Lecture 8
Surface and Atmosphere of the Inner Planets
October 1, 2018
Terrestrial Planets
<table>
<thead>
<tr>
<th></th>
<th>Mercury</th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (AU)</td>
<td>0.4</td>
<td>0.7</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Spin Period</td>
<td>59 days</td>
<td>243 days (retrograde)</td>
<td>24 hours</td>
<td>24.6 hours</td>
</tr>
<tr>
<td>Orbital Period</td>
<td>88 days</td>
<td>225 days</td>
<td>1 year</td>
<td>1.9 years</td>
</tr>
<tr>
<td>Radius ($R_\oplus$)</td>
<td>0.4</td>
<td>0.95</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Mass ($M_\oplus$)</td>
<td>0.055</td>
<td>0.8</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.21</td>
<td>0.007</td>
<td>0.017</td>
<td>0.093</td>
</tr>
<tr>
<td>Moons</td>
<td>no</td>
<td>no</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Atmosphere of the Earth

- Clouds of water vapor
- Seasonal variations (23° tilt)
- Protects us from
  - harmful radiation
  - meteoroids falling from space
- Keeps surface of planet warm
  - Greenhouse effect

<table>
<thead>
<tr>
<th>Nitrogen (78%)</th>
<th>Oxygen (21%) + trace compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>184 - 330 K</td>
<td>(−123 to 134°F)</td>
</tr>
<tr>
<td>1 atm</td>
<td></td>
</tr>
</tbody>
</table>
Atmosphere of Mercury

- No true atmosphere
  - Temperature too high
  - Cannot hold gases

- Extreme temperature variations
  - No insulating atmosphere
  - One solar day on Mercury = 176 Earth days!

- No tilt

<table>
<thead>
<tr>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 K (night) – 700 K (day)</td>
</tr>
<tr>
<td>−279°F</td>
</tr>
<tr>
<td>0 atm</td>
</tr>
</tbody>
</table>
Atmosphere of Venus

- Permanent cloud cover keeps surface hidden.
- Tilt = 177° (i.e. retrograde)
- Little daily or seasonal temperature variation.
- High temperatures due to Greenhouse effect

<table>
<thead>
<tr>
<th>CO₂; clouds = sulfuric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>750 K (890°F)</td>
</tr>
<tr>
<td>90 atm</td>
</tr>
</tbody>
</table>
Greenhouse Effect

- Sunlight hits surface of planet warming the ground.
- Planet radiates heat in the form of infrared radiation
Greenhouse Effect

- Greenhouse gases ($\text{CO}_2$, $\text{H}_2\text{O}$) traps infrared radiation, keeping the planet warm.
- Planet eventually comes to equilibrium and temperature stops increasing.
Greenhouse Effect

• Greenhouse effect elevates average temperature of Earth by ~23°C (~41 °F).
• Too much CO$_2$ or other greenhouse gas in atmosphere could elevate temperature even more, changing climate on the Earth
Moons of Mars

- Phobos and Deimos
- Irregular shape
- Heavily cratered
- Rotate synchronously (like Earth’s Moon)

Deimos (MRO)
Size ~ 15 × 12 × 11 km

Phobos (MRO)
Size ~ 27 × 22 × 19 km

Phobos (Viking 1)
10/19/1978
Atmosphere of Mars

- Thin water vapor clouds and fog but no rain.
- Strong winds cause dust storms
- Tilt = 24° gives seasonal variation similar to Earth.

<table>
<thead>
<tr>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 to 300 K</td>
</tr>
<tr>
<td>(−279°F to 80°F)</td>
</tr>
<tr>
<td>0.007 atm</td>
</tr>
</tbody>
</table>
Wind Features on Mars

Sand dunes in Hellas Region

Image area ~ 2.3 x 3.6 km

Sand Dunes in Endurance Crater (Opportunity)

Global Dust-storm
Why is the surface of Mercury cooler than the surface of Venus?

A. Mercury moves too rapidly around the Sun to be heated up significantly.

B. Mercury, unlike Venus, does not have an atmosphere and there is no greenhouse effect.

C. Mercury is a very reflective body, so most of the electromagnetic radiation incident on it is not absorbed.

D. Mercury is much smaller than Venus.
# Atmospheres of the Inner Planets

<table>
<thead>
<tr>
<th></th>
<th>Mercury</th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp.</td>
<td>None</td>
<td>CO$_2$; clouds = sulfuric acid</td>
<td>Nitrogen (78%) + Oxygen (21%) + trace compounds</td>
<td>CO$_2$</td>
</tr>
<tr>
<td>Temp.</td>
<td>100 K (night) – 700 K (day)</td>
<td>750 K</td>
<td>184-330 K (−123 to 134 °F)</td>
<td>100-300 K</td>
</tr>
<tr>
<td>Pressure</td>
<td>0 atm</td>
<td>90 atm</td>
<td>1 atm</td>
<td>0.007 atm</td>
</tr>
</tbody>
</table>
Why are Venus and Mars Different from the Earth?

• Venus -- too close to Sun
  – Too hot for water to condense.
  – CO$_2$ was not trapped in the oceans.
  – Increased the greenhouse effect
    ⇒ “Runaway Greenhouse Effect”

• Mars -- too far from the Sun
  – Initially warm after formation, water condensed.
  – Water froze, trapping CO$_2$
  – Less greenhouse effect
Surface of Mercury

- Appears similar to Moon
- Heavily cratered due to bombardment by debris in space.
- No weather or geologic activity; any crater that is formed remains.

**FIGURE 6.3**
The left image shows that Mercury’s surface is heavily cratered but also has smooth volcanic plains and long, steep cliffs. The inset shows a global composite. (Images from the MESSENGER spacecraft.)
**FIGURE 7.16**
Views of the Moon and Mercury, shown to scale. The Mercury photo is from *MESSENGER.*
Craters on Mercury

Mercury

Moon
Surface Features

- Heavily cratered areas (similar to lunar highlands)
  - Surface likely 3.8 byrs or older

- Inter-crater plains (similar to lunar maria)
  - Likely formed in same manner as maria on Moon.
  - More craters than on lunar maria – likely formed early than maria.
Scarps

Mercury’s core and mantle shrank... Some portions of the crust were forced to slide under others.

...causing Mercury’s crust to contract.

Today we see long, steep cliffs created by this crustal movement.

a  This diagram shows how Mercury’s cliffs probably formed as the core shrank and the surface crumpled.

b  This cliff extends about 100 kilometers in length, and its vertical face is as much as 2 kilometers tall. (Photo from Mariner 10.)

Mercury may still be shrinking today!
Caloris Basin

- Enormous crater – likely due to large impact
Caloris Basin (NASA Messenger 2008)
Weird Terrain

Close-up view of the chaotic terrain
Which of the following is evidence the planet Mercury shrank long ago?

A. Scarps distributed all over the planet.
B. Concentric rings around Caloris Basin
C. “Weird” terrain on opposite side from Caloris Basin
D. Large intercrater plains

47 of 62
Surface of Venus

- Mapped by Magellan (radar) probe
- Some impact craters
- Many volcanoes
- No water
Venus - Magellan

- Radar maps of Venus
  - (Left image – bright = rougher terrain)
  - (Right image – colored to resemble Earth globe)
Venus – Magellan
Craters

- Few impact craters
  - thicker atmosphere, fewer impacts
  - geologic activity erased old craters
Venera

- Venera probes (Russian) landed on Venus.
  - Hot and dry

Venera 9, 10, 13, 14 returned photographs, the latter two in color (above images from Venera 13).

Longest lasting lander was Venera 13 (127 min)

https://en.wikipedia.org/wiki/Venera
The surface of Venus is considered to be young because

A. very few volcanoes are active on its surface.
B. it has a large number of impact craters.
C. most of the impact craters have been erased by lava flows.
D. large quantities of flowing water have eroded and smoothed it out.

47 of 62
Surface of Mars

- Red colored -- iron oxide (rust) in surface rocks.
- Canali
  - Dark lines observed by Sciaparelli (1877)
  - Believed to be irrigation channels.
  - Natural surface features.
- No liquid water (too cold; Avg. temp 210 K = −81°F)
General Surface Features

• Northern Hemisphere = “lowlands”
  – Few craters = younger surface
  – Lower average elevation
  – Evidence for geologic activity

• Southern Hemisphere = “highlands”
  – Many craters = much older surface
  – Age ~3-4 byrs

Google Mars Map
Surface -- Pathfinder Mission
Mars Landscape in Gusev Crater – Spirit Rover

Martian Landscape near Gusev Crater – Spirit Rover

http://photojournal.jpl.nasa.gov/jpeg/PIA06770.jpg
Water on Mars

• Dry riverbeds
  – Channels are ~4 billion years old.

• Geologic evidence from Mars Explorations Rovers
  – Condensates
  – Apparent sedimentary rocks

⇒ Mars was warmer earlier in its history.
  – Thicker atmosphere.
  – Cooled slowly
Spherules on Mars appear to have condensed out of water.

http://antwrp.gsfc.nasa.gov/apod/ap040210.htm


Opportunity Rover in Meridian Planum

http://antwrp.gsfc.nasa.gov/apod/ap040210.htm
Dry Riverbeds on Mars

Nirgal Vallis

Martian Gullies
Water on Mars

NASA Confirms Evidence that Liquid Water Flows on Today’s Mars

Oblique View of Warm Season Flows in Newton Crater

Close-up images can be found here

NASA Finds Evidence of Liquid Water on Mars

Streaks that appear and vanish on steep slopes are evidence of liquid water on Mars, NASA says. The streaks of highly salted water lengthen in warm months and fade in cooler periods.
Where is the Water Now?

• Polar caps.
  – water polar caps -- permanent
  – CO$_2$ caps grow during winter and shrink during summer.

• A small amount of atmospheric water vapor
• Frozen under surface as permafrost.
• Occasional melting
  – Volcanic activity
  – Meteor impacts
Polar Caps
Water Distribution on Mars – Mars Odyssey

Water Equivalent Hydrogen Abundance

Distribution of Water on Mars: Overlay of water equivalent hydrogen abundances and a shaded relief map derived from MOLA topography. Mass percents of water were determined from epithermal neutron counting rates using the Neutron Spectrometer aboard Mars Odyssey between Feb. 2002 and Apr. 2003.


The neutron spectrometer aboard Mars Odyssey, a component of the Gamma-ray Spectrometer suite of instruments, was designed and built by the Los Alamos National Laboratory and is operated by the University of Arizona in Tucson. The Mars Odyssey mission is managed by the Jet Propulsion Laboratory.
Water Distribution on Mars – Mars Odyssey

Water Equivalent Hydrogen Abundance

0% 12.5 25 37.5 50% 62.5 75 87.5 100%

NORTH
> 60°

SOUTH
< -60°

Distribution of Water on Mars: Overlay of water equivalent hydrogen abundances and a shaded relief map derived from MOLA topography. Mass percent of water were determined from epithermal neutron counting rates using the Neutron Spectrometer aboard Mars Odyssey between Feb. 2007 and Apr. 2008.


These data were generated by the Planetary Science Team at Los Alamos, B. Barnouki, D. Beik, D. Delapp, R. Elphic, W. Feldman, H. Potterton, O. Gunaratne, D. Lawrence, S. Mansoor, D. McKinnon, R. Moon, T. Potterton, R. Tocher, D. Vauterin, and R. Wijes. © 2005 Los Alamos National Laboratory, Los Alamos, NM. The neutron spectrometer aboard Mars Odyssey, a component of the Gamma-ray Spectrometer suite of instruments, was designed and built by the Los Alamos National Laboratory and is operated by the University of Arizona in Tucson. The Mars Odyssey mission is managed by the Jet Propulsion Laboratory.
We now know that water exists on Mars. This water is in the form of

A. liquid in rivers only.
B. atmospheric water vapor only.
C. ice in polar icecaps only.
D. permafrost, polar icecaps, and atmospheric vapor.