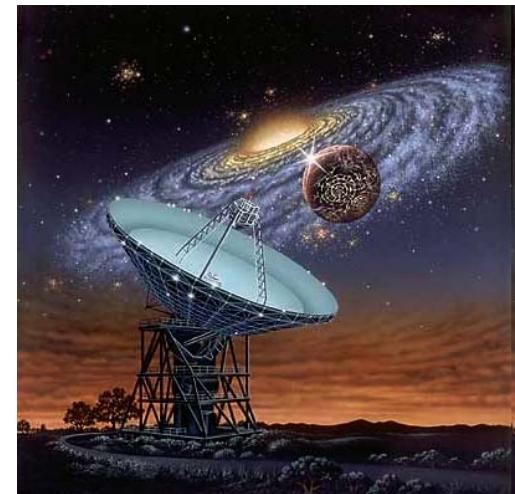


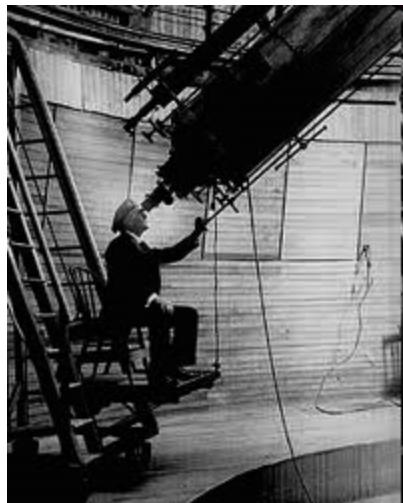
AST 309
part 2:
Extraterrestrial Life

The Search and Prospects for Life on Mars

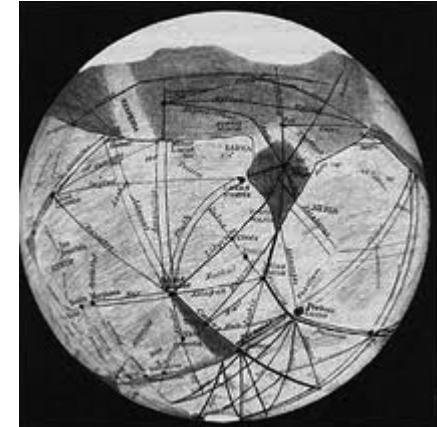
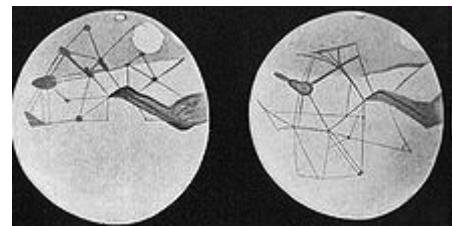


Our perception of Mars through history:

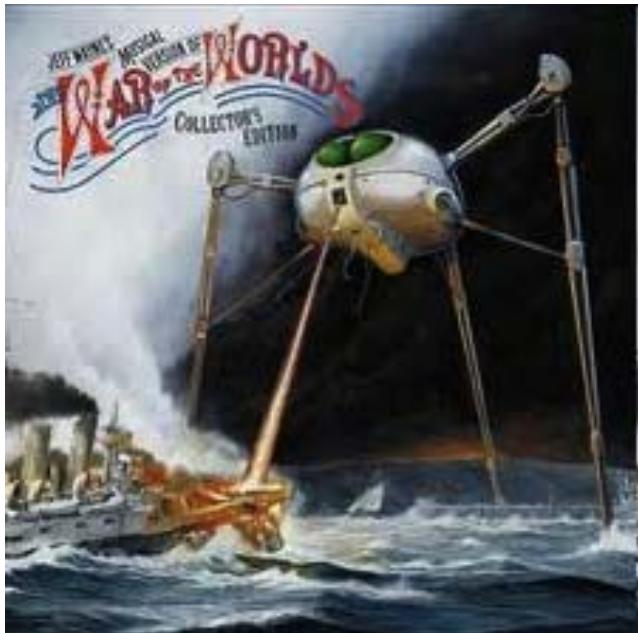
- named after the roman god of war (probably due to its color)
- (mainly) used by Johannes Kepler to derive laws of planetary motion
- early observations with telescopes showed polar caps, dark areas and moons
=> very Earth-like?
- Percival Lowell: canals on Mars? Intelligent life?



Lowell in the 1890s



Our perception of Mars through history:



H.G. Wells: "The War of the Worlds" (1898)



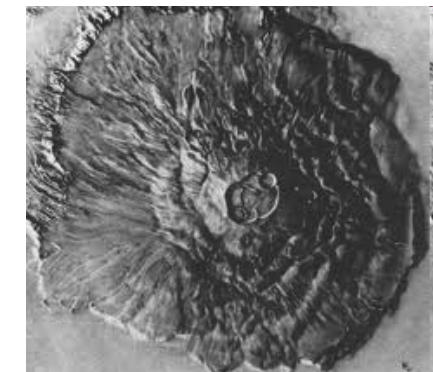
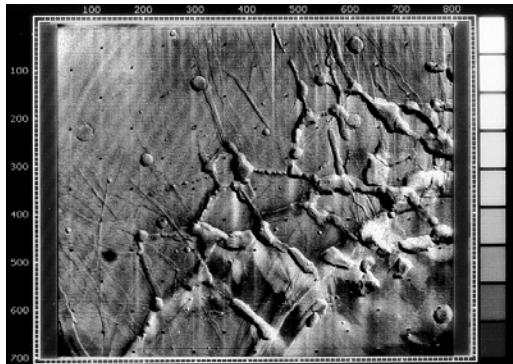
Orson Welles' radio broadcast
in 1938

Modern exploration of Mars:

Early missions:

- 1964 Mariner 4 first flyby
- 1971 Mariner 9 orbits Mars
- Mars 3 & 4 land (but stopped working)
- 1976 2 Viking orbiter + Landers
- 1988 Phobos 1 & 2 failed
- 1992 Mars Observer failed
- 1997 Mars Global Surveyor & Mars Pathfinder begin modern era

Mariner 4



Olympus Mons

Mars basic facts:

Distance: 1.5 AU

Period: 1.87 years

Radius: 0.53 R_Earth

Mass: 0.11 M_Earth

Density: 4.0 g/cm³

Satellites: Phobos and Deimos

Structure: Dense Core (~1700 km), rocky mantle, thin crust

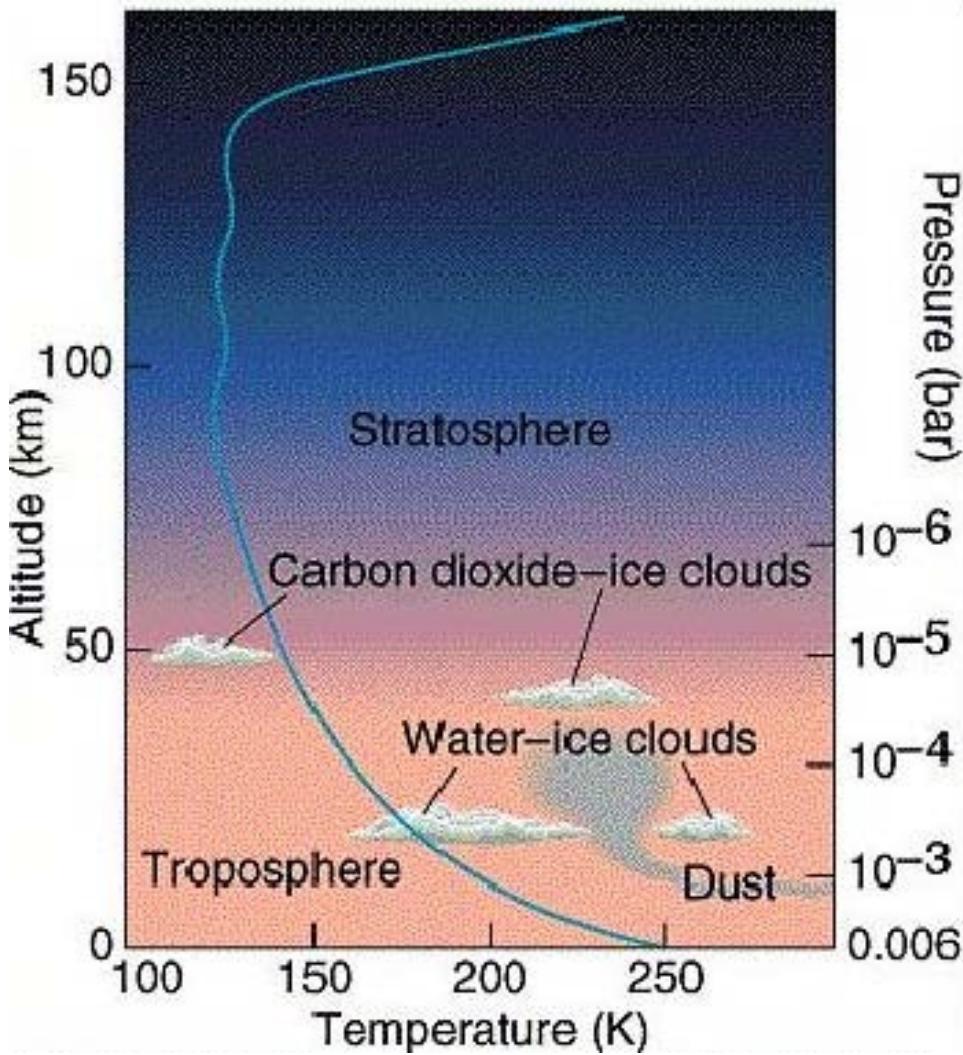
Temperature: -87 to -5 C

Magnetic Field: Weak and variable (some parts strong)

Atmosphere: 95% CO₂, 3% Nitrogen, argon, traces of oxygen



Mars atmosphere:



Very thin! ~0.7% of Earth's pressure

Pressure can change significantly because it gets so cold that CO₂ freezes out on polar caps

Viking atmospheric measurements

Composition
Surface pressure

95.3%	carbon dioxide
2.7%	nitrogen
1.6%	argon
0.13%	oxygen
0.07%	carbon monoxide
0.03%	water vapor
trace	neon, krypton, xenon, ozone, methane
1-9 millibars, depending on altitude; average 7 mb	

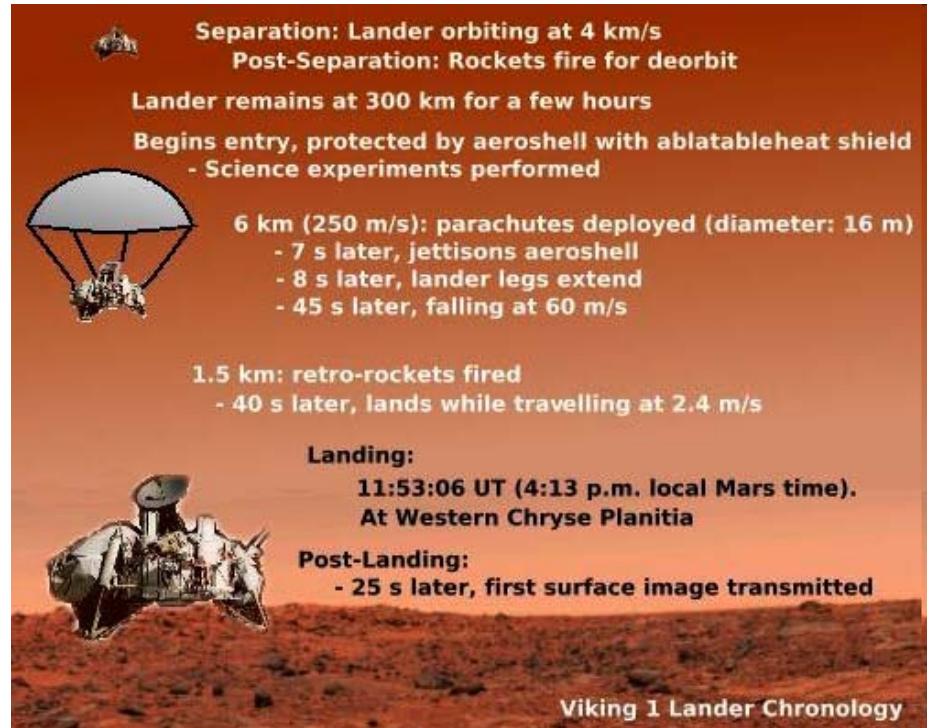
Viking on Mars:



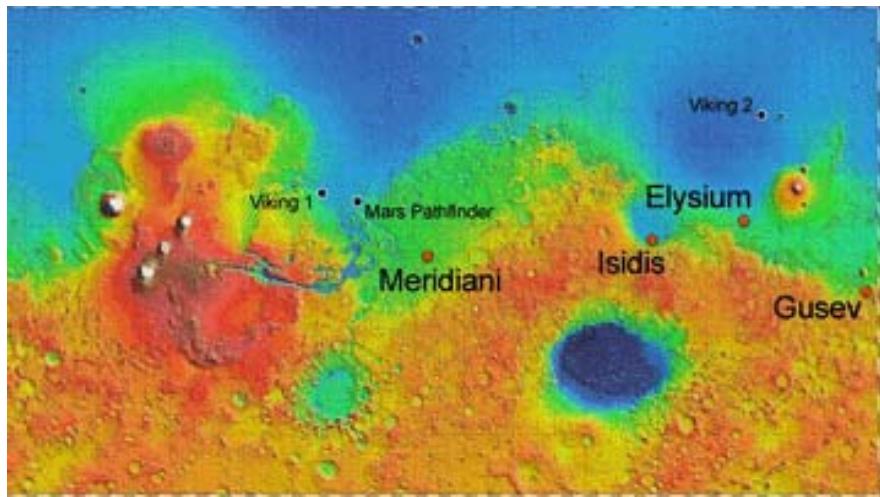
Viking 1 Lander touched down at Chryse Planitia (22.48° N, 49.97° W planetographic, 1.5 km below the datum (6.1 mbar) elevation). The Viking 2 Lander touched down at Utopia Planitia (47.97° N, 225.74° W, 3 km below the datum elevation) on September 3, 1976



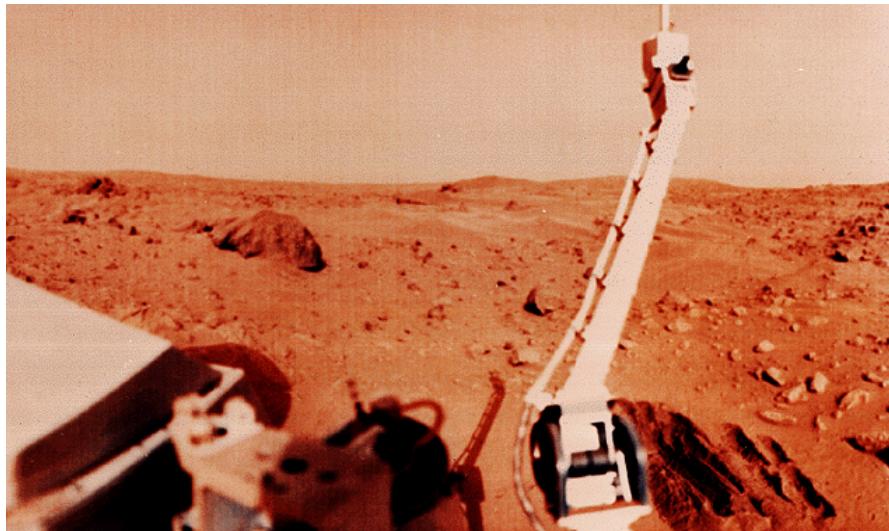
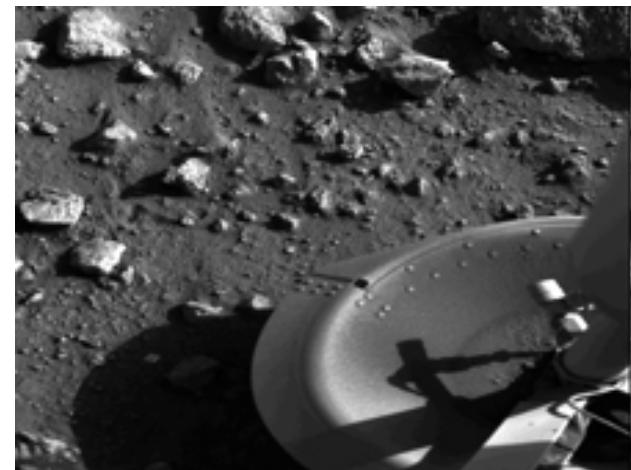
Milestone: both landers contained 3 micro-biological experiments!



Viking on Mars:

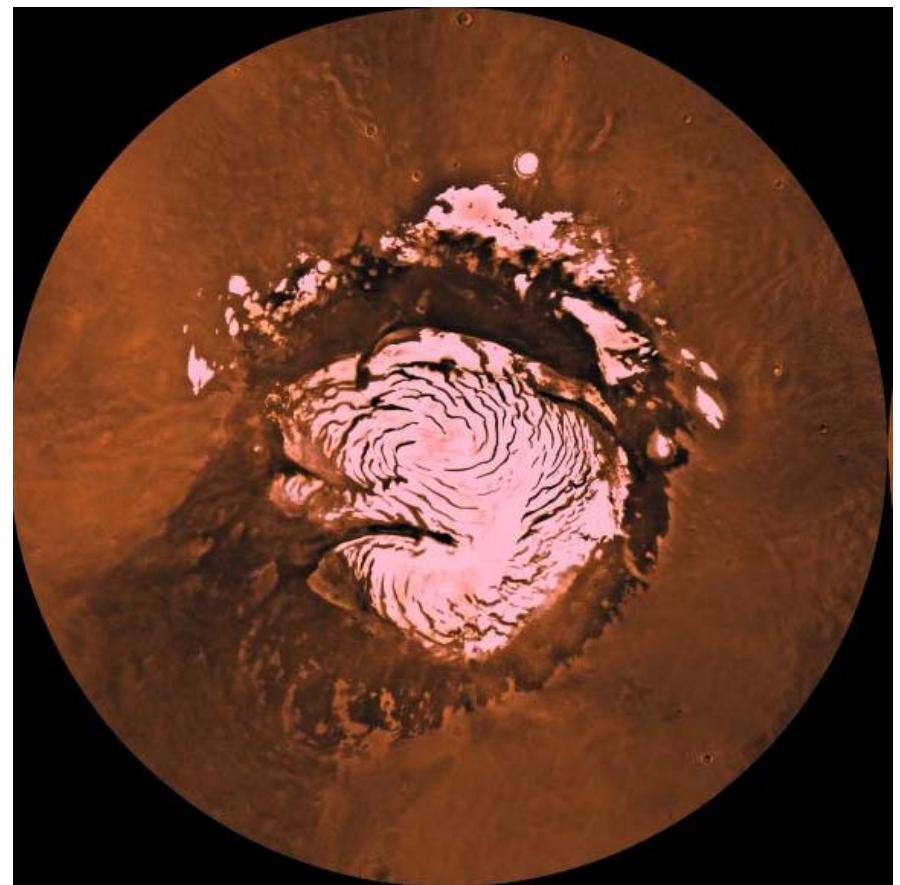


1st picture from the surface of Mars:



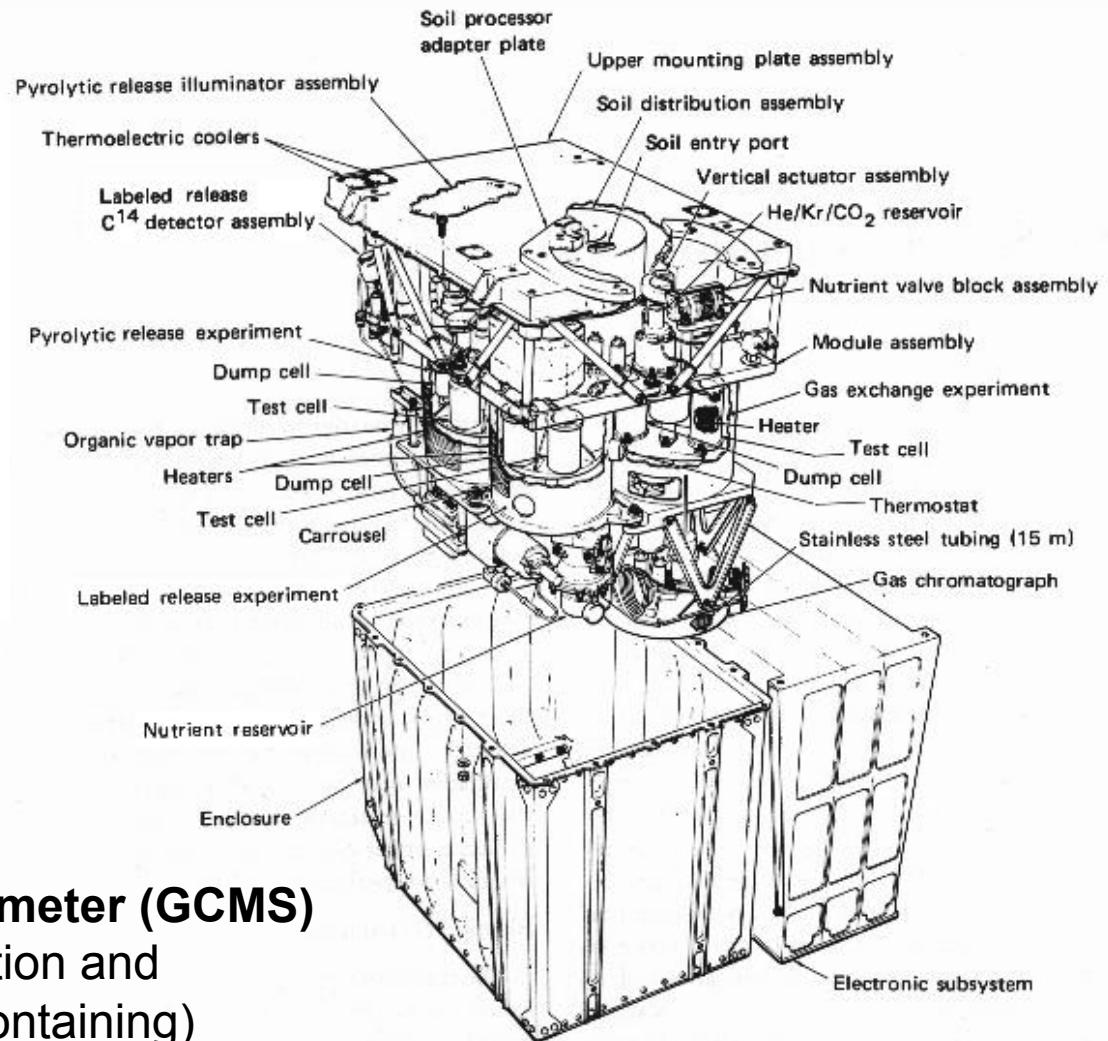
Viking on Mars:

pictures from orbit:



Viking on Mars:

Viking's biological package:



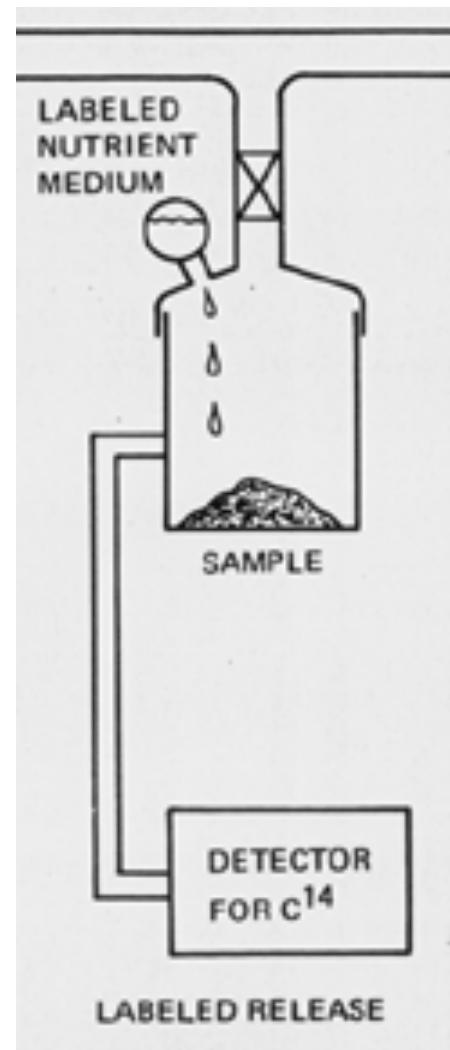
In addition, Viking carried a **Gas Chromatograph/Mass Spectrometer (GCMS)** that could measure the composition and abundance of organic (carbon containing) compounds in the martian soil.

Viking on Mars:

Viking's Biological Experiments:

1. The Labeled Release (LR) Experiment:

The LR experiment moistened a 0.5-cc sample of soil with 1 cc of a nutrient consisting of distilled water and organic compounds. The organic compounds had been labeled with radioactive carbon-14. After moistening, the sample would be allowed to incubate for at least 10 days, and any microorganisms would hopefully consume the nutrient and give off gases containing the carbon-14, which would then be detected. (Terrestrial organisms would give off CO₂, carbon monoxide (CO), or methane (CH₄.)

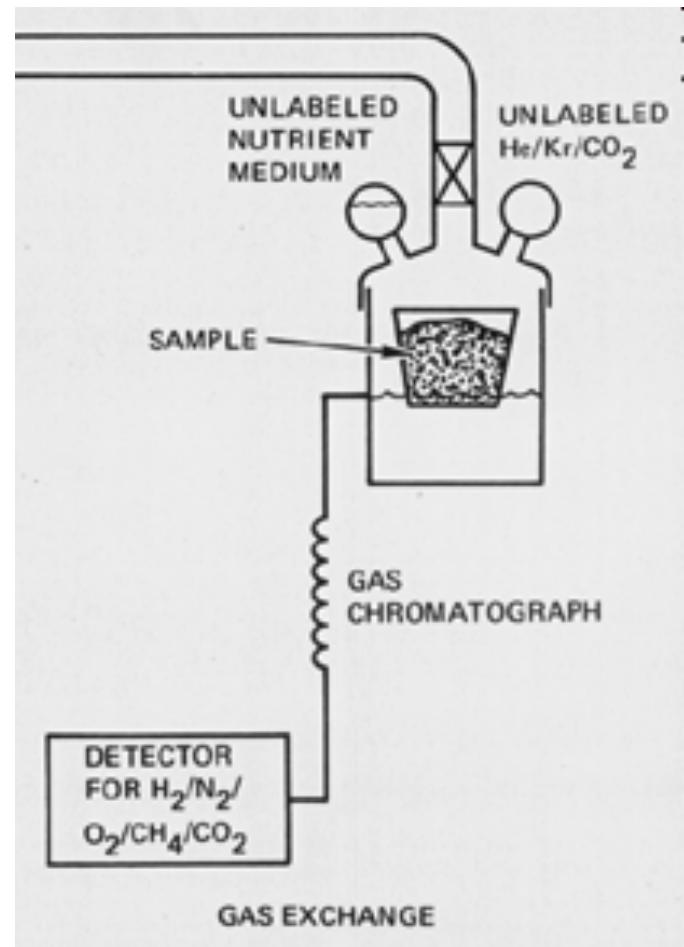


Viking on Mars:

Viking's Biological Experiments:

2. The Gas Exchange Experiment (GEX):

The GEX experiment partially submerged a 1-cc sample of soil in a complex mixture of compounds the investigators called "chicken soup". The soil would then be incubated for at least 12 days in a simulated martian atmosphere of CO₂, with helium and krypton added. Gases that might be emitted from organisms consuming the nutrient would then be detected by a gas chromatograph -- this instrument could detect CO₂, oxygen (O₂), CH₄, hydrogen (H₂), and nitrogen (N₂).

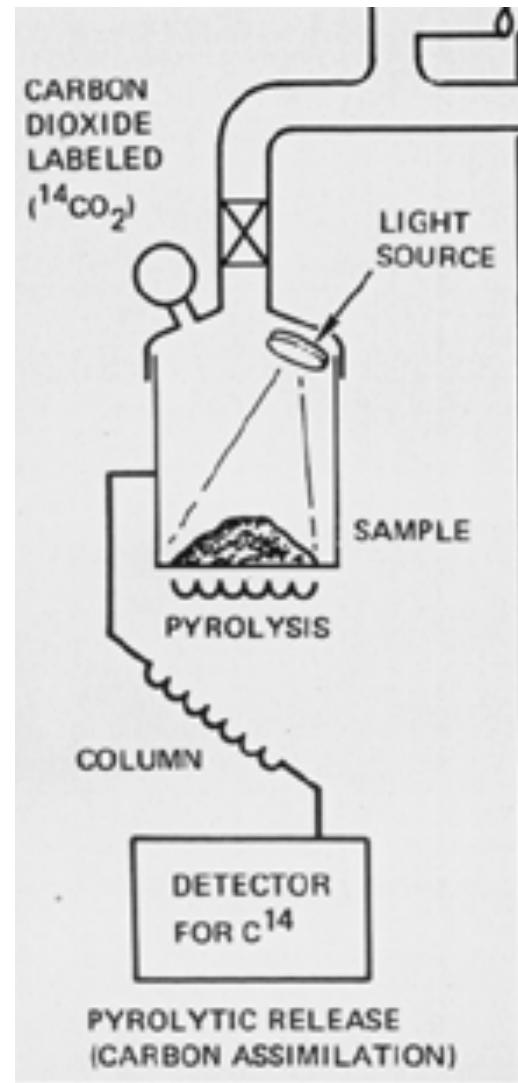


Viking on Mars:

Viking's Biological Experiments:

3. The Pyrolytic Release Experiment (PR):

Of the three Viking biology experiments, only the PR experiment approximated actual martian surface conditions and did not use water. In this experiment, a 0.25-cc soil sample was incubated in a simulated martian atmosphere of CO₂ and CO labeled with carbon-14. A xenon arc lamp provided simulated sunlight. After 5 days, the atmosphere was flushed and the sample heated to 625 degrees C (1157F) to break down, or *pyrolyze*, any organic material, and the resulting gases were passed through a carbon-14 detector to see if any organisms had ingested the labeled atmosphere.



Viking on Mars:

Viking's Biological Experiments Results:

To reduce the chance of false positives, the biology experiments not only had to detect life in a soil sample, they had to *fail* to detect it in another soil sample that had been heat-sterilized (the *control* sample). Had terrestrial life been tested with the Viking biology instrument, the following results would have been expected:

	<u>response for sample</u>	<u>response to heat-sterilized control</u>
GEX	oxygen or CO ₂ emitted	none
LR	labeled gas emitted	none
PR	carbon detected	none

Viking on Mars:

Viking's Biological Experiments Results:

In highly simplified form, these were the actual results from Mars:

	<u>response for sample</u>	<u>response to heat-sterilized control</u>
GEX	oxygen emitted	oxygen emitted
LR	labeled gas emitted	none
PR	carbon detected	carbon detected

The fact that both the GEX and PR experiments produced positive results even with the control sample indicates that **non-biological processes** are at work. Subsequent laboratory experiments on Earth demonstrated that highly-reactive oxidizing compounds (oxides or superoxides) in the soil would, when exposed to water, produce hydrogen peroxide. Oxidized iron, such as maghemite, could act as a catalyst to produce the results seen by the PR experiment.

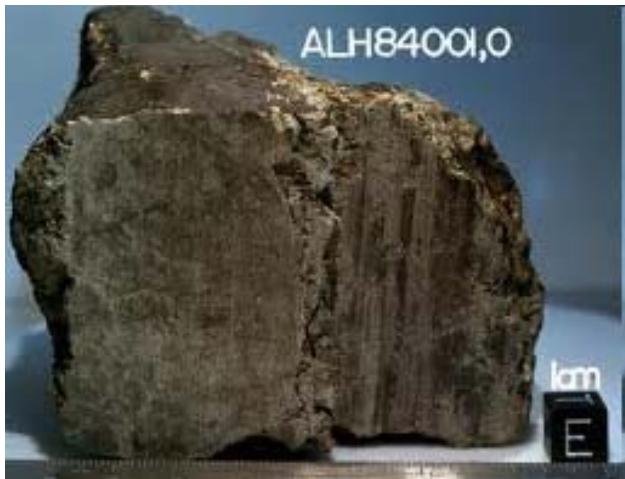
Viking on Mars:

The fact that the LR experiment released an initial positive result could be best explained by the fact that the soil has a strong oxidant built up due to a lack of ozone layer on the planet. This exposes the surface to UV light from the Sun. An oxidizing molecule would react with water, to produce hydrogen and oxygen, and nutrients to make carbon dioxide. This theory was upheld in August 2008 when the Phoenix lander detected a strong oxidizer known as perchlorate

Most important to the entire mission was that the GCMS experiment did not reveal any significant levels of carbon!

So we don't have any evidence for current surface life on Mars, but what about extinct life?

Martian Microfossils?



A martian microfossil?



A group of scientists led by David McKay of NASA's Johnson Space Center published an article in the 16 August 1996 issue of *Science* magazine announcing the discovery of evidence for primitive bacterial life on Mars.

An examination of a meteorite found in Antarctica and believed to be from Mars shows: 1) hydrocarbons which are the same as breakdown products of dead micro-organisms on Earth, 2) mineral phases consistent with by-products of bacterial activity, and 3) tiny carbonate globules which may be microfossils of the primitive bacteria, all within a few hundred-thousandths of an inch of each other.

Martian Microfossils?

McKay et al. proposed the following scenario:

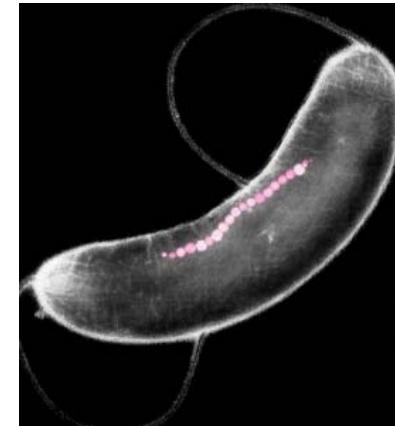
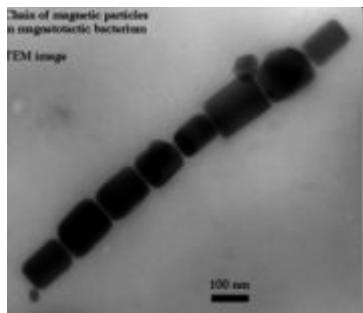
1. The original igneous rock solidified within Mars about 4.5 billion years ago, about 100 million years after the formation of the planet. (Based on isotope ages of the igneous component of the meteorite)
2. Between 3.6 and 4 billion years ago the rock was fractured, presumably by meteorite impacts. Water then permeated the cracks, depositing carbonate minerals and allowing primitive bacteria to live in the fractures.
3. About 3.6 billion years ago, the bacteria and their by-products became fossilized in the fractures. (Based on isotope ages of the minerals in the fractures)
4. 16 million years ago, a large meteorite struck Mars, dislodging a large chunk of this rock and ejecting it into space. (Based on the cosmic ray exposure age of the meteorite)
5. 13,000 years ago, the meteorite landed in Antarctica.
6. The meteorite, ALH84001, was discovered in 1984 in the Allan Hills region of Antarctica.

Martian Microfossils?

The case of AHL 84001 is still hotly contested!

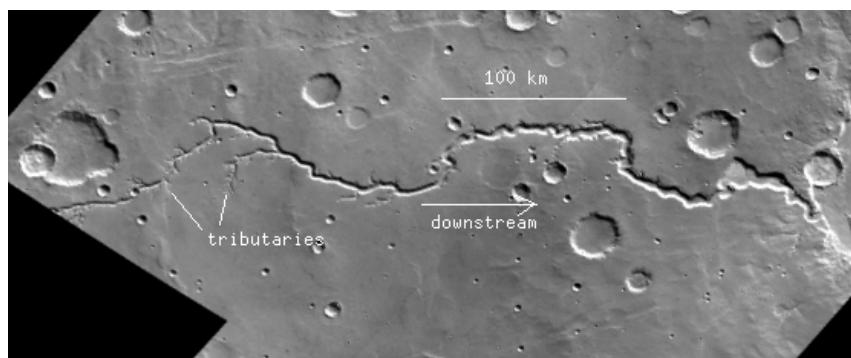
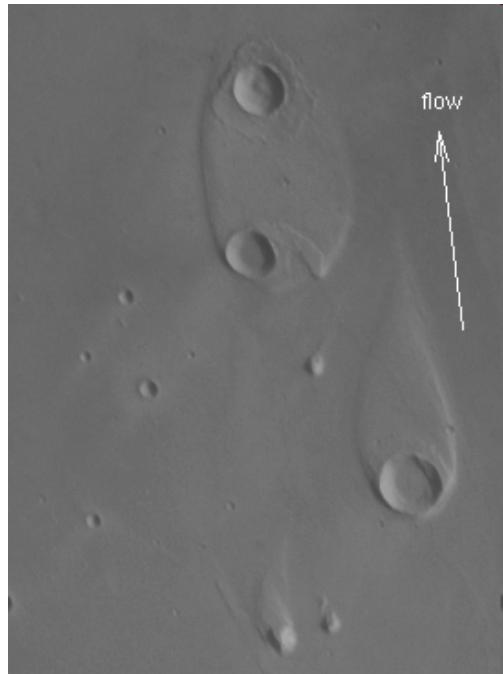
1. The organic compounds could be contamination or unrelated to life
2. The microfossils are too micro to be life (no space for DNA)
3. The shapes could be misleading, (crystals, or effects of impact, etc...)

Best “surviving” line of evidence is the presence of very small crystals of magnetite and iron pyrite:



Magnetotactic bacteria on Earth

Evidence for surface water on early Mars:



Nirgal Vallis



Evidence for surface water on early Mars:

Superficially, the valley networks resemble river-cut valleys on Earth, and initial speculation focused on this explanation for them. Despite the fact that there is no running water or rain on Mars at the present time, earlier in martian history such conditions might have prevailed. However, on further examination, there are significant differences between the martian valleys and river valleys on Earth. First and most important, a terrestrial river valley contains a river, or at least a dry river bed, and no such features have been seen on Mars at the resolution limit of current images. In addition, even the densest tributary networks on Mars are much sparser than their terrestrial counterparts. These facts argue against a purely running-water origin for the martian valleys.

An alternate explanation involves **sapping processes**, the weathering and erosion of terrain by emerging groundwater. When the underlying soil is weakened by groundwater flow, the overlying surface collapses. Similar processes have acted on Earth in, for example, the Navajo Sandstone of the Colorado Plateau. This explanation works well for the long winding valleys such as Nirgal Vallis. For the more complex small valley networks, a mixture of the two mechanisms may be required, in which the valleys were initially formed by runoff of water, and then enhanced by sapping.

Evidence for surface water on early Mars:

Today, Mars appears to be very dry. There is little water in the atmosphere and only a small amount of water ice in evidence on the surface. Yet the planet is covered with features that are best explained by the movement of water, either in catastrophic floods or the slow movement of groundwater.

This water that was present early in the history of Mars was lost to space over eons, some of it still present in great underground deposits of ice and maybe some groundwater. To explore the past and present hydrosphere of Mars is a task for the future exploration of Mars.



Present day ice inside a crater



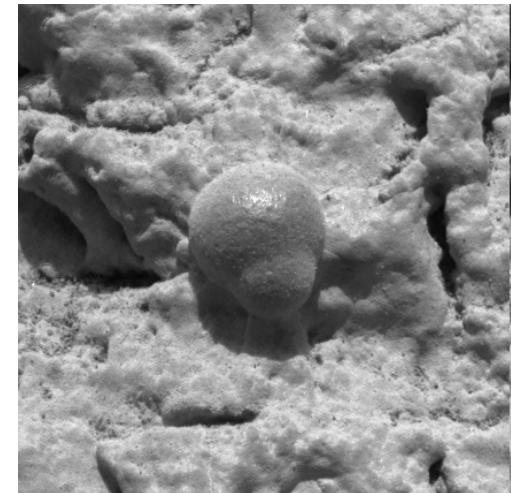
A debris-covered glacier on Mars

Mars Rovers:

Field geologists on wheels!



Found hematite (may form in liquid water):



Looking for Signs of Past Water on Mars



Found jarosite (forms only in acidic water)!



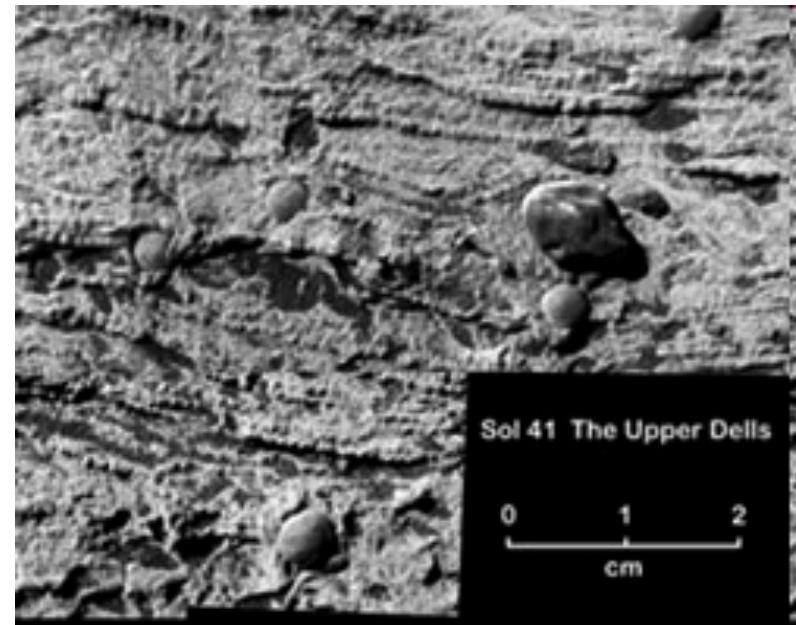
Mars Rovers:

Acidic Water on Earth:



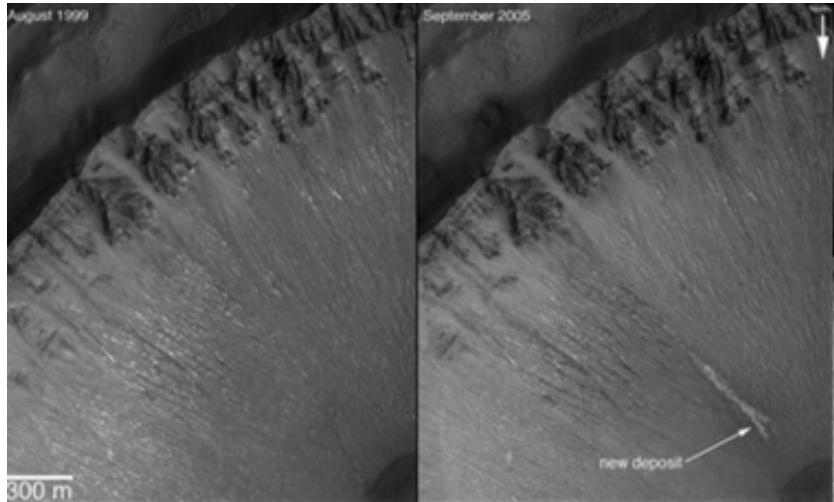
On Earth, microbial communities thrive in highly acidic waters rich in iron and sulfur, such as the blood-red waters of the Rio Tinto in southwestern Spain. Among the minerals dissolved in the Rio Tinto is jarosite, an iron- and sulfur-bearing mineral also found on Mars

Even flowing water?

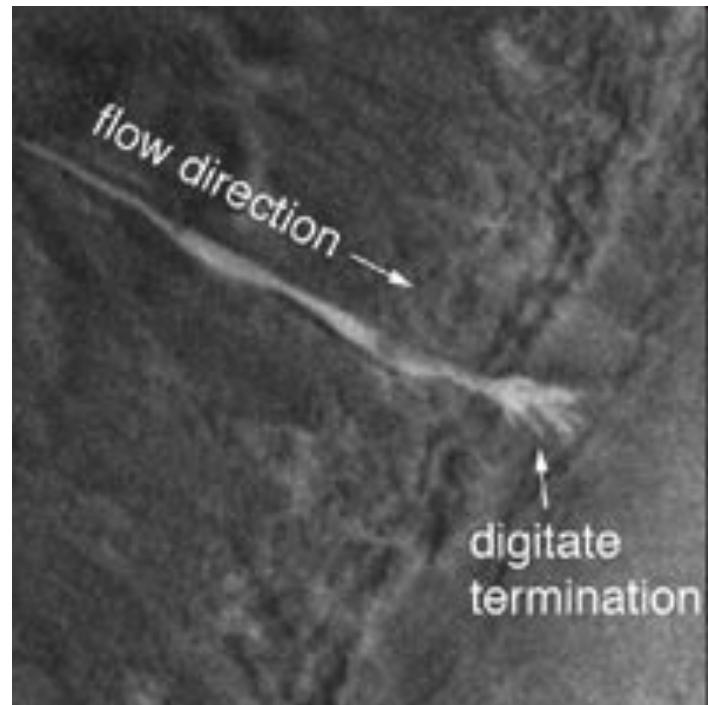


One characteristic of rocks formed by flowing water are fine, undulating layers of sediment, like those at the bottom of a stream, that flow over and cut into one another, known as crossbeds.

Evidence for present flowing water:



Two images taken by Mars Global Surveyor in Aug. 1999 (left) and Sep. 2005 (right) of gullies on the wall of a crater in the Centauri Montes region of Mars. The later one shows the appearance of new, light-colored deposit, possibly due to running water



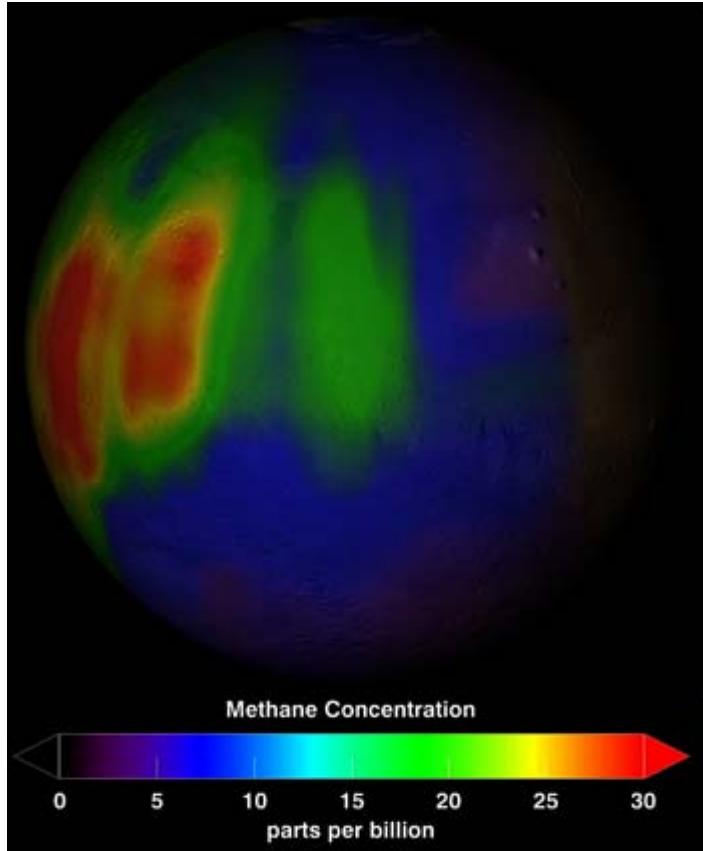
Wet (and Warm) Mars?

Two models for early Mars (~4 Gyrs ago):

- 1.) Mars had a much thicker atmosphere (mostly CO₂) that allowed a moderate greenhouse effect and thus warmer temperatures. Water was liquid on the surface (picture left). The CO₂ slowly dissolved in the water and got incorporated into rocks. CO₂ got thus removed from the atmosphere and greenhouse effect shut down. Temperatures and pressure dropped to today's values. Most of the water evaporated (and escaped into space) or got locked in a thick permafrost layer. (Problem: more greenhouse gas would also create more clouds and limit warming effect, plus no carbonates have been found on Mars (yet).)
- 2.) Mars was always cold and all surface features (rivers, valleys) were created by sudden floods due to asteroid or comet impacts. (Problem: some features look like they were created by lots of water over a very long time (Myrs).)



Methane on Mars!

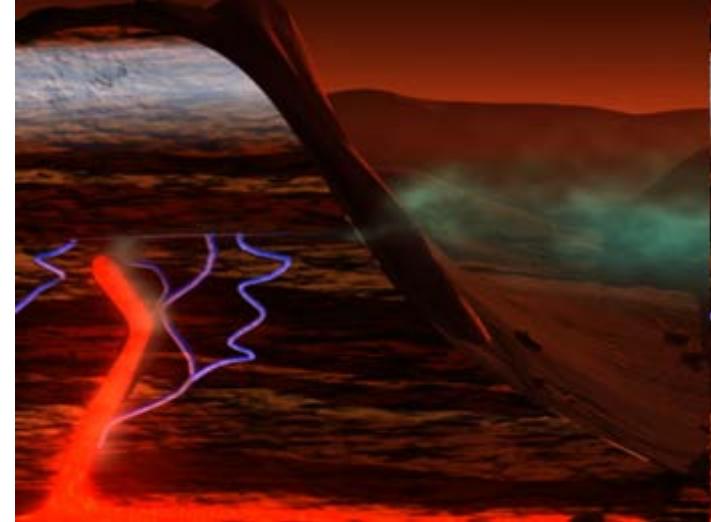


A color-coded map of the release of methane in the northern summer on Mars.
Credit: Mumma, et al., (NASA)

Trace amounts of Methane (CH_4)
Detected by space probes and
ground-based telescopes.
And it is seasonal!

So what releases this methane?

1. life (methanogenic bacteria)
2. Volcanoes

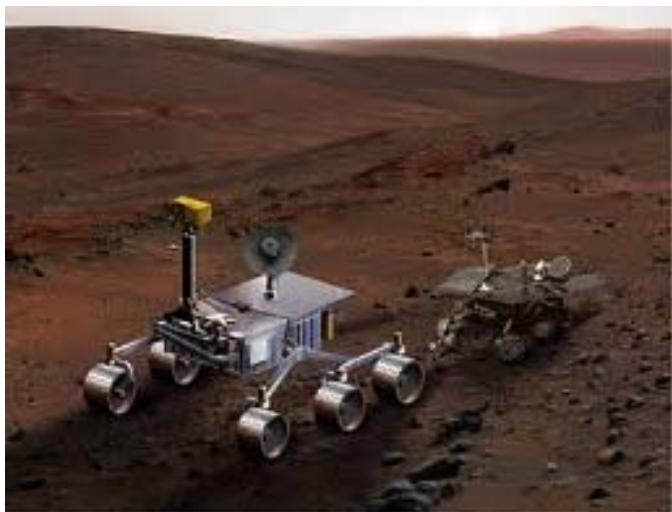


Subsurface water, carbon dioxide, and the planet's internal heat combine to release methane that had been trapped in the ice. Credit: NASA/Susan Twardy

Mars Science Laboratory:



Huge rover! Scheduled for launch in 112 days from today (Aug. 3rd 2011)
Landing on Mars in Aug 2012



Target site: Gale crater

Mars Science Laboratory:

Mars Science Laboratory will study Mars' habitability. To find out, the rover will carry the biggest, most advanced suite of instruments for scientific studies ever sent to the martian surface. The rover will analyze dozens of samples scooped from the soil and drilled from rocks. The record of the planet's climate and geology is essentially "written in the rocks and soil" -- in their formation, structure, and chemical composition. The rover's onboard laboratory will study rocks, soils, and the local geologic setting in order to detect chemical building blocks of life (e.g., forms of carbon) on Mars and will assess what the martian environment was like in the past.



Mars Science Laboratory:

The MSL mission has **four primary science objectives** to meet the overall habitability assessment goal:

The first is to assess the **biological potential of at least one target environment** by determining *the nature and inventory of organic carbon compounds*, searching for the chemical building blocks of life, and identifying features that may record the actions of biologically relevant processes.

The second objective is to characterize the **geology** of the landing region at all appropriate spatial scales by investigating the chemical, isotopic, and mineralogical composition of surface and near-surface materials, and interpreting the processes that have formed rocks and soils.

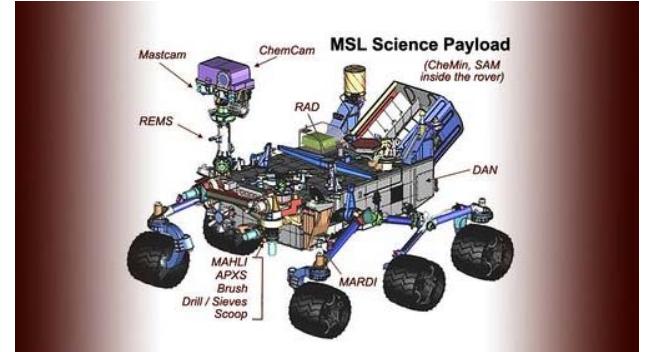
The third objective is to investigate planetary processes of relevance to **past habitability (including the role of water)** by assessing the long timescale atmospheric evolution and determining the present state, distribution, and cycling of water and carbon dioxide.

The fourth objective is to characterize the broad spectrum of **surface radiation**, including galactic cosmic radiation, solar proton events, and secondary neutrons.

Mars Science Laboratory:

MSL instruments:

- Mastcam is the Mast Camera instrument.
- ChemCam is the Chemistry and Camera instrument.
- RAD is the Radiation Assessment Detector instrument.
- CheMin is the Chemistry and Mineralogy instrument.
- SAM is the Sample Analysis at Mars instrument.
- DAN is the Dynamic Albedo of Neutrons instrument.
- MARDI is the Mars Descent Imager instrument.
- MAHLI is the Mars Hand Lens Imager instrument.
- APXS is the Alpha Particle X-ray Spectrometer instrument.
- The brush, drill, sieves and scoop are tools on the rover's robotic arm.
- REMS is the Rover Environmental Monitoring Station.



If you want to learn more about this cool mission go to:

<http://marsprogram.jpl.nasa.gov/msl/>

The Future:

Mars Sample Return mission:
> 2020



Manned mission:
> 20??

Summary:

- Present-day Mars is cold and dry
- Atmosphere is very thin, mostly CO₂
- The Viking Mission bio-results are inconclusive, but most likely due to non-biological chemistry
- The evidence for ancient life in AHL 84001 is still debated and contested
- Mars Exploration Rovers find evidence for past water
- Early Mars warmer and with oceans? Maybe...
- Methane on Mars!
- **Mars remains a mysterious but cool planet!**