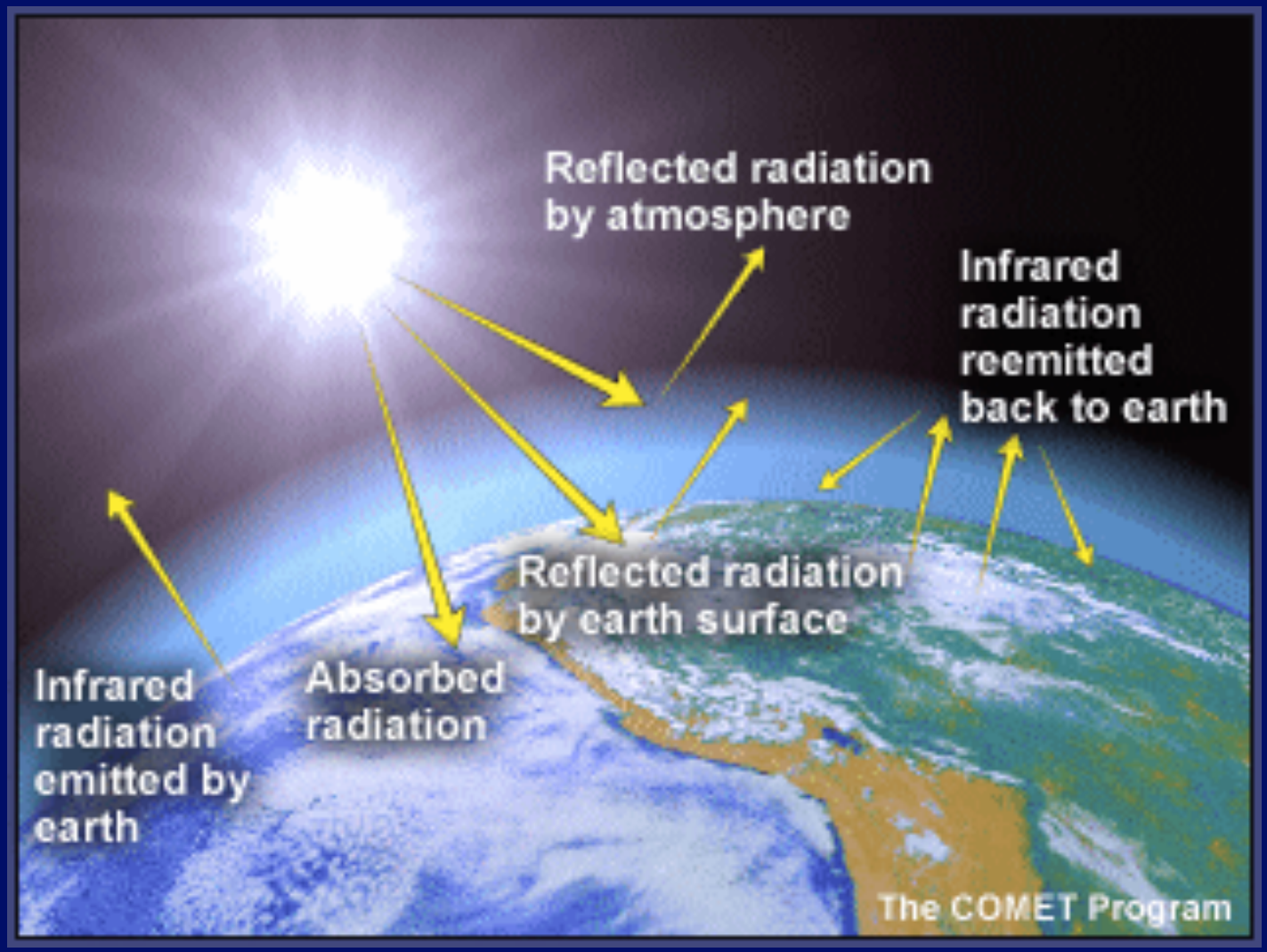
Life in the Inner Solar System

Life in the Solar System

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

2. Life elsewhere in Solar System? (f_ℓ)

Greenhouse effect



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

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: $R_{♀} = 0.95\ R_{\oplus}$

$d_{♀} = 0.72\ d_{\oplus}$

BUT HOT!

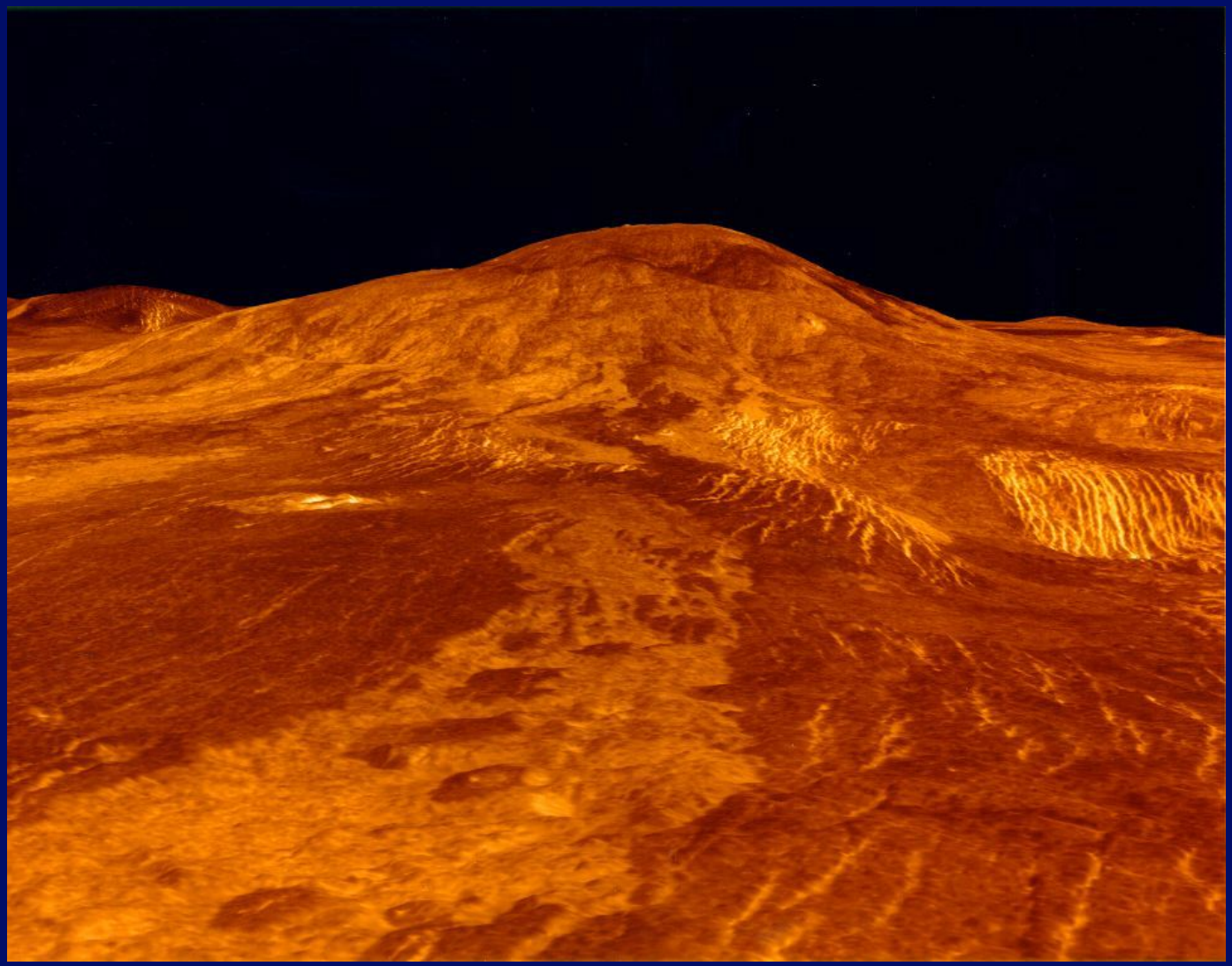
Clouds: Sulfuric Acid droplets

Radar "Active" surface

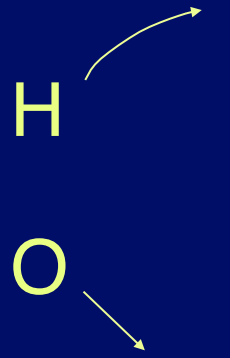
Age < Age of Planet

But no large-scale plates

View of Venus from Radar Mapping



Evolution of the Atmosphere



$\Rightarrow$ no oceans

$\Downarrow$

CO_2 remained in atm

$\Downarrow$

Thick atm, Greenhouse

$\Leftarrow$

Hot!

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

Runaway Greenhouse

Example of positive feedback

Mars: Basic Facts

Smaller $R_{♀} = 0.53\ R_{⊕}$

Less Massive $M_{♀} = 0.11\ M_{⊕}$

Less Dense $\rho_{♀} = 0.71\ \rho_{⊕}$

Mars year = 687 Earth days

Mars day = 24.5 Earth hours

Seasons

2 small moons (captured asteroids)

Mars

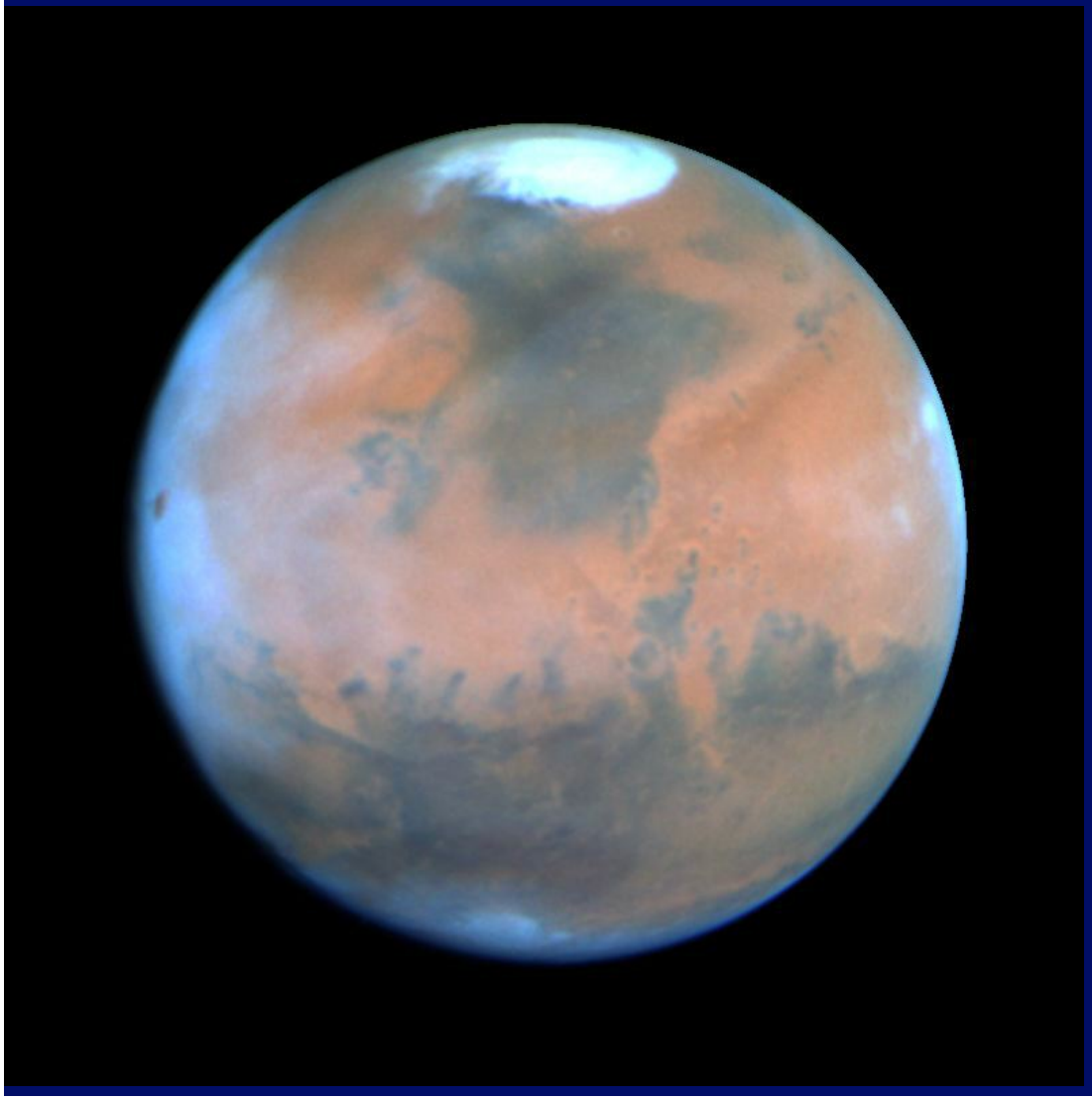
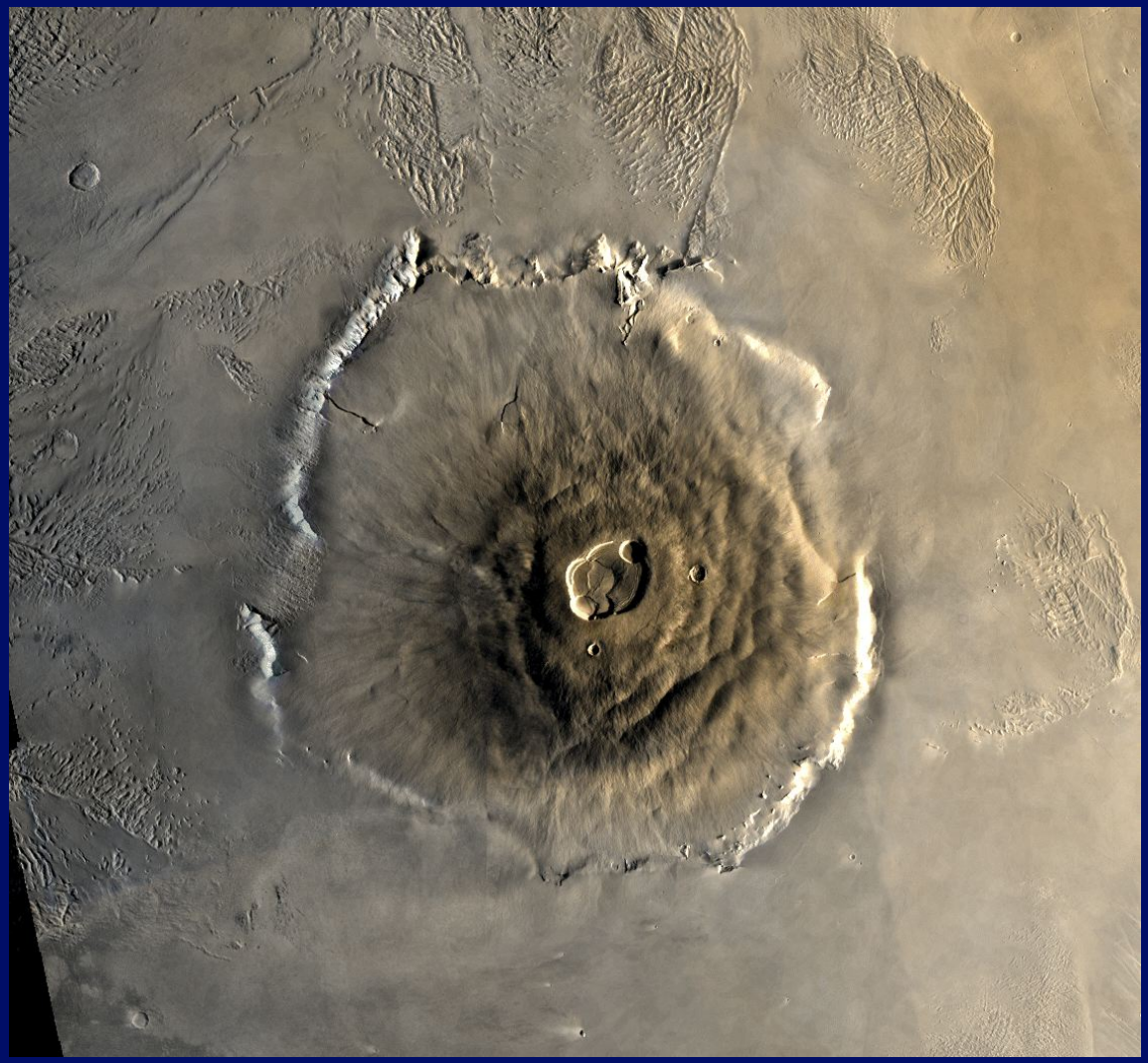


Image from the Hubble Space Telescope during close approach of Earth and Mars. Shows polar ice caps.

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_2O

but pressure is too low

Active in past, but not now: Fossil river beds

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

Life?

Survive another 0.7×10^9 yr 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.

⇒ 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 × 10^9 yr

Viking Mission

Two spacecraft, launched in 1976

1. Chryse Planitia 22º N. Lat
2. Utopia Planitia 48º N

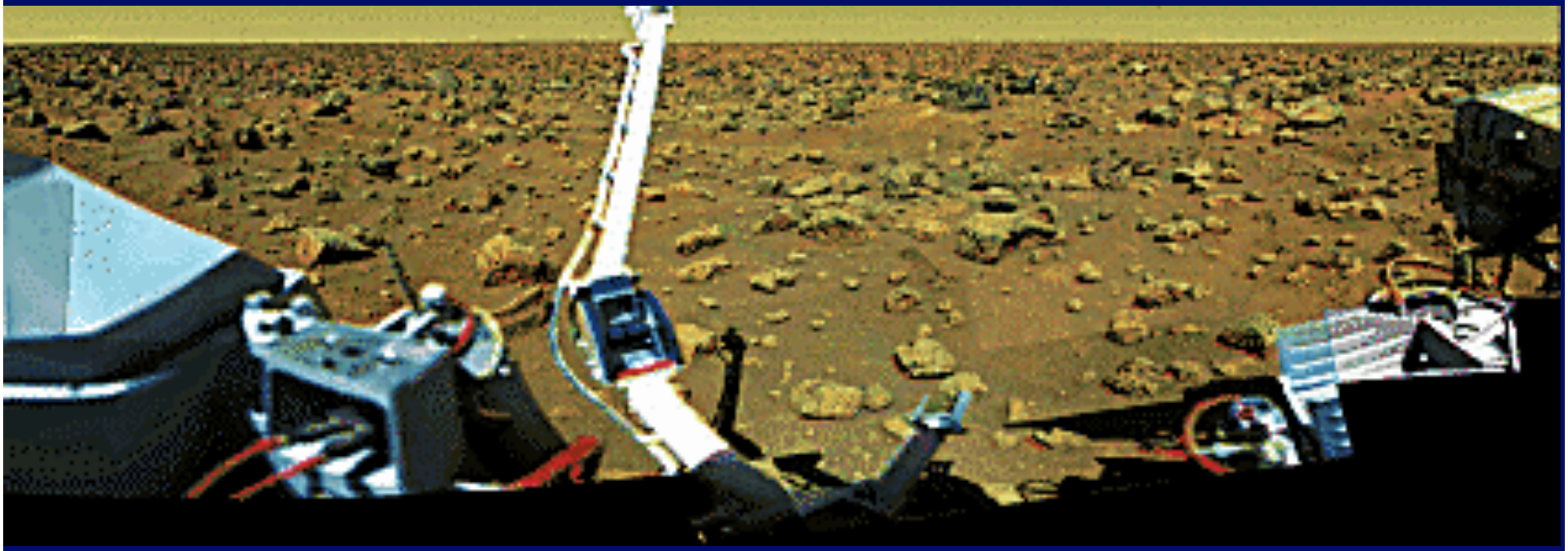
Cameras, …

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

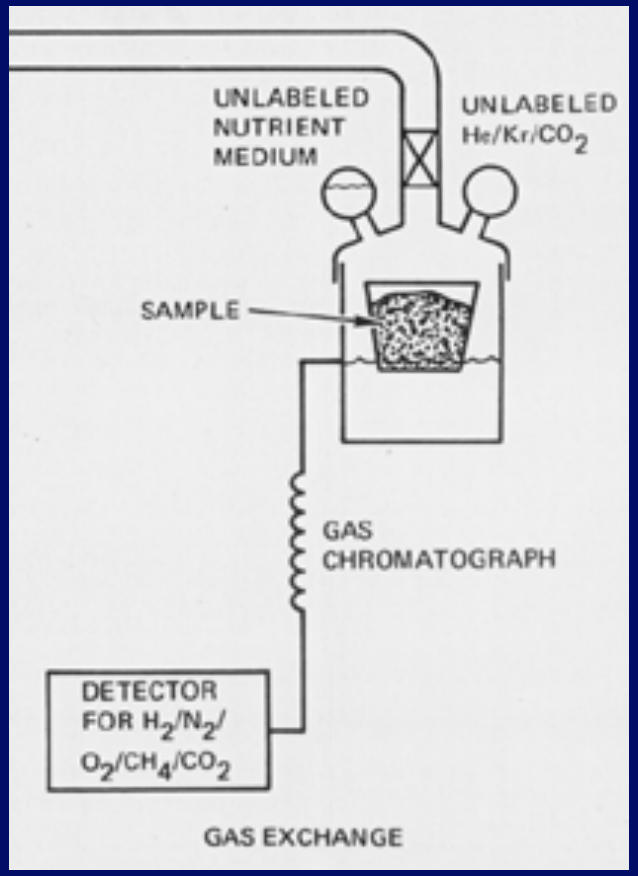
Life Detection Experiments

- 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

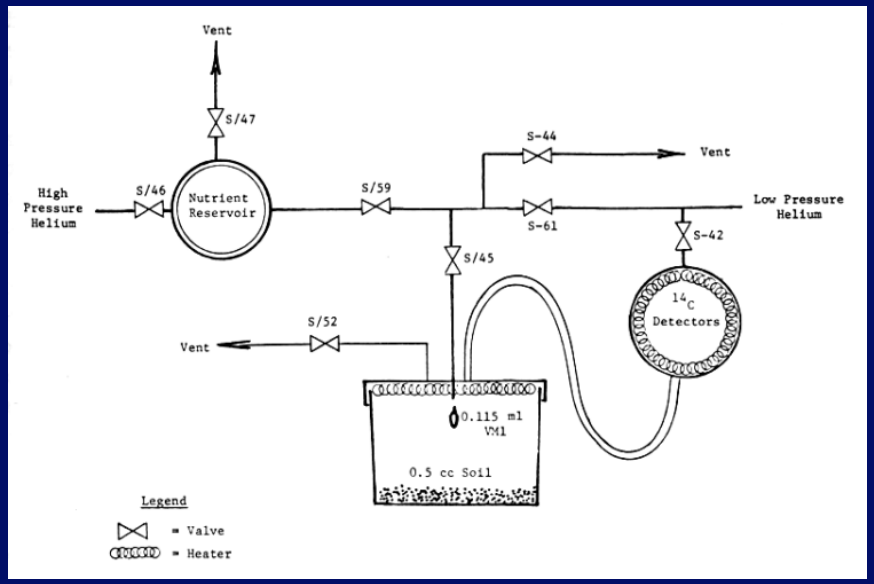


- Looks for metabolism
- Detects gaseous products
- Using gas chromatograph

Labeled Release Experiment

- Assumed metabolizing Martians
  - But less Earth like
  - Simpler mix of nutrients, labeled with ^{14}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

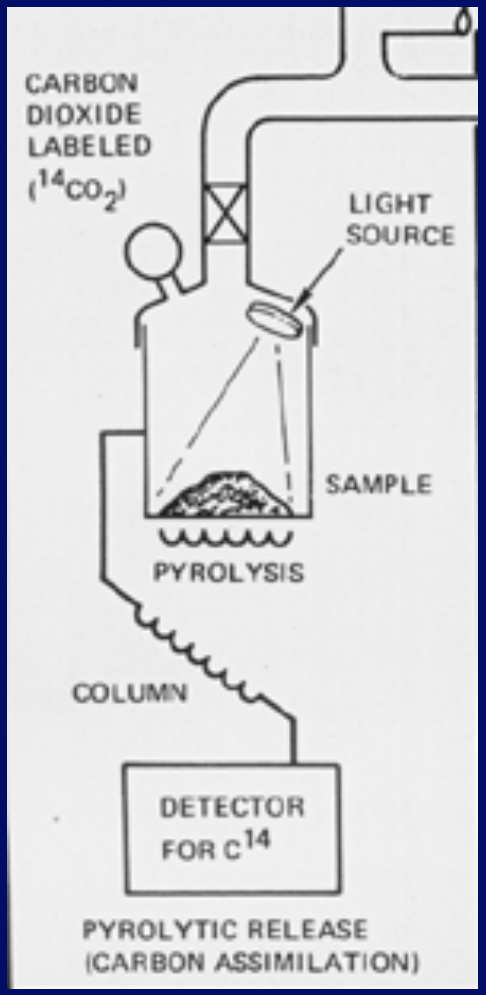


- Looks for metabolism
- Nutrients labeled with ^{14}C

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)….

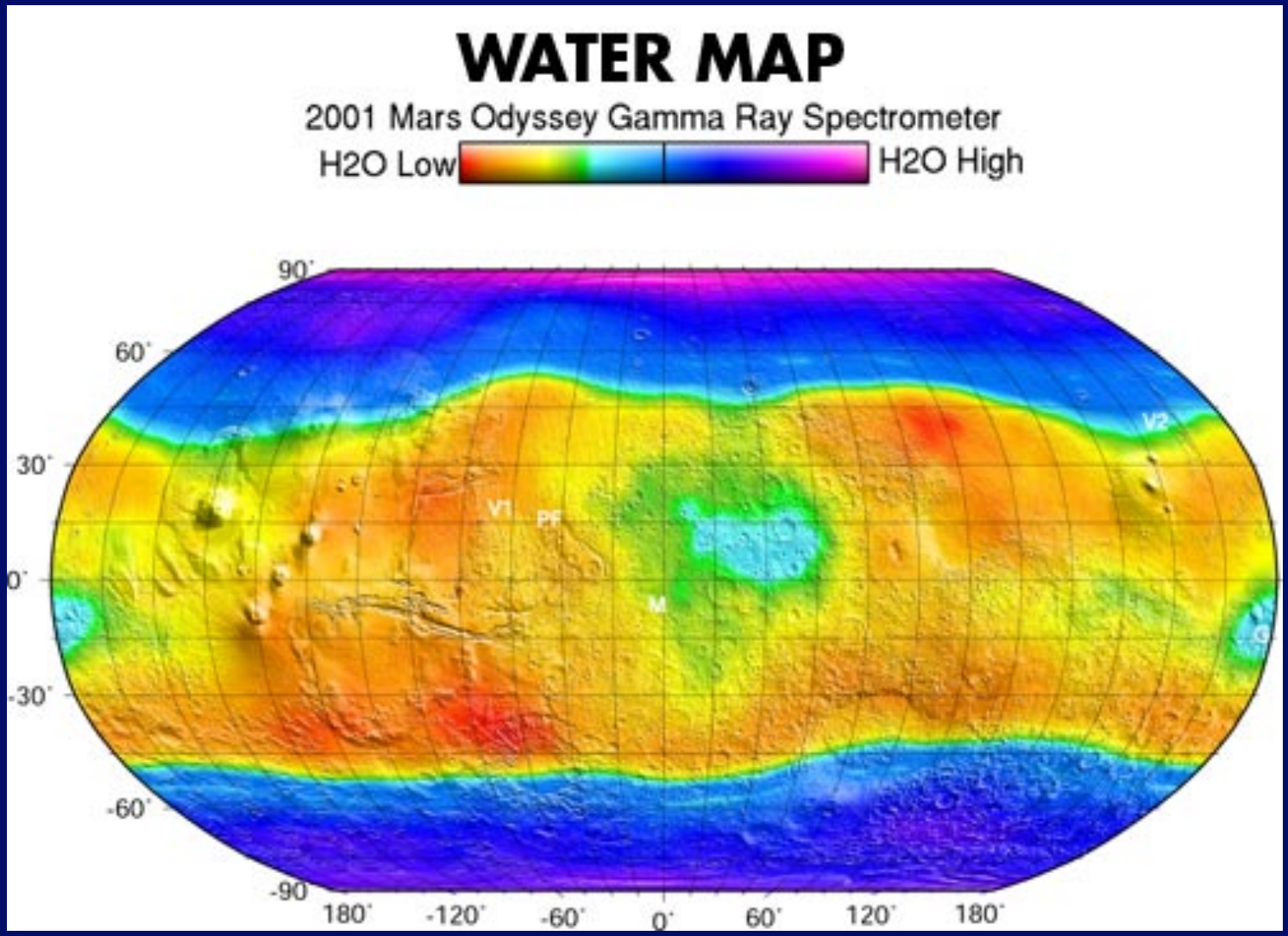
Dig Deeper!

And remember that your experiments determine what you can find…

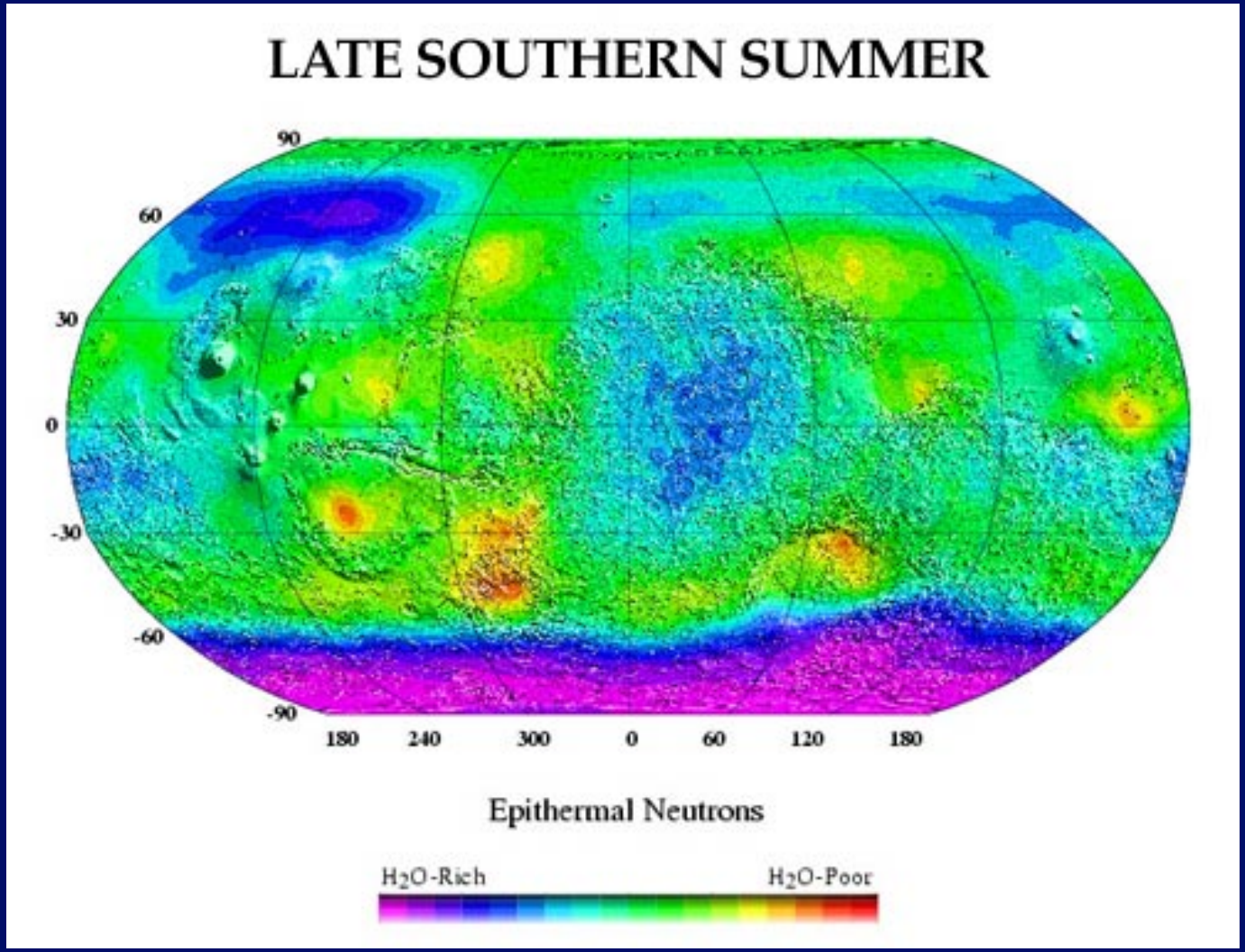
More Recent Mars Missions

- Pathfinder/Sojourner 1997
- Global Surveyor 1998
- Mars Odyssey 2002: 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

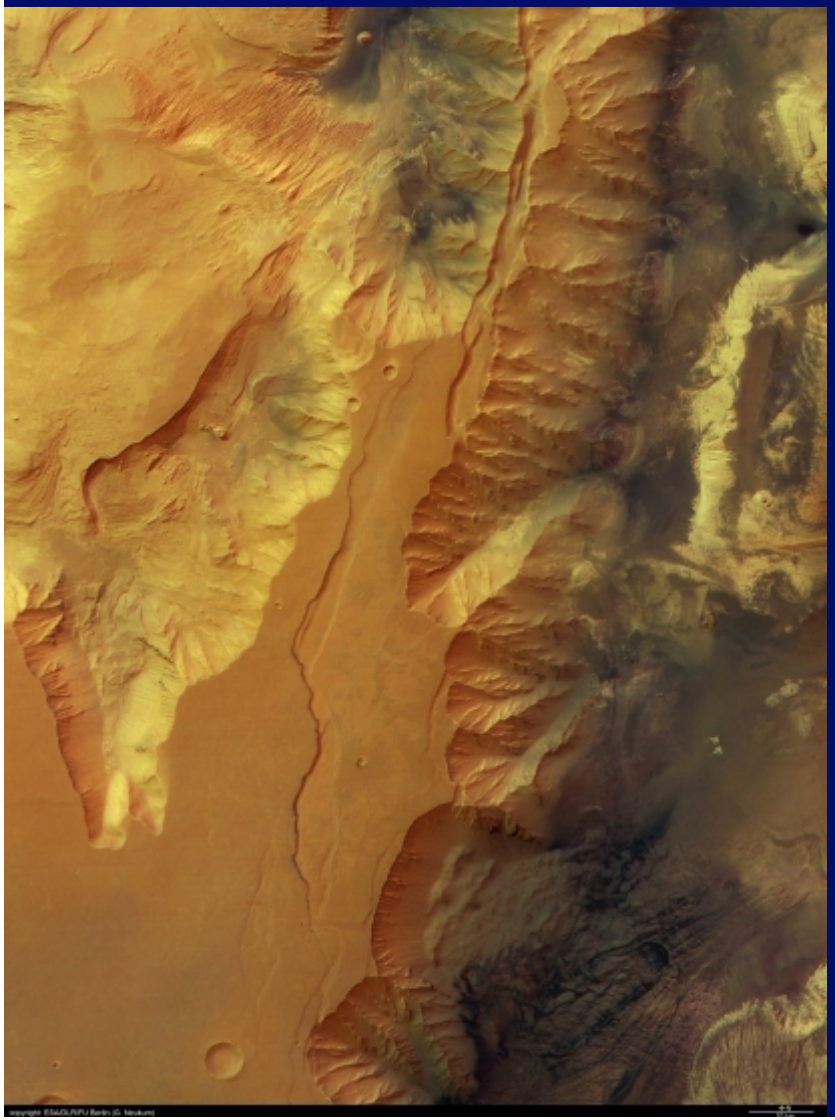
2001 Mars Odyssey Water Map



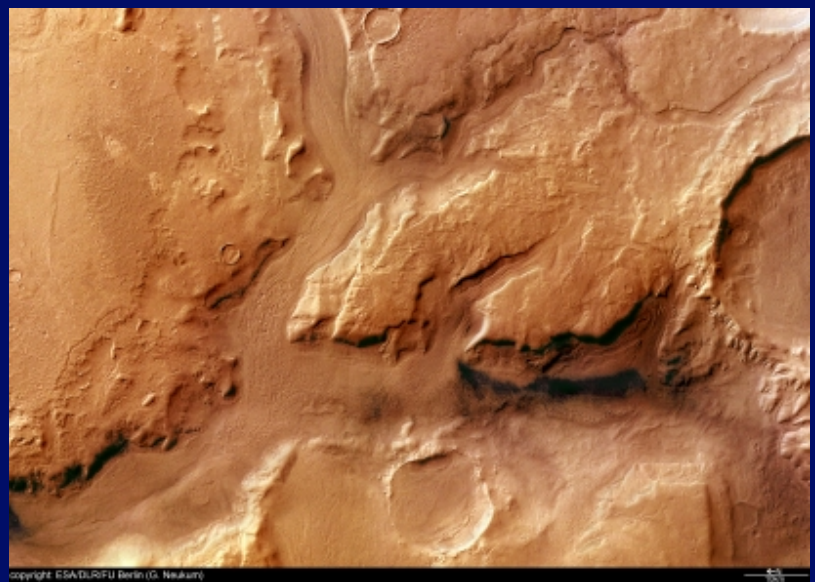
Mars Odyssey



Mars Express



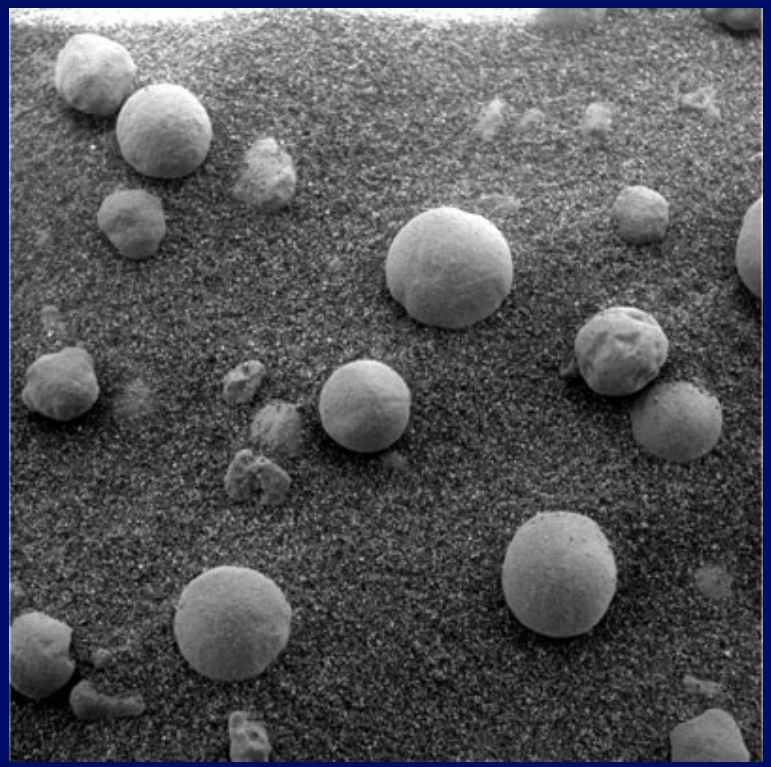
- Walls of Candor Chasma
- Part of Valles Marineris
- Appears to be erosion
- Branching channels
- Signs of water



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)
- http://marsrovers.jpl.nasa.gov/home/index.html

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

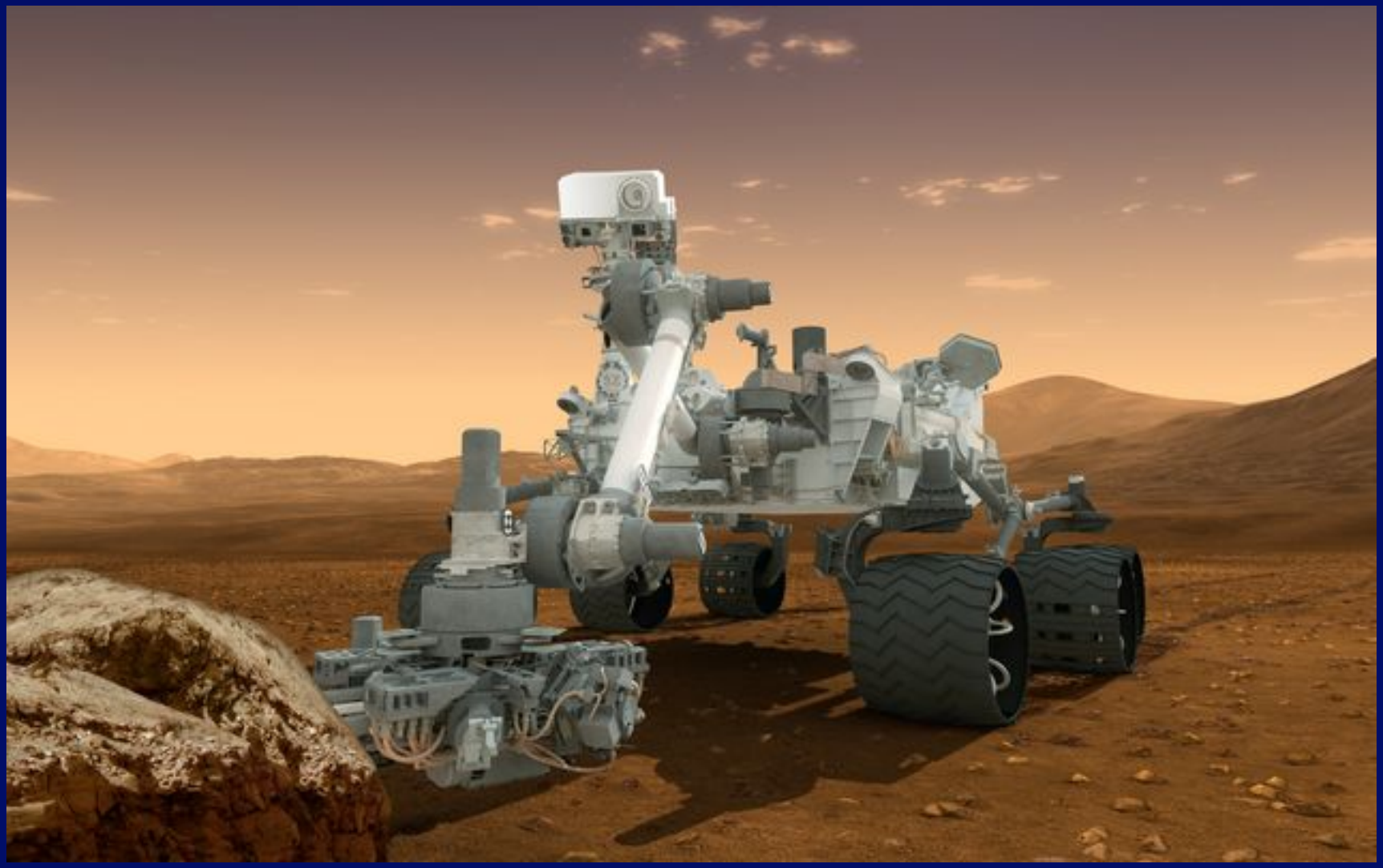
- Phoenix (NASA)
  - Launch Aug. 2007, landed near North pole May 2008, Last contact in Nov. 2008
    - Winter, less sunlight, loss of solar power
    - Dug trenches, did chemical analysis
    - Some problems, soil was sticky
    - Clearly there was ice in the soil

Phoenix sees frost on Mars

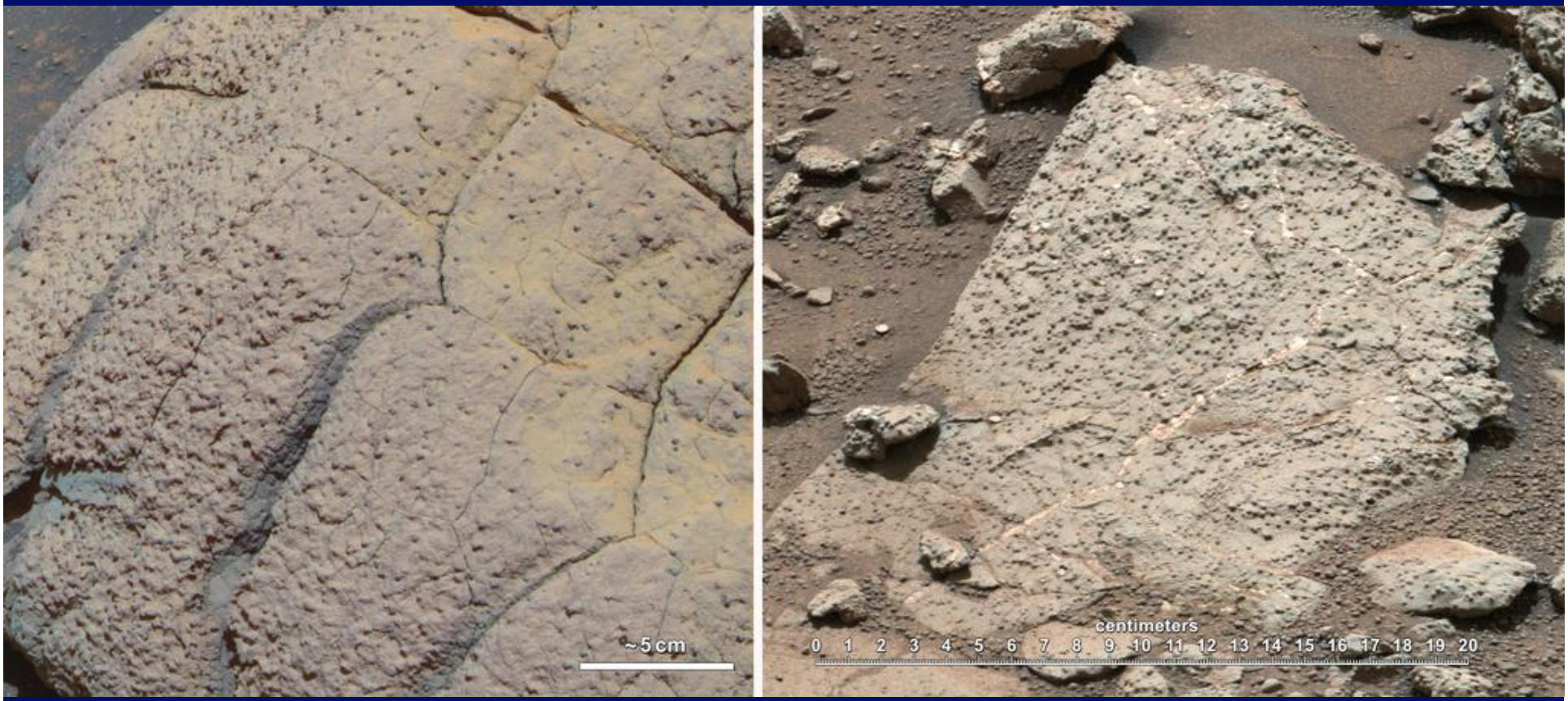
Curiosity Rover

- 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



Mudstone 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/

Los Angeles 2002

Martian meteorite found in LA county in 1999

245 gm

AlH 84001

1.9 kg (softball-sized) found in 1984 in Allan Hills Region (AlH)
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

Signs of Life?

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

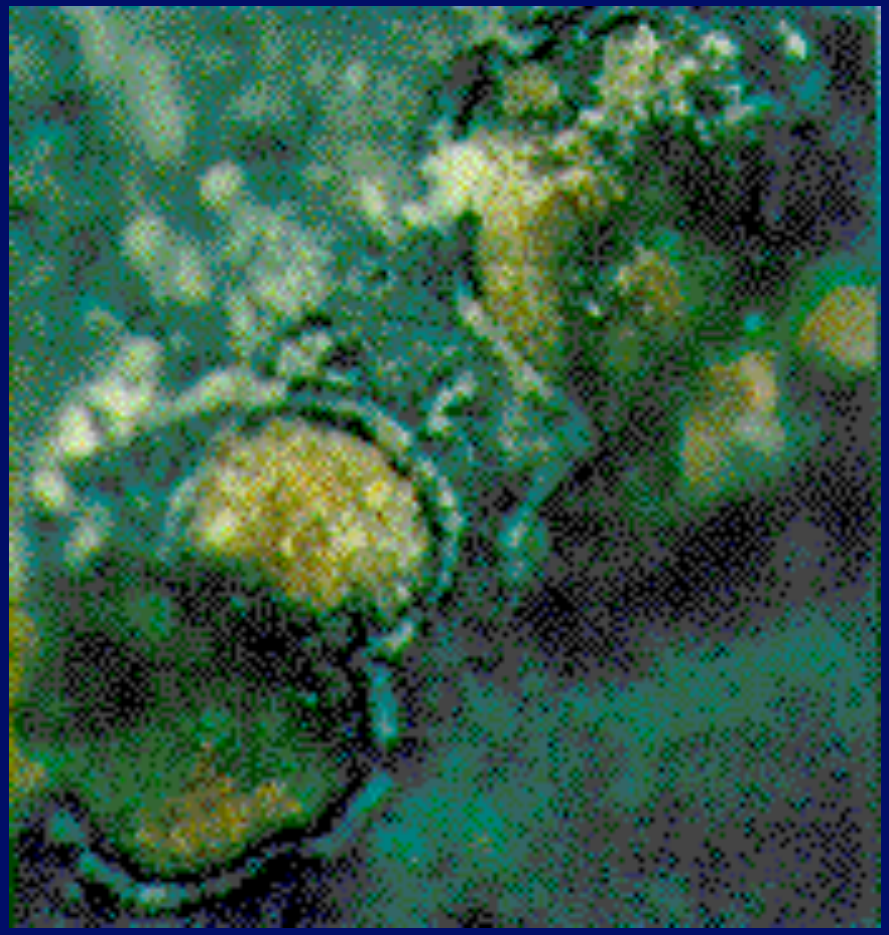
Found in fractures - $\sim 3.6 \times 10^9$ yrs old
When water existed

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

Martian Life in ALH84001?

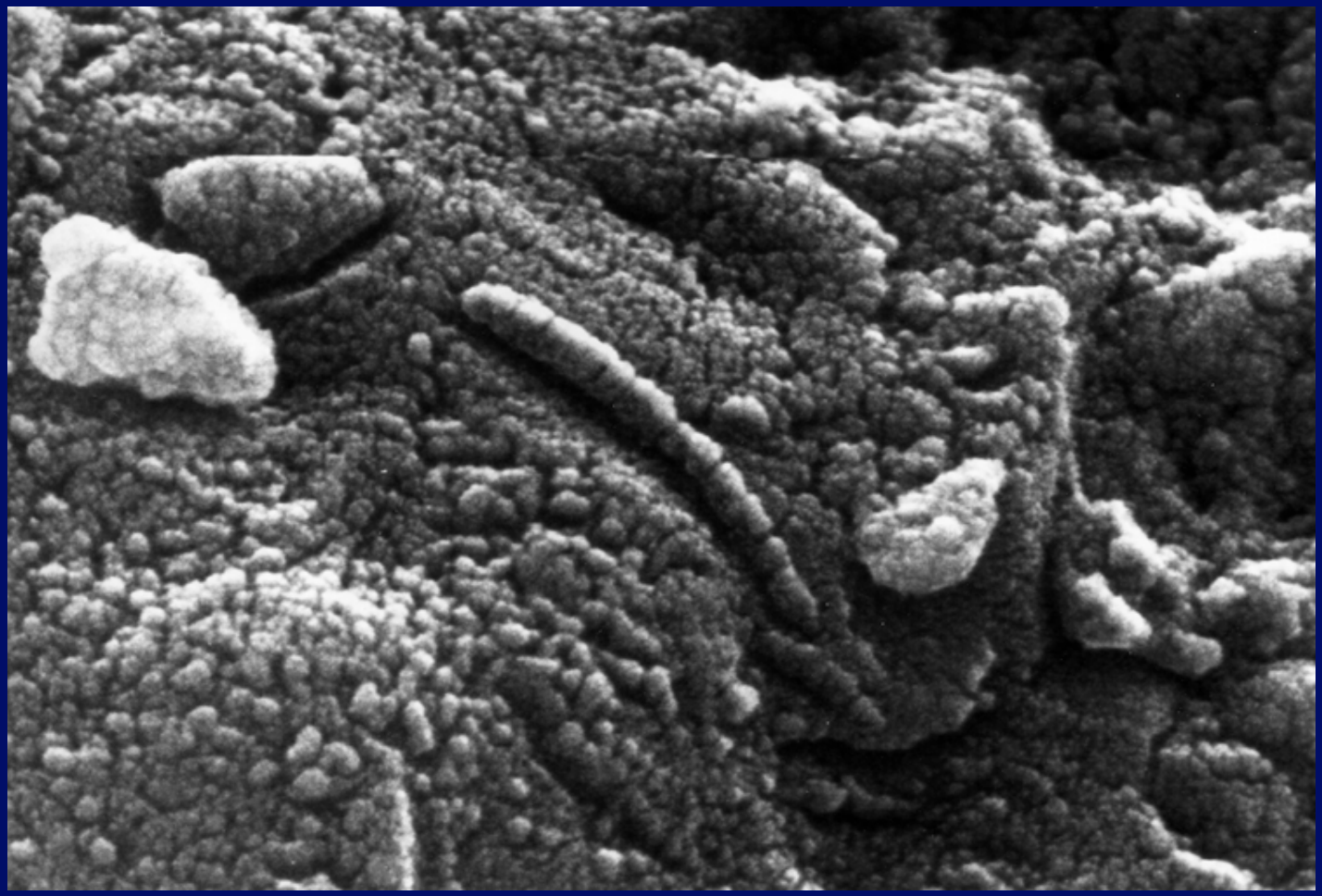
- PAHs (break down from life or abiogenic?)
- Carbonate globules (form in liquid water)
- Magnetite grains (on Earth, associated with microbes)
- Structures that look like “nano-bacteria”
  - 10 to100 times smaller than bacteria
- Nano-bacteria controversial even on Earth
- Hot springs deposits: life 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…