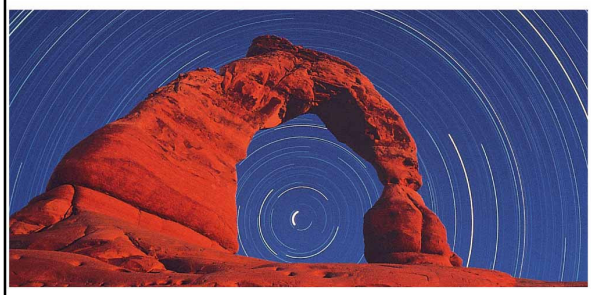
Chapter 2
Discovering the Universe for Yourself



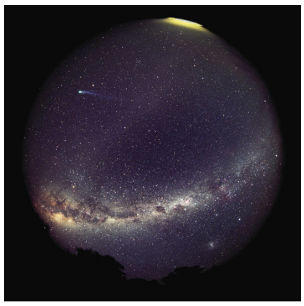
2.1 Patterns in the Night Sky

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?

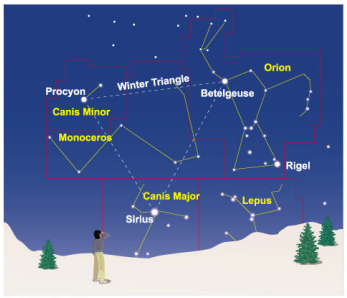
With the naked eye, we can see more than 2,000 stars as well as the Milky Way.



Constellations

A constellation is a *region* of the sky.

88 constellations fill the entire sky.



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.

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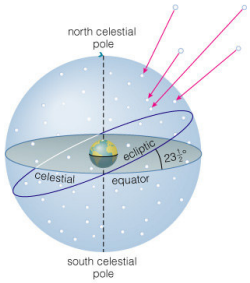
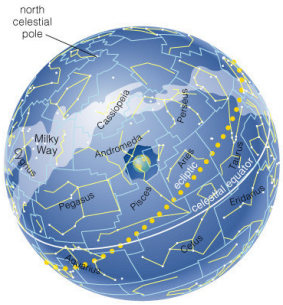
The Celestial Sphere



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

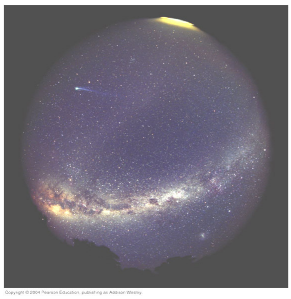
Ecliptic is Sun's apparent path through the celestial sphere.

The Celestial Sphere



The 88 official constellations cover the celestial sphere.

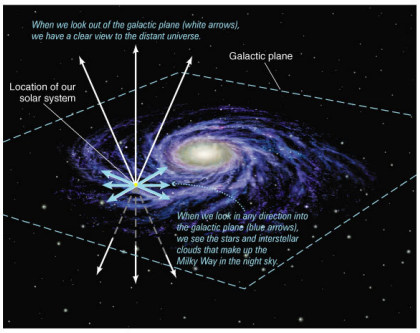
The Milky Way



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

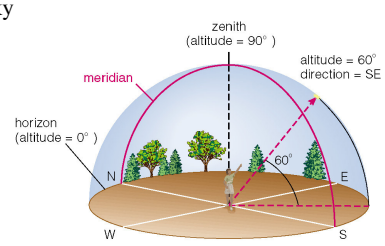
What is it?
Our view into the plane of our galaxy.

The Milky Way

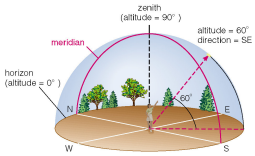


The Local Sky

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



The Local Sky

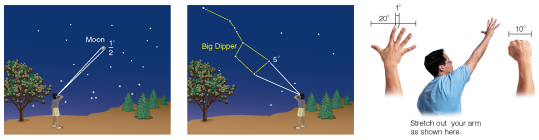


Zenith: The point directly overhead

Horizon: All points 90° away from zenith

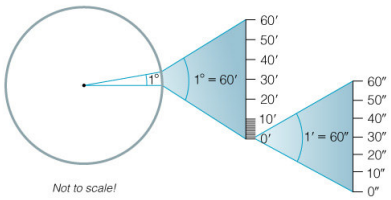
Meridian: Line passing through zenith and connecting N and S points on horizon

We measure the sky using *angles*



Angular Measurements

- Full circle = 360º
- 1º = 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 × 60 = 3,600 arcseconds

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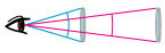
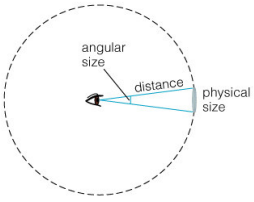
Angular Size

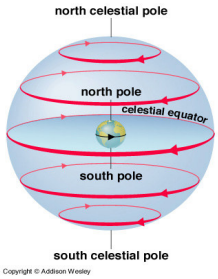
$$\text{angular size} = \text{physical size} \times \frac{360 \text{ degrees}}{2\pi \times \text{distance}}$$



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



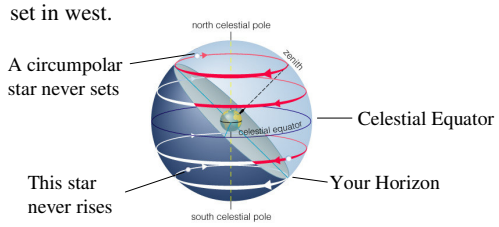
Why do stars rise and set?



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

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.



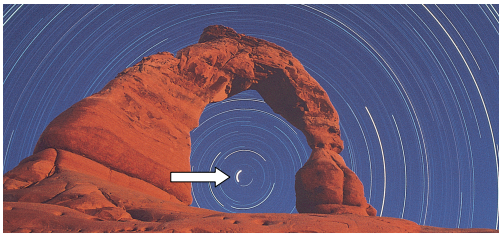
Thought Question

What is the arrow pointing to?

A. the zenith

B. the north celestial pole

C. the celestial equator



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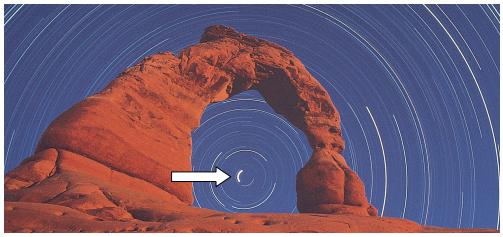
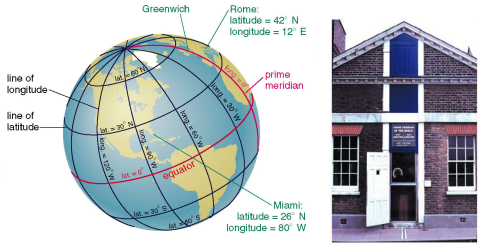


Why do the constellations we see depend on latitude and time of year?

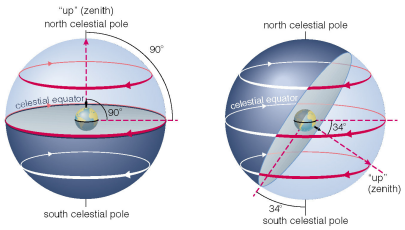
- They depend on latitude because your position on Earth determines which constellations remain below the horizon.
- They depend on time of year because Earth's orbit changes the apparent location of the Sun among the stars.

Review: Coordinates on the Earth

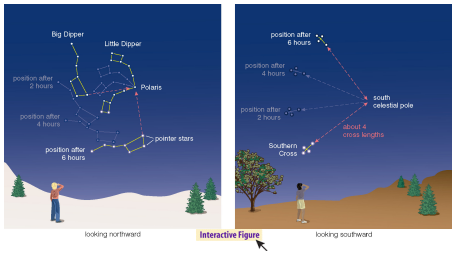
- Latitude: position north or south of equator
- Longitude: position east or west of prime meridian (runs through Greenwich, England)



The sky varies with latitude but not longitude.



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.

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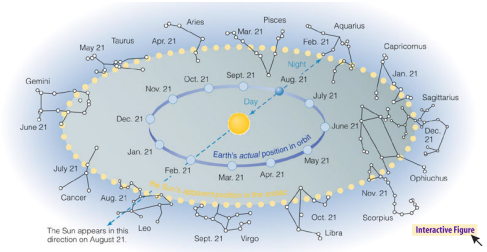
The sky varies as Earth orbits the Sun

- 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.



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?

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.

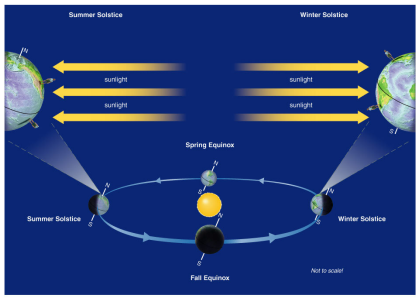
Hint: When it is summer in the U.S., it is winter in Australia.

Thought Question

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

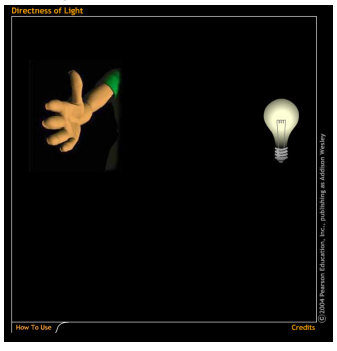
- Seasons are opposite in the N and S hemispheres, so distance cannot be the reason.
- The real reason for seasons involves Earth's axis tilt.

What causes the seasons?

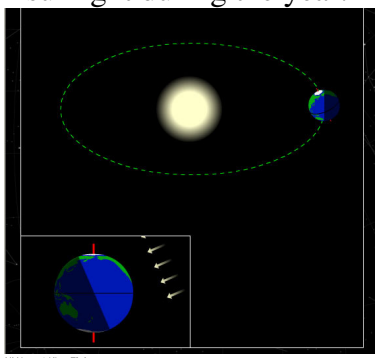


Seasons depend on how Earth's axis affects the directness of sunlight

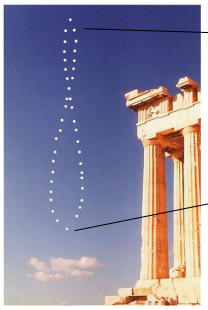
Direct light causes more heating.



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.

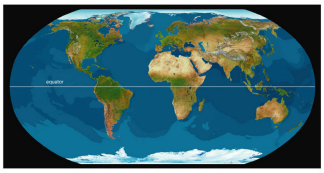
Sun's position at noon in winter: lower altitude means less direct sunlight.

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.

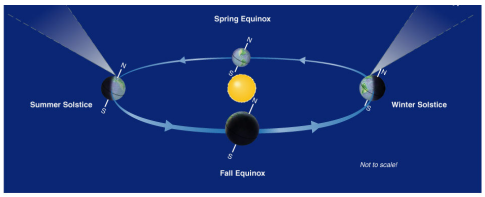
Why *doesn't* distance matter?

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

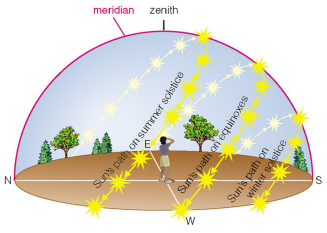


How do we mark the progression of the seasons?

- 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:

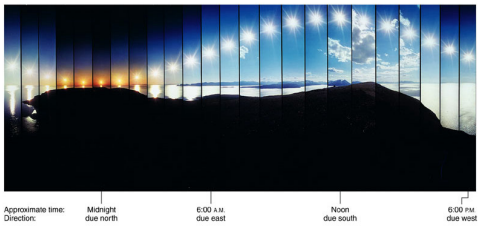


Summer solstice: Highest path, rise and set at most extreme north of due east.

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.

Seasonal changes are more extreme at high latitudes



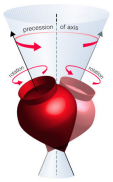
Path of the Sun on the summer solstice at the Arctic Circle

How does the orientation of Earth's axis change with time?

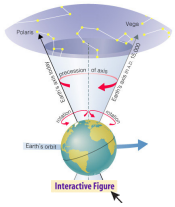
•Although the axis seems fixed on human time scales, it actually precesses over about 26,000 years.

⇒ 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



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?

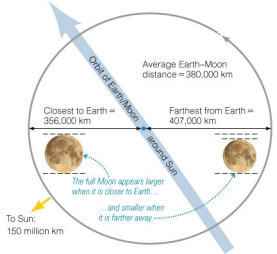
- How do we mark the progression of the seasons?
  - The **summer and winter solstices** are when the Northern Hemisphere gets its most and least direct sunlight, respectively. The **spring and fall equinoxes** are when both hemispheres get equally direct sunlight.
- How does the orientation of Earth's 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 axis

2.3 The Moon, Our Constant Companion

Our goals for learning:

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

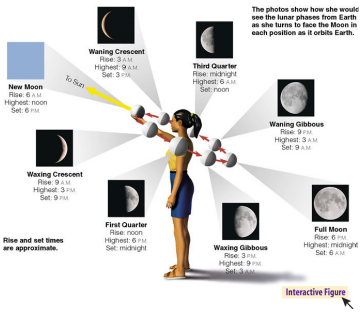
Why do we see phases of the Moon?



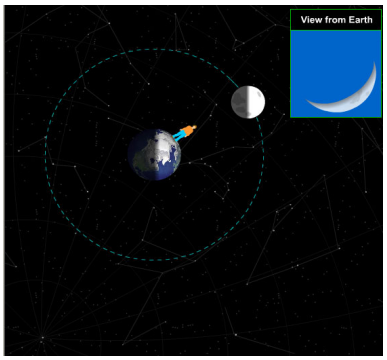
- Lunar phases are a consequence of the Moon's 27.3-day orbit around Earth

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



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.

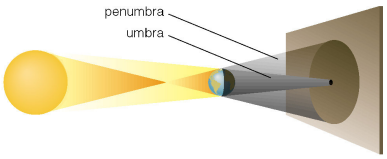
We see only one side of Moon

Synchronous rotation: the Moon rotates exactly once with each orbit

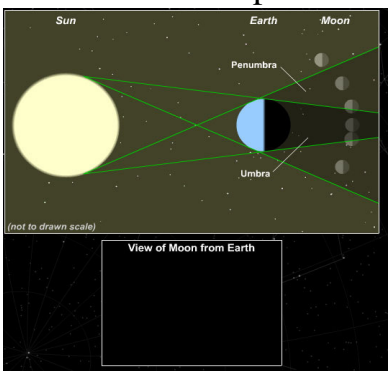
That is why only one side is visible from Earth

What causes eclipses?

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

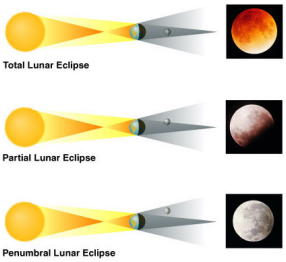


Lunar Eclipse

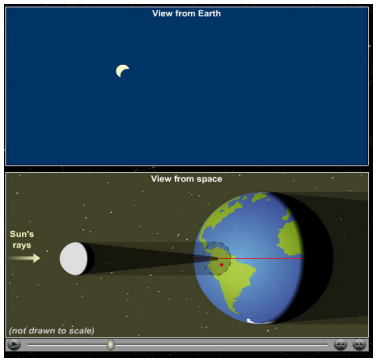


When can eclipses occur?

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

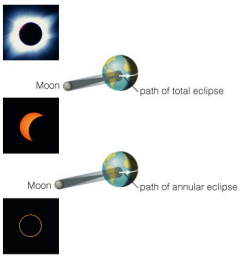


Solar Eclipse



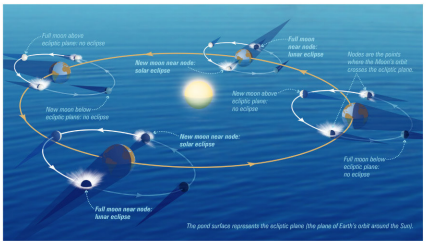
When can eclipses occur?

- **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:

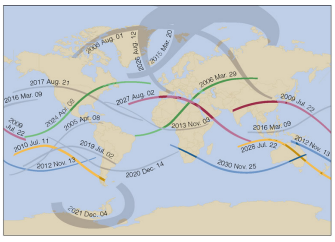
1. It must be full moon (for a lunar eclipse) or new moon (for a solar eclipse).

   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).

Predicting Eclipses

- Eclipses recur with the 18 yr, 11 1/3 day **saros cycle**, but type (e.g., partial, total) and location may vary.



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:

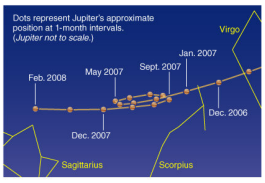
- What was once so mysterious about planetary motion in our sky?
- Why did the ancient Greeks reject the real explanation for planetary motion?

Planets Known in Ancient Times

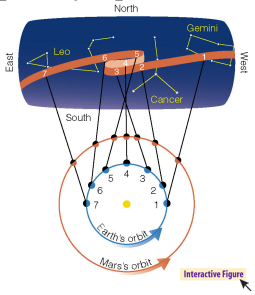
- Mercury
  - difficult to see; always close to Sun in sky
- Venus
  - very bright when visible; morning or evening "star"
- Mars
  - noticeably red
- Jupiter
  - very bright
- Saturn
  - moderately bright

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**



We see apparent retrograde motion when we pass by a planet in its orbit.

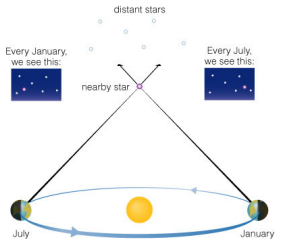


Explaining Apparent Retrograde Motion

- 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.

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