Mars Missions: Learning about Environment & Habitability

Karen J. Meech, Astronomer
Institute for Astronomy
Astronomy 281

The Fascination of Mars...

- Mars Exploration Themes
  - Past & Present environment, climate, geology
  - What is the biological potential of Mars?

Mariner 4 (1965)
1st close up

Viking 1 Orbiter
1976 & Lander

Mars Exploration Themes
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Early Missions

- Mars 1, 2, 3, 4 – USSR Mars Flyby – (November 1, 1962)
  - Communications failed en route.
- Sputnik 22 – USSR Mars Flyby – (October 24, 1962)
  - Spacecraft failed to leave Earth orbit after the final rocket stage exploded.
  - Failed to leave Earth orbit.
- Mariner 3 – USA Mars Flyby – (November 5, 1964)
  - Mars flyby attempt. Solar panels did not open, preventing flyby.
  - Mariner 3 is now in a solar orbit.
  - Arrived on July 14, 1965 after 8 mos; passes within 9,845 km
  - 1st close-up images of the red planet: 22 photos showing a cratered surface
  - Atmosphere found composed of CO2 with pressure of 5-10 mbar
  - A small intrinsic magnetic field was detected. Mariner 4 is now in a solar orbit.
- Zond 2 – USSR Mars Flyby – (November 30, 1964)
  - Contact was lost en route.

Last time – ALH 84001...

- Different types of meteorite
- Viking Mission Details
- Arguments for and against the remnants of life in ALH 84001

Mariner 6 and 7 – USA Mars Flyby – (February and March, 1969)
- Measurements of surface & atmosphere T, surface molecular composition, and atmospheric pressure
- Over 200 pictures were taken. They are both now in a solar orbit.

- Arrived Nov. 24. 1st US spacecraft to enter orbit around a planet other than Earth.
- Upon arrival a huge dust storm was in progress on the planet; delayed expts.
- 1st hi-resolution images of the moons Phobos and Deimos were taken.
- River and channel-like features were discovered. Mariner 9 is still in martian orbit.
Early Missions

Mars 1969A and B, USSR
Launch Failure
Mariner 8 - USA Mars Flyby - (May 8, 1971)
Failed to reach Earth orbit.
Kosmos 419 - USSR Mars Probe - (May 10, 1971)
Failed to leave Earth orbit.

Mars 2–7 - USSR Mars Orbiters/Soft Landers - (1971-3)
Mars 4 - failed to go into Mars orbit. It returned some images and data.
Mars 5 - acquired imaging data for the Mars 6 and 7 missions.
Mars 6 - lander returned atmospheric descent data, but failed on its way down
Mars 7 - failed to go into orbit about Mars and the lander missed the planet. Carrier and lander are now in a solar orbit.

Mars 3, 4, 5 images

Early Missions – Viking

Viking Mars (Launch 1975, arrive 1976, end 1982)
- 4 experiments designed to detect life \( \rightarrow \) none
- Debate about life erupts again with the Mars Meteorite ALH84001
- 2008 Mars Phoenix mission results \( \rightarrow \) revisit Viking experiments
- Mars soils may have contained building blocks of life

What came Next?

Between 1988 and 1999 a total of 7 failed Mars missions
- US Mars Observer (1992)
- USSR Mars 96 (1996)
Successful missions during this period ...
- Mars Global Surveyor
- Mars Pathfinder

Mars Pathfinder Experiment

Discovery mission (\$280M – 1/15 of Viking)
- Demo a low cost surface micro rover – Sojourner
Launch 2/4/97; Land 7/4/97, EOM 9/27/97
- Land at mouth of outflow Ares Vallis
Science objectives
- Surface geology, geochemistry, petrology
- Magnetic properties of soil
- Atmosphere studies
Instruments
- Imager on the mast
- X-ray spectrometer (APX) – elemental composition
- Atmosphere meteorology package (ASI/MET)
**Why land at an outflow channel?**

A. Easier to land
B. May collect material from the highlands in addition to lowlands
C. Best habitability
D. A and B
E. None of the above

**Science Results – Pathfinder**

- **Geology** – site shaped by floods
  - Rounded boulders
  - Low erosion now – no recent water
  - Rock composition similar to earth crust
- **Atmosphere**
  - Patterns of diurnal T and P variation
  - Max T at 13pm 263K, min at sunrise 197K
  - Pressure varies with seasons – 20-30% of atm freezes out in winter
  - Strong T variation from surface at sunrise (nose 20°C colder than feet in morning)
  - Dust devils – sharp pressure changes

**Mission Highlights**

- **Mars Pathfinder (1997)**
  - Geology shaped by water from warmer, wetter era
- **Mars Global Surveyor (1997-2006)**
  - Launch 11/7/96, Arrive 9/11/97, End 11/2/06
  - Solar panel problem – loss of power
  - Key new science from orbiter: 240,000 images!

**Mars Global Surveyor Science**

**Top 10 Hits**

- Remnant magnetic field → dynamo
- Structure of lithosphere
- Global topography better than Earth!
- Layered regions (water deposit?)
- Hydrothermal past – hematite
- Global atm circulation models
- Erosional history
- Polar caps – H2O inventory
- Origins of channels – recent water?

**MOLA Topography**

- Better resolution than on Earth
- Possible past northern hemisphere ocean?
  - Lower elevations
  - Possible shoreline trace

**Polar Regions—Volatile inventory**

- **North pole** – 1200 km diameter
  - 3 km thick, 1 km deep canyons
  - Wind / sublimation erosion
  - Volume < 0.1 ocean
- **South pole** – 420 km diameter
  - Mostly CO2 & H2O
  - Summertime sublimation → dust storms

**Hydrothermal systems: Hematite (Fe2O3)**

- Product of aqueous mineralization
  - Hot H2O moves through Fe-rich rocks → dissolves Fe
  - Water cools, Fe-minerals precipitate out
  - Often associated with hydrothermal systems
  - Implies long-term water stability
Apollinaris Sulci Yardangs

Cydonia Controversy

Mission Highlights
- Mars Pathfinder (1997)
  - Geology shaped by water from warmer wetter era
- Mars Global Surveyor (1997-2007)
  - Insight into history of water
  - MOLA topography \( \rightarrow \) ocean?
  - Hydrothermal minerals?
  - Recent water?
- Mars Odyssey (2001-present (2015))
  - GRS – Surface water ice distribution
  - Cameras
    - Evidence of lake filled craters, many more channels
    - Selection of sites for future Mars missions
  - Thermal imager
    - Gives idea of how insulating the surface materials were

Noctis Labyrinthus
**Odyssey – Mariner Valley**

**Mission Highlights**
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  - MOLA topography
  - Hydrothermal minerals?
  - Recent water?
- **Mars Odyssey (2001-present)**
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  - Evidence of lake filled craters, many more channels
  - Selection of sites for future Mars missions
- **Mars Exploration Rovers (2003-2010 & present)**
  - Hematite – precipitates in water; Sulfate deposits
  - Water flowed on Mars – altering mineralogy
  - Amount of water fluctuated

**Mars Exploration Rovers (MER)**
- **Determine habitability history at 2 sites**
  - Geologic history
  - Aqueous history
  - Climate history
- **Ultimate goal**
  - Understand if life ever arose on Mars
- **Nominal mission lifetime – 90 dys**
  - Spirit [Gusev crater]
    - Launch 6/10/03, landed 1/4/2004
  - Opportunity [Meridiani]
    - Launch 7/7/2003, landed 1/25/04

**MER-Spirit Rover**
- **Instruments observing Comanche**
  - Moessbauer spectrometer
  - Mini thermal emission spectrometer
  - Alpha particle X-ray spectrometer
- **Composition**
  - 25% Mg,Fe-carbonate
- **Results from initial travels in Gusev Crater**
  - Revealed a basaltic setting
  - At Columbia Hills – early Mars was characterized by
    - Impacts, explosive volcanism, subsurface water
**Spherules at Meridini**

- Mm-sized balls – possible origins
  - Mineral precipitates in water
  - Volcanic ejecta
  - Impact origin
- The Evidence
  - Spectra consistent with hematite

**More Evidence of Water**

- Opportunity at Eagle and Endurance craters
  - More spherules
  - Layering (sedimentation)
  - Evaporated lakes forming sulphate-rich sands, similar to those seen on earth
  - Jarosite (mineral forming in dilute sulfuric acid solutions) $\text{KFe}_2\text{(OH)}_6\text{(SO}_4\text{)}_2$
  - Ripples in rocks → gentle lake edge

**Rio Tinto Spain**

- Few places on Earth have such sulfate deposits – one is Rio Tinto
  - Deep red color
  - Highly acidic ($\text{pH}=2$)
  - High concentration of heavy metals (mine dump)
  - Sulfide minerals associated with microorganisms

**MER – Iron Meteorite on Mars**

**MER Pancam after Spirit’s 2\textsuperscript{nd} Winter Aug 17, 2006**
MER Pancam

MER – Spirit
Sadly, Spirit has been unresponsive since 2010

Victoria Crater – 750 m diam, 70m deep
Sols 950-1630 – arrive Sep. 2006

Opportunity approaching Endurance Crater
130 m diam, 30 m deep

Opportunity – Late afternoon at Endurance Crater
Day 2888 (March 9, 2012)

Mission Status March 2015

• No comm from Spirit since 3/22/2010
  – Fell into a ditch and solar panels no longer active (RIP)

Opportunity – Jan 2015

• MER Highlights
  – Evidence of flowing and standing water, altering minerals (sulfates, hematite)
  – Amount of water fluctuated
Mission Highlights

• ESA Mars Express (2003-Present)
  - MARSIS evidence of ancient ocean
  - Dust covered frozen seas
  - Sulfate deposits
  - Evidence for ground-water

• ESA – US Collaboration
  - High resolution stereo cameras
  - Ground penetrating radar
  - Beagle 2 Rover (UK: geology, mineralogy, biogeochem)

• Beagle Rover – lost?
  - 12/19/03 – separation, 12/25/03 Landing, 2/11/04 - lost

Mars Express – MARSIS Radar

• Deployed May 2005
  - Uses 2 20-m antenna to record the echo from Mars
  - How far the radio penetrates depends on material
  - Imaged ice beneath the surface
  - Strong evidence for a former ocean on Mars
    • North consistent with sediments

Mars Reconnaissance Orbiter

• Timeline
  - Launch 8/05, Arrive 2006, EOM 12/2010 (extended)
• Goal
  - Was water around long enough to create habitable environments
• Instrumentation
  - High resolution camera / spectrometer
  - Climate & high resolution mineralogy
  - Sounder for subsurface water
  - First of a telecom satellite network

MRO finds Beagle 2 – Jan 16, 2015

Hebes Chasma
ESA
Mawrth Vallis, NASA

Image of Viking lander!
Dust Devils – late spring, N. Mars

Tithonium Chasma (Valles Marineris)

Arabia Terra

Ceraunius Fossae

Pavonis Mons – 8.4 mi high shield volcano
Pavonis Mons - oval pits

Olympus Mons

MRO

Chaotic Terrain

Columbia Hills

Mission Highlights

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  - Sulfate deposits
  - Evidence for ground-water

- ESA/DLR/FU (G. Neukum)

- Mars Reconnaissance Orbiter (2005-Present)
  - Groundwater flow
  - Climate variations (polar deposits)
  - Buried glaciers, subsurface ice
  - Mineral deposits $\rightarrow$ wet past

  - Near surface ice $\rightarrow$ climate cycles
  - Chemicals (perchlorate) lower freezing point of H$_2$O

Hebes Chasma ESA

Mawrth Vallis, NASA
Mars Phoenix Mission

- Scout mission opportunities
  - Phoenix is the first one
  - End operations 5/25/2010
- Science Goals
  - Land near water-ice rich N polar region
  - Robotic arm for digging
  - Samples heated to study gases
  - Search for environments suitable for life

Mars Science Lander

- Mission Timeline
  - Surface operations: ~3 Mars year (687 days), 20 km
- Science Goals
  - Was Mars Ever Habitable?
  - Find elements important for life
  - Studies of the atmosphere and geology
- Instruments (12)
  - Cameras (descent, hand lens, panoramic)
  - Radiation detectors, Atmospheric sensors
  - Chemical analysis of surface materials

Mars Science Lander Objectives

- Biological objectives
  - Determine the nature and inventory of organic compounds
  - Inventory the chemical building blocks of life (C, H, N, O, P, S)
- Geochemistry/Geological goals
  - Investigate chemical, isotopic and mineral composition of surface
  - Interpret the processes that have formed and modified rocks
- Planetary processes
  - Assess long-timescale atmospheric evolution (4 Gyr)
- Surface Radiation Objective
  - Characterize the surface radiation (GCRs, protons, neutrons)

The Significance of Gale Crater

- Samples Early Mars Environment
  - Formed 3.8-3.5 Gy ago
  - Had water in its history; Thick sediment layers
  - Clays & sulfates present
  - How long was Mars habitable?
- Curiosity Rover
  - Search for minerals altered by water
  - Look for organic molecules – preserved in clay?
A Safe Landing – Aug. 5, 2012

Parachute & backshell HIRISE Image

Early Images

Aug. 5 – Image during descent

Aug. 7, 2012

Effects of descent rocket on the surface
Exposed by rocket; crust formed by dehydration of wet material

Early Images

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MastCam. Aug. 8, 2012

Closeup of Mount Sharp

100mm telephoto image from Mastcam

Goal – layered regions: clays & hydrated minerals

Voyager image of Earth, Feb. 14, 1990, from 6.4 billion km

Earth as Seen from Mars – April 29, 2005 – Imaged by Opportunity

Curiosity Looking towards Mt. Sharp

Curiosity Looking towards Mt. Sharp

– Imaged by Opportunity

– Curiosity Looking towards Mt. Sharp
First Drilled Sample

MSL at end of 11/2014
817 Sol

Curiosity at Pahrump Hills – 2014 Dec 13 – Sol 903

After 2 years and nearly 9 km of driving, Curiosity is at the base of Mount Sharp

Mars Was an Environment Suitable for Life

- **Current Mars Conditions**
  - Pressure 6.9-7.8 millibars, T = -91 to 3°C
- **Early Chemical results**
  - If life ingredients were present, they can be preserved

MSL Results

- **Rocks and dust**
  - Gale crater – mostly sedimentary rocks
  - Mars dust everywhere – uniform composition – dust storms
- **Volatiles evidence**
  - Evidence of water in hydrated clays – shows that when they formed a large part of Mars atm had been lost (D/H)
  - Methane has been detected – and is variable
- **Surface conditions habitable for chemolithotrophs**
  - Neutral pH
  - Fresh water streams ran, cross bedding → water movement in lake
  - Minerals are common to earth (like big island)
  - Examples of volcanic glasses (no contact w/H2O – not weathered)
  - So far no detection of “evolved” minerals (changed by life)
- **Organics**
  - Detected in sample from Cumberland (near eroding scarp) – chlorobenzene

Evidence of currents in lake
The Science continuing to flow from the MSL adventure . . .

It is clear Mars was wet long ago and scientists want to see if it was suitable for life . . .

Many of us, though, already understand the importance of water on Mars . . .

Science From Mars Samples

• Returns Versus In-situ
  – Terrestrial contamination
  – Benefits of a terrestrial lab
  – ALH 84001 – 100 metric tons of analysis!

• Variety and Context
  – Information on past climate
  – Need info on surrounding geology to know history

Planetary Protection Issues

• Backward / Forward Contamination
  – Protection of Earth & sample
  – Public concerns

• Sample handling
  – Transport to Earth
  – Containment facilities on Earth – BSL 4

• Sterilization & Distribution
  – Heating – geochemical destruction
  – Gamma radiation
  – Certification

Courses of Action

• Backward / Forward Contamination
  – Legalities: EIS, NASA-DoD
  – Presidential Directive

• ICAMSR
  – Smallpox in US: 10,000 dead
  – Europeans in polynesia → 50% mortality
  – 1347-1350 – 25% Europe dies (black death)

  – Need to make public aware of the issues

Public Perceptions

• Technical Description
  – “The risks of pathogenicity from putative life forms are extremely low because it is highly unlikely that extraterrestrial organisms could have evolved pathogenic traits in the absence of host organisms, however the risk is not zero” (NRC)

• Plain English “interpretation”
  – “First you start coughing, then a slime-flecked, fanged weasel from Hell bursts out of your chest cavity”
Containment and Release

- Current Plans
  - Capture & cache at Mars, return
  - USAMRIID BSL4 lab
- Alternative quarantines?
  - Aerocapture is hard
  - Humans are hard to decontaminate
  - Earth orbit – disaster?
  - Sterilization – launch radioactive material?
- Risks
  - Very low – need a host-relationship
  - We get 15-300 Mars meteorites per year

Lessons from the Apollo Quarantine Experience

- Construction 8/1966
  - Only 3 yrs before first Apollo manned flight
  - Unreasonable environment requirement
  - Flawed quarantine protocol
- Keep things simple
  - BSL4 quarantine
  - Clean room
  - Only life experiments inside
  - Sterilize out samples

Life Detection Protocol

- Different type of biomarkers
  - Search for fossils
  - Search for organics at ppb level
  - Look for chiral molecules
  - Look for isotopic evidence
- Caution
  - Absence of evidence is not equal to evidence of absence

Sterilization Procedures

- Heating – to what temperature?
  - Preserve geology (melting is too hot)
  - Moderate T – can destroy isotopes
  - Lower T – harms aqueous alteration product evidence
  - Organics
    - Racemization (chiral → non-chiral) at 150°C
    - T> 275°C morphological alteration
- Gamma radiation
  - Unknown effects
  - Surveyor 3 bacteria – survived for 2.5 yr
  - LDEF materials survived 7 yr

Long Duration Exposure Facility - LDEF

- Mission Particulars
  - Shuttle deployment 4/7/84
  - 21,000 lbs, 30 x 14 ft
  - On orbit 5.7 yrs (design for < 1 yr) – return 2/26/90
- Science Experiments (57)
  - Biostack – radiation on microbes
    - Discovery of radiodurans microbe
  - Many expts to look at cratering, debris, micro impactors
  - Experiments for high E radiation

What is in the Future?

- Discovery 12 - Insight
  - Investigation of Mars interior
  - Seismic equipment, cameras, heat flow
- Mars Science Lab & Mars 2020
  - MSL is just beginning the great science
  - Mars 2020 just approved – replicate MSL – cache rocks for sample return