Week #2: Mars!

• **Mon:** Properties of Solar System, Mars (Ch 6, 7)
  - *Lab: MEETS in VAN 666 8:30-10:30 pm*
  - *TAs: Dominic Ludovici & Natalie Butterfield*

• **Tues:** Exploring Mars, What has been found?
  - **In class worksheet/activity**

• **Wed:** Searching for Life on Mars, Extremophiles

• **Thurs:** Should Humans Go to Mars?
  – **In class worksheet/activity**

Understanding the Solar System and the Basic Properties of Mars

I. What basic properties can we study of the planets?
   - orbits
   - mass, size, average density
   - satellites

II. What are the basic properties of Mars?
Many of the planets are similar: Earth & Mars

We know Earth, Mars both have volcanoes, craters, water features

Each planet has its unique set of properties

Jupiter – huge gas giant with colored atmosphere
Saturn has a similar composition as Jupiter, but prominent rings!

**ORBITS**

- Planets have elliptical orbits (with low eccentricity)
- Planets orbit in the same direction around the Sun
- This is related to their formation (Monday)

Pluto’s orbit has $e=0.25$
Mercury’s orbit has $e=0.21$
**Inner vs. outer planets**

Mercury, Venus, Earth, Mars

- small, rocky, “terrestrial” (Earth-like)
- can stand on hard surface
- all have evidence of craters, mts., volcanoes, valleys

**Mercury: craters**  **Mars: rocks**  **Earth: Rocky Mts.**

**Inner vs. outer planets**

Jupiter, Saturn, Uranus, Neptune

- “Jovian” planets (Jupiter-like)
- planets made mostly of liquids, gases
- ‘surface’ is actually the atmosphere of planet

**Jupiter’s bands**  **Saturn’s Rings**  **Neptune’s Clouds**
Relative sizes

*How do we measure the diameters of the planets?*

- know distances (from Newton, Kepler)
- observe angular size ($\alpha$, in arcseconds)
- derive the diameter from the angular size equation: $D = \alpha \cdot d / 206265$

Masses of the planets

*Relative Masses?*

- Sun ~ 300,000 times mass of Earth
- Jupiter ~ 320 x mass of Earth
- Mars ~ 0.1 x mass of Earth
- Neptune ~ 17 x mass of Earth

*How do we measure masses of planets?*

1. If planet has satellite(s), then measure using Kepler, Newton Laws
   - measure distance between satellite & planet, satellite’s orbit, assume $M >> m$

2. Send a spacecraft by the planet, measure “tug” of planet on craft
   - spacecraft’s path gets deflected by an amount proportional to the mass of the planet
Densities of the planets

• gives insight as to the composition of a planet
• need to know mass, diameter
• density = mass/volume = mass divided by \(\frac{4}{3}\pi r^3\) = kg/m\(^3\)

What are some average densities?

Air (near sea level) = 1.2 kg/m\(^3\)

Water (average) = 1000 kg/m\(^3\)

Concrete = 2000 kg/m\(^3\)

Can get an idea if the planet is air-like or rock-like

Densities of the planets

What are the average densities of the planets?

Water density = 1000 kg/m\(^3\)

687 kg/m\(^3\)

1326 kg/m\(^3\)

3934 kg/m\(^3\)

5515 kg/m\(^3\)
Satellites – many of the planets have moons
*and a number have rings

<table>
<thead>
<tr>
<th>Planet</th>
<th>Satellites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth</td>
<td>1 satellite (Moon)</td>
</tr>
<tr>
<td>Mars</td>
<td>2 satellites (Phobos, Deimos)</td>
</tr>
<tr>
<td>Jupiter*</td>
<td>&gt; 67 satellites (first seen by Galileo!)</td>
</tr>
<tr>
<td>Saturn*</td>
<td>&gt; 62 satellites (Titan - largest)</td>
</tr>
<tr>
<td>Uranus*</td>
<td>&gt; 27 satellites</td>
</tr>
<tr>
<td>Neptune*</td>
<td>&gt; 13 satellites (Triton - largest)</td>
</tr>
</tbody>
</table>

Jupiter’s ring from Galileo spacecraft

The Seven Largest Satellites in Solar System

- average densities of the satellites ~ 2000 kg/m³
- some satellites are bigger than Pluto, Mercury
- some satellites are very small – Mars’ Deimos!

Mars’ tiny moon Deimos – only 6 km radius
Chemical Composition of the Planets

How is their chemical make up different (heavy metals, lighter soils?)

→ Iron is denser than other compounds – Earth has more Iron

Earth average density
= 5515 kg/m³

Moon average density
= 3344 kg/m³

• Crust – lowest density rock (granite/basalt)
• Mantle – rocky material of moderate density (minerals: Si, O)
• Metal core – highest density material (iron, nickel)

→ differentiation: layering based on density
→ the lithosphere: the cool & rigid rock; floats on the warmer core thick prevents volcanic eruptions, thin can crack easily

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Chemical Composition of the Planets

- Ideally, take atmospheric and soil samples from each of the planets
- Analyze them in detail on spacecraft or on Earth

- The main information we have from planets is their reflected sunlight!

What external things shape planetary surfaces?

1. Impact Cratering – asteroids/comets
2. Volcanism – eruption of lava onto surface
3. Tectonics – disruption of surface by internal stress
4. Erosion – wearing down of surface features
1. What is the relative size of Mars compared to Earth?

A. about the same

B. much smaller (about the size of Mercury, 10% Earth)

C. quite a bit bigger (about the size of Neptune)

D. somewhat smaller (about 50% that of Earth)

2. Which of the following best describes Mars’ surface?

A. mostly rough lava with a number of impact sites

B. a mix of volcanoes, craters and smooth features

C. millions of craters and tectonic fault lines

D. three large volcanoes dominate the geology
How to view planets: opposition & conjunction

**opposition:** planet is located exactly OPPOSITE from the Sun – best viewing of planet!

**conjunction:** planet is located exactly toward the Sun - not possible to observe planets at all!
Oppositions have always been best time to see Mars
“close oppositions” occur every 15-17 years

**Famous Oppositions**

1659 - Huygens (Dutch) observed dark spot (Syrtis Major)
1830, 1862 – first maps of Mars made
1877 - only 1% less close than it was this week!
   - Schiaparelli called features “canali” – *channels*
1892, 1894 – Mars fever!!

Percival Lowell (1855-1916)

- Lowell Observatory (Flagstaff)
- Martian “civilization” maps
Changes in surface coloring: thought once to be vegetation!!

Mariner missions – Mariner 6+ 7 (flyby) and 9 (orbiter) – late 1960s + 70s
→ Martian surface covered with craters and old geologic features!
  - surface isn’t smooth (as historical observations thought)
  - similar to Moon surface (being studied simultaneously)
  - must be old: peak in impacts ~3.8 billion years ago
  - many gave up hope for seeing “water”/ “life” on Mars
Changes in surface coloring: thought once to be vegetation!!

**Fast Facts on Mars:**

- **size** = 5974 km/4200 miles ~53% Earth’s size
- **mass** = 6.5 x 10^{23} kg or 0.1 Earth’s mass
- **density** = 3900 kg/m^3 (Earth’s density = 5510 kg/m^3)
- **T avg:** -55 C (218 K, -67 F)
- **highs:** 20 C (293 K, 68 F)
- **lows:** -153 C (120 K, -243 F)
- gravity/physics will be different on Mars, i.e., mts., activity in planet’s core
**Mars Global Surveyor**
- NASA launched in December 1996
- 6 instruments including
  - MOC – high resolution camera
  - MOLA – laser altimeter (first 3D look!)
  - TES – high-resolution temperature detector
  - Magnetic field detector

*How do we measure the height of features on Mars?*

Laser Altimeter (MOLA)

- bounce laser beams off surface
- time delay between signals gives height measure

**The “Face” on Mars (Viking Image from 1976)**
Mars Topographic Map
(MOLA radar 1998/99)

Low elevation Northern hemisphere
- Resurfaced by some process? \( \rightarrow \) most likely geological in nature (erosion, oceans?)

Volcanoes

Hellas impact basin (2000 km)

High elevation southern hemisphere
Many more craters! "Older surface"?

(Blue = low, red = high)

Hellas Impact Basin

\( \rightarrow \) 2000 km diameter, 9 km deep!
\( \rightarrow \) Probably formed by asteroid impact
\( \rightarrow \) Debris from collision would cover US with layer 3 km thick
Valles Marineris - “Grand Canyon of Mars”
- stretches for at least 2500 miles (NYC ↔ LA)
- “rift valley” – region broken by crust motions earlier in Mars’ history

➢ signs of river erosion in early history of Mars (3-4 Billion yrs ago) like Grand Canyon

Olympus Mons – largest volcano in S.S.
• rises 15 miles above surrounding flat plains
• three times as tall as Mt. Everest (upwelling crust ejecting runny lava)
• caldera is ~70 km across
• part of continent-sized Tharsis ridge of volcanoes
• dating of volcanic features indicates they were active only ~180-200 million years old – relatively recent! They could go off again. Martian interior in process of cooling
The atmospheres of the terrestrial planets primarily came from

a. Impacts with comets  
b. Volcanic outgassing  
c. The Solar wind  
d. The planet’s early magnetic field trapping gases in the solar system

Mars’ atmosphere is made of primarily

a. Water vapor  
b. Oxygen  
c. Neon  
d. Carbon dioxide
How do atmospheres affect planets?

- create pressure so that water can remain liquid on surfaces
- absorb and scatter electromagnetic radiation
- create wind and weather → erosion!
- interactions between solar wind particles & atmospheric gases in the magnetosphere layer of atmosphere
- contain gases which can retain heat through greenhouse effect

Atmospheric Pressure

- gas at any altitude is held down by gravity
- fast moving molecules in atmosphere also push up
- constant state of BALANCE
  - but overall, higher pressure lower down in atmosphere and less pressure higher up
  (in airplane, mountains, less pressure – ears pop, air thinner)

Where does an atmosphere end?

- atmosphere gradually fades away as density, pressure decrease
- by 60 km above Earth’s surface, the sky is black (little air to scatter)
- atmosphere extends up to 350 km
Atmospheres: Where did gases come from?

1. Outgassing
   - Outgassing is the primary source of gas for terrestrial atmospheres.

2. Evaporation of liquids to gas or sublimation of ices to gas
   - Earth’s oceans/polar caps from atmosphere
   - Mars’ polar caps: frozen CO₂ and H₂O

3. Impacts with no atmospheres → small atmospheres!
   - can release surface atoms & molecules

Atmospheres: How do you lose an atmosphere?

→ can have important consequences for climate change on a planet

1. “recycling” or non-permanent
   - Mars – icy polar caps

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Atmospheres: How do you lose an atmosphere?

→ can have important consequences for climate change on a planet

(2) Permanent atmospheric losses

1 - large impacts!

2 - Solar wind interactions - but not important if a planet has magnetosphere

3- Thermal escape

Table 10.1 Atmospheres of the Terrestrial Worlds

<table>
<thead>
<tr>
<th>World</th>
<th>Composition of Atmosphere</th>
<th>Surface Pressure*</th>
<th>Average Surface Temperature</th>
<th>Winds, Weather Patterns</th>
<th>Clouds, Hazes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>helium, sodium, oxygen</td>
<td>$10^{-11}$ bar</td>
<td>day: 425°C (797°F); night: −175°C (−283°F)</td>
<td>none (too little atmosphere)</td>
<td>none</td>
</tr>
<tr>
<td>Venus</td>
<td>96% carbon dioxide (CO₂), 3.5% nitrogen (N₂)</td>
<td>99 bars</td>
<td>470°C (878°F)</td>
<td>slow winds, no violent storms, acid rain</td>
<td>sulfuric acid clouds</td>
</tr>
<tr>
<td>Earth</td>
<td>77% nitrogen (N₂), 21% oxygen (O₂), 1% argon, H₂O (variable)</td>
<td>1 bar</td>
<td>15°C (59°F)</td>
<td>winds, hurricanes, rain, snow</td>
<td>H₂O clouds, pollution</td>
</tr>
<tr>
<td>Moon</td>
<td>helium, sodium, argon</td>
<td>$10^{-11}$ bar</td>
<td>day: 125°C (255°F); night: −175°C (−283°F)</td>
<td>none (too little atmosphere)</td>
<td>none</td>
</tr>
<tr>
<td>Mars</td>
<td>95% carbon dioxide (CO₂), 2.7% nitrogen (N₂), 1.6% argon</td>
<td>0.007 bar</td>
<td>−56°C (−68°F)</td>
<td>winds, dust storms</td>
<td>H₂O and CO₂ clouds, dust</td>
</tr>
</tbody>
</table>

* 1 bar = the pressure at sea level on Earth.
Atmospheres of Venus, Earth, Mars

Similarities:
- atmospheres originated from volcanic outgassing
- all three had substantial early atmospheres

Differences:
- atmospheres: Venus - thick; Earth - medium, Mars - thin
- three planets are different sizes in radius
Martian Atmosphere

Carbon Dioxide (CO₂): 95.32%
Nitrogen (N₂): 2.7%
Argon (Ar): 1.6%
Oxygen (O₂): 0.13%
Water (H₂O): 0.03%
Neon (Ne): 0.00025 %

• 1/1,000 as much water as our air
• only enough to cover the surface of the planet with 0.4 inches if melted out of the atmosphere!!
• Martian atmosphere does not regulate the surface temperature on the planet as Earth’s

Physical Conditions on Mars

Cold, Low Atmospheric Pressure
- “freeze-dried” state: low atmospheric pressure would cause ANY liquid water to evaporate or freeze into ice
- mostly carbon dioxide atmosphere (very little of it!)
- very thin - weak greenhouse effect
- average temperature on planet -50 C or -60 F

Seasons more dramatic than on Earth

• last twice as long as on Earth
• elliptical orbit important and makes S. seasons extreme -closer to Sun in S. Summer -farther from Sun in S. Winter
Martian Polar Ice Caps

These strong seasonal changes create winds between poles:
- the winds blow from summer pole to winter pole because of differences in atmospheric pressure (high pressure - summer pole, low-pressure at the winter pole)
- at winter pole, temperatures are -130 C or 143 K
- carbon dioxide condenses into “dry ice” at these temps.
- in summer, frozen carbon dioxide sublimes into CO$_2$ gas

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Martian Dust Storms

June 26, 2001 before dust storm
September during dust storm

A small dust storm . . . engulfs the planet just over two months later

Martian Axis Tilt – More Climate Changes

Theoretical calculations suggest axis tilt varies from 0-60 deg.
1. Jupiter’s gravity has a great influence on Mars and its orientation of axis
2. Mars’ two tiny moons don’t stabilize the tilt as much as Earth’s moon

- Phobos – size: ~10 km
- Deimos – size: ~6 km

- When tilt is small, poles stay in perpetual deep freeze for 10,000s of years
  CO₂ locked in ice at poles, less atmosphere, low pressure, weak GE and colder planet
- When tilt is bigger, summer poles get quite warm and CO₂ sublimes
  more CO₂ put into atmosphere, pressure increases, GE strengthens
Why/How did Mars change from warm and wet to dry and freezing?

- Chemical, geological evidence shows that Mars was wet and warm at some point in its history.
- Much debate over details:
  - first 1-3 billion years?
  - # of volcanoes could provide a substantial enough atmosphere (400x today Mars) to keep planet wet and warm?

Where did all of Mars’ atmospheric gas go?

- loss of carbon dioxide would slow/stop the Greenhouse effect and planet would “freeze”
- some of gas was condensed into polar ice caps
- most CO₂ gas must have been lost to space

One idea: Mars’ magnetic field was stronger?

- early on, Mars’ core was molten, produced magnetic field
- Mars’ small size forced it to cool rapidly, magnetic field weakened – Mars less protected from solar wind particles!
- Solar wind particles may have stripped Mars’ atmosphere off (including the water, which was broken apart, and the oxygen used to “rust” the surface of the planet)
- If Mars were closer to the Sun, it may not have frozen so quickly