Chapter 2
The Copernican Revolution

Ancient Astronomy

• Ancient civilizations observed the skies
• Many built structures to mark astronomical events

Summer solstice sunrise at Stonehenge:
Ancient Astronomy

Spokes of the Big Horn Medicine Wheel are aligned with the rising and setting of the Sun and other stars.

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Ancient Astronomy

This temple at Caracol, in Mexico, has many windows that are aligned with astronomical events.

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The Geocentric Universe

Ancient astronomers observed:

- Sun
- Moon
- Stars
- Five planets: Mercury, Venus, Mars, Jupiter, Saturn

The Geocentric Universe

Sun, Moon, and stars all have simple movements in the sky

Planets:

- Move with respect to fixed stars
- Change in brightness
- Change speed
- Undergo retrograde (backward) motion
The Geocentric Universe

- Inferior planets: Mercury, Venus
- Superior planets: Mars, Jupiter, Saturn

Now know:
- Inferior planets have orbits closer to Sun than Earth’s
- Superior planets’ orbits are farther away

The Geocentric Universe

Early observations:
- Inferior planets never too far from Sun
- Superior planets not tied to Sun; exhibit retrograde motion
- Superior planets brightest at opposition (closest to Earth)
- Inferior planets brightest near inferior conjunction (far from Earth)
The Geocentric Universe

Earliest models had Earth at center of solar system

Needed lots of complications to accurately track planetary motions

The Heliocentric Model of the Solar System

Sun is at center of solar system. Only Moon orbits around Earth; planets orbit around Sun.

This figure shows retrograde motion of Mars.
The Foundations of the Copernican Revolution

1. Earth is not at the center of everything.
2. Center of Earth is the center of Moon's orbit.
3. All planets revolve around the Sun.
4. The stars are very much farther away than the Sun.
5. The apparent movement of the stars around the Earth is due to the Earth's rotation.
6. The apparent movement of the Sun around the Earth is due to the Earth's rotation.
7. Retrograde motion of planets is due to Earth's motion around the Sun.

The Birth of Modern Astronomy

Telescope invented around 1600

Galileo built his own, made observations:

• Moon has mountains and valleys
• Sun has sunspots, and rotates
• Jupiter has moons (shown)
• Venus has phases
2.4 The Birth of Modern Astronomy

Phases of Venus cannot be explained by geocentric model

Stop here today
Kepler’s laws were derived using observations made by Tycho Brahe

1. Planetary orbits are ellipses, Sun at one focus
The Laws of Planetary Motion

2. Imaginary line connecting Sun and planet sweeps out equal areas in equal times

Some Properties of Planetary Orbits

Perihelion: closest approach to Sun
Aphelion: farthest distance from Sun
The Dimensions of the Solar System

Astronomical unit: mean distance from Earth to Sun
First measured during transits of Mercury and Venus, using triangulation

Newton’s Laws

Newton’s laws of motion explain how objects interact with the world and with each other.
Newton’s Laws

Newton’s first law:
An object at rest will remain at rest, and an object moving in a straight line at constant speed will not change its motion, unless an external force acts on it.

Newton’s Laws

Newton’s second law:
When a force is exerted on an object, its acceleration is inversely proportional to its mass:

\[ a = \frac{F}{m} \]

Newton’s third law:
When object A exerts a force on object B, object B exerts an equal and opposite force on object A.
Newton’s Laws
Gravity

On the Earth’s surface, acceleration of gravity is approximately constant, and directed toward the center of Earth

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2.7 Newton’s Laws
Gravity

For two massive objects, gravitational force is proportional to the product of their masses divided by the square of the distance between them

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2.7 Newton’s Laws

Gravity

\[ F = \frac{Gm_1m_2}{r^2} \]

The constant \( G \) is called the gravitational constant; it was measured experimentally and found to be

\[ G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2 \]

Newtonian Mechanics

Kepler’s laws are a consequence of Newton’s laws.

The orbit of a planet around the Sun is an ellipse, with the center of mass of the planet–Sun system at one focus.
Newtonian Mechanics

Escape speed: the speed necessary for a projectile to completely escape a planet’s gravitational field.

With a lesser speed, the projectile either returns to the planet or stays in orbit.

Summary of Chapter 2

• First models of solar system were geocentric but couldn't easily explain retrograde motion
• Heliocentric model does; also explains brightness variations
• Galileo's observations supported heliocentric model
• Kepler found three empirical laws of planetary motion from observations
Summary of Chapter 2 (cont.)

- Laws of Newtonian mechanics explained
  Kepler’s observations

- Gravitational force between two masses is proportional to the product of the masses, divided by the square of the distance between them

\[ F = \frac{Gm_1m_2}{r^2} \]