The Terrestrial Worlds

ASTR 170 • 2010 S1 • Daniel Zucker • E7A 317
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Venus and Mars

Two most similar planets to Earth:

- Similar in size and mass
- Same part of the solar system
- Atmosphere
- Similar interior structure

Yet there’s no life *(that we know of)* on either one
The Atmosphere of Venus

4 thick cloud layers (surface invisible to us from Earth).

Extremely inhospitable: 96% carbon dioxide (CO₂), 3.5% nitrogen (N₂). Other 0.5%: water (H₂O), hydrochloric acid (HCl), hydrofluoric acid (HF)

Very stable circulation patterns with high-speed winds (up to 240 km/h)

Very efficient “greenhouse”!

Extremely high surface temperature up to 745 K (880 °F)
The Surface of Venus

Early radar images already revealed mountains, plains, and craters – more details from orbiting and landing spacecraft:

Colours modified by clouds in Venus’s atmosphere

After correction for atmospheric colour effect:

- Instrument cover ejected after landing
- Edge of spacecraft

The horizon of Venus is visible at the top corners of the image.
Radar Map of Venus’s Surface

Surface features shown in artificial colours

- Scattered impact craters
- Volcanic regions
- Smooth lava flows

Beta Regio
Atla Regio
Craters on Venus

Nearly 1000 impact craters on Venus’s surface:

- Surface not very old

No water on the surface; thick, dense atmosphere

- Little erosion

- Craters appear sharp and fresh

Radar map
Volcanism on Earth

Volcanism on Earth is commonly found along subduction zones (e.g., Rocky Mountains).

This type of volcanism is not found on Venus or Mars.
Shield Volcanos

Found above hot spots:

Fluid magma chamber, from which lava erupts repeatedly through surface layers above

All volcanoes on Venus and Mars are shield volcanoes.
Shield Volcanos (2)

Tectonic plates move over hot spots, producing shield volcanos ➔ chains of volcanos

Example: the Hawaiian Islands

[Diagram showing the movement of tectonic plates over a hot spot, forming a chain of shield volcanoes, with the Hawaiian Islands as an example.]
Volcanism on Venus

Sapas Mons (radar image)

~ 400 km (250 miles)

2 lava-filled calderas

Lava flows
The Rotation of Venus

• Almost all planets rotate counterclockwise, i.e. in the same sense as orbital motion

• Exceptions: Venus, Uranus and Pluto

• Venus rotates *clockwise*, with period slightly longer than orbital period

Possible reasons:

• Off-center collision with massive protoplanet
• Tidal forces of the Sun on molten core
A History of Venus

Complicated history; still poorly understood.

Very similar to Earth in mass, size, composition, density, but no magnetic field → Core solid?

→ Solar wind interacts directly with the atmosphere, forming a bow shock and a long ion tail

$\text{CO}_2$ produced during outgassing remained in atmosphere (on Earth: dissolved in water

Any water present on the surface rapidly evaporated → feedback through enhancement of greenhouse effect
Mars

- Diameter ≈ 1/2 Earth’s diameter
- Axis tilted against orbital plane by 25°, similar to Earth’s inclination (23.5°)
- Seasons similar to Earth → Growth and shrinking of polar ice cap
- Crust not broken into tectonic plates
- Volcanic activity (including highest volcano in the solar system)

- Very thin atmosphere, mostly CO₂
- Rotation period = 24 h, 40 min.
Tales of Canals and Life on Mars

Early observers (Schiaparelli, Lowell) thought they saw canals on Mars

This, together with growth/shrinking of polar cap, sparked imagination and sci-fi tales of life on Mars

We know today that the “canals” were an optical illusion

No (direct) evidence of life on Mars
The Atmosphere of Mars

Very thin: Only 1% of pressure on Earth’s surface

95 % CO$_2$

Even thin Martian atmosphere evident through haze and clouds covering the planet

Occasionally: Strong dust storms that can enshroud the entire planet
The Atmosphere of Mars (2)

Most of the oxygen bound in oxides in rocks

⇒ Reddish colour of the surface
History of Mars’s Atmosphere

Atmosphere probably initially produced through outgassing

Loss of gasses from a planet’s atmosphere:

Compare **typical** velocity of gas molecules to **escape velocity**

Gas molecule velocity greater than escape velocity $\Rightarrow$ gases escape into space

Mars has lost all lighter gases, retained only heavier gases (CO$_2$)
History of Mars’s Atmosphere

Gases bound in the polar cap are returned to the atmosphere each spring in spots and fans.
The Geology of Mars

Giant volcanos

Valleys

Impact craters

Reddish deserts of broken rock, probably smashed by meteorite impacts

Vallis Marineris
The Geology of Mars (2)

Northern Lowlands: ~free of craters; probably re-surfaced a few billion years ago. Possibly once filled with water.

Southern Highlands: heavily cratered; probably 2 – 3 billion years old.
Volcanism on Mars

Volcanos on Mars are shield volcanos

Olympus Mons:

Highest and largest volcano in the Solar System
Volcanism on Mars (2)

**Tharsis rise**
(volcanic bulge):

Nearly as large as Australia

Rises ~ 10 km above mean radius of Mars

Rising magma has repeatedly broken through crust to form volcanos
Finding the Water on Mars

No liquid water on the surface:

  Would evaporate due to low pressure

But evidence for liquid water in the past:

  Outflow channels from sudden, massive floods

  Collapsed structures after withdrawal of sub-surface water

  Valleys resembling meandering river beds

  Gullies, possibly from debris flows

  Central channel in a valley suggests long-term flowing water
Finding the Water on Mars (2)

Formations possibly arising from broken pack ice, covered by dust and volcanic ash

Cracks in the surface near the pole, probably due to seasonal expansion and contraction of ice under the surface
Finding the Water on Mars (3)

Hematite concretions in Martian Rocks, photographed by the Mars Rover Opportunity

Sedimentary rock layers, formed by rapidly flowing water
Finding the Water on Mars (4)

Large impacts may have ejected rocks into space

Galle, the “happy face crater”

Meteorite ALH84001:
Identified as ancient rock from Mars
Some minerals in this meteorite were deposited in water ➔ Martian crust must have been richer in water than it is today
The Moons of Mars

Two small moons: Phobos and Deimos

Too small to pull themselves into spherical shape

Typical of small, rocky bodies: Dark grey, low density

Very close to Mars; orbits around Mars faster than Mars’ rotation

Probably captured from outer asteroid belt
From Earth, we always see the same side of the moon.

The Moon rotates around its axis in the same time that it takes to orbit around Earth.

**Tidal coupling:**

Earth’s gravitation has produced tidal bulges on the Moon.

Tidal forces have slowed the rotation down to the same period as the orbital period.
Lunar Surface Features

Two dramatically different kinds of terrain:

- Highlands:
  Mountainous terrain, scarred by *craters*

- Lowlands: ~ 3 km lower than highlands; smooth surfaces:

  Maria (pl. of *mare*):

  Basins flooded by lava flows
Highlands and Lowlands

Sinuous rilles = remains of ancient lava flows

May have been lava tubes which later collapsed due to meteorite bombardment
The Highlands

Saturated with craters

- Older craters partially obliterated by more recent impacts
- ... or flooded by lava flows
Impact Cratering

Impact craters on the moon can be seen easily even with small telescopes.

Ejecta from the impact can be seen as bright rays originating from young craters.

A meteorite approaches the lunar surface at high velocity.

On impact, the meteorite is deformed, heated, and vaporized.

The resulting explosion blasts out a round crater.

Slumping produces terraces in crater walls, and rebound can raise a central peak.
Impact Craters

Impact craters are best seen when they are near the day-night boundary, called the **terminator**.

Ejecta from a major impact sometimes leave traces of secondary craters.
History of Impact Cratering

Rate of impacts due to interplanetary bombardment decreased rapidly within the first $\frac{1}{2}$ billion years after the formation of the Solar System.

The age of Moon rocks provides evidence of a Late Heavy Bombardment (LHB) 4.1 to 3.8 billion years ago.

Cratering events in the inner solar system are now roughly a million times less common than they were when the solar system was young.

The age of Moon rocks provides evidence of a Late Heavy Bombardment 4.1 to 3.8 billion years ago.
All moon rocks brought back to Earth are **igneous** (= solidified lava)
No sedimentary rocks ➔ no sign of water ever present on the Moon

Different types of moon rocks:

**Vesicular**
(= containing holes from gas bubbles in the lava)
basalts, typical of dark rocks found in maria

**Breccias**
(= fragments of different types of rock cemented together)

Older rocks become pitted with small micrometeorite craters
The History of the Moon

Moon is small; low mass \( \Rightarrow \) rapidly cooling off; small escape velocity \( \Rightarrow \) no atmosphere \( \Rightarrow \) unprotected against meteorite impacts
Moon must have formed in a molten state ("sea of lava")

Heavy rocks sink to bottom, lighter rocks at the surface

No magnetic field \( \Rightarrow \) small core with little metallic iron

Surface solidified \( \sim \) 4.6 – 4.1 billion years ago

Heavy meteorite bombardment for the next \( \sim \) 1/2 billion years

Alan Shepard (Apollo 14)
analyzing a Moon rock, probably ejected from a distant crater.
Impacts of heavy meteorites broke the crust and produced large basins, which flooded with lava.
The Origin of Earth’s Moon

The Large-Impact Hypothesis

• Impact heated material enough to melt it
  ➔ consistent with “sea of magma”

• Collision not head-on
  ➔ Large angular momentum of Earth-Moon system

• Collision after differentiation of Earth’s interior
  ➔ Different chemical compositions of Earth and Moon

A protoplanet nearly the size of Earth differentiates to form an iron core.

Another body that has also formed an iron core strikes the larger body and merges, trapping most of the iron inside.

Iron-poor rock from the mantles of the two bodies forms a ring of debris.

Volatile are lost to space as the particles in the ring begin to accrete into larger bodies.

Eventually the moon forms from the iron-poor and volatile-poor matter in the disk.
Mercury

Very similar to Earth’s moon in several ways:

• Small; no atmosphere
• lowlands flooded by ancient lava flows
• heavily cratered surfaces

Until very recently, most of our knowledge was based on measurements by the Mariner 10 spacecraft (1974 – 1975)

The MESSENGER spacecraft will go into orbit around Mercury in 2011
Rotation and Revolution

Like Earth’s moon (tidally locked to revolution around Earth), Mercury’s rotation has been altered by the sun’s tidal forces, but not completely tidally locked.
Rotation and Revolution

Revolution period = 3/2 times rotation period

Revolution: ≈ 88 days
Rotation: ≈ 59 days

Extreme day-night temperature contrast:

100 K (-173 °C) – 600 K (330 °C)
The Surface of Mercury

Very similar to Earth’s moon:
Heavily battered with craters, including some large basins

Most craters on Mercury were formed after the era of heaviest bombardment
The Surface of Mercury (2)

Largest basin: **Caloris Basin**

Terrain on the opposite side of Mercury jumbled by seismic waves from the impact
Class Announcements

• Lecture PDFs and other materials available from: web.science.mq.edu.au/~zucker/Astronomy_170.html
• Assignment #2 is due TODAY in box on 2nd floor of E7B, next to bridge to E7A
• Observing practical write-ups from last week due Wednesday in labs
• If you did not attend one of the three observing practicals or the public night last Friday, please e-mail me ASAP