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.
A constellation is a region of the sky.

88 constellations fill the entire sky.
In ancient times, constellations only referred to the brightest stars that appeared to form groups, representing mythological figures.
Constellations now have official boundaries

Asterism/ = looks familiar: square, triangle, cross, etc
Bayer System Star Names

Ex. Rigel = Beta Orionis

NOTE BETA > ALPHA
Thought Question

The brightest stars in a constellation…

A. All belong to the same star cluster.
B. All lie at about the same distance from Earth.
C. May actually be quite far away from each other.
The brightest stars in a constellation...

A. All belong to the same star cluster.
B. All lie at about the same distance from Earth.
C. May actually be quite far away from each other.
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 Milky Way

When we look out of the galactic plane (white arrows), we have a clear view to the distant universe.

Location of our solar system

Galactic plane

When we look in any direction into the galactic plane (blue arrows), we see the stars and interstellar clouds that make up the Milky Way in the night 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
We measure the sky using *angles*
Angular Measurements

- Full circle = 360°
- 1° = 60′ (arcminutes)
- 1′ = 60″ (arcseconds)
Thought Question
The angular size of your finger at arm’s length is about 1°. How many arcseconds is this?

A. 60 arcseconds
B. 600 arcseconds
C. $60 \times 60 = 3,600$ arcseconds
The angular size of your finger at arm’s length is about 1°. How many arcseconds is this?

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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.
Our view from Earth:

- Stars near the north celestial pole are circumpolar and never set.
- We cannot see stars near the south celestial pole.
- All other stars (and Sun, Moon, planets) rise in east and set in west.
The Celestial Sphere (3) Travel south!
Apparent Motion of The Celestial Sphere
Apparent Motion of The Celestial Sphere (2)
Which way are YOU Moving. West or East?

Earth’s Rotation Defines Cardinal Points

Zenith

North celestial pole

West point

South point

South celestial pole

East

YOU

Earth horizon

Nadir

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Why do they Move?

What direction is this image?
Thought Question

What is the arrow pointing to?
A. the zenith
B. the north celestial pole
C. the celestial equator
Thought Question

What is the arrow pointing to?
A. the zenith
B. the north celestial pole
C. the celestial equator
Why do the constellations we see depend on latitude and time of year?

- They depend on latitude because your position on Earth determines which constellations remain below the horizon.
- They depend on time of year because Earth’s orbit changes the apparent location of the Sun among the stars.
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 with latitude but not longitude.
The Celestial Sphere (2)

- From geographic latitude $\ell$ (northern hemisphere), you see the celestial north pole $\ell$ degrees above the northern horizon;
- From geographic latitude $-\ell$ (southern hemisphere), you see the celestial south pole $\ell$ degrees above the southern horizon.
- Celestial equator culminates $90^\circ - \ell$ above the horizon.

*Polaris,* the pole star, is within 1° of the NCP.
The Celestial Sphere (Example)

New York City: $\ell \approx 40.7^\circ$

The Celestial South Pole is **not** visible from the northern hemisphere.

Celestial North Pole

40.7°

Horizon

North

Celestial Equator

49.3°

Horizon

South

Yo Prof!… What’s with the 49.3? Peace Bro!
The Celestial Sphere (2)

• From NYC geographic latitude 40.7 (northern hemisphere), you see the celestial north pole 40.7 degrees above the northern horizon;

• Celestial equator (CE) culminates 90° - 40.7 = 49.3 above the horizon in NYC.

Note: The sun is above the CE in Summer and below in winter.
Altitude of the celestial pole = your latitude
Thought Question

The North Star (Polaris) is 50° above your horizon, due north. Where are you?

A. You are on the equator.
B. You are at the North Pole.
C. You are at latitude 50°N.
D. You are at longitude 50°E.
E. You are at latitude 50°N and longitude 50°E.
Thought Question

The North Star (Polaris) is 50° above your horizon, due north. Where are you?

A. You are on the equator.
B. You are at the North Pole.
C. You are at latitude 50°N.
D. You are at longitude 50°E.
E. You are at latitude 50°N and longitude 50°E.
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.
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?
Thought Question

TRUE OR FALSE? Earth is closer to the Sun in summer and farther from the Sun in winter.
Thought Question

TRUE OR FALSE? Earth is closer to the Sun in summer and farther from the Sun in winter.

*Hint: When it is summer in the U.S., it is winter in Australia.*
Thought Question

TRUE OR FALSE! Earth is closer to the Sun in summer and farther from the Sun in winter.

• Seasons are opposite in the N and S hemispheres, so distance cannot be the reason.
• The real reason for seasons involves Earth’s axis tilt.
SEASONS FOR US IN THE NORTHERN HEMISPHERE

- Spring in the Northern Hemisphere; autumn in the Southern Hemisphere.
- Summer in the Northern Hemisphere; winter in the Southern Hemisphere.
- Autumn in the Northern Hemisphere; spring in the Southern Hemisphere.
Earth’s axis of rotation is inclined vs. the normal to its orbital plane by 23.5°, which causes the seasons.
Causes for Seasons  Solstice Positions

Earth is at aphelion about July 4  Earth is at perihelion about Jan 4.

Note: day and night lengths and angle of sunlight!
What causes the seasons?

Seasons depend on how Earth’s axis affects the directness of sunlight
Direct light causes more heating.
Axis tilt changes directness of sunlight during the year.
Sun’s altitude also changes with seasons

Sun’s position at noon in summer: higher altitude means more direct sunlight.

Sun’s position at noon in winter: lower altitude means less direct sunlight.
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.
Note length
Of Noon
Shadow

Hey let’s put
Some stones
At the end
Of the shadow
We can
Predict seasons
Hence
Farmers will
Pay us.
And think we’re
Devine!
Seasonal changes are more extreme at high latitudes

Path of the Sun on the summer solstice at the Arctic Circle

Approximate time: Direction: Midnight due north 6:00 A.M. due east Noon due south 6:00 P.M. due west

Path of the Sun on the summer solstice at the Arctic Circle
How does the orientation of Earth’s axis change with time?

• Although the axis seems fixed on human time scales, it actually precesses over about 26,000 years.
  ⇒ Polaris won’t always be the North Star.
  ⇒ Positions of equinoxes shift around orbit; e.g., spring equinox, once in Aries, is now in Pisces!

Earth’s axis precesses like the axis of a spinning top.
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

Show Horizon

Show time of day

Sun's rays
Moon Rise/Set by Phase
Phases of the Moon: 29.5-day cycle

- **new**
- **crescent**
- **first quarter**
- **gibbous**
- **full**
- **gibbous**
- **last quarter**
- **crescent**

**waxing**
- Moon visible in afternoon/evening.
- Gets “fuller” and rises later each day.

**waning**
- Moon visible in late night/morning.
- Gets “less” and sets later each day.
Thought Question

It’s 9 am. You look up in the sky and see a moon with half its face bright and half dark. What phase is it?

A. First quarter
B. Waxing gibbous
C. Third quarter
D. Half moon
Thought Question

It’s 9 am. You look up in the sky and see a moon with half its face bright and half dark. What phase is it?

A. First quarter
B. Waxing gibbous
C. Third quarter
D. Half moon
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

b You will face the model at all times only if you rotate exactly once during each orbit.
What causes eclipses?

- The Earth and Moon cast shadows.
- When either passes through the other’s shadow, we have an **eclipse**.
Lunar Eclipse
When can eclipses occur?

• **Lunar eclipses** can occur only at *full moon*.

• Lunar eclipses can be *penumbral, partial, or total*.
Solar Eclipse

Simulation of a Total Eclipse of the Sun

View from Earth

View from space

Sun’s rays

(not drawn to scale)
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 full moon and solar eclipse at new 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).
Predicting Eclipses

- Eclipses recur with the 18 yr, 11 1/3 day saros cycle, but type (e.g., partial, total) and location may vary.
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
The Motion of the Planets as known Today

The planets are orbiting the sun almost exactly in the plane of the Ecliptic.

The Moon is orbiting Earth in almost the same plane (Ecliptic).
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**
We see apparent retrograde motion when we pass by a planet in its orbit.
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.*