Atmosphere is CO$_2$ around $6/1000$ths of Earth pressure. Seasons like Earth. Day is only $\sim40$ min longer. Temperature from above freezing to far below (dynamic polar caps).

Changing surface patterns: Martians building canals?! No, wind moving dust.
Proposed History of Mineral Alteration on Mars

Mars Express OMEGA spectrometer mineral detections from orbit indicate:

**Phyllosilicates (clay minerals)** formed in the earliest aqueous environments, the surface environment changed.

**Sulfates** formed from later aqueous environments (e.g., evaporation -> salts)

**Anhydrous ferric oxides** dominate weathering during the last half of Mars history.

Simplified from Fig. 5 of Bibring et al. (2006) *Science*; 312, 400-404.
“Was there ever life on Mars?”
Tackling an essential part of the question: *Habitability*

- We know from the last 15 years of exploration that Mars supported diverse aqueous environments.
- Habitability is a necessary component of trying to answer “Is or was there ever life on Mars?”

*Was Mars ever habitable by life as we know it?*

- Assume this revolves around the viability of a class of single-celled bacteria called “chemolithotropes” — microbes that feed on chemical energy available in rocks.
  - Water: How much was available on site, and for how long?
  - Chemical building blocks of life: Were C, H, N, O, P, S present and not too strongly bound up in compounds to be available?
  - Energy: Were there chemical/redox gradients available as an energy source?

- Mobile rovers (Pathfinder, MER, MSL, Mars2020) can help address whether Mars had habitable environments in its past.
# SOLAR SYSTEM EXPLORATION 2014

<table>
<thead>
<tr>
<th>Planet</th>
<th>Telescopic Observation</th>
<th>Flyby</th>
<th>Orbiter</th>
<th>Lander Return</th>
<th>Rover Mission</th>
<th>Sample</th>
<th>Manned</th>
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<td>Mar10</td>
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<td>Lun16</td>
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<td>Hayabusa</td>
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<td>Pluto</td>
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<td>Kuiper Belt</td>
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</table>

WHY ROVERS?

Advantages:

• Mobility: Assess multiple sites or locations on a planet’s surface
• Higher spatial resolution of surface features
• In Situ Studies: Direct measurement of rock/soil/ice or atmospheric compositions & physical properties

Types of Rovers

• Drivers (wheels)
• Walkers (legs)
• Hoppers (jumping)
• Floaters (balloons)
• Flyers (planes)
Driving Rovers
Walking Rovers
Recent *Discovery* mission proposal for 2016 (Not Selected): Comet Hopper

- Multiple landings on Comet 46P/Wirtanen
- Study as comet changes from inactive to active during orbit
Floating Rovers (Balloons)
Flying Rovers (Planes)
Dragonfly (Titan)
### Planetary Rover Missions

<table>
<thead>
<tr>
<th>Mission</th>
<th>Launch Date</th>
<th>Country</th>
<th>Target</th>
<th>Type</th>
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<tbody>
<tr>
<td>Luna 17</td>
<td>10 Nov 1970</td>
<td>USSR</td>
<td>Moon</td>
<td>Lunokhod 1: 1st driver</td>
</tr>
<tr>
<td>Mars 3</td>
<td>28 May 1971</td>
<td>USSR</td>
<td>Mars</td>
<td>Test driver, not deployed</td>
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<tr>
<td>Luna 21</td>
<td>08 Jan 1973</td>
<td>USSR</td>
<td>Moon</td>
<td>Lunokhod 2</td>
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<tr>
<td>Vega 1</td>
<td>15 Dec 1984</td>
<td>USSR</td>
<td>Venus</td>
<td>1st balloon, last &gt;46 hr at 54 km altitude</td>
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<tr>
<td>Vega 2</td>
<td>21 Dec 1984</td>
<td>USSR</td>
<td>Venus</td>
<td>Balloon</td>
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<tr>
<td>Mars Pathfinder</td>
<td>04 Dec 1996</td>
<td>USA</td>
<td>Mars</td>
<td>Sojourner test rover</td>
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<tr>
<td>MER-Spirit</td>
<td>10 Jun 2003</td>
<td>USA</td>
<td>Mars</td>
<td>Stuck Apr 2009, last contact: 22 Mar 2010</td>
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<tr>
<td>MSL-Curiosity</td>
<td>26 Nov 2011</td>
<td>USA</td>
<td>Mars</td>
<td>Driver, chemistry</td>
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</table>

**Future Missions**

<table>
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<th>Mission</th>
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<th>Target</th>
<th>Type</th>
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<td>ExoMars</td>
<td>2018</td>
<td>ESA-RSA</td>
<td>Mars</td>
<td>Driver, drill</td>
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<tr>
<td>Mars Rover</td>
<td>2020</td>
<td>USA</td>
<td>Mars</td>
<td>Driver, sample cache</td>
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</table>
Lunokhod

Soviet Lunokhod-2
The second in a series of Soviet lunar and planetary rovers was launched on January 8, 1973

Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Weight</td>
<td>83.6 kg</td>
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<tr>
<td>Length (with unhinged solar panel lid)</td>
<td>4.42 m</td>
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<tr>
<td>Width</td>
<td>2.15 m</td>
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<tr>
<td>Height</td>
<td>1.92 m</td>
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<tr>
<td>Booster rocket</td>
<td>Proton</td>
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<tr>
<td>Launch</td>
<td>Baikonur Space Center</td>
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</table>

Lunokhod 2 mission route

Landed on moon: January 16, 1973

Distance covered on the moon: 37 km (3.5 times farther than Lunokhod-1)

Mission duration:
- 4 terrestrial months
- 5 lunar days

First lunar rover's hibernation site
- Dzungarian Hills
- Le Monnier crater

Second lunar rover's hibernation site
- Second lunar rover's hibernation site

Third lunar rover's hibernation site
- Third lunar rover's hibernation site

Near Cape
- Near Cape
- Circle Harbor

Less of contact: May 10, 1973
• Operated for 322 Earth days
• Traveled 10,540 meters (10.54 km), returned more than 20,000 TV images, 206 high-resolution panoramas
• Performed 25 lunar soil analyses with its x-ray fluorescence spectrometer, used its penetrometer at 500 different locations
- Operated for about 4 months
- Traveled 37 km (held longest distance record until MER Opportunity beat it), returned more than 80,000 TV images, 86 high-resolution panoramas
- Completed many mechanical tests of the surface, laser ranging measurements, and other experiments
LRO Images Lunokhod

Lunokhod-2

Luna 17 Lander
Soviet Mars 3 Lander & Rover

- Launch 28 May 1971
- Landed in dust storm 2 Dec 1971
- Arm would have put rover on surface, attached to lander by umbilical, use skis to move around
- Contact lost 14.5 seconds after landing, no usable data returned, rover not deployed
1996 Mars Pathfinder Mission
Go to https://www.maasdigital.com/gallery.html
• Last communication was 22 Mar 2010 (Sol 2210)
• Total odometry remains at 7,730.50 meters (4.80 miles)

• *Spirit* became stuck on 1 May 2009, 5 years, 3 months, 27 Earth days after landing
• Lasted 21.6Xs planned mission duration
MER-Spirit Discovers Mg-rich Carbonate (16-34 wt%) Outcrops on Mars
=>
A Warmer, Wetter Past
NASA Mars Rover
*Opportunity* in
Meridiani Planum

OSU Mapping and GIS Laboratory
Image sources: NASA/JPL/Cornell/University of Arizona/MSSS
Endeavour is attractive because of its age, and hints (detected from orbit) of clay minerals on its ancient rim.

MER Opportunity traverse: 38.73 kilometers (24.07 miles)
Pinks: Younger rocks

Blues and greens: Older rocks

Older rocks are partly eroded Endeavour crater rim material, probably “Noachian” in age.
Cape York

(color HiRISE image from Mars Global Surveyor)

Area of intensive fieldwork where Mars Global Surveyor spectrometer detected faint signature of clays from orbit.
Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) is a visible-infrared spectrometer on the Mars Global Surveyor spacecraft.

CRISM detected possible clay minerals (e.g., smectites) on the east side of Cape York, which is an eroded remnant of the rim of ancient Endeavour crater.
Local stratigraphy

Arvidson et al. (2014)
MER-Opportunity
Views First Dust Devil in 6.5 Years,
Discovers Iron Meteorites in Meridiani Planum
Spirit and Opportunity
BY THE NUMBERS

6 YEARS lifespan

124,838 raw images

4.8 MILES traveled

30 DEGREES steepest slope

14+ YEARS lifespan

217,594 raw images

28 MILES traveled

32 DEGREES steepest slope

Updated February 4, 2019