Chapter 2
Discovering the Universe for Yourself

2.1 Patterns in the Night Sky

Our goals for learning:

- What does the universe look like from Earth?
- Why do stars rise and set?
- Why do the constellations we see depend on latitude and time of year?

What does the universe look like from Earth?

With the naked eye, we can see more than 2,000 stars as well as the Milky Way.

Constellations

A constellation is a *region* of the sky.

88 constellations fill the entire sky.

The Celestial Sphere

Stars at different distances all appear to lie on the celestial sphere.

Ecliptic is Sun's apparent path through the celestial sphere.

The Celestial Sphere

The 88 official constellations cover the celestial sphere.

The Milky Way

A band of light making a circle around the celestial sphere.

What is it?
Our view into the plane of our galaxy.

The Local Sky

An object's **altitude** (above horizon) and **direction** (along horizon) specifies its location in your local sky

The Local Sky

Zenith: The point directly overhead

Horizon: All points 90° away from zenith

Meridian: Line passing through zenith and connecting N and S points on horizon

Angular Measurements

- Full circle = 360º
- 1º = 60′ (arcminutes)
- 1′ = 60″ (arcseconds)

Angular Size

$$\text{angular size} = \text{physical size} \times \frac{360\ \text{degrees}}{2\pi \times \text{distance}}$$

An object's angular size appears smaller if it is farther away

Why do stars rise and set?

Earth rotates west to east, so stars appear to circle from east to west.

Review: Coordinates on the Earth

- Latitude: position north or south of equator
- Longitude: position east or west of prime meridian (runs through Greenwich, England)

The sky varies as Earth orbits the Sun

- As the Earth orbits the Sun, the Sun appears to move eastward along the ecliptic.
- At midnight, the stars on our meridian are opposite the Sun in the sky.

Interactive Figure

What have we learned?

- What does the universe look like from Earth?
  - We can see over 2,000 stars and the Milky Way with our naked eyes, and each position on the sky belongs to one of 88 constellations
  - We can specify the position of an object in the local sky by its **altitude** above the **horizon** and its **direction** along the horizon
- Why do stars rise and set?
  - Because of Earth's rotation.

What have we learned?

- Why do the constellations we see depend on latitude and time of year?
  - Your location determines which constellations are hidden by Earth.
  - Time of year determines location of Sun in sky

2.2 The Reason for Seasons

Our goals for learning:

- What causes the seasons?
- How do we mark the progression of the seasons?
- How does the orientation of Earth's axis change with time?

Summary: The Real Reason for Seasons

- Earth's axis points in the same direction (to Polaris) all year round, so its orientation *relative to the Sun* changes as Earth orbits the Sun.
- Summer occurs in your hemisphere when sunlight hits it more directly; winter occurs when the sunlight is less direct.
- **AXIS TILT** is the key to the seasons; without it, we would not have seasons on Earth.

Why *doesn't* distance matter?

- Variation of Earth-Sun distance is small — about 3%; this small variation is overwhelmed by the effects of axis tilt.

How do we mark the progression of the seasons?

- We define four special points:
  - summer solstice
  - winter solstice
  - spring (vernal) equinox
  - fall (autumnal) equinox

We can recognize solstices and equinoxes by Sun's path across sky:

Summer solstice: Highest path, rise and set at most extreme north of due east.

Winter solstice: Lowest path, rise and set at most extreme south of due east.

Equinoxes: Sun rises precisely due east and sets precisely due west.

What have we learned?

- What causes the seasons?
  - **The tilt of the Earth's axis** causes sunlight to hit different parts of the Earth more directly during the summer and less directly during the winter
  - We can specify the position of an object in the local sky by its **altitude** above the **horizon** and its **direction** along the horizon

What have we learned?

- How do we mark the progression of the seasons?
  - The **summer and winter solstices** are when the Northern Hemisphere gets its most and least direct sunlight, respectively. The **spring and fall equinoxes** are when both hemispheres get equally direct sunlight.
- How does the orientation of Earth's axis change with time?
  - The tilt remains about 23.5 degrees (so the season pattern is not affected), but Earth has a 26,000 year precession cycle that slowly and subtly changes the orientation of the Earth's

2.3 The Moon, Our Constant Companion

Our goals for learning:

- Why do we see phases of the Moon?
- What causes eclipses?

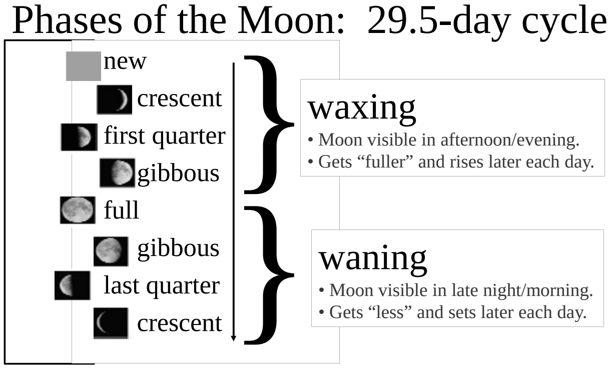
Why do we see phases of the Moon?

- Lunar phases are a consequence of the Moon's 27.3-day orbit around Earth

Phases of Moon

- Half of Moon is illuminated by Sun and half is dark
- We see a changing combination of the bright and dark faces as Moon orbits

Phases of the Moon: 29.5-day cycle



We see only one side of Moon

Synchronous rotation: the Moon rotates exactly once with each orbit

That is why only one side is visible from Earth

What causes eclipses?

- The Earth and Moon cast shadows.
- When either passes through the other's shadow, we have an **eclipse**.

When can eclipses occur?

- **Lunar eclipses** can occur only at *full moon*.
- Lunar eclipses can be **penumbral**, **partial**, or **total**.

When can eclipses occur?

- **Solar eclipses** can occur only at *new moon*.
- Solar eclipses can be **partial**, **total,** or **annular**.

Why don't we have an eclipse at every new and full moon?

- The Moon's orbit is tilted 5° to ecliptic plane…
- So we have about two **eclipse seasons** each year, with a lunar eclipse at new moon and solar eclipse at full moon.

Summary: Two conditions must be met to have an eclipse:

1. It must be full moon (for a lunar eclipse) or new moon (for a solar eclipse).

   AND

2. The Moon must be at or near one of the two points in its orbit where it crosses the ecliptic plane (its nodes).

What have we learned?

- Why do we see phases of the Moon?
  - Half the Moon is lit by the Sun; half is in shadow, and its appearance to us is determined by the relative positions of Sun, Moon, and Earth
- What causes eclipses?
  - Lunar eclipse: Earth's shadow on the Moon
  - Solar eclipse: Moon's shadow on Earth
  - Tilt of Moon's orbit means eclipses occur during two periods each year

2.4 The Ancient Mystery of the Planets

Our goals for learning:

- What was once so mysterious about planetary motion in our sky?
- Why did the ancient Greeks reject the real explanation for planetary motion?

Planets Known in Ancient Times

- Mercury
  - difficult to see; always close to Sun in sky
- Venus
  - very bright when visible; morning or evening "star"
- Mars
  - noticeably red
- Jupiter
  - very bright
- Saturn
  - moderately bright

What was once so mysterious about planetary motion in our sky?

- Planets usually move slightly *eastward* from night to night relative to the stars.
- But sometimes they go *westward* relative to the stars for a few weeks: **apparent retrograde motion**

Explaining Apparent Retrograde Motion

- Easy *for us* to explain: occurs when we "lap" another planet (or when Mercury or Venus laps us)
- But very difficult to explain if you think that Earth is the center of the universe!
- *In fact, ancients considered but rejected the correct explanation*

Why did the ancient Greeks reject the real explanation for planetary motion?

- Their inability to observe **stellar parallax** was a major factor.

The Greeks knew that the lack of observable parallax could mean one of two things:

1. Stars are so far away that stellar parallax is too small to notice with the naked eye
2. Earth does not orbit Sun; it is the center of the universe

With rare exceptions such as Aristarchus, the Greeks rejected the correct explanation (1) because they did not think the stars could be *that* far away

Thus setting the stage for the long, historical showdown between Earth-centered and Sun-centered systems.

What have we learned?

- What was so mysterious about planetary motion in our sky?
  - Like the Sun and Moon, planets usually drift eastward relative to the stars from night to night; but sometimes, for a few weeks or few months, a planet turns westward in its **apparent retrograde motion**
- Why did the ancient Greeks reject the real explanation for planetary motion?
  - Most Greeks concluded that Earth must be stationary, because they thought the stars could not be so far away as to make parallax undetectable