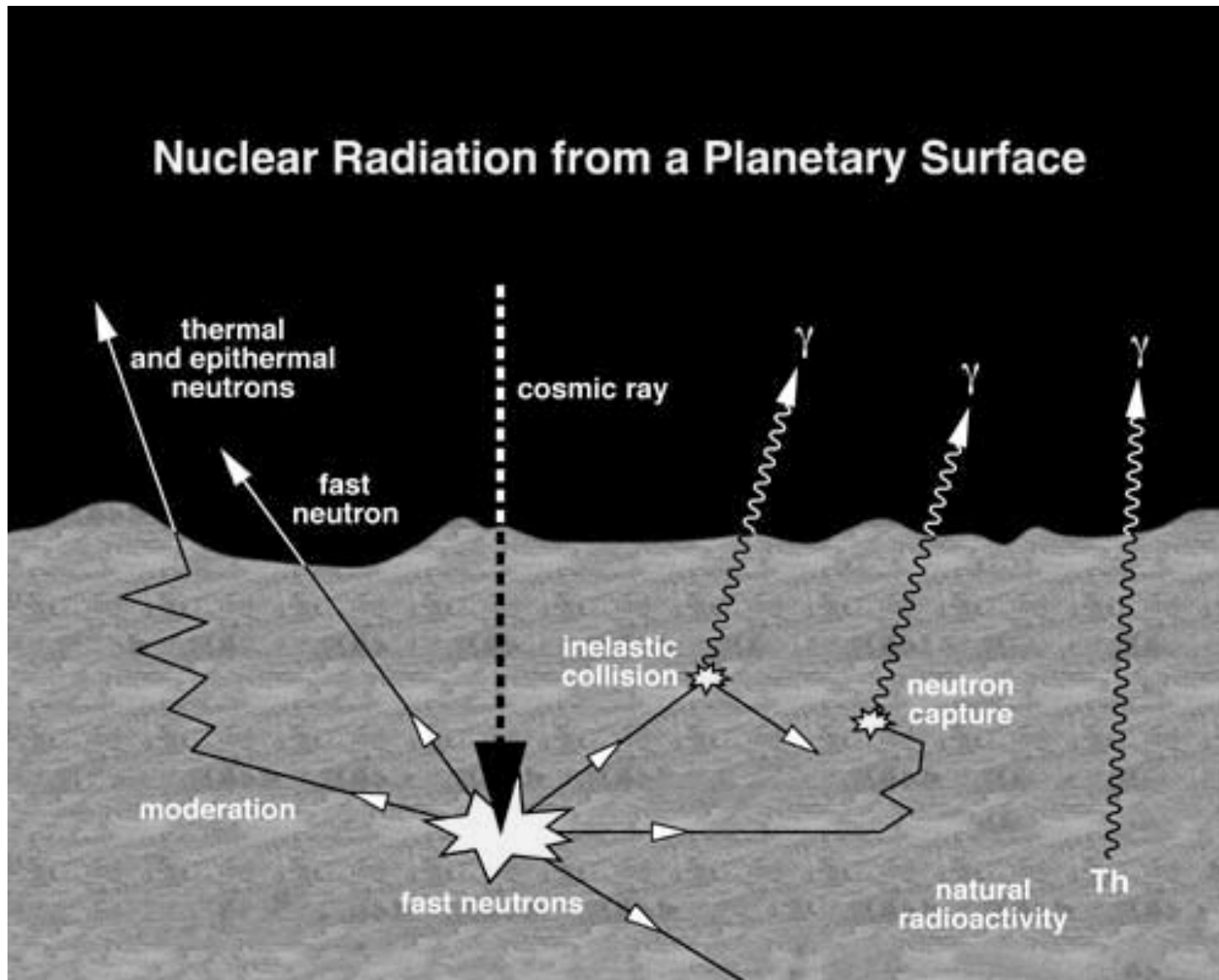
Wavelength of gamma rays characteristic of element

Also neutron detector

Can detect hydrogen (stand in for  $\text{H}_2\text{O}$ ) in top meter

Evidence indicates substantial  $\text{H}_2\text{O}$  near south pole

## Mars Odyssey



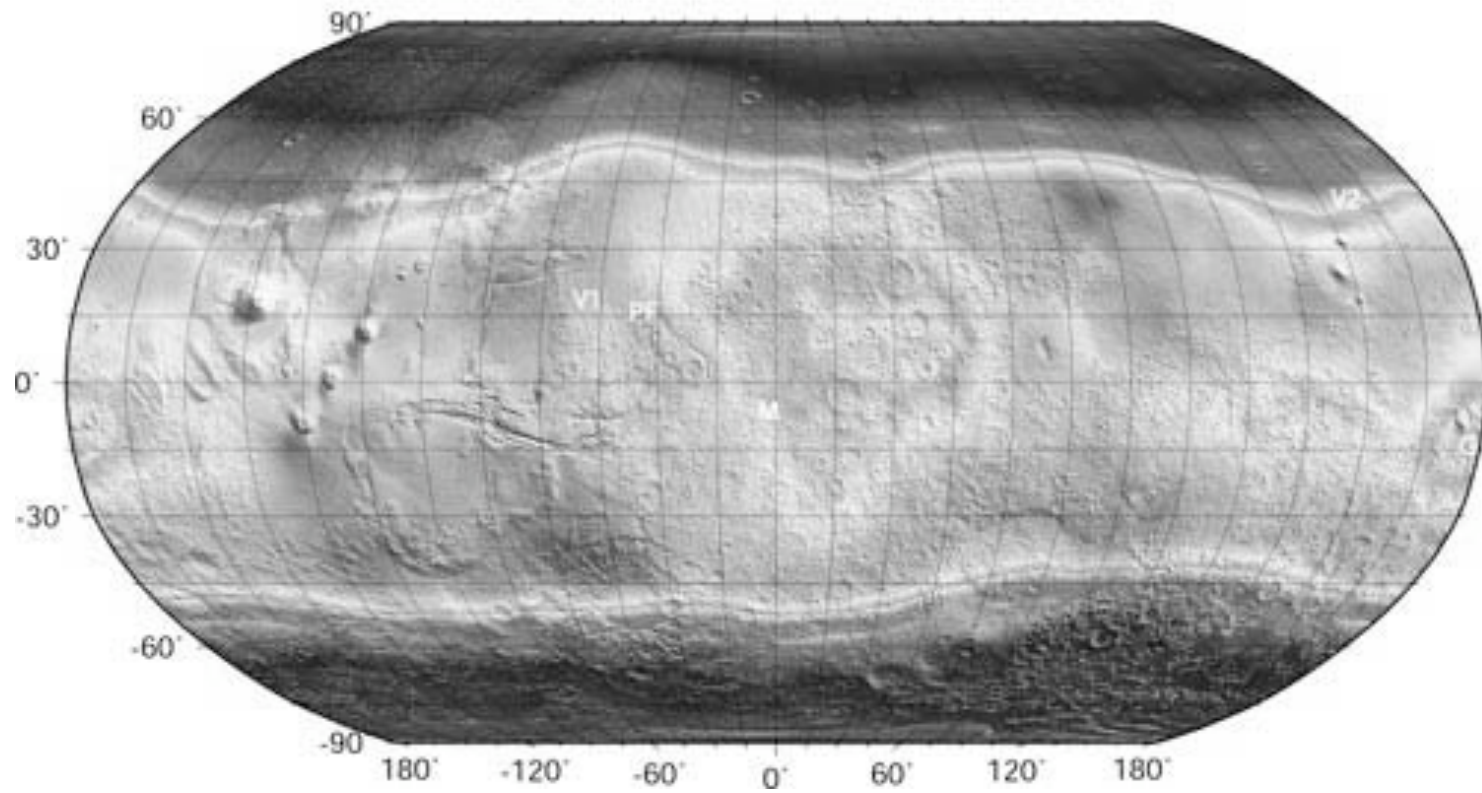


# 2001 Mars Odyssey Water Map

## **WATER MAP**

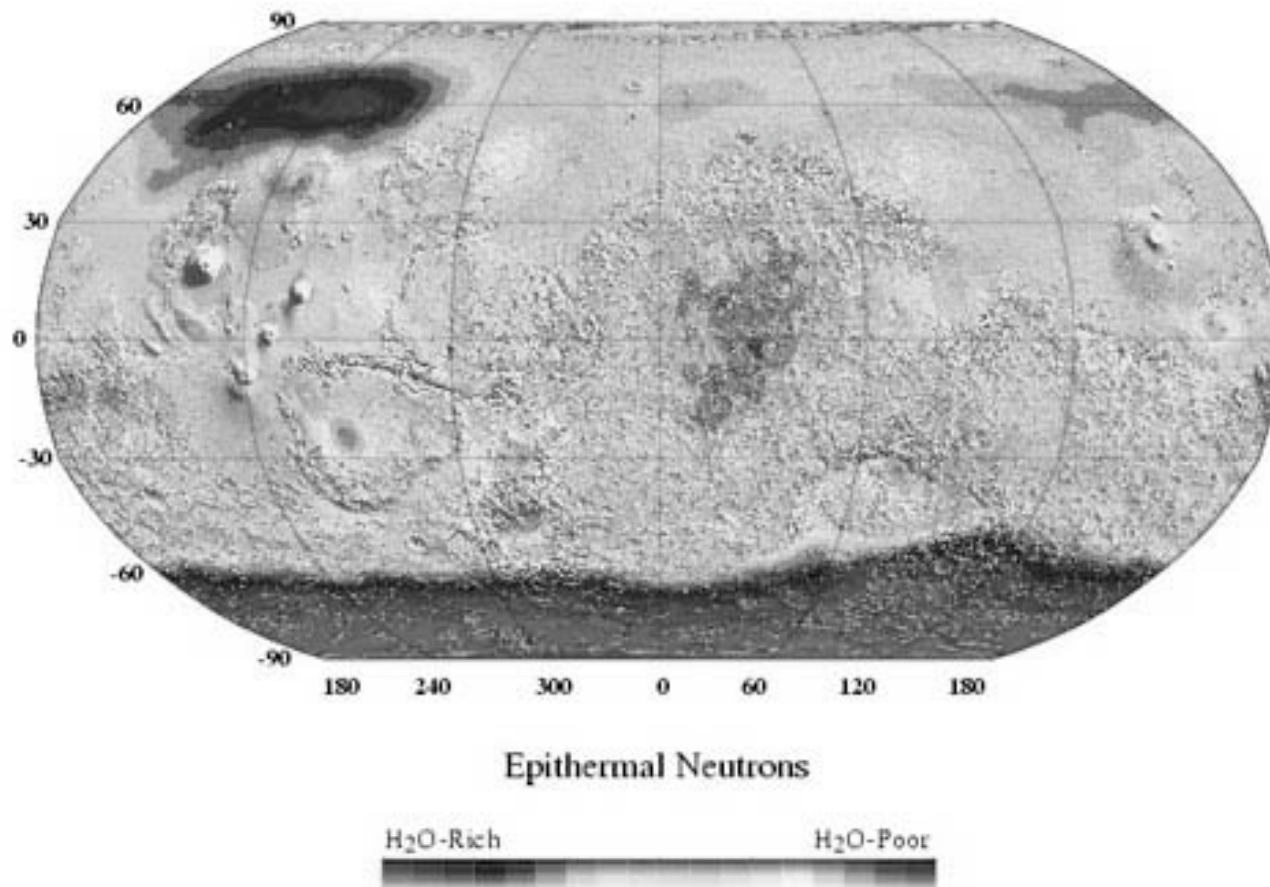
2001 Mars Odyssey Gamma Ray Spectrometer

H<sub>2</sub>O Low  H<sub>2</sub>O High



# Mars Odyssey

## LATE SOUTHERN SUMMER



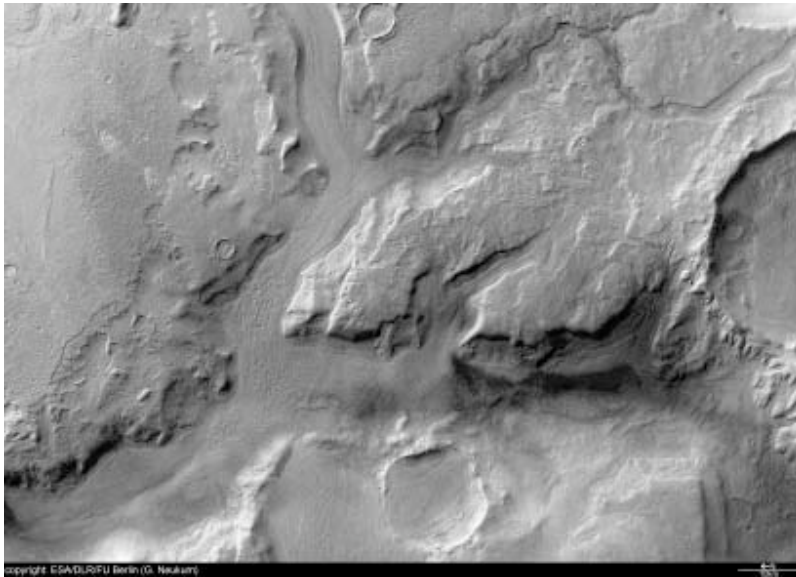
# Mars Express



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

# Mars Express

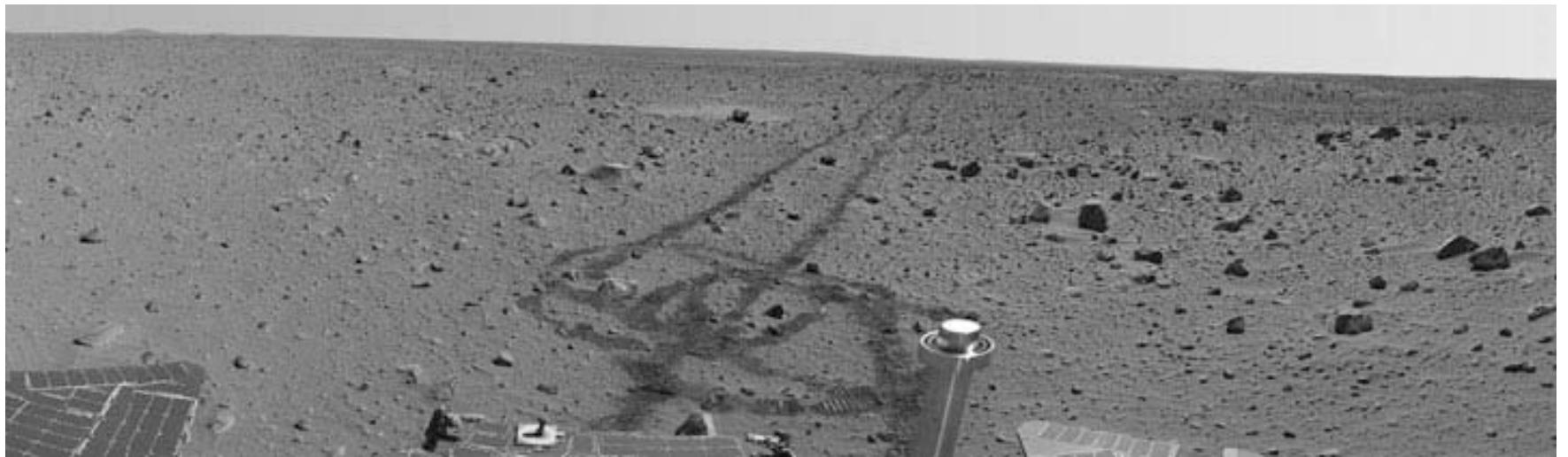
- Branching channels
- More evidence of water?



# 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 2009
  - (**much** longer than expected)
- <http://marsrovers.jpl.nasa.gov/home/index.html>

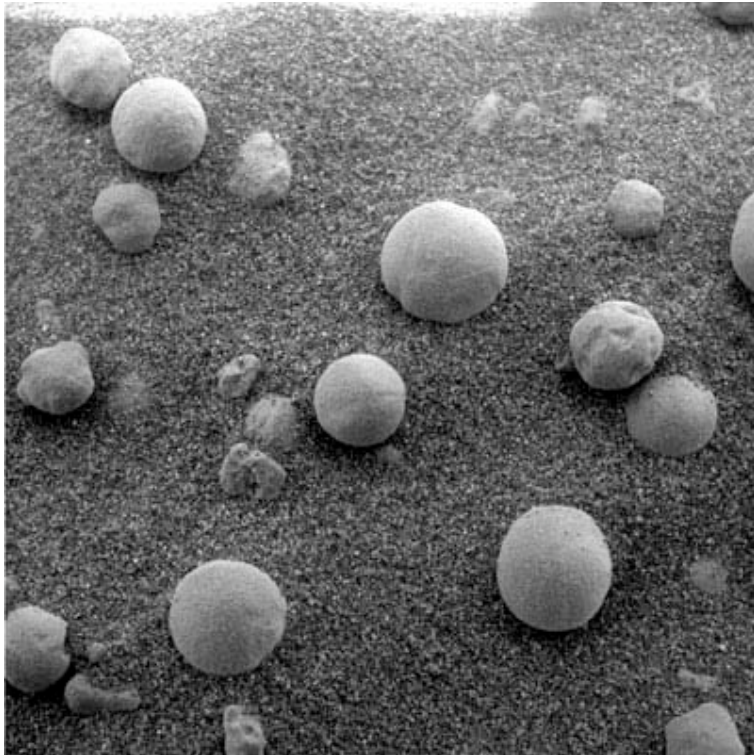
# Panorama from Spirit



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.

# Mars Reconnaissance Orbiter

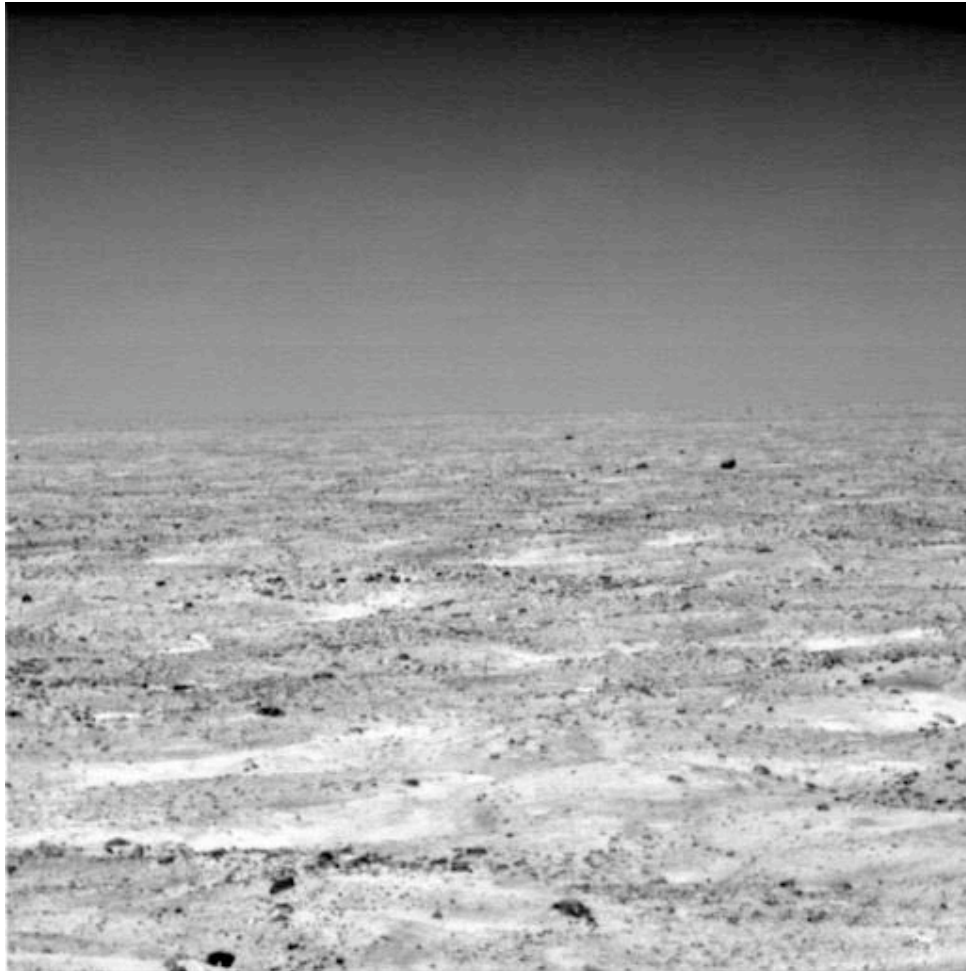
- Orbiter with variety of instruments
  - Launched Aug. 2005, arrived Mar. 2006
  - <http://mars.jpl.nasa.gov/mro/>
  - Detailed minerals, subsurface water
  - Resolution down to 1 m
  - Evidence of fluid (gas or liquid) along cracks originally underground



# Phoenix Lander

- Phoenix (NASA)
  - Launch Aug. 2007, landed near North pole May 2008, Last contact in Nov. 2008
    - 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



# 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  
[AIH 84001]

A few meteorites (~12) are so similar to Mars

Minerals & isotope ratios, that they are assumed to come from Mars

2002 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

## 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 -  $\sim 3.6 \times 10^9$  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

## 2. Carbonate Globules (50 $\mu\text{m}$ across)

cores of manganese & rings of iron carbonate  
and iron sulfide

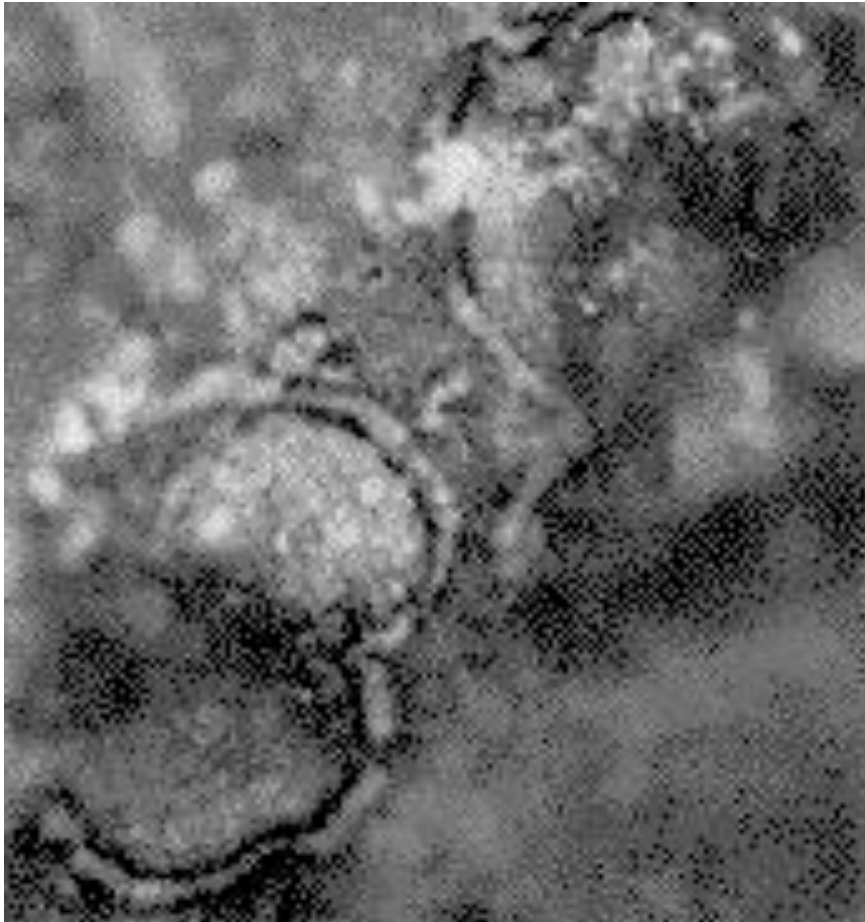
similar to globules associated with bacterial  
action in liquid on Earth

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)  
( $100 \times 10^{-9} \text{ m} = 0.1 \text{ } \mu\text{m}$ )

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)

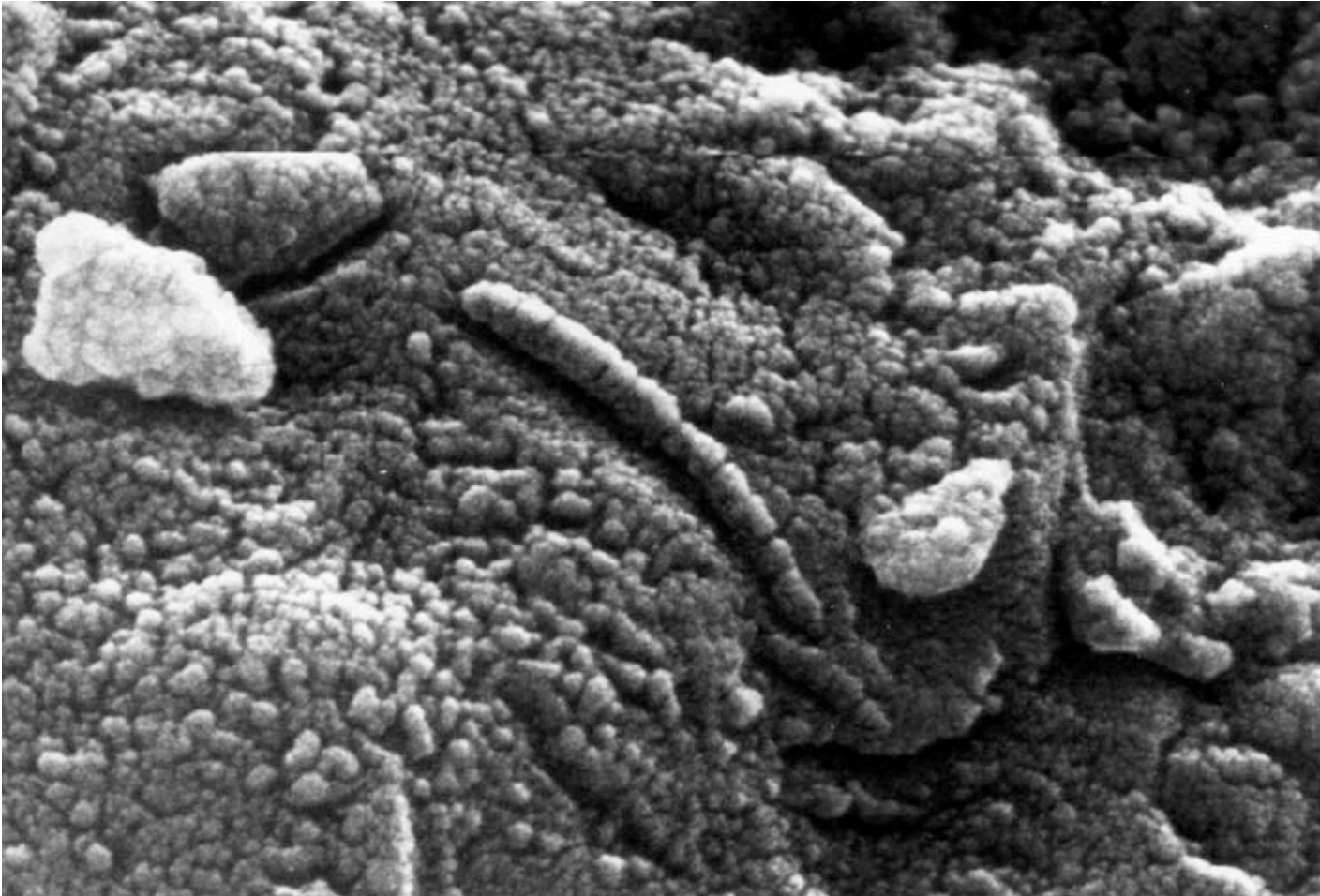
nanobacteria →

~ 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 meteorite (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.

# 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/SEM0D3808BE\\_0.html](http://www.esa.int/SPECIALS/Venus_Express/SEM0D3808BE_0.html)

## Future Missions

- Planet-C (Japan) Venus Orbiter
  - Launch 2009
- Mars Scientific Laboratory (rover)
  - Launch 2009 (delayed)
  - Mineral and possible organic matter analysis