Mars: Science and Engineering (Week 3)

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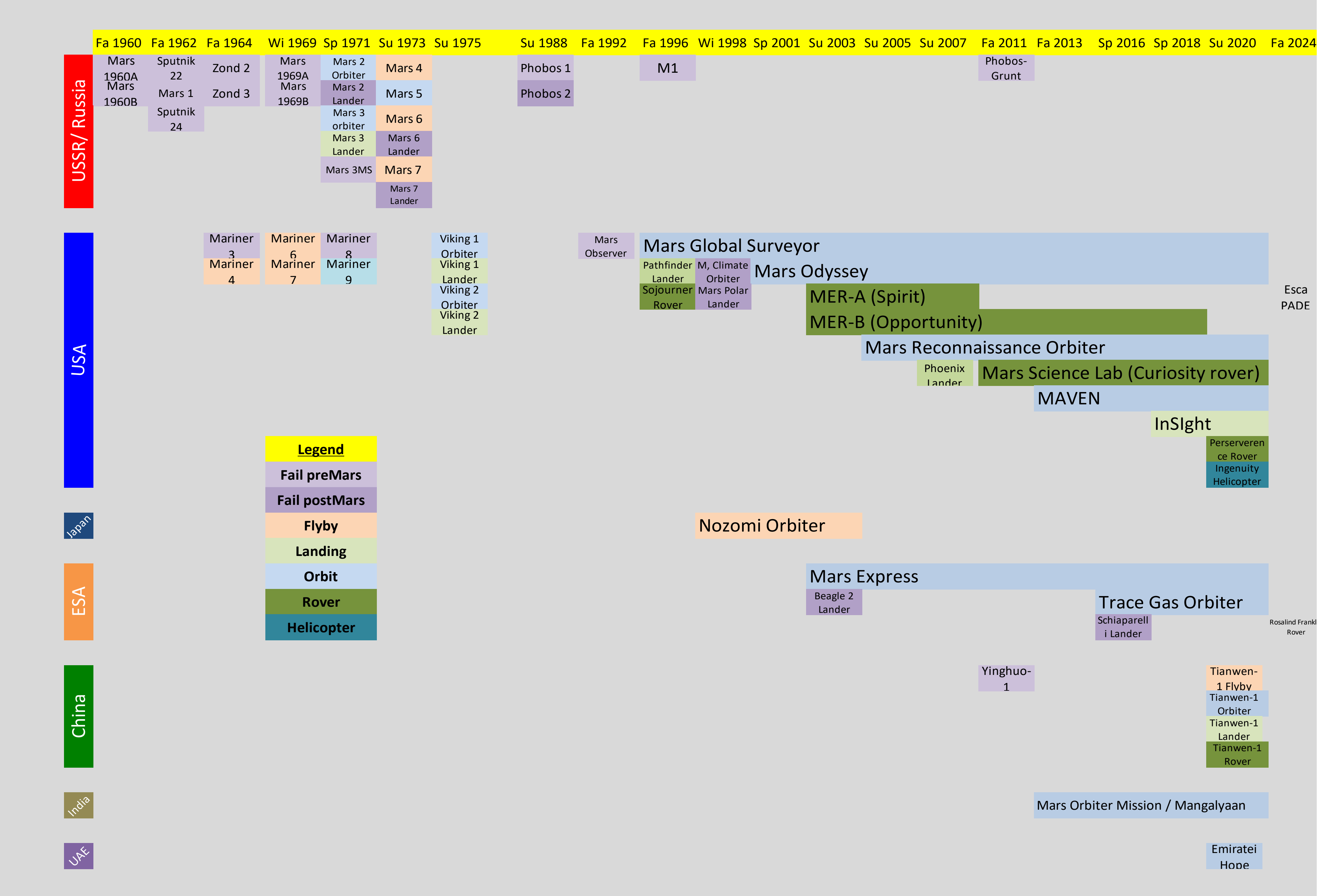
Course Outline

- 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
- Old issues: ATP, accumulated dust, radiation, airbags
- **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
  - Mars science summary
  - Unlaunched: Exo-Mars
  - Humans?



Fa 1960
Fa 1962
Fa 1964
Wi 1969
Sp 1971
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Su 2007
Fa 2011
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Sp 2016
Sp 2018
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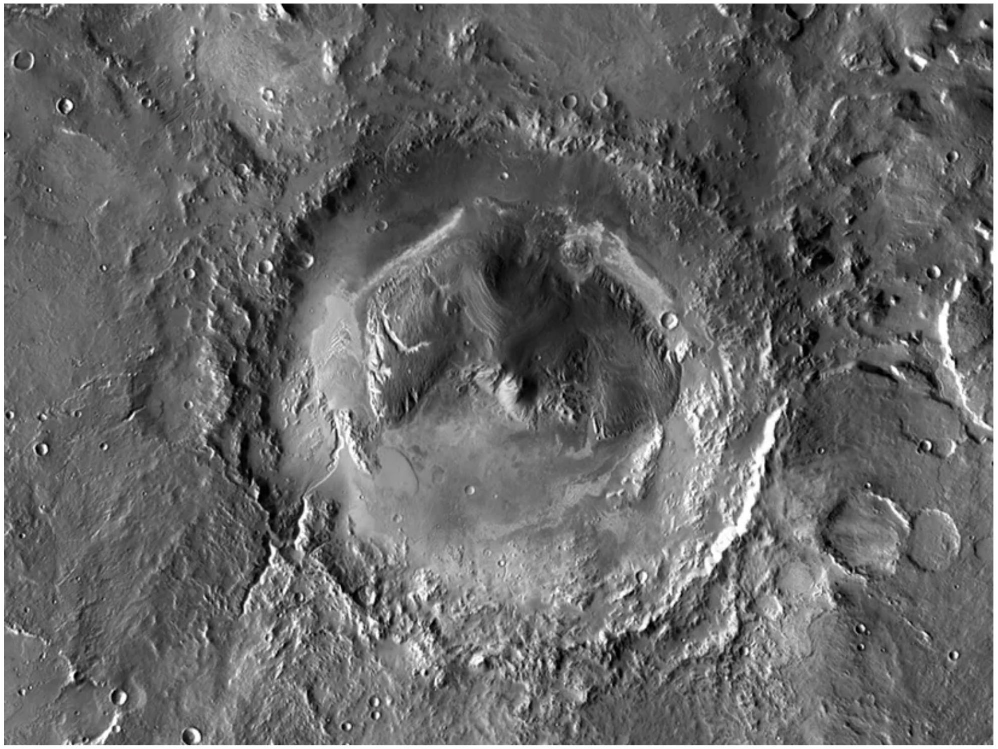
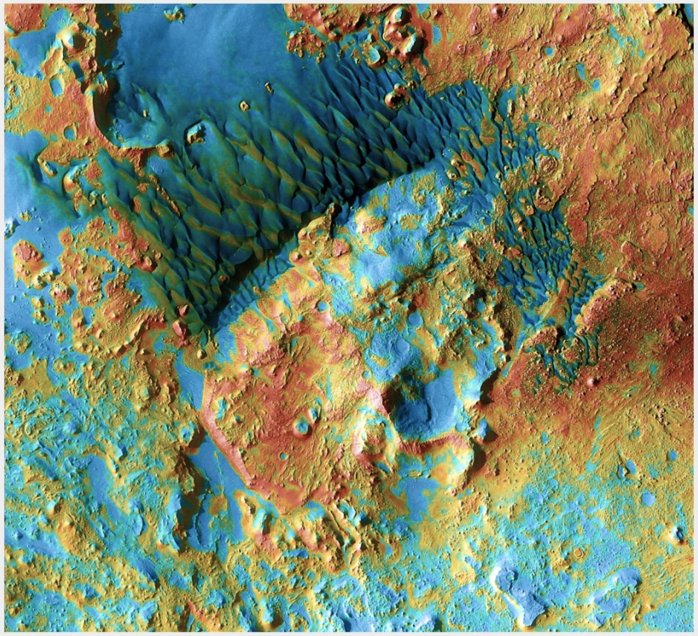
Fa 2024
USSR/ Russia
Mars 1960A
Mars 1960B
Sputnik 22
Mars 1
Sputnik 24
Zond 2
Zond 3
Mars 1969A
Mars 1969B
Mars 2 Orbiter
Mars 2 Lander
Mars 3 orbiter
Mars 3 Lander
Mars 3MS
Mars 4
Mars 5
Mars 6
Mars 6 Lander
Mars 7
Mars 7 Lander
Phobos 1
Phobos 2
M1
Phobos-Grunt
USA
Mariner 3
Mariner 4
Mariner 6
Mariner 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
Esca PADE
Legend
Fail preMars
Fail postMars
Flyby
Landing
Orbit
Rover
Helicopter
Japan
Nozomi Orbiter
ESA
Mars Express
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

US Mars Odyssey

- $300 million orbiter launched April 2001
- In polar orbit since October 2001 and still operating
- High resolution images, thermal imaging, and a radiation detector
- Carries Russian High Energy Neutron Detector to see H of H_20
- Radio relay for Spirit and Opportunity



A photo mosaic of Gale Crater, which is 154 kilometers in diameter, taken by the Thermal Emission Imaging System camera on NASA's Mars Odyssey orbiter. Credit: NASA/JPL-Caltech/ASU



Arabia Dunes: Sand dunes shaped like blue-black flames lie next to a central hill within an unnamed 75-mile-wide crater in eastern Arabia on Mars. Areas in bluish tints have more fine sand at the surface, while redder tints indicate harder sediments and outcrops of rock. This scene combines images taken during the period from February 2003 to August 2004 by the Thermal Emission Imaging System instrument on NASA's Mars Odyssey orbiter. NASA/JPL-Caltech/ASU

Digression: Challenges of Getting to Mars

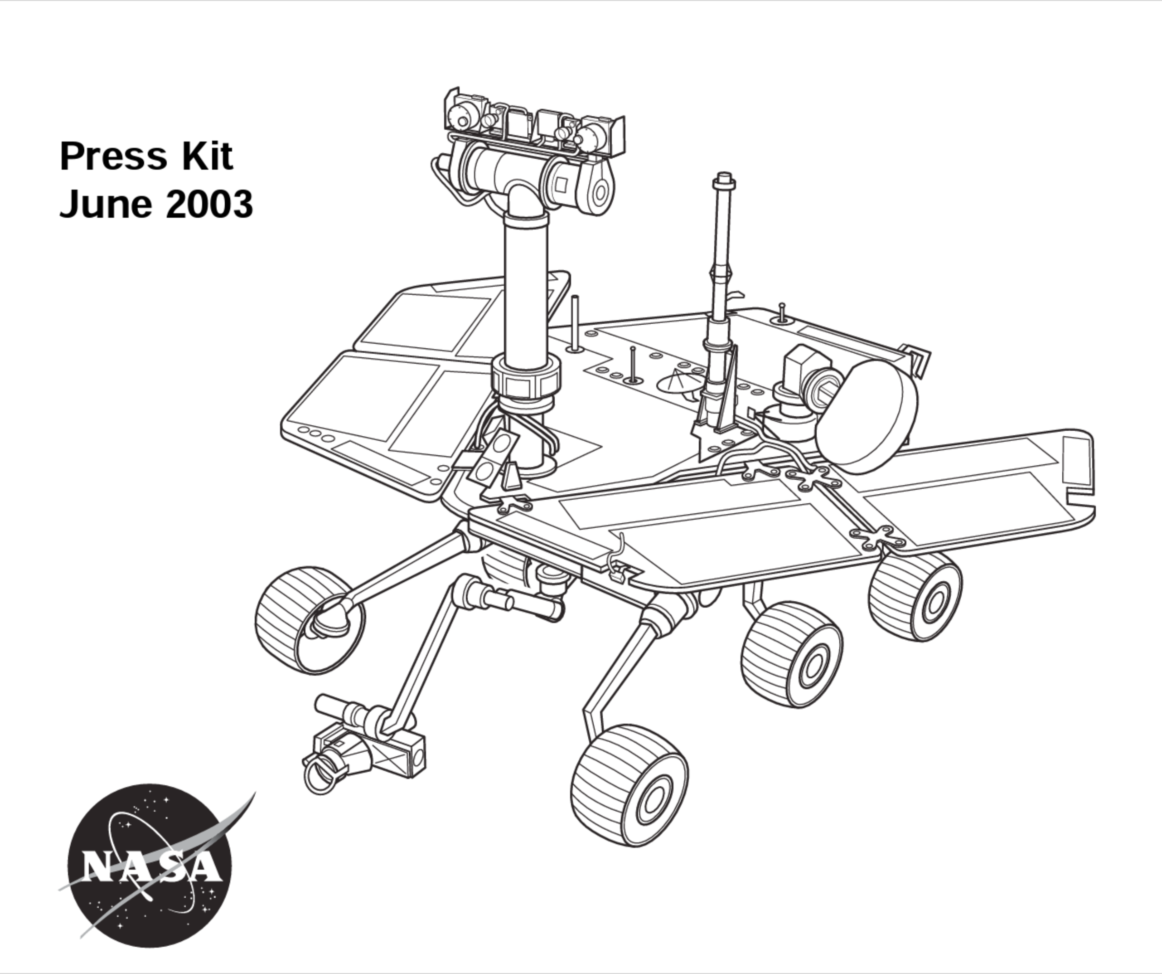
- Telecommunications (2:54)
- Interplanetary Cruise (3:01)
- Aerobraking (3:20)

Mars Odyssey: Results

- First Infrared Images (1:54)
- Results to date
  - Identified large amounts of hydrogen in the soil, implying the presence of water, much in the form of hydrated minerals, from 2% to 10% near the equator and up to 50% at some high latitudes (55^o)
  - “Found evidence of salt deposits in 200 locations in southern Mars. These chloride minerals were left behind in places where water was once abundant”
  - “Observed the year-to-year variations in polar ice, clouds and dust storms”
  - “Helped select a landing site for the Mars Science Laboratory (MSL) and it later acted as a relay for the MSL rover Curiosity”
  - “Mars Odyssey’s camera had helped construct the most accurate global map of Mars ever, using 21,000 images from the THEMIS instrument. These pictures have been smoothed, matched, blended, and cartographically controlled to make a giant mosaic available to users online”

US Mars Exploration Rovers [MERs]

- Spirit and Opportunity “robotic geologists” that arrived January 2004
- Sharper images, further travel, first microscopic views of rocks
- Communication via Mars Odyssey
- Lander base without instrumentation
- EDL with airbags



MER Science Plan

- Chief Scientist: Steve Squyres of Cornell University
- EDL Lead: Adam Steltzner (NASA's "rock star" engineer)
- Panoramic camera at human height and thermal emission spectrometer used to help scientists on Earth to identify target sites
- Rover goes to the site, avoiding hazards on its own
- Microscopic imager sends back hand-lens equivalent images
- Spectrometers identify composition
  - Mössbauer spectrometer: measures nuclear recoil of gamma rays (Co-57, half life 272 days, 300mCi) to identify and quantify iron-containing minerals
  - Alpha Particle X-Ray Spectrometer (APXS): determines elemental composition of rocks via response to alpha particle bombardment
- Rock abrasion tool (RAT) substitutes for the geologist's hammer, scraping away the weathered surface
- Scraped rock is re-analyzed by spectrometers

Spirit and Opportunity Development

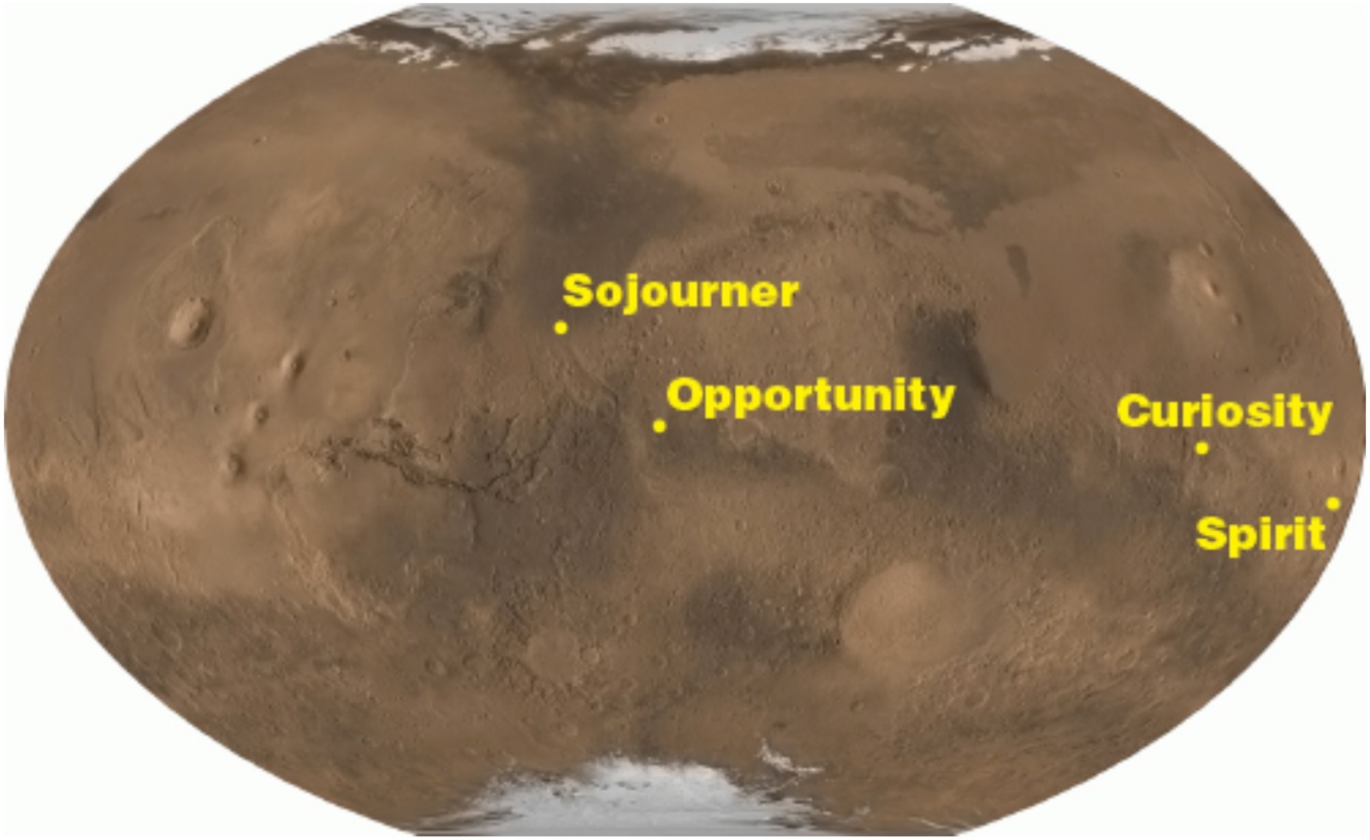
- JPL Mission To Mars Documentary (13:45)
  - NASA seamstresses
  - Airbag testing
  - Review board
  - Science vs. engineering for choosing the landing site
  - Parachute testing
  - Integration and testing
  - Retrorocket testing
  - Field Integrated Design and Operation
  - Parachute testing after design changes

Digression: Choosing a Landing Site

Choosing A Landing Site (0:59)

MER landing sites

- Spirit (MER-A) proposed landing site: Gusev Crater, possible former lake in giant impact crater
- Opportunity (MER-B) proposed landing site: Meridiani Planum, where mineral deposits suggest wet past



The landing sites of all four Mars rovers on a map of Mars. Credit: National Geographic Society, MOLA Science Team, MSS, JPL, NASA

Spirit's "Six Minutes of Terror" (Jan. 3, 2004)

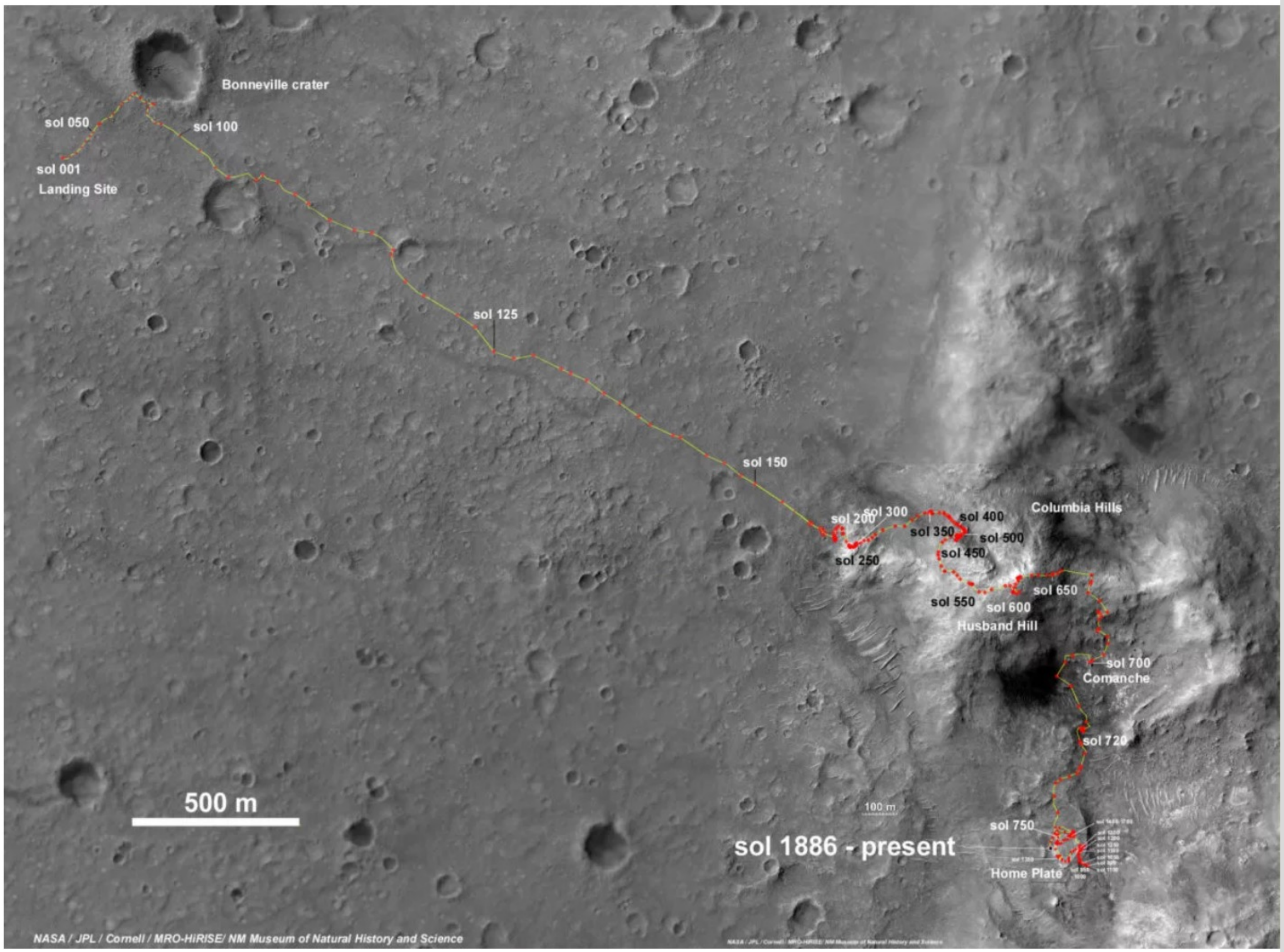
- Spirit Six Minutes of Terror (5:59)

- Opportunity landing (at higher altitude) also successful after adjustments made based on Spirit descent data

Mars Exploration Rover Mission members Pete Theisinger, right, and Mark Boyles are seen in the Mission Control Center in Pasadena, Calif. in this January 15, 2004 photo.

Spirit operations and findings

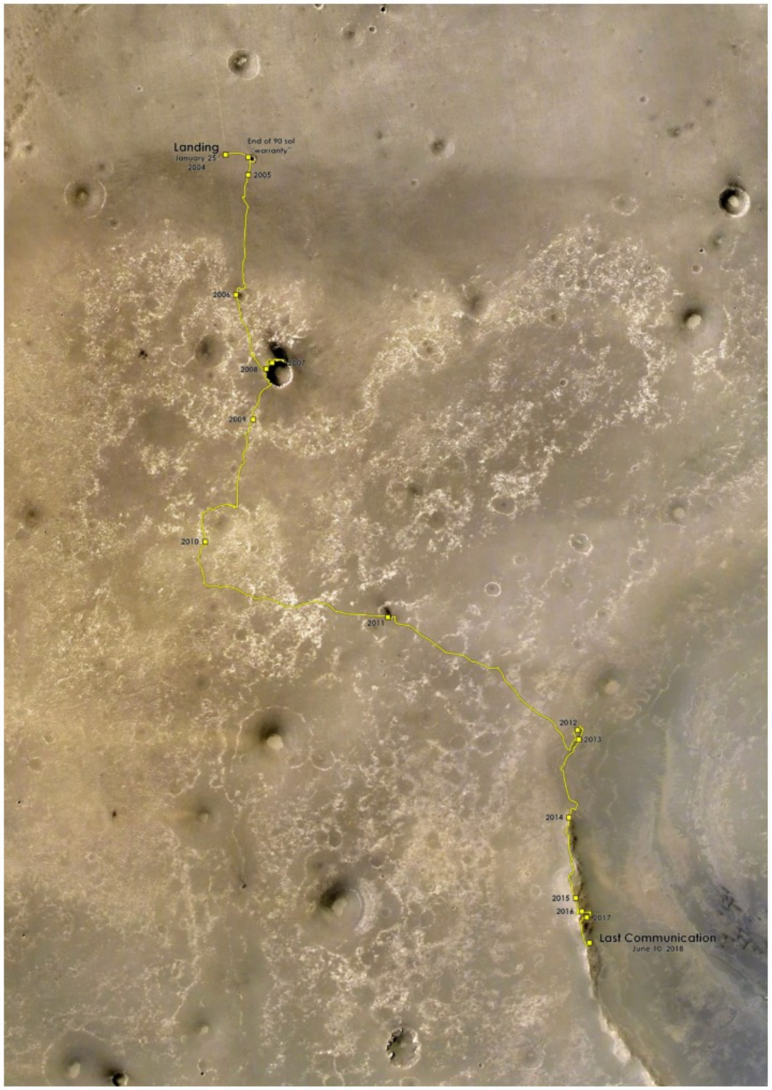
- Lander protective shell holds rover with 126 cables and can turn the rover upright and provide a ramp for rover exit
- Six years and 5 miles: [NASA Spirit's Triumph (4:36)]



SPIRIT ROUTE MAP The Mars Exploration Rover mission's official route

Opportunity operations and findings

- 15 years and 28 miles
- Opportunity summary (3:34)



OPPORTUNITY ROUTE MAP The base image for this map is a mosaic of

ESA Mars Express Orbiter and Beagle Lander

- 2003 Mars Express Orbiter and Beagle lander were built by Astrium, an aerospace company based in Paris with employees also in Germany, UK, Spain, and the Netherlands
- Operated out of ESA Operations Centre in Darmstadt, Germany
- Launched from Baikonur on a Soyez/Fregat rocket

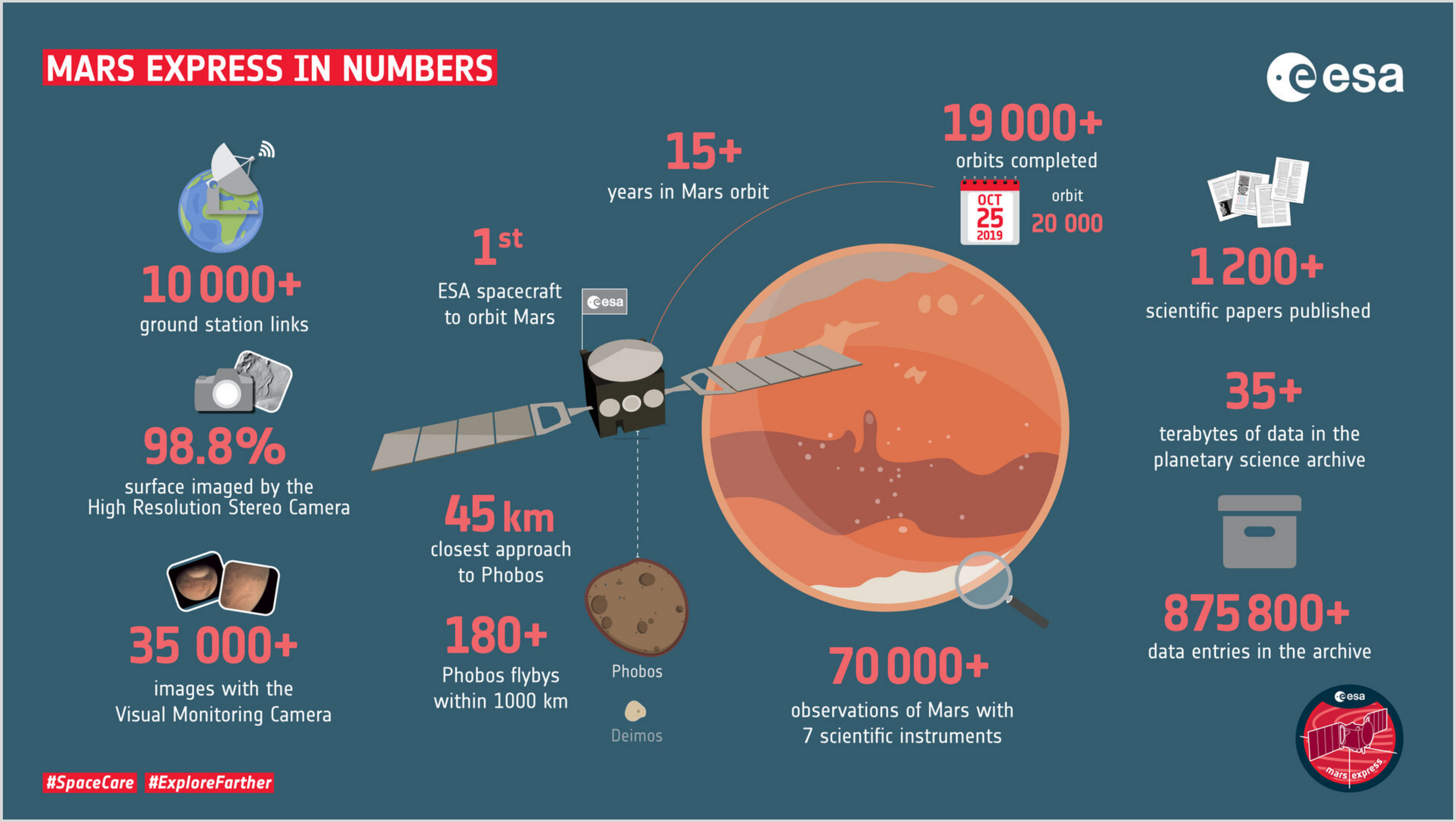
Mars Express Instruments

- Visible and Infrared Mineralogical Mapping Spectrometer (France): Determines mineral composition of the surface up to 100 m resolution
- Ultraviolet and Infrared Atmospheric Spectrometer (France): Assesses elemental composition of the atmosphere
- Sub-Surface Sounding Radar Altimeter (Italy): A radar altimeter used to assess composition of sub-surface aimed at search for frozen water
- Planetary Fourier Spectrometer (Italy): Makes observations of atmospheric temperature and pressure
- Analyzer of Space Plasmas and Energetic Atoms (Sweden): Investigates interactions between upper atmosphere and solar wind
- High Resolution Stereo Camera (Germany): Produces color images with up to 2 m resolution
- Mars Express Lander Communications (UK): Allows Mars Express to act as a communication relay for landers on the Martian surface
- Visual Monitoring Camera, a small camera to monitor the lander release

Beagle Lander

- British built
- Named after Darwin’s ship
- Focus on habitability and detection of organic chemicals
- Robotic arm known as the Payload Adjustable Workbench (PAW) contained a pair of stereoscopic cameras, a microscope with a 6-micrometre resolution, a Mössbauer spectrometer, an X-ray spectrometer, a drill for collecting rock samples and a spot lamp
- The PAW could transfer samples to GC/MS to measure isotope ratios of carbon and methane
- Also had a burrowing tool to get deeper samples
- Deployed December 25, 2003, with no confirmation of a successful landing
- Fate unknown until 2015 when MRO photographed the remains and found that solar panels only partially deployed, and the antenna remained covered

Mars Express Summary



[ESA Documentary (3:13)]

Mars Express Scientific Findings

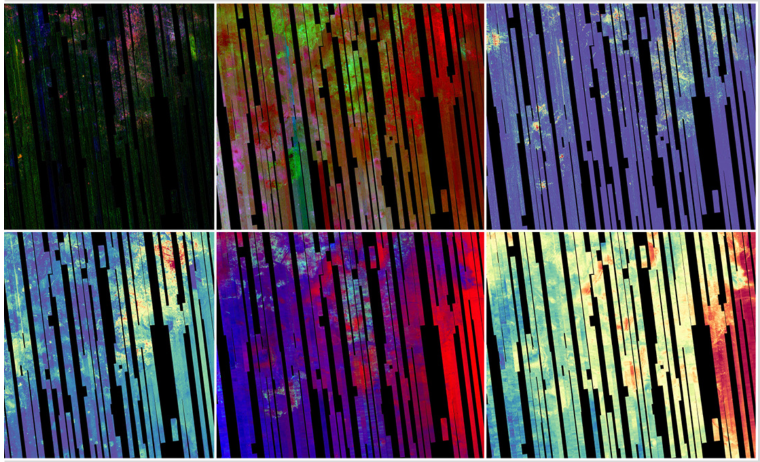
- Producing global maps tracing the planet's geologic activity, water, volcanism and minerals
- Studying immense volcanoes, canyons, polar ice caps, and ancient impact craters.
- Probing the sub-surface with radar, detecting subsurface layers of water ice and liquid water hidden under the planet's south pole
- Explored the Martian atmosphere, finding signs of ozone and methane, fleeting cloud layers up to 100 km above Mars' surface, and mighty dust storms
- Witnessing charged particles escaping to space
- Finding the first evidence of a planet-wide groundwater system where interconnected underground lakes may contain minerals crucial to life
- Examining Mars' moons Phobos and Deimos, with the revised mass and density data opening the possibility that the interior of Phobos resembles a porous sponge
- Identifying dried-up river valleys, traces of catastrophic floods, and buried glaciers
- Discovering localized auroras on Mars
- Measuring the quantity and composition of ice at the polar regions, finding that there is enough water ice in the south polar cap to create a global ocean 11-metres deep
- Detecting volcanic activity as recently as 100 million years ago, leading to speculation that some volcanoes may still be active today

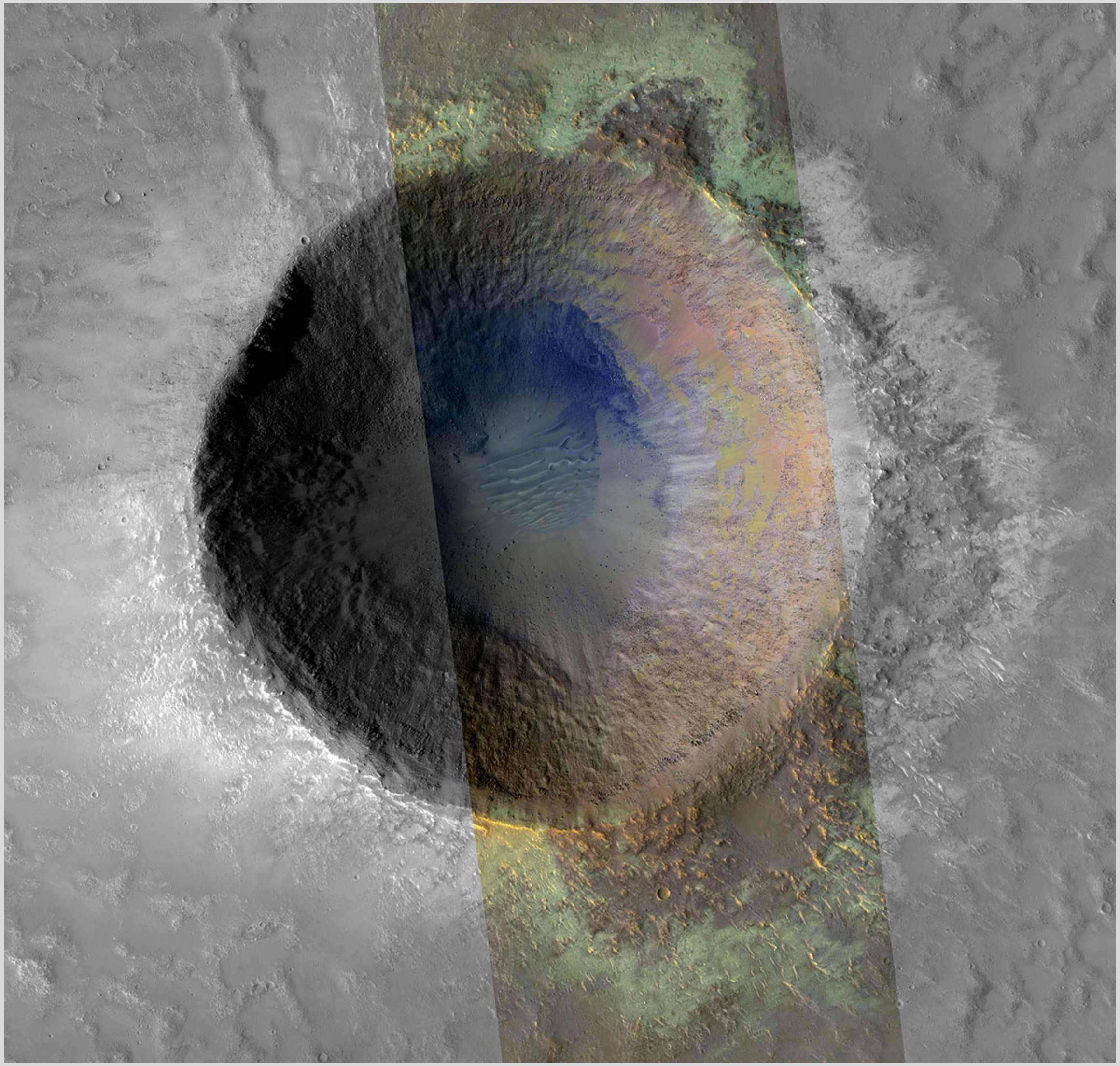
US Mars Reconnaissance Orbiter

- Launch August 2005
- Arrival March 2006, still working
- $500 million to build and launch, $30 million per year to operate
- Goals: Investigate history of water on Mars
- Instrumentation
  - Hi-res cameras (1 foot resolution)
  - Spectrometers
  - Shallow Subsurface Radar (Italian Space Agency) to probe the internal structure of the Martian polar ice caps
- As of July 2023, returned 450 terabytes of data
- Looking for
  - Deposits of minerals that may have formed in water over long periods of time
  - Evidence of shorelines of ancient seas and lakes
  - Deposits placed in layers over time by flowing water.
  - Evidence of whether underground Martian ice seen by Odyssey is the top layer of a deep ice deposit or a shallow layer in equilibrium with the atmosphere and its seasonal cycle of water vapor

MRO Results

"tie mineral deposits observed in high-resolution images to regional scale trends, landscape features, and geology”





Mostly iron oxides, silicates, chlorides, and carbonates

MRO Results

- More recently created craters show excavated water ice, which gradually sublimes
- Piles of rock debris below cliffs also show large amounts of water ice with a strong suggestion that these may be analogous to glaciers on Earth
- Widespread chloride deposits are thought to be due to evaporation of mineral-rich waters, suggesting prior lakes
- Several types of clay were found
- Originally suggested that “recurring slope lineae” were caused by current flowing salt water, but these were later shown to be created by grains of sand and dust
- Confirmed the presence of subsurface water ice up to a depth of 29 inches at latitudes between 40° and 60° N

US Phoenix Lander

- First NASA mission led by a public university (U of Arizona) in cooperation with JPL and partners in Canada, Switzerland, Denmark, Germany, Finland and the UK
- Used copies of instruments from failed prior missions
- First to land in the polar region (68^{o} North)
- Not a rover because the landing area is uniform, and more weight budget could be used for instrumentation
- Built by Lockheed Martin for $325 million (plus $95 million to launch)
- Launched August 2007, landed May 2008
- Planned to operate for 90 sols, operated for 157 sols
- Objectives
  - Dig through topsoil to study the chemistry of ice below
  - Look for organics at a depth protected from radiation
- Also contained a DVD similar to the Voyager “golden record”

Phoenix Lander Instrumentation and Overview

- Robotic arm can dig 7.5 feet out and 1.5 feet deep using a rotating rasp tool
- Thermal and Evolved Gas Analyzer (TEGA) heats the samples and feed the gasses released to a mass spectrometer
- Microscopy, Electrochemistry and Conductivity Analyzer (MECA) does microscopic analysis of soil to determine mineralogy, and measures water and ice content, salinity and acidity
- Meteorology Station records daily weather with temperature, pressure and LIDAR to detect dust, clouds and fog
- No organic compounds were detected by the GC-MS, possibly due to destruction by perchlorates

- Overview video (2:30)
- PBS Documentary (1:22)

Summary of Week 3

- Odyssey is an example of a very long-lived orbiter
- Spirit and Opportunity rovers performed superbly
- ESA's first Mars mission was a big success, but UK's Beagle failed
- US MRO returned unprecedented amounts of data
- US successfully carried out the first high latitude mission (Phoenix) and sampled water ice for the first time

What’s next

- 2010s: Curiosity, MAVEN, Mangalayan, Insight
- 2020s: Perseverance, Ingenuity, Tianwen, Emirati Hope
- Mars science summary
- Unlaunched: Exo-Mars
- Humans?