Mars: Science and Engineering (Week 2)

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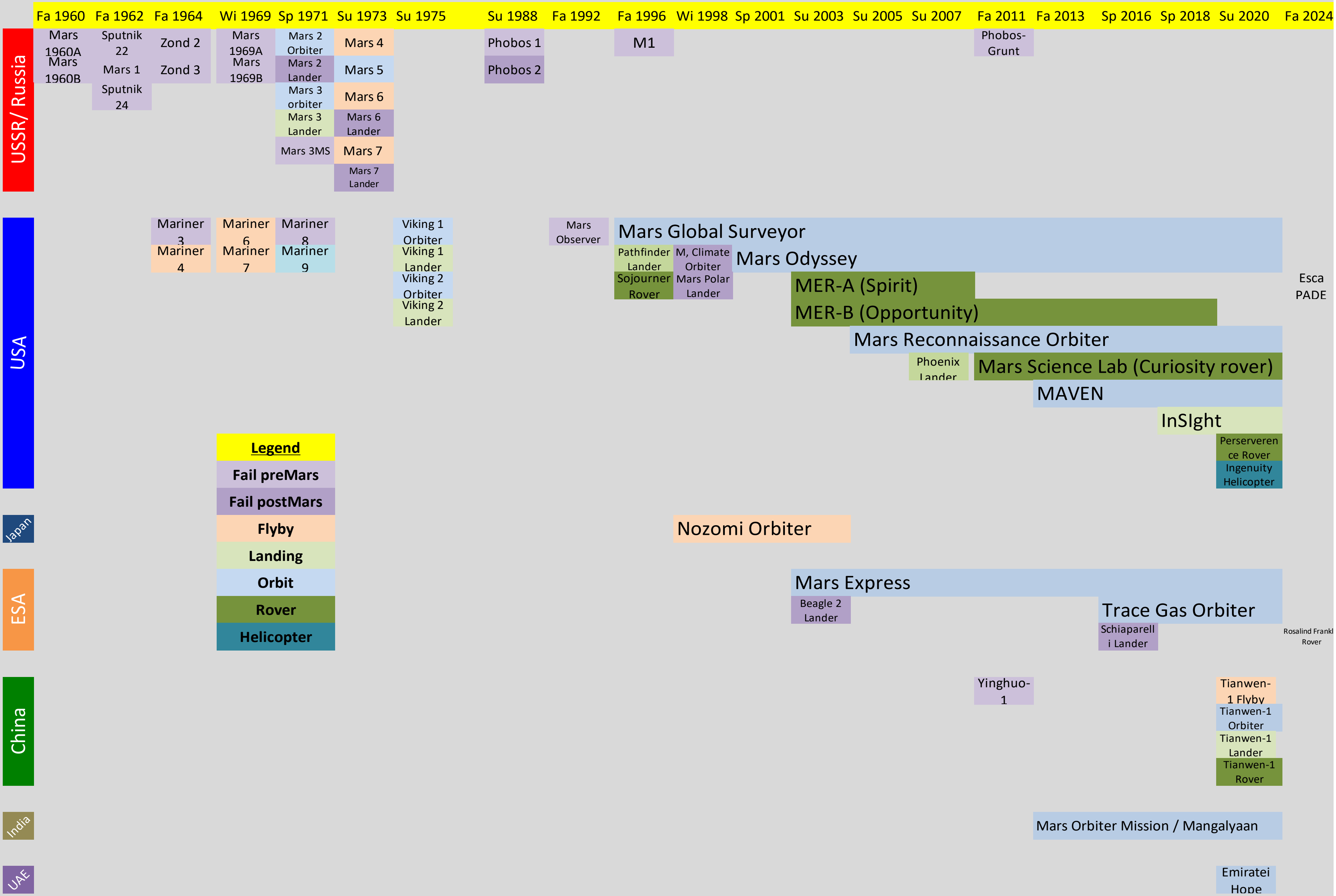
CMU Osher

Fall 2023

Course Outline

- Week 1
  - Astronomy background
  - Early flights with no or minimal success
  - Mariner Program
- **Week 2**
  - 1973: Soviet Mars program
  - 1975: US Viking program
  - 1990s: MGS, Pathfinder, Sojourner, Nozomi
- Week 3
  - Early 2000s: Odyssey, Spirit & Opportunity, Mars Express
  - Late 2000s: Mars Reconnaissance Orbiter, Phoenix lander
- Week 4
  - 2010s: Curiosity, MAVEN, Mangalayan, Insight
  - 2020s: Perseverance, Ingenuity, Tianwen, Emirati Hope
  - Future: EscaPADE, Exo-Mars
  - Far future: humans on Mars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Sputnik 22
Mars 1
Sputnik 24
Zond 2
Zond 3
Mars 1969A
Mars 1969B
Mars 2 Orbiter
Mars 2 Lander
Mars 3 orbiter
Mars 3 Lander
Mars 3MS
Mars 4
Mars 5
Mars 6
Mars 6 Lander
Mars 7
Mars 7 Lander
Phobos 1
Phobos 2
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Phobos-Grunt
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Mariner 3
Mariner 4
Mariner 6
Mariner 7
Mariner 8
Mariner 9
Viking 1 Orbiter
Viking 1 Lander
Viking 2 Orbiter
Viking 2 Lander
Mars Observer
Mars Global Surveyor
Pathfinder Lander
Sojourner Rover
M, Climate Orbiter
Mars Polar Lander
Mars Odyssey
MER-A (Spirit)
MER-B (Opportunity)
Mars Reconnaissance Orbiter
Phoenix Lander
Mars Science Lab (Curiosity rover)
MAVEN
InSIght
Perserverence Rover
Ingenuity Helicopter
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Nozomi Orbiter
ESA
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Beagle 2 Lander
Trace Gas Orbiter
Schiaparelli Lander
Rosalind Frankl Rover
China
Yinghuo-1
Tianwen-1 Flyby
Tianwen-1 Orbiter
Tianwen-1 Lander
Tianwen-1 Rover
India
Mars Orbiter Mission / Mangalyaan
UAE
Emiratei Hope

Pre-Viking Soviet Missions

- Mars 4 to Mars 7 were intended for 1973 launch to pre-empt the 1976 US Viking missions, but planetary positioning was poor necessitating smaller payloads in the form of separate orbiter and lander launches
- **Mars 4** lander could not do course correction to due transistor failure but sent back 12 pictures at 1200 miles
- **Mars 5** orbiter developed an instrument compartment leak, so it operated in orbit for only 3 weeks and returned about 60 pictures and surface chemical composition data
- **Mars 6** lander returned data on a near-successful landing but crashed (or lost its radio)
- **Mars 7** lander failed to enter the Martian atmosphere and remained in heliocentric orbit

Early US Landers

- JPL's Surveyors 1, 3, and 5-7 soft-landed on the moon starting in 1966

The Cancelled "Voyager Mars" Program

- "Voyager Mars" was part of the Apollo Applications Program
- Planning was in 1966-1968 for 1974 launch with manned missions planned for the 1980s!
- Based on Apollo spaceships, but later dismissed based on Mariner data on the Martian atmosphere
- First major NASA program cancelled by Congress
- Evolved into Viking 1 and 2
- (Mariner 11 and 12 were sent to the outer planets and beyond, renamed as Voyager 1 and 2)

Viking Mission Overview

- Viking 1 and 2 each comprised an orbiter and a lander to reach Mars in 1976
- Cost $1 billion ($5 billion in current value)
- Search for life was a major goal
- Over 20% of the cost relates to sterilization

Viking Spacecraft

Viking Engineering

- 5115-pound orbiters, 8 feet in diameter, powered by four 32-foot solar panels (620 watts), similar to the Mariners
- Entry, Descent and Landing were the biggest unknowns
  - Earth landings are based on aerobraking, sub-sonic parachutes, and a water landing (US) or retrorockets (USSR)
  - Without an atmosphere, *moon* landings are based on retrorockets (and the lander need not be aerodynamic)
  - On Mars the atmosphere is thin, but significant
  - The strategy was aerobraking, hypersonic parachutes, and then retrorockets
- 1270-pound lander made of aluminum and titanium included RTG power source (60 watts from plutonium-236), twin 18K RAM onboard computers, weather station, seismometer, S-band radio with high and low gain antennas, UHF radio, 2 cameras, surface sampler boom, biology processor, descent engine and propellant tank. Similar to the Surveyors.

Contemporaneous Viking Video

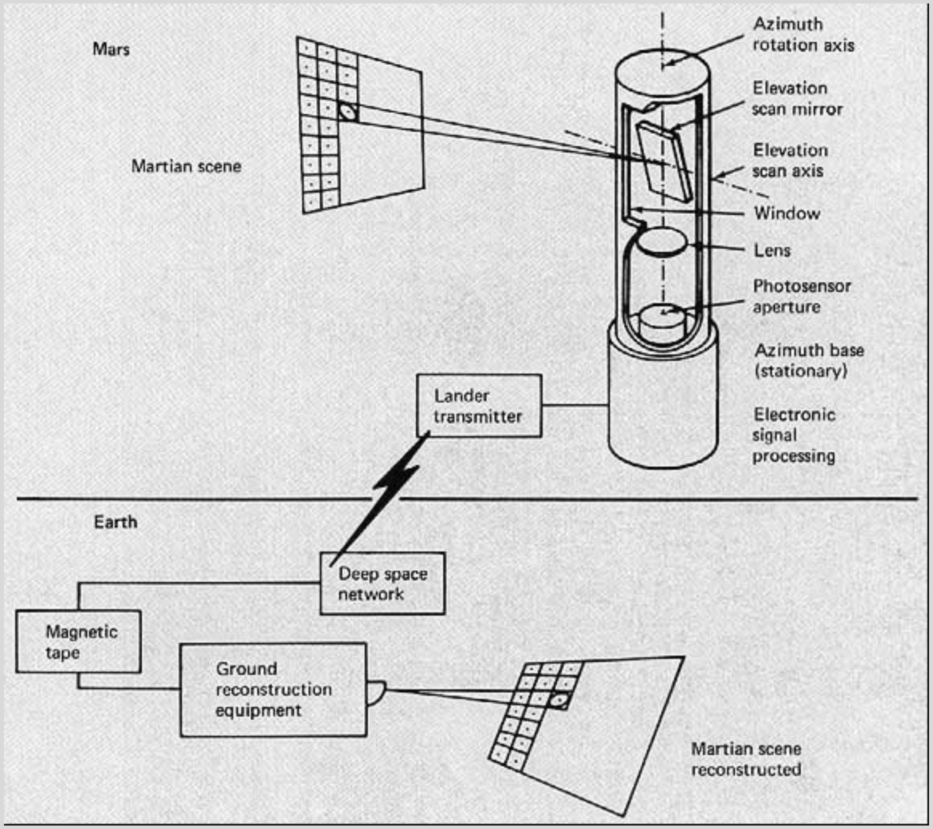
- Viking Documentary (12:08) [garbled start, some bad subtitles]

Orbiter Instrumentation

- Twin 88-pound television cameras with telescopes and mechanical shutters and 160-megabyte tape recorders
  - 1056 lines by 1182 samples at 7 bits (128 intensity levels)
  - 1 megabyte per picture
  - Six color filters: blue (0.35 to 0.53 μm), yellow (0.48 - 0.70), violet (0.35 - 0.47), green (0.50 - 0.60), red (0.55 - 0.70), and clear
  - Each pixel is about 120 feet on a side at 900 miles elevation
- Infrared spectrometer for water vapor mapping
- Infrared radiometer for thermal mapping

Lander Imager Engineering

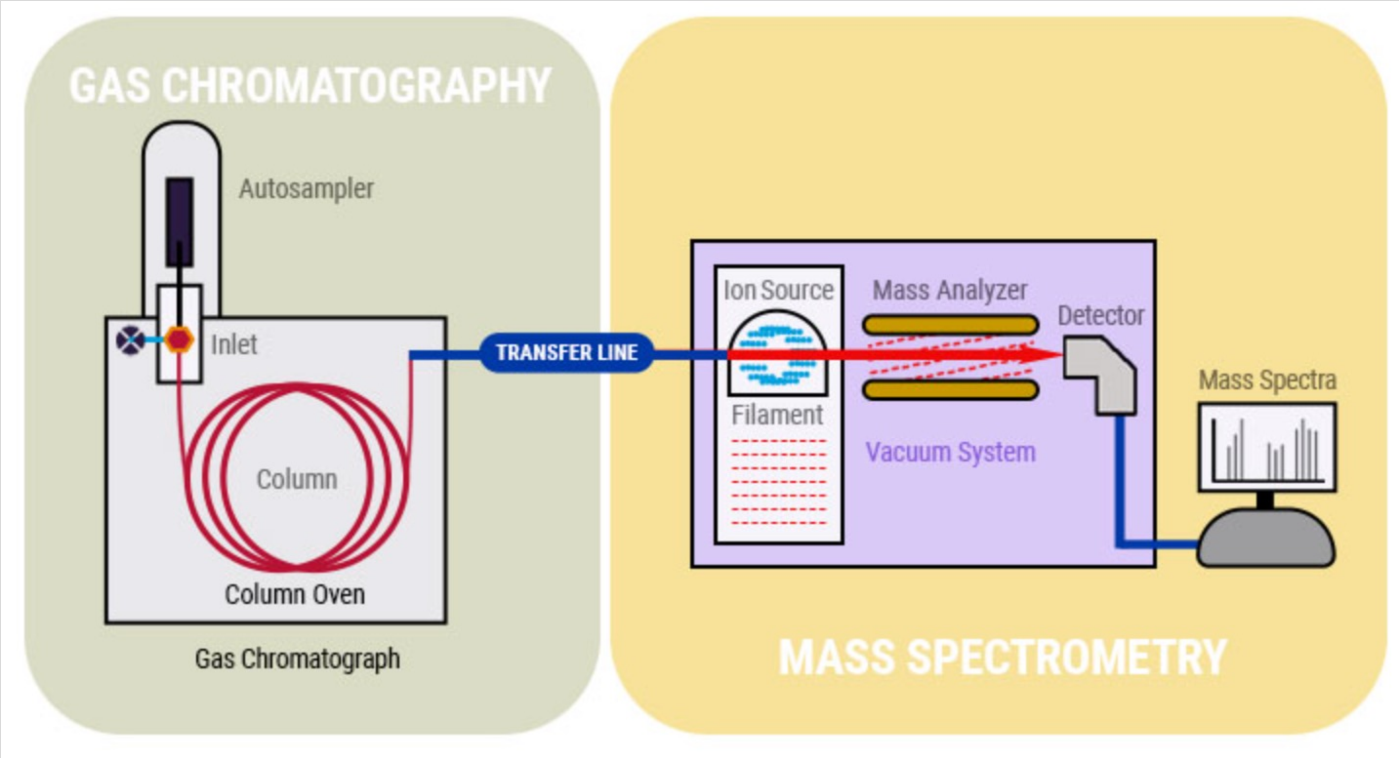
- Used cutting edge "facsimile" technology that had few moving parts and good balance of reliability and image quality for a reasonable (high) price and weight (16 pounds each)
- Image rate is 4.7 lines per second



- Could be baked to 110° C, and could transmit in real time (no storage) at 16K and 250 bits per second

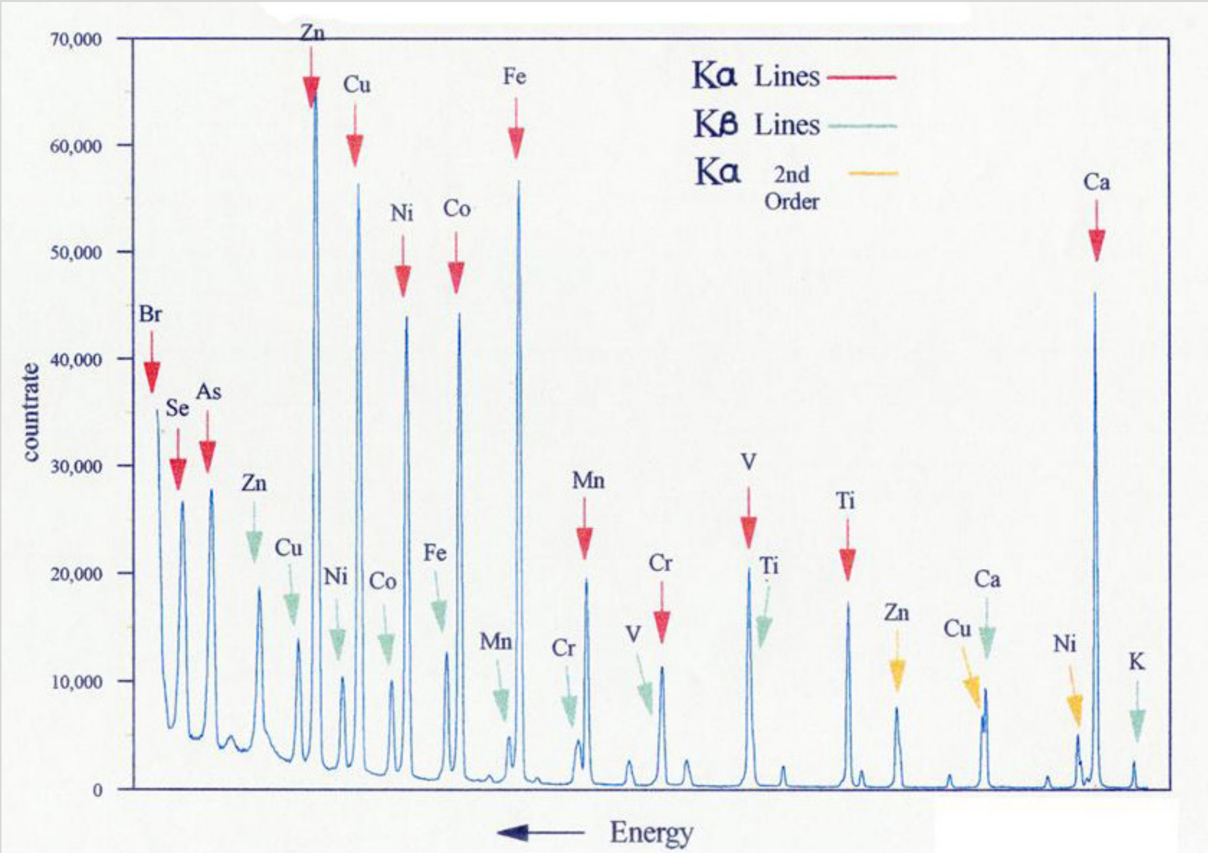
Lander Instrumentation

- Gas chromatograph mass spectrometer for organic chemistry analysis of soil
  - GC separates a mixture of volatile substances based on general chemical and/or physical properties
  - MS creates ions and fragment ions and measures mass to charge ratio: fingerprints of specific organic chemicals
  - Needed to get from room-sized to 1 cubic foot
  - Costs rose from $15 million to $41 million



Lander Instrumentation

- Seismometer (only detected wind)
- X-ray fluorescence spectrometer for composition of heavier elements in rocks and soils
  - X-rays (from iron-55 and cadmium-109) bombard the soil, then each element produces its own characteristic x-rays, which are counted and recorded



- Biological laboratory (3 different instruments)

Biology Experiments in Soil

- Contemporaneous Viking Documentary (5:28)

Vikings' Trip to Mars

- Viking 1
  - Launched August 20, 1975, on Titan / Centaur
  - Course corrections August 27, 1975, and June 10 & 15, 1976
  - Entered orbit June 19, 1976 (periapsis 1K mi, apoapsis 20K mi)
  - Immediately found that the proposed landing site in Chryse Planitia ("Golden Plain") was rougher than expected, and a new site on its western slope was chosen
  - Successful landing July 20, 1976 (16 days late). Due to the speed-of-light time delay, touchdown on Earth was recorded 19 minutes after actual touchdown. The first pictures showed nearby rocks large enough to have prevented a safe landing.
- Viking 2:
  - Launched September 2, 1975
  - Course correction September 19, 1975
  - Entered orbit August 7, 1976
  - Re-routed landing in Utopia Planitia
  - Successful landing September 3, 1976, tilted 8.5°

Vikings 1 Launch (NY Times, p. 40)

After 9-Day Delay, Viking Is Launched on 10-Month Trip to Mars

By VICTOR K. Mc ELHENY
Special to The New York Times

CAPE CANAVERAL, Fla., Aug. 20 — A Viking spacecraft set off on a 10-month cruise to Mars today, beginning a mission to search for evidence of life.

The Viking orbiter-lander combination rose from Launch Complex 41 after nine days of delays caused by a problem with the rocket's steering mechanism followed by a problem in the orbiter's batteries for storing power.

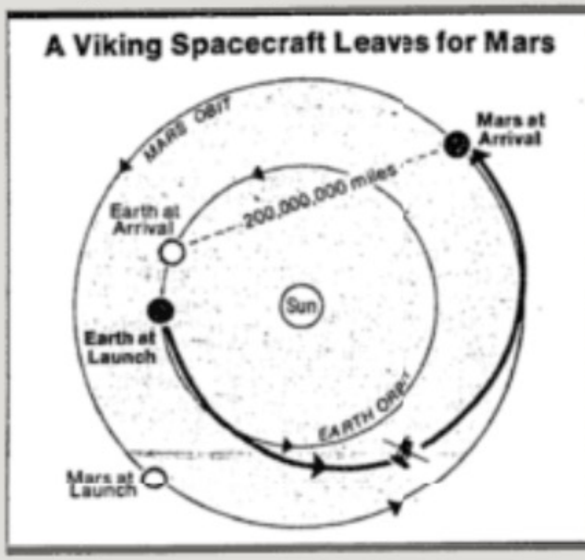
The most elaborate unmanned scientific spacecraft ever launched by the United States started its journey by going into earth orbit aboard a Titan 3I Centaur rocket that had operated successfully only once before.

Less than half an hour after the launching at 5:22 P.M., Eastern daylight time, more than 100 miles above the earth the Centaur upper stage fired again for more than five minutes, setting the Viking loose from the pull of the earth's gravity and aiming the craft for Mars.

The Centaur rocket then separated from the Viking, which unfolded its four power-generating solar panels, with a total area of 150 square feet, and turned then toward the sun.

With its power supply assured, the Viking rolled, keeping the panels sunward, while a small tracker sought and focused on the light of the bright star Canopus.

This star has maintained the pointing accuracy—and hence



The New York Times — Martin Marietta/Aug. 21, 1975

The Viking probe of Mars will travel 50 million miles through space for almost a year, reaching Mars when the planet is on the opposite side of the sun from earth. It will then orbit the planet many times, as in artist's rendering at right, before the lander (the semicircular bottom section) disengages and descends to the surface.

Day, 1976. For some two weeks before and after, radiocommunications with Viking orbiters and landers will be blocked. According to space agency plans, the primary missions of the craft must be completed before the loss of communications.

The Viking is scheduled to go into orbit around Mars June 19, 1976, survey landing sites and then put down its lander at a site called Chryse on July 7, 1976.

The official landing date presupposes that the craft will need the full period of 18 days allowed for trimming its orbit around Mars and surveying the landing site. If this can be shortened, a landing on July 4, the nation's Bicentennial, might be possible.

The project manager, James S. Martin of the Langley Research Center in Hampton, Va., said in a briefing Aug. 12, "I don't consider the Fourth of July all that sacred. We're going to land when we're ready to land. I personally would not like to wait in orbit if we are ready." This view was endorsed Monday by Dr. James C. Fletcher, administrator of the National Aeronautics and Space Administration.

The Chryse site is near channels that may have been carved by flowing water—hundreds of millions of years ago, around the apparent time when four huge volcanoes formed in the upland region called Tharsis, which borders a 2,500-mile-long system of canyons. One of the missions purposes is to search for evidence of life. Water is a prerequisite for life as it is known on earth.

These canyons have been named the Valleys of Mariner, or Valles Marineris, after the American craft, Mariner 9, that first photographed them, along with the channels and volcanoes, during months of orbital surveys in 1972.

The Chryse site is some three miles below the average spherical surface of the planet, so that the maximum of Martian atmosphere will be available for braking the lander's descent. On the average, the air pressure on the surface of Mars is 200 times less than at sea level on earth.

Preparations are scheduled to begin tomorrow for launching the second Viking craft on Sept. 1 from the same launching pad used today.

The second Viking is scheduled to reach Mars Aug. 7, 1976, and to set down its lander at a site called Cydonia, near the southern limit of the northern polar cap, on Sept. 9, 1976. Then, the second orbiter will be shifted to a pathway passing near the Martian poles.

The four-ton Viking craft will require nearly a year to reach Mars, rather than just the few months needed by previous expeditions, because the relative positions of earth and Mars go through a 17-year cycle.

While earth follows a nearly circular path between 9 and 94 million miles from the sun, Mars travels on an ellipse that varies between 128 and 15 million miles out.

This means that earth, as it passes Mars on the inside track every two years, can be as close as 35 million miles or as far as 63 million.

When Mariner 9 journeyed for less than six months to go into orbit around Mars in 1971, the closest approach distance was the minimum.

This year, earth will make its closest approach to Mars Dec. 8, at a distance of 53 million miles.

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Vikings 1 Landing

"All the News That's Fit to Print"

The New York Times

LATE CITY EDITION

Weather: Chance of rain late today, tonight. Partly sunny tomorrow. Temperature range: today 72-86; Tuesday 66-90. Details on page 65.

VOL. CXXV . . No. 43,278 — NEW YORK, WEDNESDAY, JULY 21, 1976 — 20 CENTS

VIKING ROBOT SETS DOWN SAFELY ON MARS AND SENDS BACK PICTURES OF ROCKY PLAIN

Associated Press

A composite photo showing a 300-degree panorama of the surface of Mars, made by a camera on the Viking 1 landing craft just after touchdown on the planet yesterday morning. Parts of the craft are visible in foreground.

Nitrogen, Key to Life, Is Found

By WALTER SULLIVAN
Special to The New York Times

PASADENA, Calif., July 20—The first definitive analysis of the Martian atmosphere has disclosed the presence of a small component of nitrogen. Until now the absence of any evidence of that gas stood as a major obstacle to speculation that life might exist on the planet.

The analysis has also provided long-sought clues to the history of Mars, including the possibility that enough water is hidden beneath its surface to cover the planet one mile deep.

This and other detailed determinations should bear on such questions as the history of the Earth's known atmosphere, including the proposal that the atmosphere of both Earth and Mars were formed in eruptions very early in each planet's history.

Such an early formation of the atmosphere would mean, as well, the early appearance of oceans or smaller water bodies suitable for the evolution of life.

Higher Ratio Suggested

When the Soviet Union's Mars 6 plunged into the Mars atmosphere in its unsuccessful

The lower abundance of argon is good news for those experimenters hoping to learn the composition of Mars's surface materials. Their instrument aboard the lander will determine such compositions with a gas chromatograph mass spectrometer that could have been rendered useless by an atmosphere rich in argon.

The project's scientists believe that today's measurements will help clarify whether, as some of them believe, there is still enough water hidden beneath the surface of Mars to cover that planet to a depth of

3¼-HOUR DESCENT

Scientists Are Jubilant as News Is Flashed, Taking 19 Minutes

By JOHN NOBLE WILFORD
Special to The New York Times

PASADENA, Calif., July 20—An explorer from Earth, the robot craft Viking 1, made the first successful landing on Mars today and transmitted spectacular photographs of a rocky, wind-scoured desert plain, the site for the first direct search for life on another world.

The squat, three-legged Viking landing craft came to rest, upright and intact, on the Chryse Plain of Mars at 7:53 A.M. Eastern daylight time after a voyage of 11 months and nearly half a billion miles. The final and most suspenseful step, the craft's descent to the surface from its mother ship in Mars orbit, took 3 hours 13 minutes.

Then, Touchdown

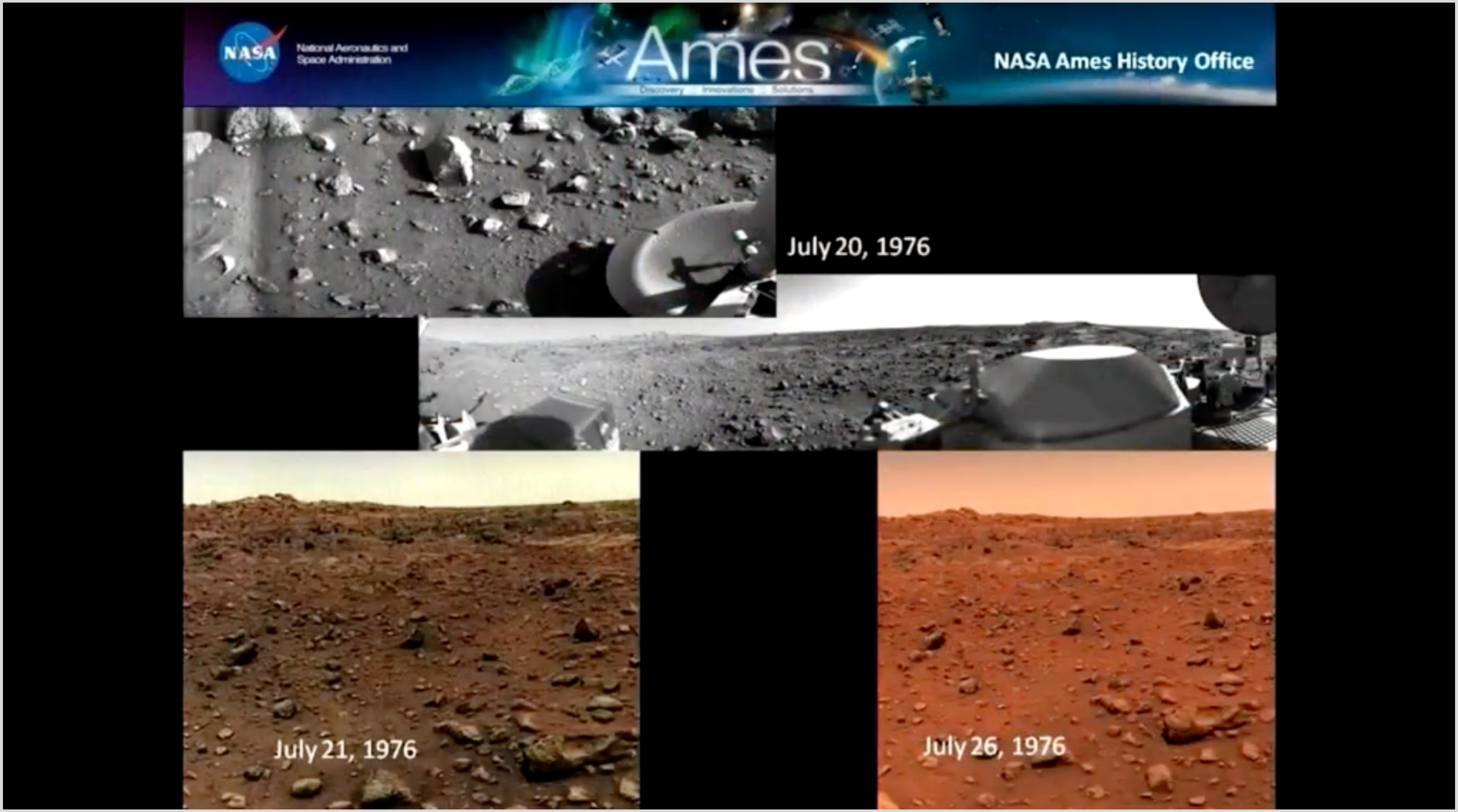
Responding to automatic computer commands, the lander's rockets fired, its parachute unfurled, protective shielding broke away, more rockets were fired—and then, touchdown. It was 19 minutes, because of the great distance between Mars and Earth, now more than 212 million miles, before confirmation of the safe landing reached the control rooms here at the Jet Propulsion Laboratory.

"Touchdown!" announced Richard Bender, one of the flight controllers. "We have touchdown. We have several indications of touchdown."

It was an emotional moment for the scientists and engineers of the $1 billion Viking project, many of whom had spent eight years preparing for this day.

Applause and Amazement

First Viking Photographs



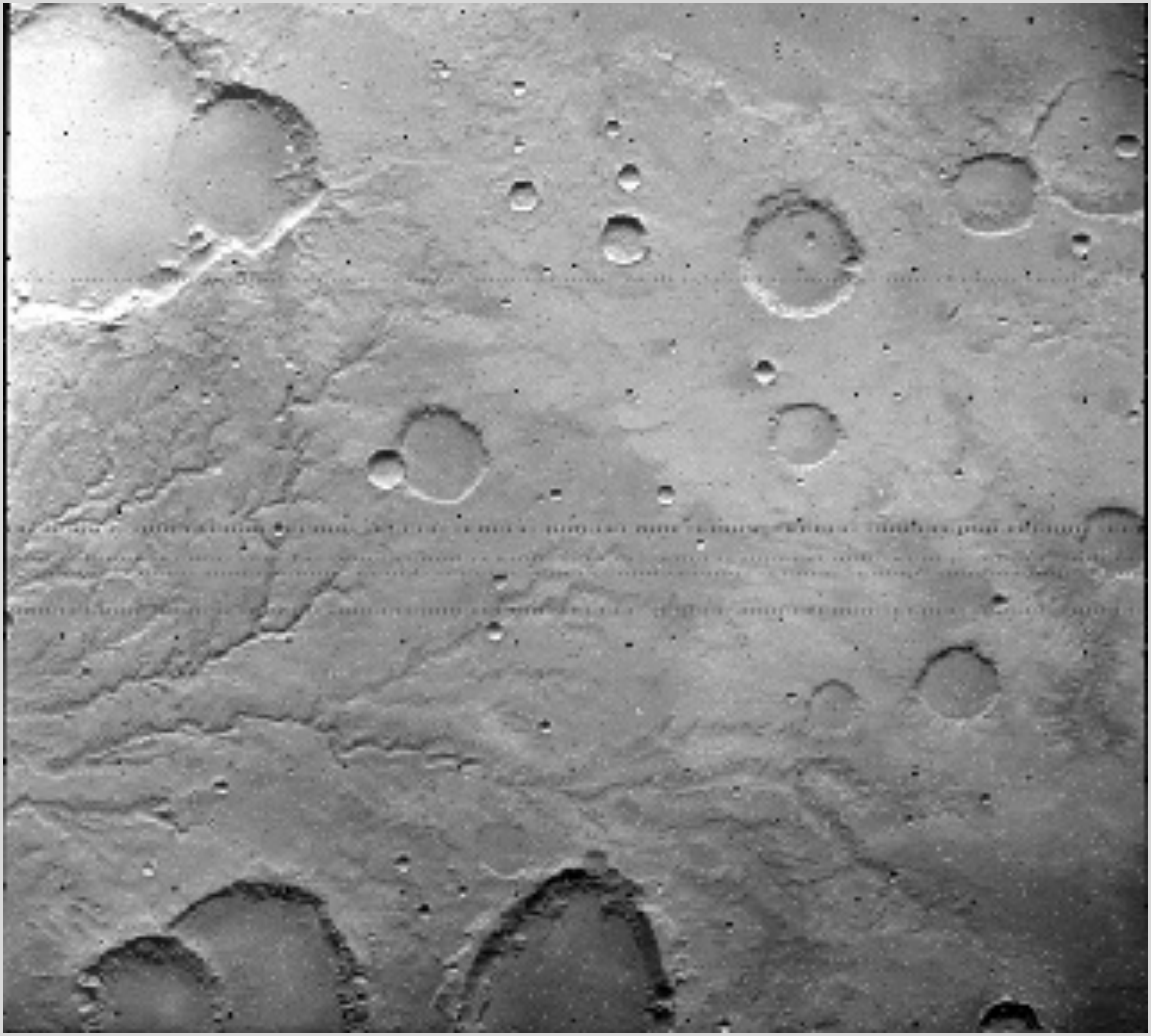
Viking Lander Results

- Rated for 30 days, Viking 1 lander operated for 6 (Earth) years
- Viking 2 lander operated for 3 ½ years
- Sky was pinkish rather than blue, due to dust in the air
- Winds were measured at 0 to 22 mph, temperatures from -122 to -22 Fahrenheit, pressures from 7 to 8 mbar with a 5% drop as CO_2 froze onto the ice caps
- The 6-foot robotic arm scooped up soil and deposited it in the chemistry lab
  - X-ray fluorescence spectrometry showed primarily silicon and iron, with higher-than-expected sulfur
  - Biology tests
    - Results were positive, but generally concluded to be due to chemical oxidants produced by the effect of UV light on the soils
    - Two original scientists and some recent work dissent
  - GCMS showed no detectable organic chemicals except chlorinated compounds thought to be cleaning contaminants

Viking Orbiter Results

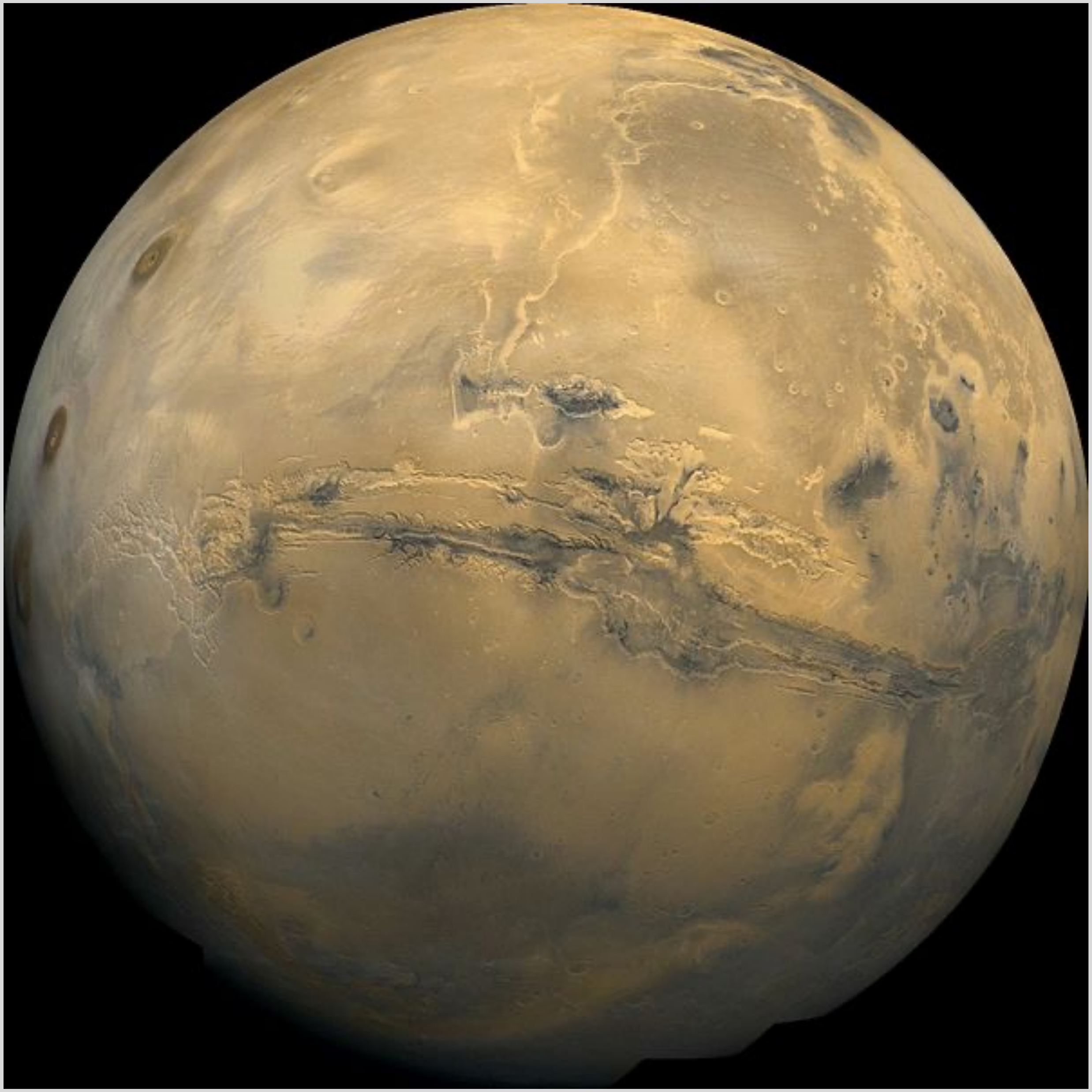
- Orbiters ran out of attitude control gas at 5 and 3 years respectively
- North polar ice cap is water ice, not CO_2 (dry ice)
- Permafrost (subsurface ice) is prevalent
- Moons appear similar in composition to asteroids
- Thousands of pictures were taken

Viking Photo of Drainage



Viking Composite Picture

Valles Marineris



Viking 1 and 2 Summary

- Technical wins with first successful EDL and miniaturized GCMS
- Clear evidence of past liquid water along with current conditions without liquid water stimulated research in global climate change
- Negative biologic results reduced interest in Mars for several years
- 25th Anniversary (1:42) [original Viking team aged 25 years]

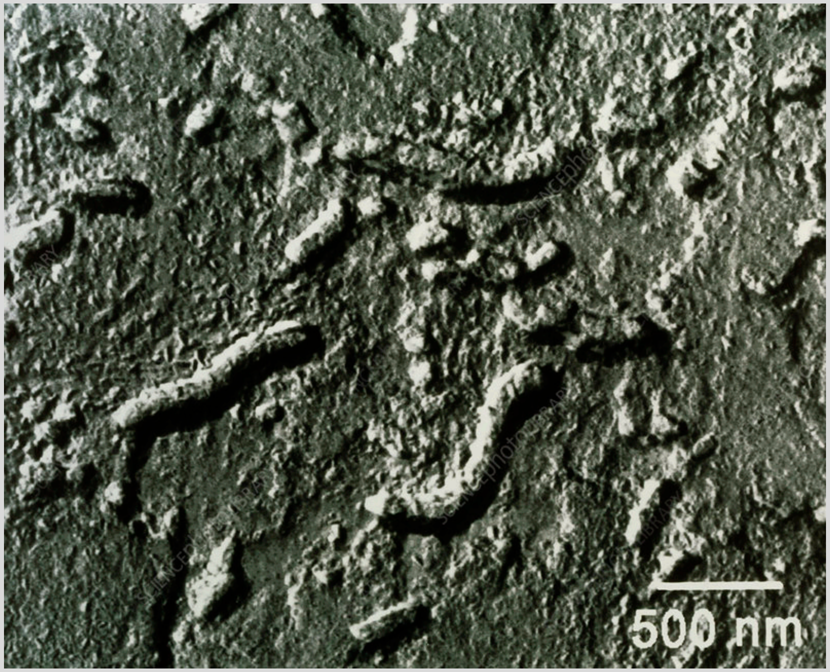
Two Failures: Phobos and Mars Observer

- Soviet Phobos 1 and 2 orbiters with landers (1988)
  - Cooperation of 14 nations including US Deep Space Network
  - Phobos 1 failed en-route: a single character error in an uploaded program resulted in turning off attitude control, and the batteries ran down
  - Phobos 2 entered orbit around Mars and took 37 images of Phobos, but failed before the lander could be de-orbited
- US Mars Observer (1992)
  - $813 million orbiter designed to study elemental and mineralogical composition of the surface, gravitational and magnetic fields, temporal and spatial distribution of volatiles and dust, and circulation of the atmosphere
  - Contact was lost 3 days before planned orbital insertion
  - Likely cause was fuel and oxidizer leakage through a check valve during cruise resulting in an explosion when the engine was restarted for course correction

Digression: Allan Hills 84001

- Meteorite fragment found in Allan Hills Antarctica in 1984
- Consensus Scientific Results
  - Crystalized 4 billion years ago on Mars
  - Blasted off Mars by a meteorite 17 million years ago
  - Landed on Earth 13,000 years ago
- Claims from McKay, et al. in *Science*, August 1996
  - Bacteria-like structures found by scanning EM
  - 20-100 nm in diameter (smallest Earth bacteria are 200-300 nm)
  - Used to bolster interest in detecting life on Mars

- Current consensus is that these may be abiotic, and that morphology alone is too subjective to be used to declare life

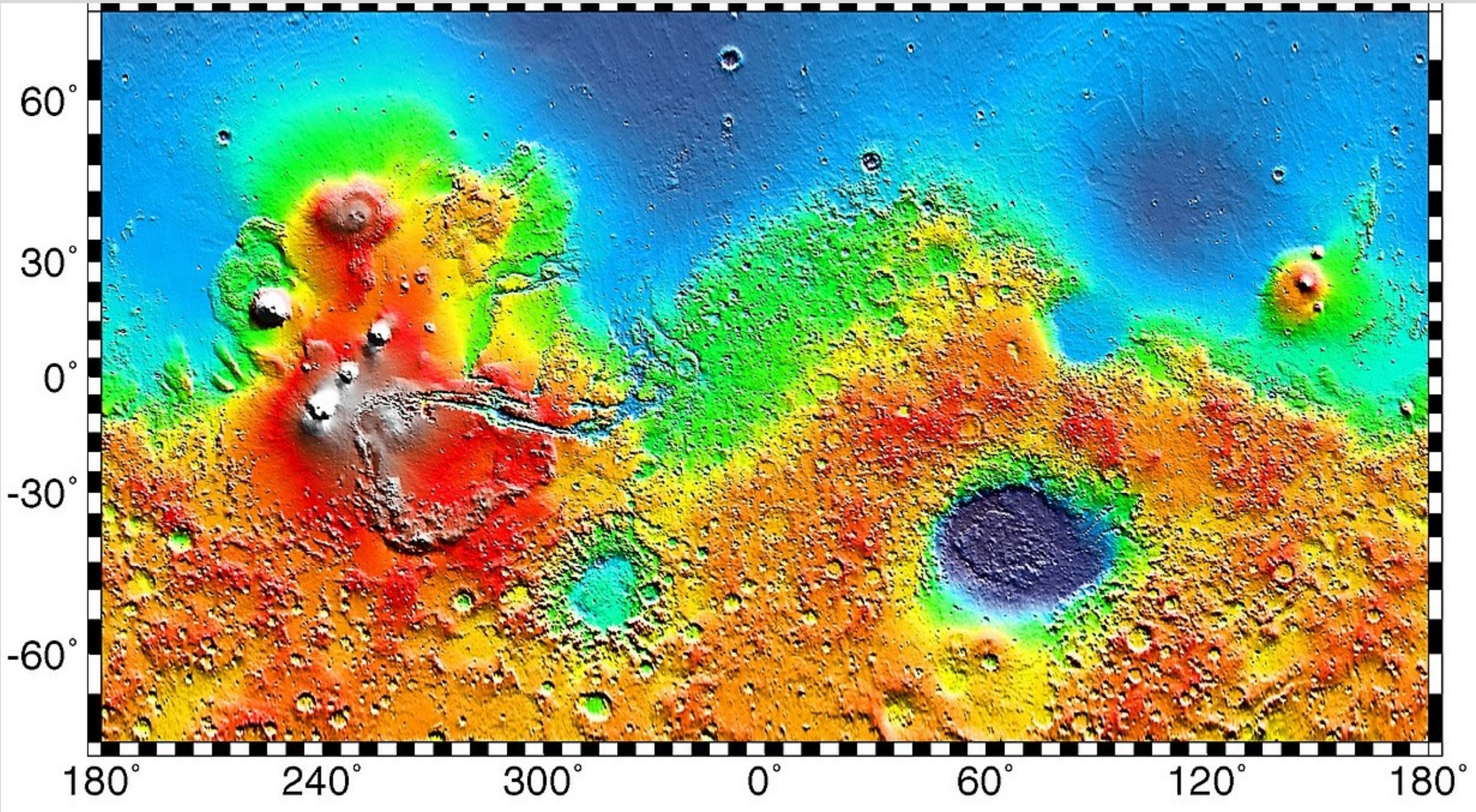


Three Mars missions launched in late 1996

- Russia's Mars 96
  - Orbiter with 26 instruments built by multiple countries
  - Two penetrators with 9 instruments each to measure ~15 feet into the surface
  - Two landers with 8 instruments each
  - Successfully placed in Earth parking orbit
  - Failed ignition of rocket to leave Earth orbit
  - Probably fell over Chile with 200 gm of plutonium-238, never recovered
- US Mars Global Surveyor
  - Launch November 1996
  - Entered Mars orbit September 12, 1997
  - Long orbital adjustment period via aerobraking
  - Mapping began March 1999
  - Operated until November 2006
- US Pathfinder lander with Sojourner rover
  - Launch December 1996
  - Landing July 4, 1997
  - Operated until September 27, 1997

Mars Global Surveyor

- Mapping mission designed to scout out landing sites
- 240,000 pictures at about ¼ mile resolution
- First use of laser altimeter in space
- Also measured temperature and magnetic fields
- Polar orbit allowed essentially 100% coverage of the surface



Blue = low

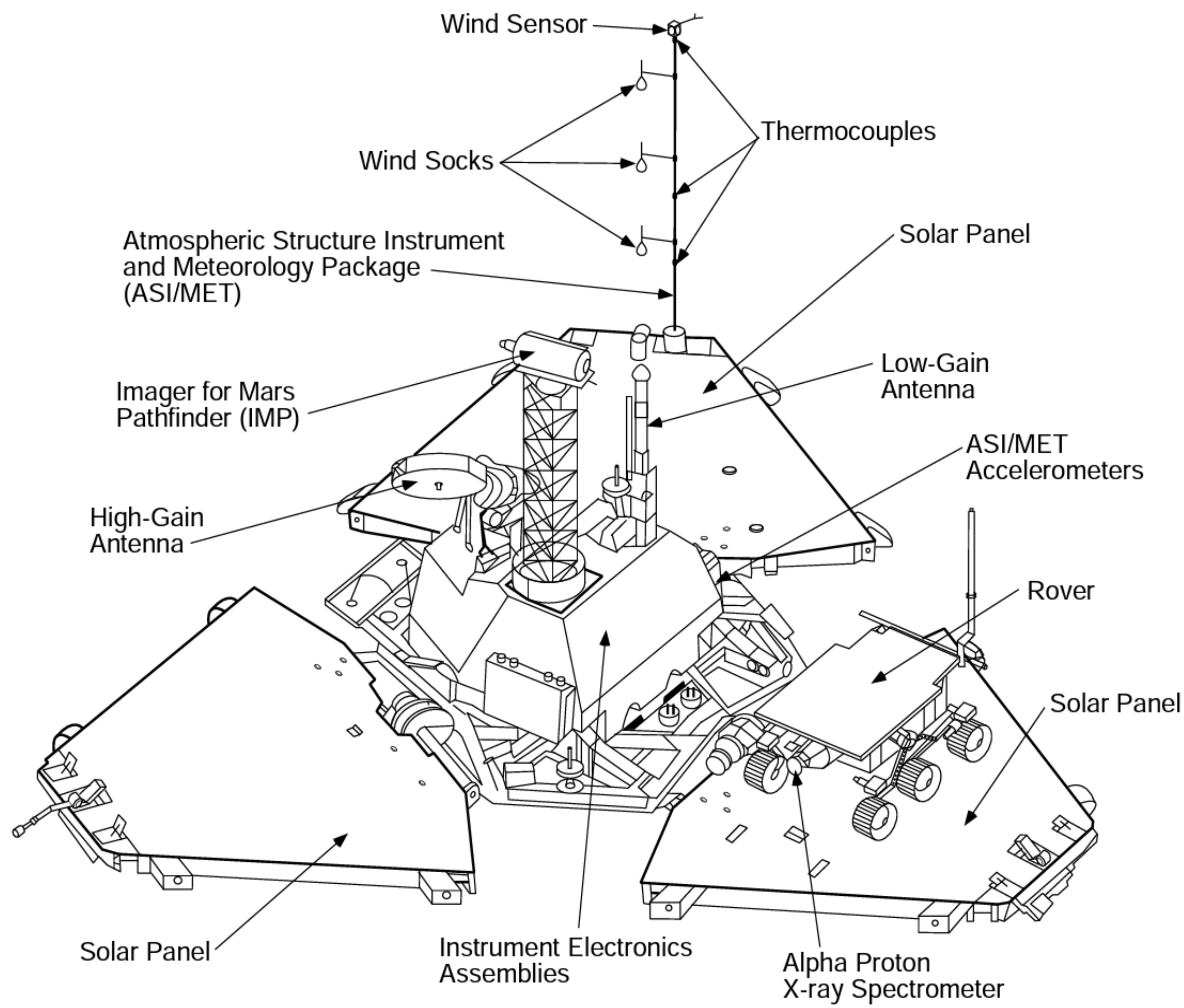
Red and Grey = high

Pathfinder and Sojourner (Truth)

- Follow-up to 1975-1976 Viking landers
- Part of the post-Cold-War "cheaper, faster, better" Discovery Program of NASA administrator Dan Goldin
- Project manager: Tony Spear
- 20th Anniversary: Initial idea (1:56) [Charles Elachi of JPL]
- $150 million lander and $25 million rover
- 20th Anniversary: Development overview (6:31) [Brian Muirhead of JPL]
- Landed July 4, 1996, on a plain 2.4 km below the average planetary surface altitude called Chryse Planitia in the north equatorial region
- 20th Anniversary: Control Room with artist renderings of the landing (5:35)

Pathfinder Lander

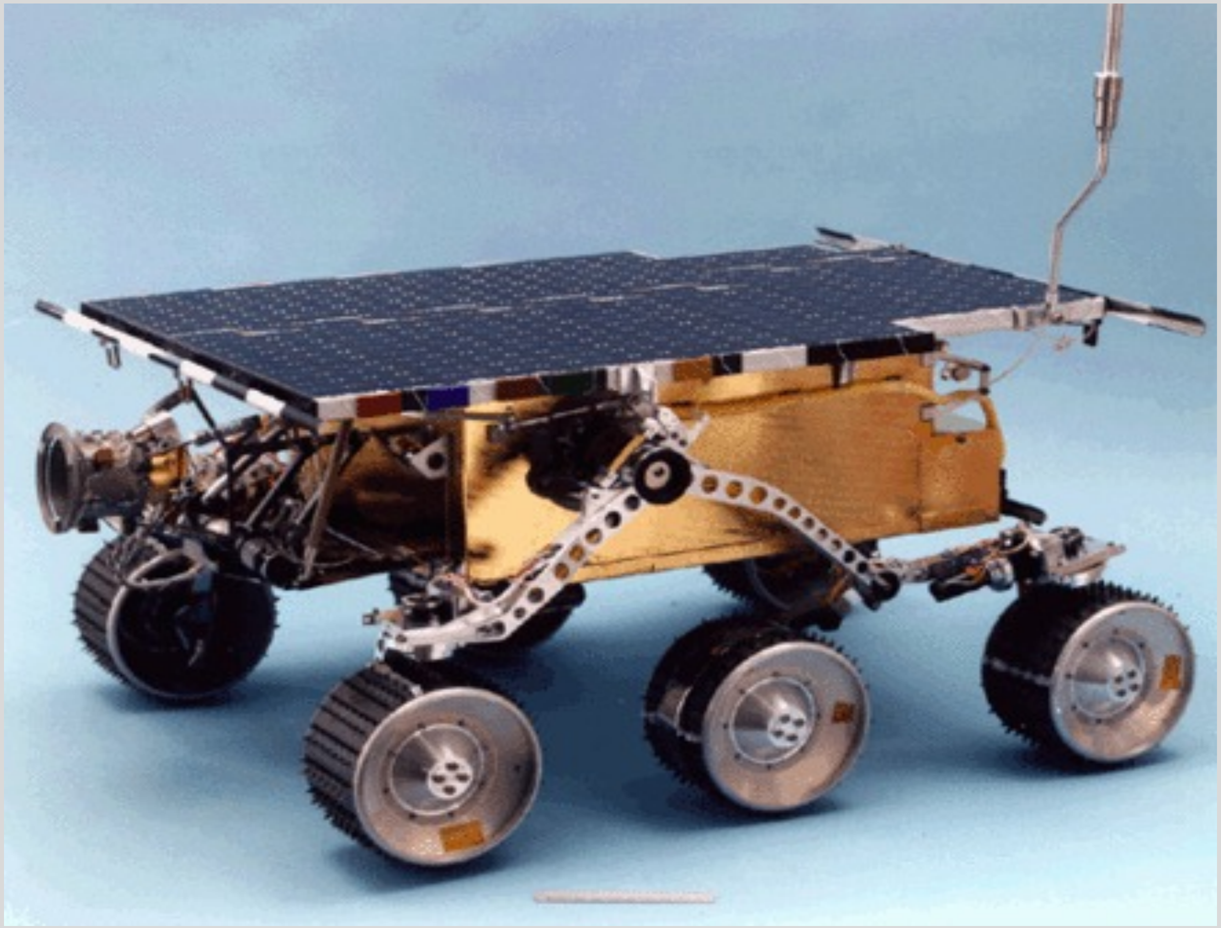
- 3 feet tall, 1973 pounds at launch, 793 pounds at landing
- IBM computer at 20 megaflops with 128 megabytes RAM
- Stereo CCD cameras with 12 color filters, 256x256 pixels
- Weather station
- Radios



Mars Pathfinder lander

Sojourner (Truth) Rover

- Named by the 12-year-old winner of a student competition to submit an essay about the historical accomplishments of a heroine
- 25 pounds, solar panels and a non-rechargeable battery, front and back cameras, radio, alpha proton x-ray spectrometer
- Warm electronics box, rocker bogie with 6 independently actuated wheels, front and rear steering, obstacle avoidance, 1.5 ft/sec



Sojourner (Truth) Rover: Instrumentation

- APXS: Curium 244 (half life 18 years) emits alpha particles and measures alpha particles, protons, and x-rays scattered or emitted to determine elemental composition in the first few tens of μm of soil
- Mounted on an actuator with contact sensors
- Each measurement takes tens of hours

Rover and Donna Shirley

- Donna Shirley was a pilot and an aerospace engineer who worked at JPL on heat shields, rovers and robotics
- Shirley was manager of the Mars Exploration Program at JPL, a key advocate of the rover, and the first woman Program Manager at NASA
- NBC News (4:00) [A few garbled seconds]
- Donna Shirley Hall of Fame: Sojourner (4:01)

Pathfinder and Sojourner Science Results

- Proved the workability of airbags for EDL
- Lander returned 16,500 images
- Pioneered Mars rover technology: 550 pictures, 40 feet from the lander, 330 feet total, collected APXS data at 16 locations
- Lander provided extensive weather data including evidence of frequent dust devils and early morning water ice clouds
- Found rounded rocks thought to be evidence of a time of flowing water
- Found high silica content in rocks, different from the few Martian meteorites found on Earth
- Soil chemistry was similar to Viking 1 and Viking 2, suggested planet wide circulation of soil and dust
- Radio tracking of Pathfinder and its rotation was used to determine that the planetary core is 800 to 1250 miles in radius
- Airborne dust was found to contain a magnetic form of iron oxide about 3 μm in diameter

Winter 1998/1999 Launches

- US Mars Climate Orbiter ($327 million)
  - Designed to study atmosphere, climate and surface and do radio relay
  - Failed at Mars orbit insertion due to Lockheed Martin's failure to convert English to metric units
- US Mars Polar Lander ($165 million)
  - Designed to study soil and climate at the south pole
  - "The Failure Review Board concluded that the most likely cause of the mishap was a software error that incorrectly identified vibrations, caused by the deployment of the stowed legs, as surface touchdown. The resulting action by the spacecraft was the shutdown of the descent engines, while still likely 40 meters above the surface."
- Japanese Nozomi ("Hope")
  - Designed to study Mars' atmosphere and its interaction with the solar wind
  - Designed to use moon and Earth swingbys to reduce fuel expenditure
  - Valve failure during the Earth swingby left insufficient fuel
  - Mission changed to heliocentric orbit with Mars flyby in December 2003
  - Did provide data about deep space

Summary of Week 2

- Russia continues to fail in the 1990s, joined by Japan
- US has a mix of successes and dramatic failures under NASA administrator Dan Goldin's "faster, better, cheaper" approach

What’s next

- Early 2000s: Odyssey, Spirit & Opportunity, Mars Express
- Late 2000s: Mars Reconnaissance Orbiter, Phoenix lander

Pre-Viking Soviet Missions

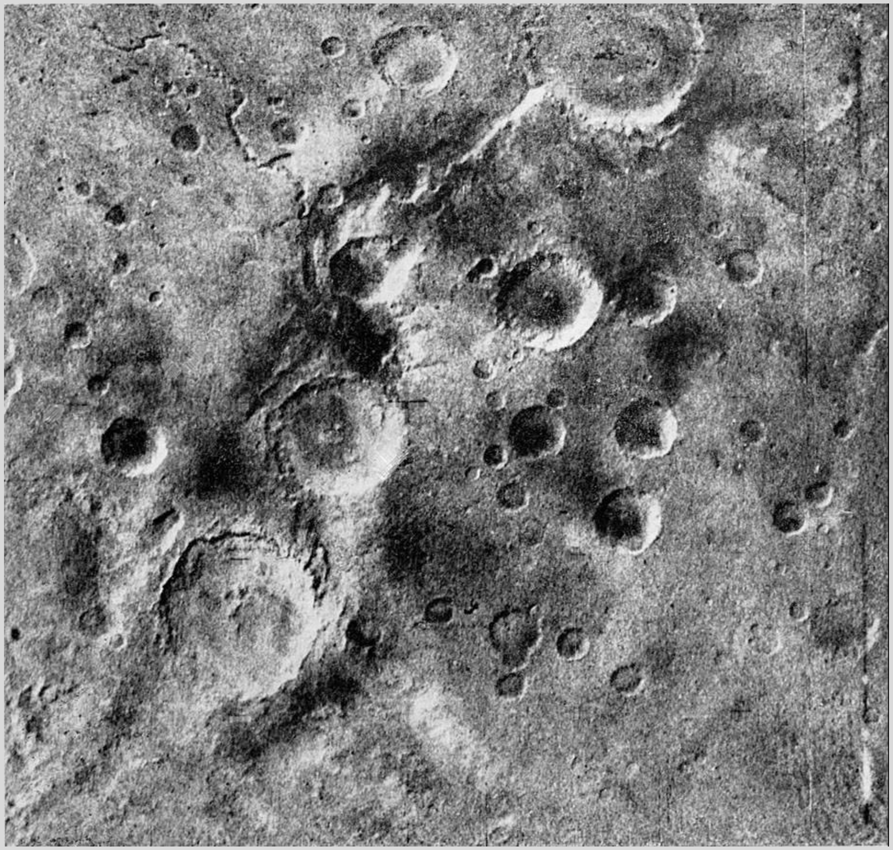
- Mars 4 to Mars 7 were intended for 1973 launch to pre-empt the 1976 US Viking mission, but planetary positioning was poor necessitating smaller payloads in the form of separate orbiter and lander launches.

  - A high failure rate of transistors made with aluminum rather than gold contacts predicted a 50% failure rate, but the missions were continued
  - **Mars 4** lander could not do course correction to due transistor failure but sent back 12 pictures at 1200 miles.

Pre-Viking Soviet Missions

- **Mars 5** orbiter successfully performed course corrections and entered Martian orbit February 2, 1974
- A leak of the pressurized instrument compartment was detected, probably due to a micrometeroid, and only three weeks of operation was predicted. This meant the landers would have no orbiting relays.

- An accelerated program of photography and scientific instrument observation was devised
- Chemical composition of rocks was measured for the first time



Pre-Viking Soviet Missions

- **Mars 6** was a lander with a flyby component
- Multiple problems developed, one by one, with partial recovery by backup systems
- Lander data rates were greatly reduced due the need for direct communication with Earth
- The lander detached and decelerated, and the parachutes deployed but with evidence of instability
- The first direct measurements of the Martian atmosphere were made: temperature and pressure and about 1/3 argon as measured by mass spectrometry (real value 1.6%)
- Landing engines ignited, but no further data was received
- Possible explanations include failure of the radio system or landing on large rocks
- The **Mars 7** lander failed to fire retro rockets and did not enter the Martian atmosphere

Viking Rockets and Guidance

- Titan III-Centaur
- Solid booster rockets (polybutadiene acrylonitrile) assist main hydrazine/dinitrogen tetroxide engines
- Hydrazine/dinitrogen-tetroxide second stage
- Liquid hydrogen / liquid oxygen third launch stage
- Hydrazine/dinitrogen-tetroxide engine on the spacecraft, plus compressed nitrogen attitude control jets
- Course corrections based on Deep Space Network observations on Earth

Entry, Descent and Landing

- Biggest unknown: atmosphere too thin for Earth-like landing and too thick for Moon-like landing
- Deorbit burn
- Enters the atmosphere of Mars about 100 miles above the surface, traveling at about 18,000 miles per hour
- Seven minutes later, it has to be traveling at one or two miles an hour to make a soft landing
- Aeroshell braking until 3.7 miles and 600 mph
- Supersonic parachute until about 5000 feet (by radar) when backshell separation occurs
- Throttleable rockets slow to 1.5 mph
- Shock absorbing legs
- All with no Earth intervention (40-minute round trip communication delay)

Biology Experiments in Soil

- Gas Exchange
  - Looked for a change in oxygen, CO2, nitrogen, hydrogen, or methane after adding nutrients or nutrients plus water
- Labeled Release
  - Added radioactive ^{14}C labeled nutrients, then looked for ^{14}C labeled gasses in the air above the soil
  - Subsequently the samples were heated to 160 ℃ and retested as a control
- Pyrolytic release
  - Looking for carbon fixation through photosynthesis, ^{14}C carbon dioxide and carbon monoxide were incubated with the soil for several days, then release of radioactivity from the soil was observed as it was heated

Engineering Management

- from Thomas A. Mutch and Kenneth L. Jones in "The Martian Landscape" (https://history.nasa.gov/SP-425/contents.htm)
- Described about 400 meetings over 8 years in four locations:

"Useful exchanges of information prevented isolated journeys up blind alleys. When no obvious solution to a problem was apparent, we proceeded by vote. The majority opinion dictated the next step. In one sense, that appears absurd. Certain things are matters of fact. To what useful end can one vote on the proposition that a camera should cost no more than X dollars, whereas a biology instrument should cost Y dollars? Or that the average Martian atmospheric pressure is 1 percent of the Earth's atmosphere as opposed to 0.5 percent? Viewed in another context, an open meeting in which all participants have equal vote has served Americans well in many previous situations. Perhaps more than we realize, it is a method of pooling information with which we have grown up. I like to think that the ultimate success of Viking can be traced back to those countless meetings at which we chewed on one problem after another- hours of thoughtful criticism and, sometimes, clamorous sharp-edged debate."