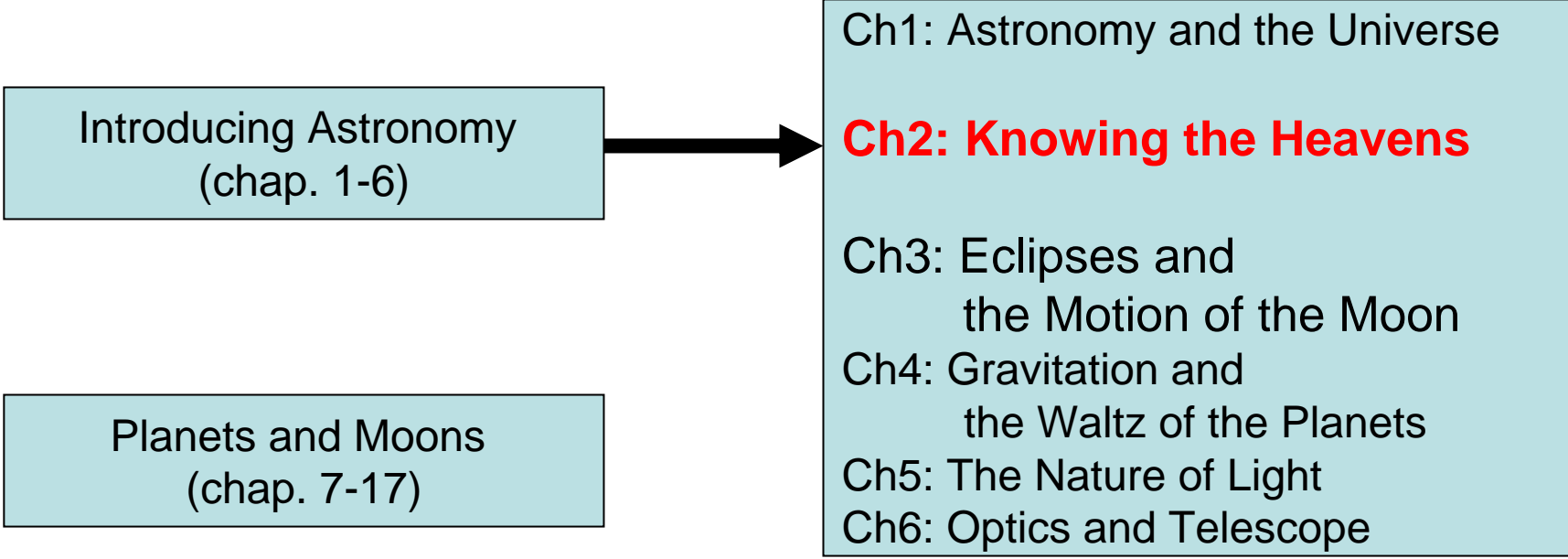


# Introduction To Modern Astronomy II

Introducing Astronomy  
(chap. 1-6)



Planets and Moons  
(chap. 7-17)

Ch1: Astronomy and the Universe

**Ch2: Knowing the Heavens**

Ch3: Eclipses and  
the Motion of the Moon

Ch4: Gravitation and  
the Waltz of the Planets

Ch5: The Nature of Light

Ch6: Optics and Telescope

A long-exposure photograph of a telescope dome on a mountain peak at night. The sky is filled with concentric star trails, indicating the Earth's rotation. The dome is illuminated from below, and the horizon shows some distant lights.

# Knowing the Heavens

## Chapter Two

**Hawaii: latitude 20 deg**

**Washington D.C.: latitude 38 deg**

# Guiding Questions

1. What role did astronomy play in ancient civilizations?
2. Are the stars that make up a constellation actually close to one another?
3. Are the same stars visible every night of the year? What is so special about the North Star?
4. Are the same stars visible from any location on Earth?
5. What causes the seasons? Why are they opposite in the northern and southern hemispheres?
6. Has the same star always been the North Star?
7. Can we use the rising and setting of the Sun as the basis of our system of keeping time?
8. Why are there leap years?

# Astronomy in ancient civilizations

- **Positional astronomy**
  - the study of the positions of objects in the sky and how these positions change
- **Naked-eye astronomy**
  - the sort that requires only human vision (no telescope)
- **Has roots in almost all ancient civilizations**



**Mayan Observatory**

**Yucatan Peninsula  
Central American**



# Astronomy in ancient civilizations

- **Positional astronomy using naked Eyes**
  - Position of stars, ecliptic orbit, constellations
  - Path of Sun, Moon, Planets, zodiac band



Ancient Astronomical Instrument  
Purple Mountain Observatory  
Nanjing, China

# Astronomy in ancient civilizations



# Constellations



- **Constellations:** from the Latin for “group of stars”
- Ancient peoples looked at the stars and imagined groupings made pictures in the sky
- We still refer to many of these groupings

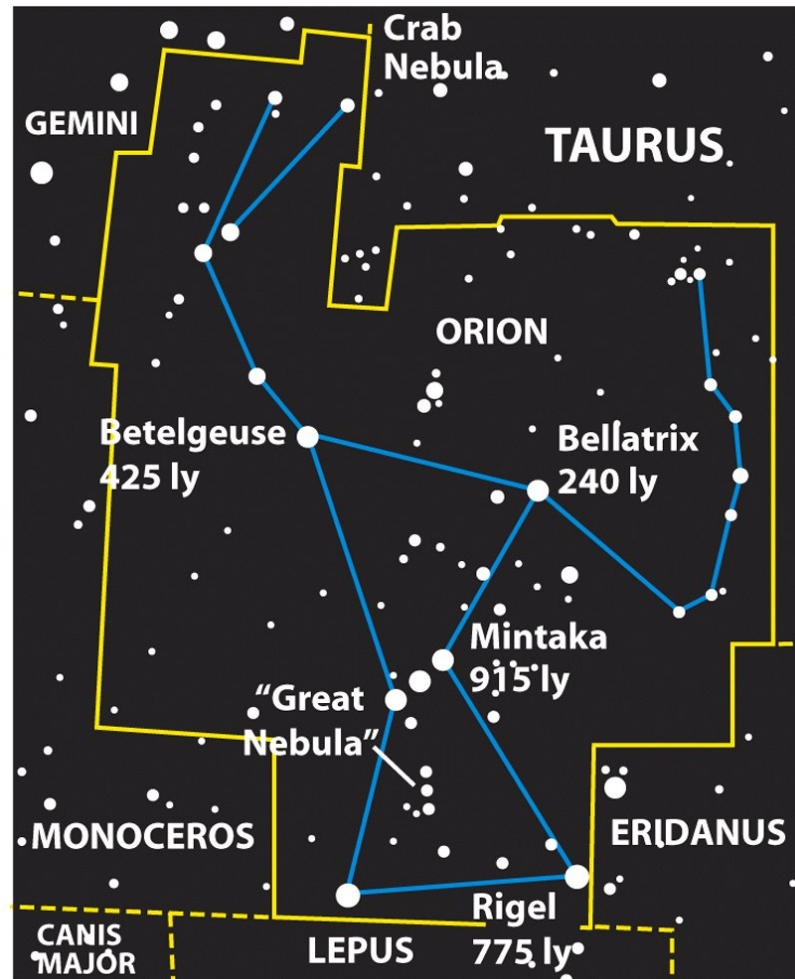
Orion (the Hunter)

Betelgeuse: the armpit  
Mintaka: the belt



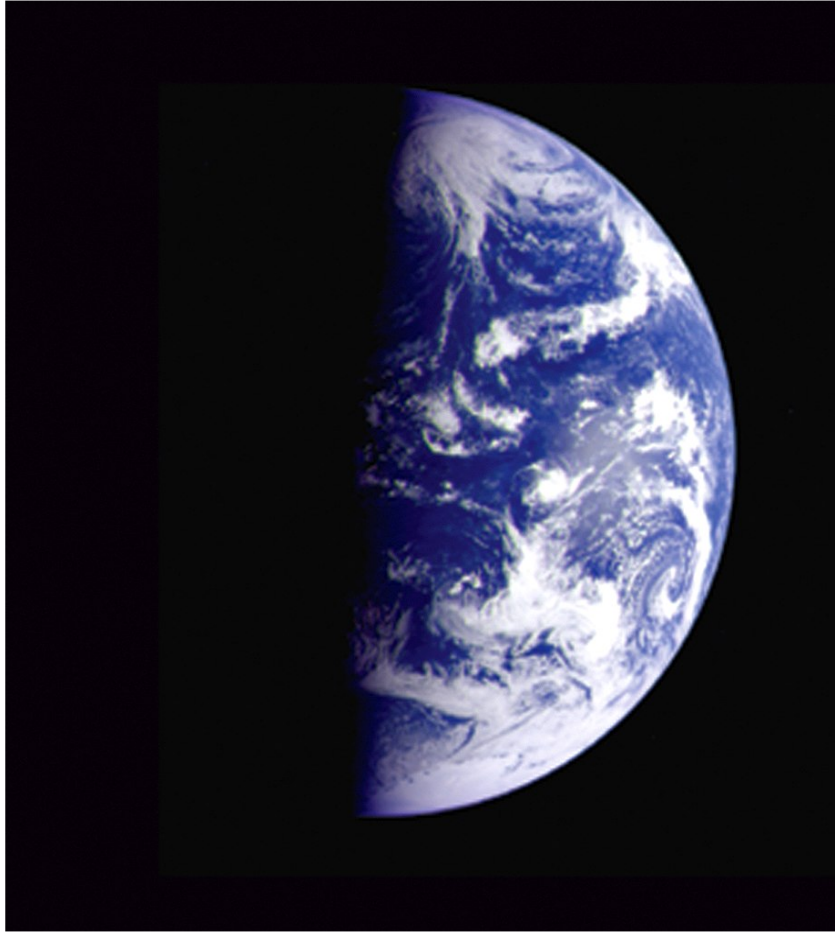
# Eighty-eight constellations --- entire sky

- On modern star charts, the entire sky is divided into 88 regions
- Each is a constellation
- Most stars in a constellation are nowhere near one another in real 3-D distance.
- They only *appear* to be close together because they are in nearly the same direction as seen from Earth



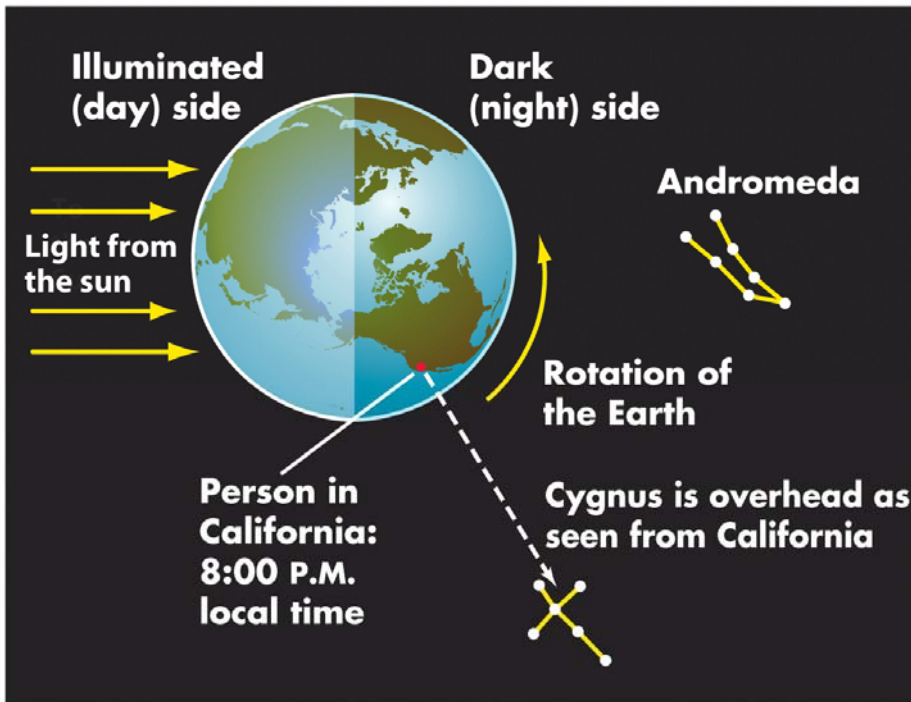


# Diurnal Motion of Stars

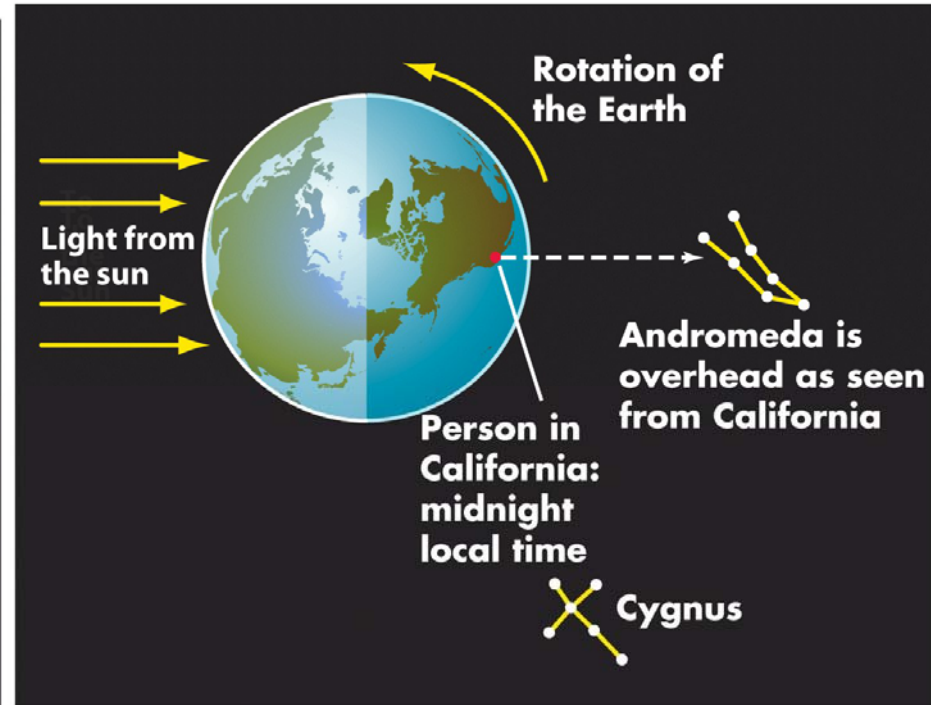


- Stars appear to rise in the east, slowly rotate about the earth and set in the west.
- This diurnal or daily motion of the stars is actually caused by the 24-hour rotation of the earth.
- Earth is a rotating sphere illuminated by Sunlight

# Diurnal Motion of Stars



(a) Earth as seen from above the North Pole

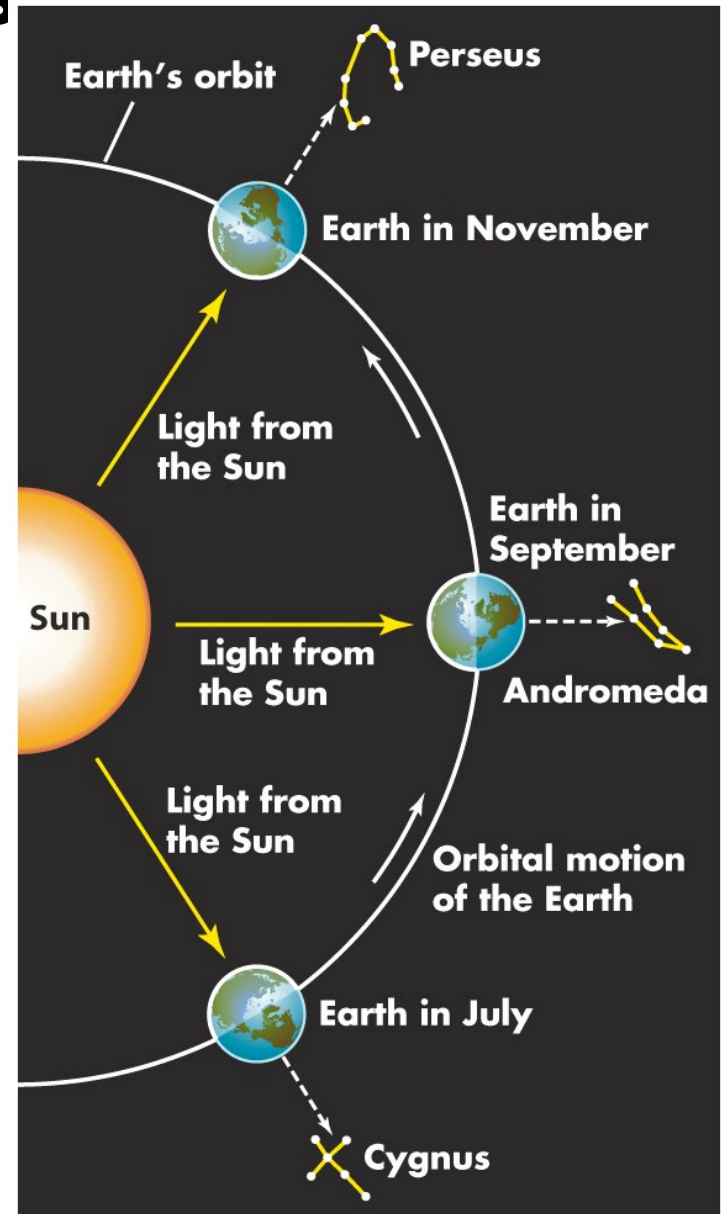


(b) 4 hours (one-sixth of a complete rotation) later

- View from the vantage point of above the North Pole
  - Earth rotates counter-clockwise, from west to east
- View from people on Earth
  - Stars rotate clockwise, from east to west

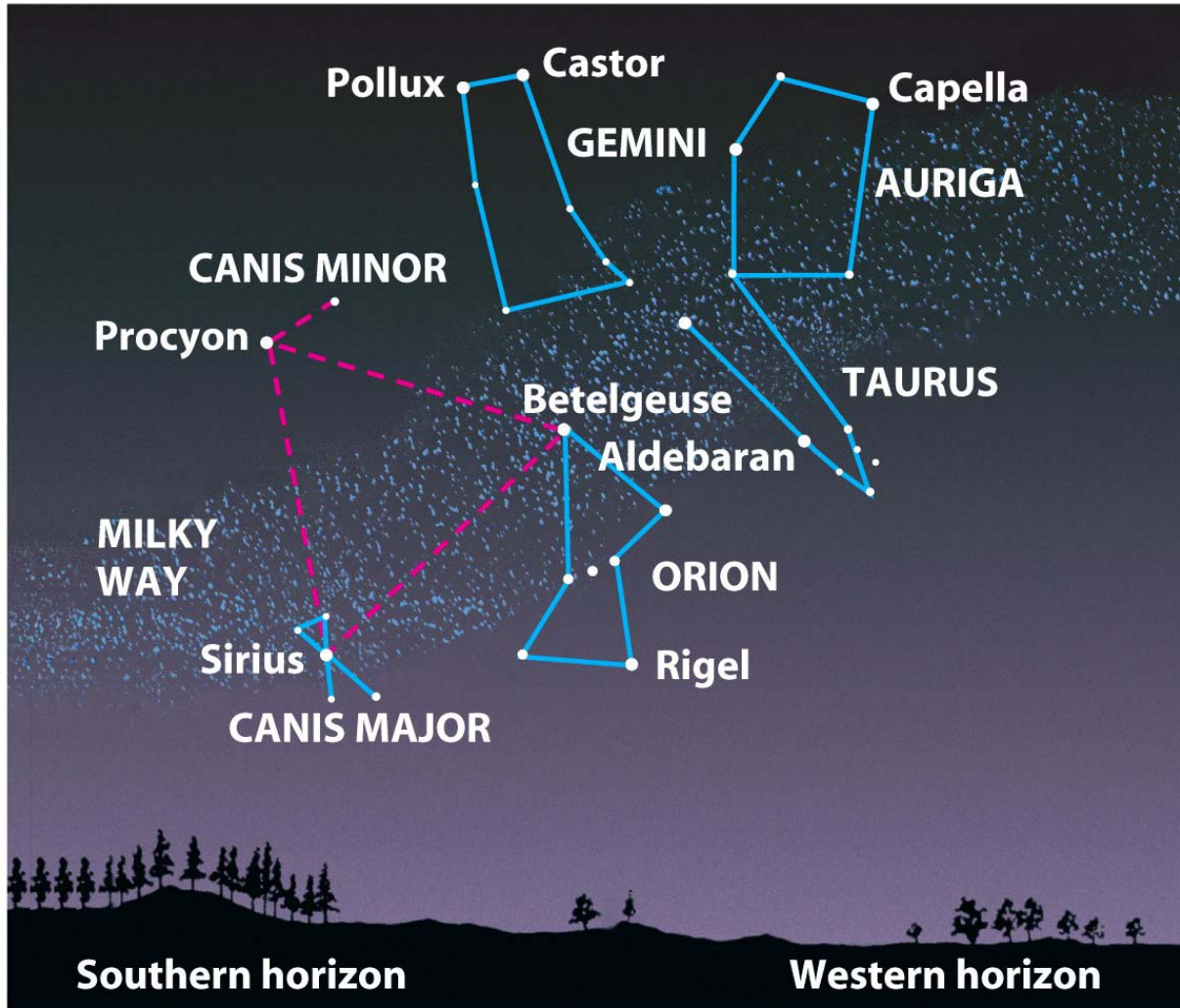
# Annual Motion of Stars

- The stars also appear to slowly shift in position throughout the year, when viewed at the same time (e.g., midnight) at the same location on the Earth
- **The shift is due to the orbit of the earth around the sun**
- If you follow a particular star on successive evenings, you will find that it rises approximately 4 minutes earlier each night, or 2 hours earlier each month
- **Annual motion:** the star pattern in the evening (e.g., midnight) will be exactly the same after one year.



# “Winter Triangle”

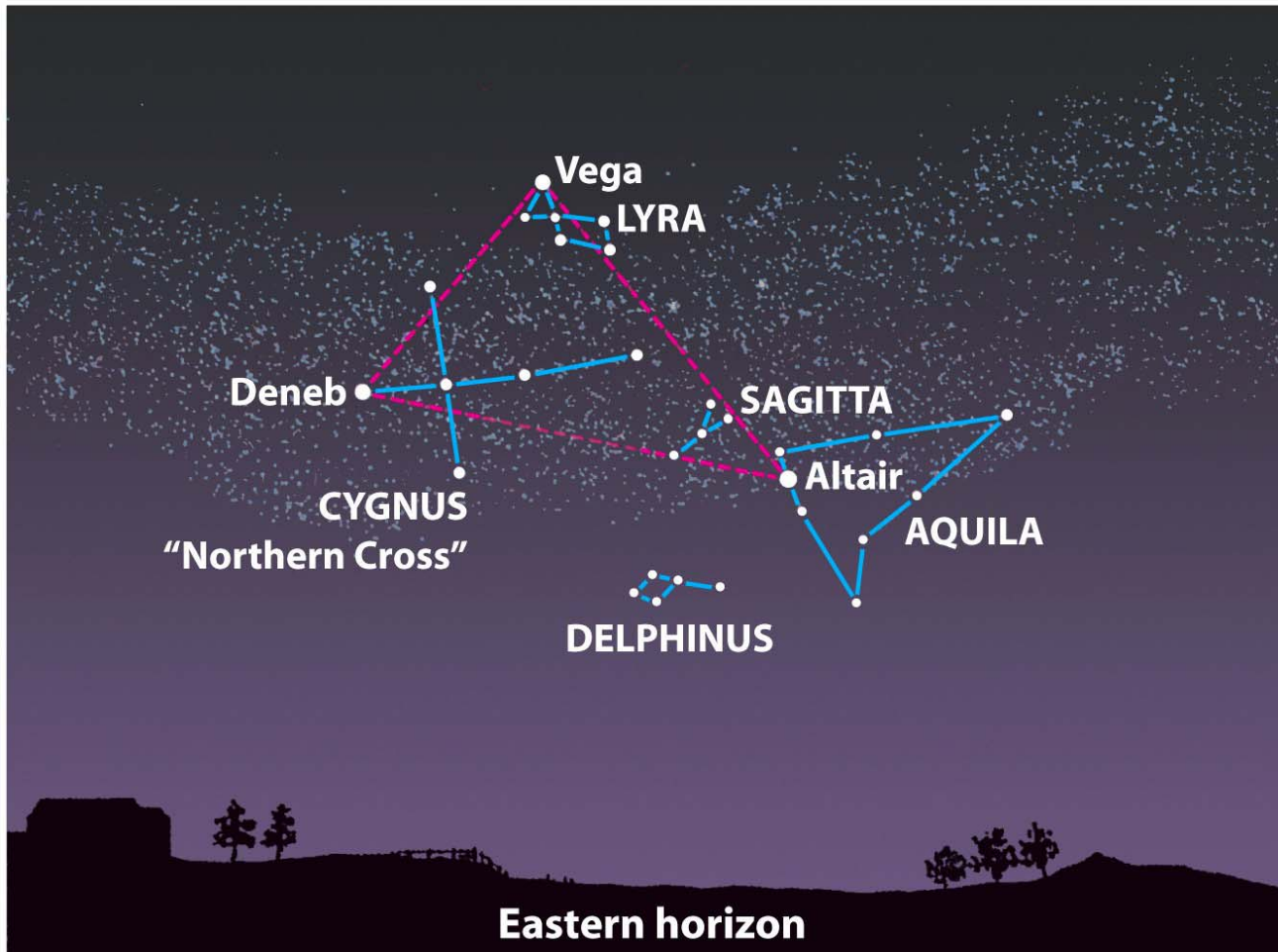
- Three of the brightest stars in the winter evening in the northern hemisphere





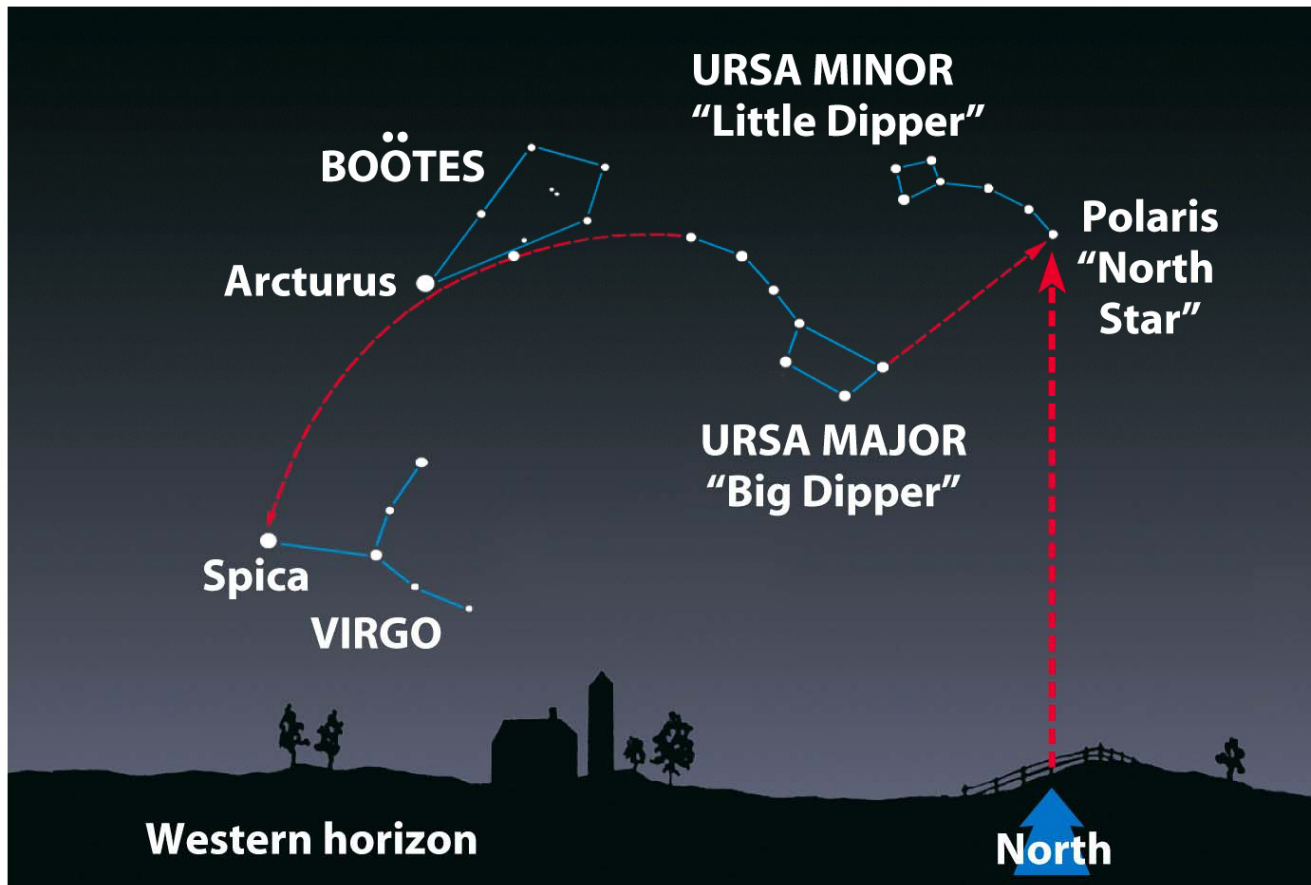
# “Summer Triangle”

- Three of the brightest stars in the summer evening in the northern hemisphere



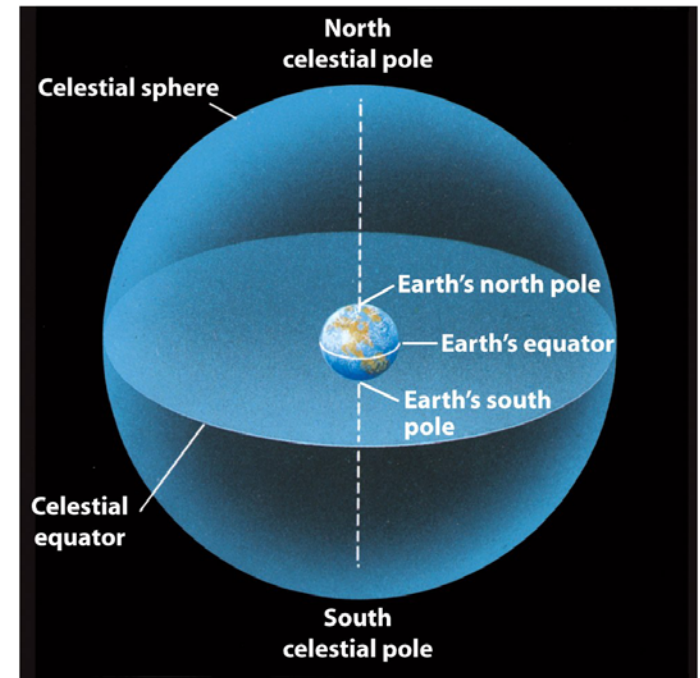
# North Star: Polaris

- Visible anywhere in the northern hemisphere
- The position of the extended Earth rotation axis into the sky
- The North direction can be found by drawing a line straight down to the horizon

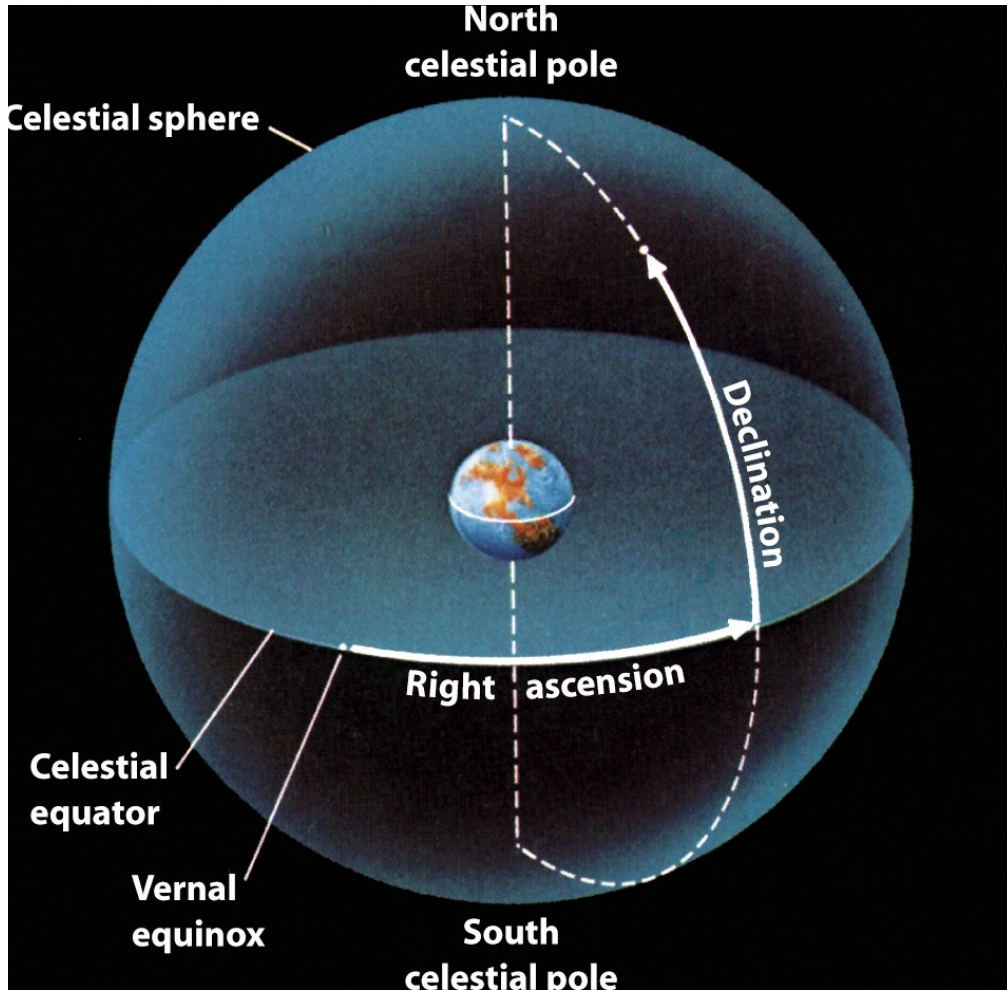


# Celestial Sphere

- **Celestial sphere: an imaginary sphere that all stars are fixed on its surface**
- In the sphere, all stars are assumed in the same distance
- Note that it is an *imaginary* object that has no basis in physical reality
- However, it is a model that remains a useful tool of positional astronomy, since it represents well the diurnal motion, by assuming the whole sphere rotates in a daily basis.



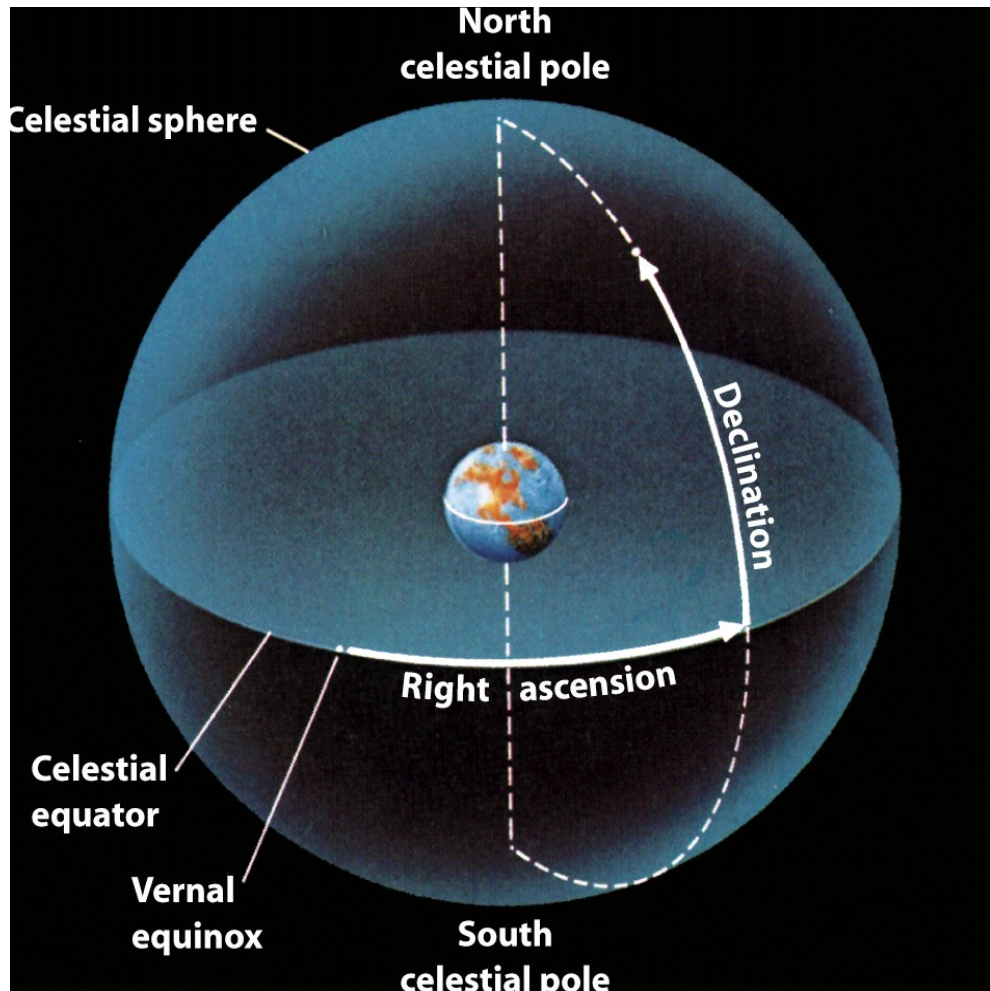
# Celestial Sphere



- **Celestial equator :**
  - Earth's equator projected out into space
  - divides the sky into northern and southern hemispheres
- **Celestial poles;**
  - Earth's axis of rotation intersect the celestial sphere
  - **North celestial pole**
  - **South celestial pole**
- Polaris is less than  $1^\circ$  away from the north celestial pole

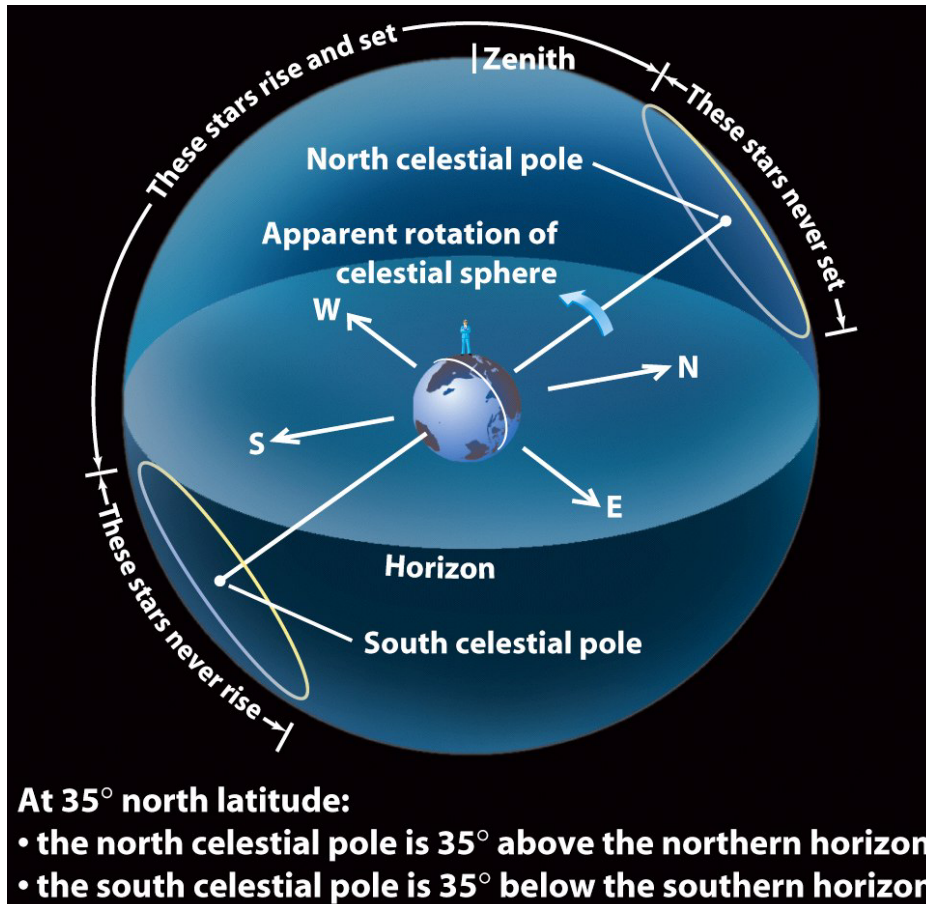


# Celestial Sphere: coordinates (tools in Box 2-1)



- **Celestial coordinates:**
- Denote position of objects in the sky
- Based on **Right Ascension** and **Declination**
  
- **Right Ascension (0-24h)**
- Corresponds to longitude
- Starting from **Vernal Equinox** (the point where the Sun's path crosses the celestial equator in late March)
  
- **Declination (-90, 90 deg)**
- Corresponds to latitude

# Celestial Sphere



- The celestial sphere appears “tipped” viewed by an observer (e.g., at 35° North)

## • Zenith

- Point in the sky directly overhead

- At any time, observer can see only half of the celestial sphere
- The other half is below the horizon
- The stars close to north pole never sets

# Celestial Sphere

- The apparent motion of stars at different latitudes



**(a) At middle northern latitudes**



**(b) At the north pole**



**(c) At the equator**

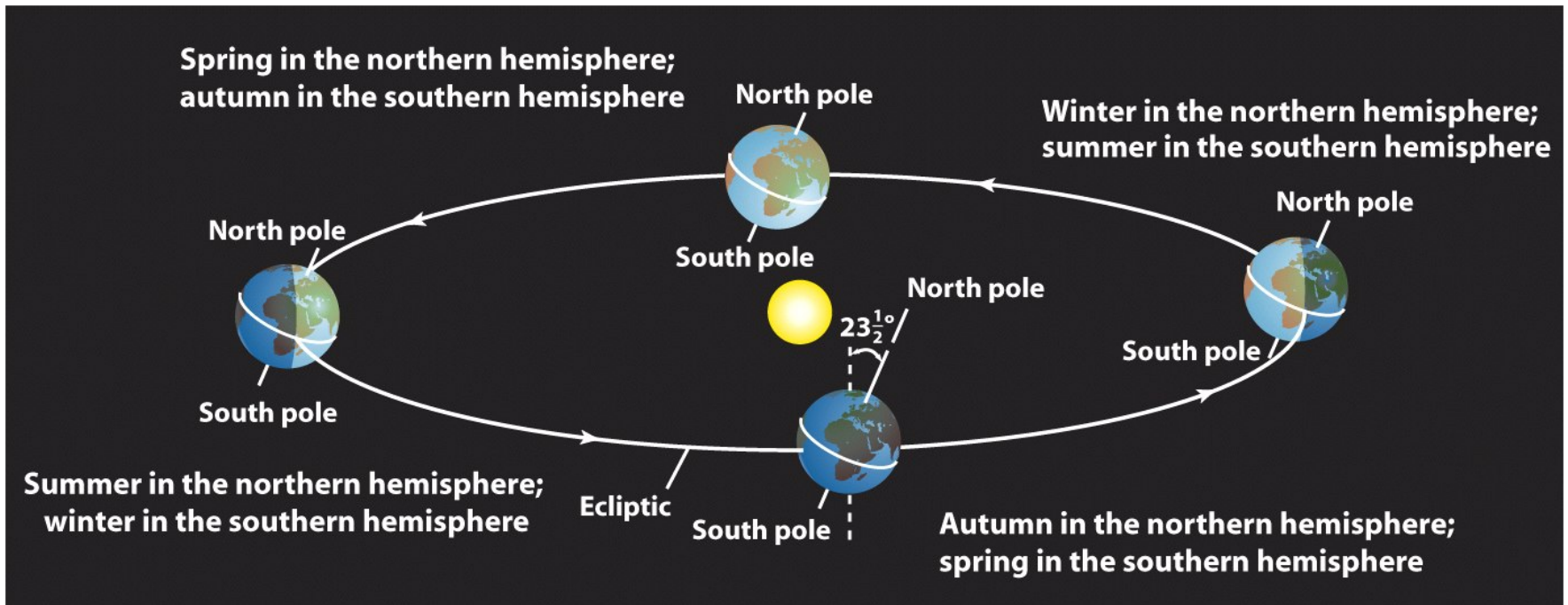
# Seasons

- Spring, Summer, Autumn, Winter
- Summer days are longer than 12 hours
- Winter days are shorter than 12 hours
- Seasons are opposite in the two hemispheres
- The Sun is higher in the summer at noon than in the winter



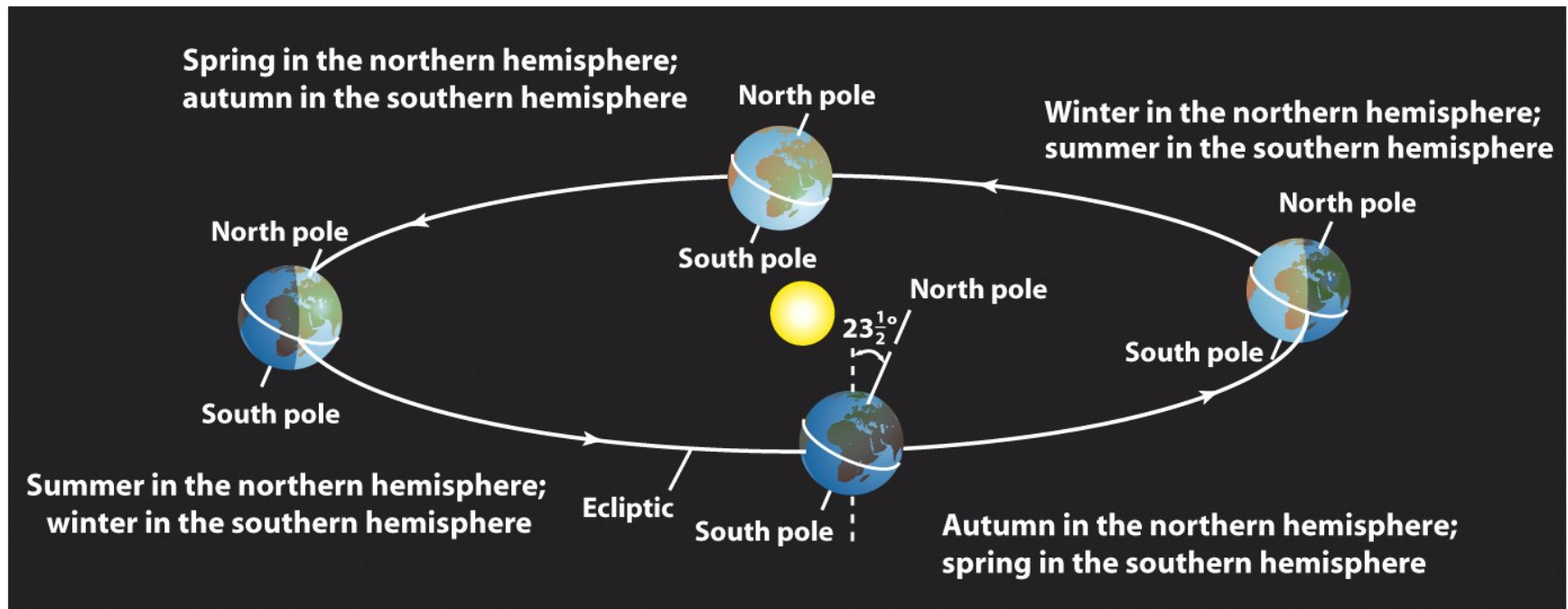
# Seasons: the cause

- **Seasons are caused by the tilt of Earth's axis rotation**
- The Earth's axis is tilted about  $23\frac{1}{2}^{\circ}$  away from the orbital plane



# Seasons

- **Ecliptic:** the plane of the Earth annual orbit around the Sun; also the plane of the Sun's annual orbit in the celestial sphere
- The Earth maintains this tilt as it orbits the Sun.



# Seasons

The summer is hotter, because

**(1) the surface receives the Sun's light (or heat) longer**

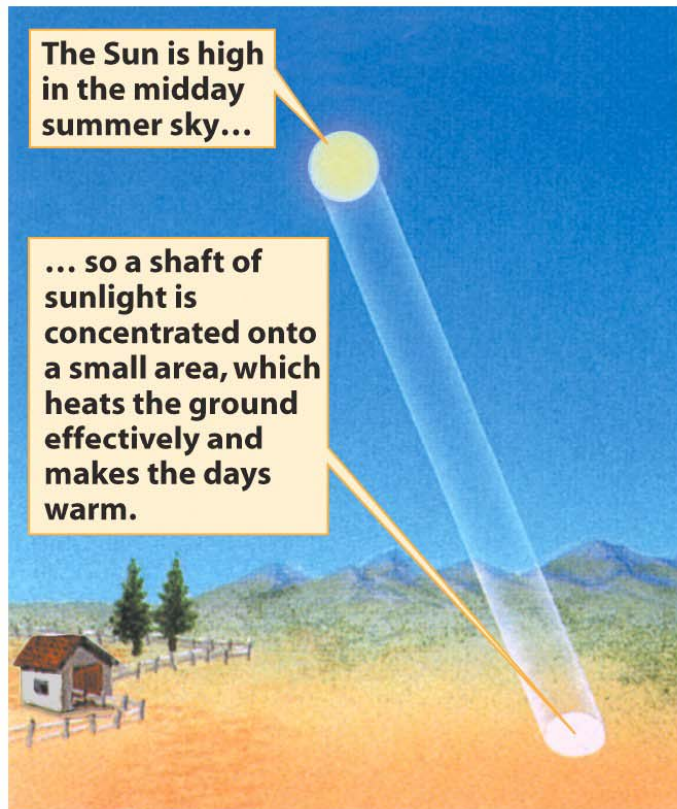
- the Earth is tilted toward the Sun
  - E.g., July in Northern Hemisphere
  - E.g., January in Southern Hemisphere
- As the Earth spins on its axis, the surface spends more than 12 hours in the sunlight
- The days there are long and the nights are short

**(2) The Sun heats the surface more efficiently**

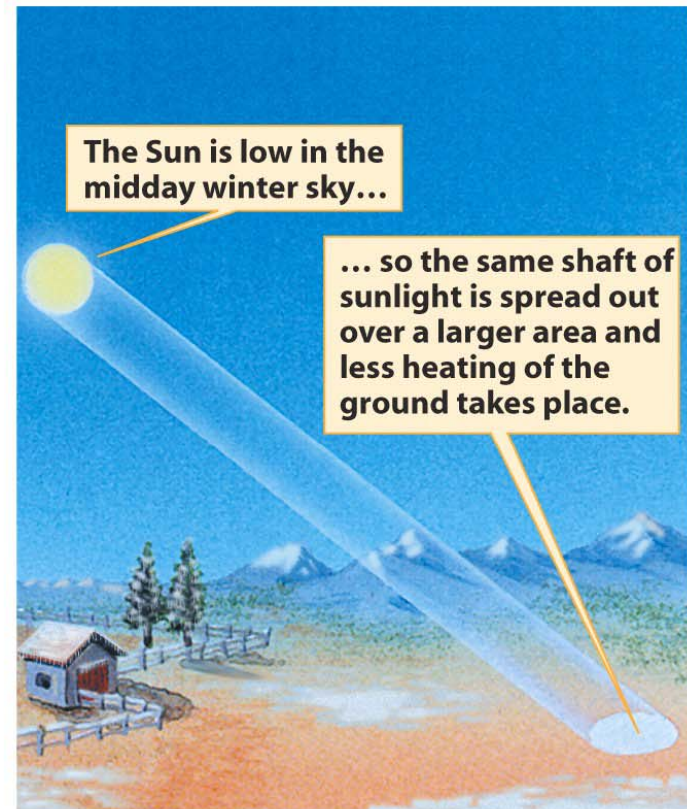
- the Sun is high in the sky
- sunlight strikes the ground at a nearly perpendicular angle that heats the ground efficiently

# Seasons

- When the Sun is high in the summer, the sunlight is more concentrated, and thus increases the heating
- In the winter the Sun is lower, the sunlight is less concentrated, and thus reduces the heating



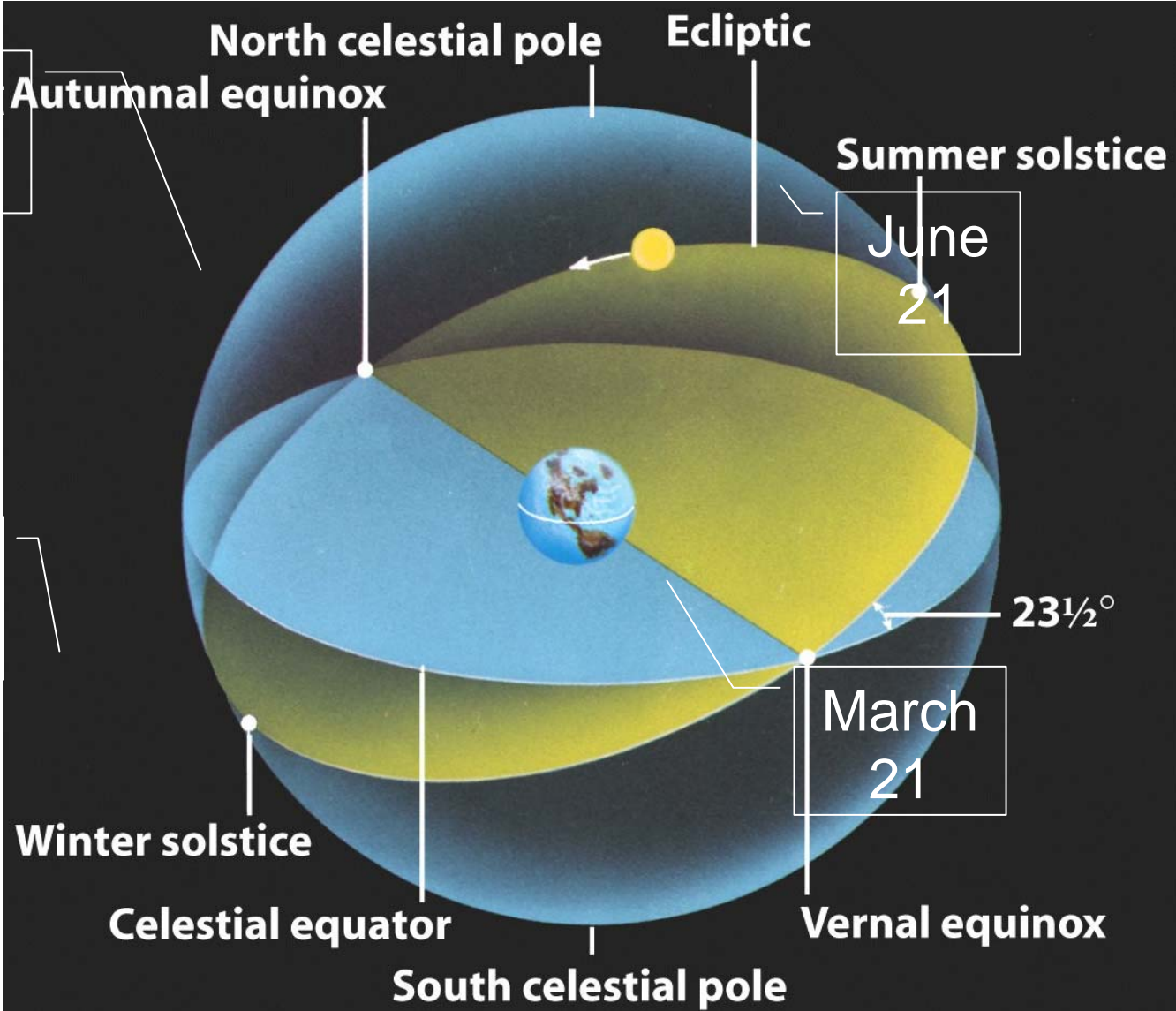
**(a) The Sun in summer**



**(b) The Sun in winter**



# Ecliptic, Equinoxes, Solstices



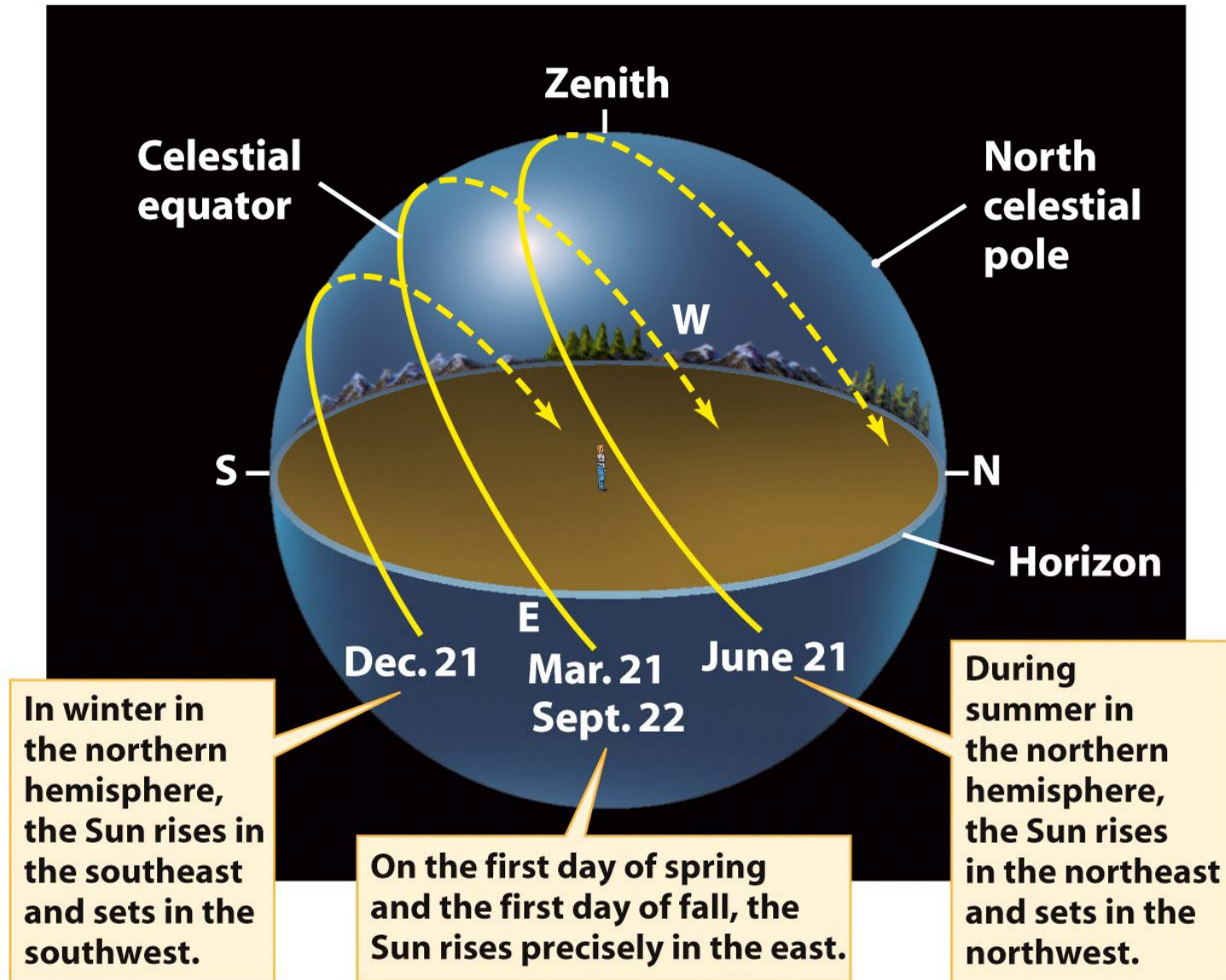
# Ecliptic, Equinoxes, Solstices

- **Ecliptic:** a circular path the Sun appears to trace on the celestial sphere.
  - Ecliptic plane is tilted at  $23\frac{1}{2}$  degrees to the celestial equator
- **Equinoxes:** the points that the ecliptic path and the celestial equator intersect
  - There are only two points, thus two equinoxes
- **Vernal equinox:** the Sun crosses northward across the celestial equator
  - Occurs on about March 21
  - Marks beginning of spring in northern hemisphere
- **Autumnal equinox:** the Sun crosses southward across the celestial equator
  - Occurs on about Sep. 22
  - Marks beginning of autumn in northern hemisphere
- **At equinoxes, the day time is exactly 12 hours**

# Ecliptic, Equinoxes, Solstices

- **Summer Solstice:** the point on the ecliptic farthest north of the celestial equator
  - Occurs on about June 21
  - marks the location of the Sun at the beginning of summer in the northern hemisphere
  - the day time is the longest
  
- **Winter Solstice:** the point on the ecliptic farthest south of the celestial equator
  - Occurs on about Dec 21
  - marks the location of the Sun at the beginning of winter in the northern hemisphere
  - The day time is the shortest

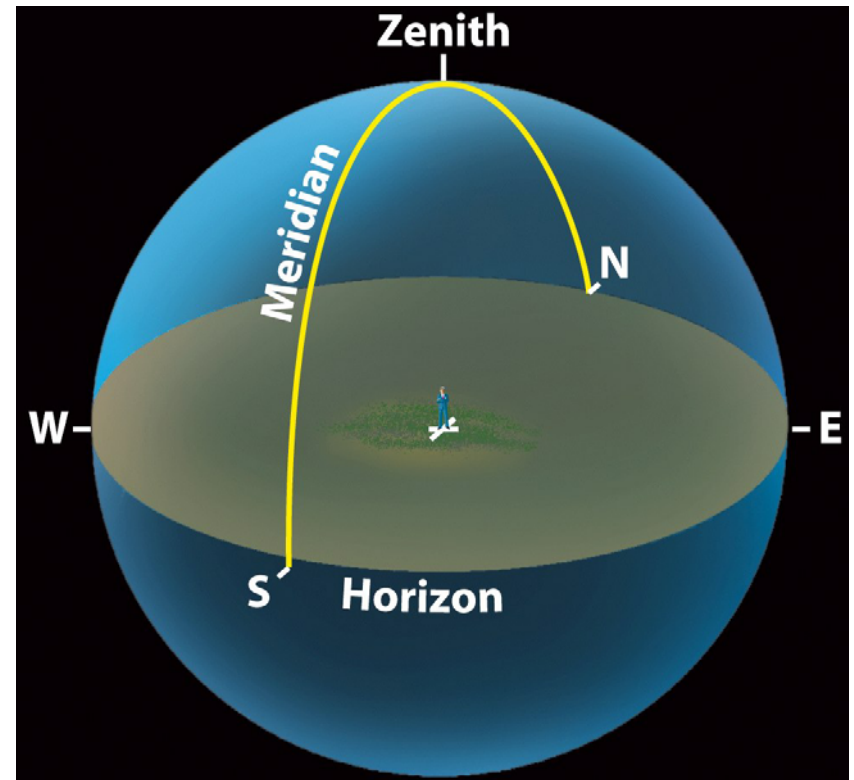
# The Sun's Daily Path in Different Season





# Timekeeping

- A day is the interval between the successive upper **meridian** transits of the Sun
- **Meridian**: the north-south circle on the celestial sphere that passes through the zenith and both celestial poles
- **Noon**: defined as the Sun crosses the upper **meridian**
- **Note**: meridian circle, zenith and noon are all **local**; in other words, they depend on the location on the Earth



# Timekeeping

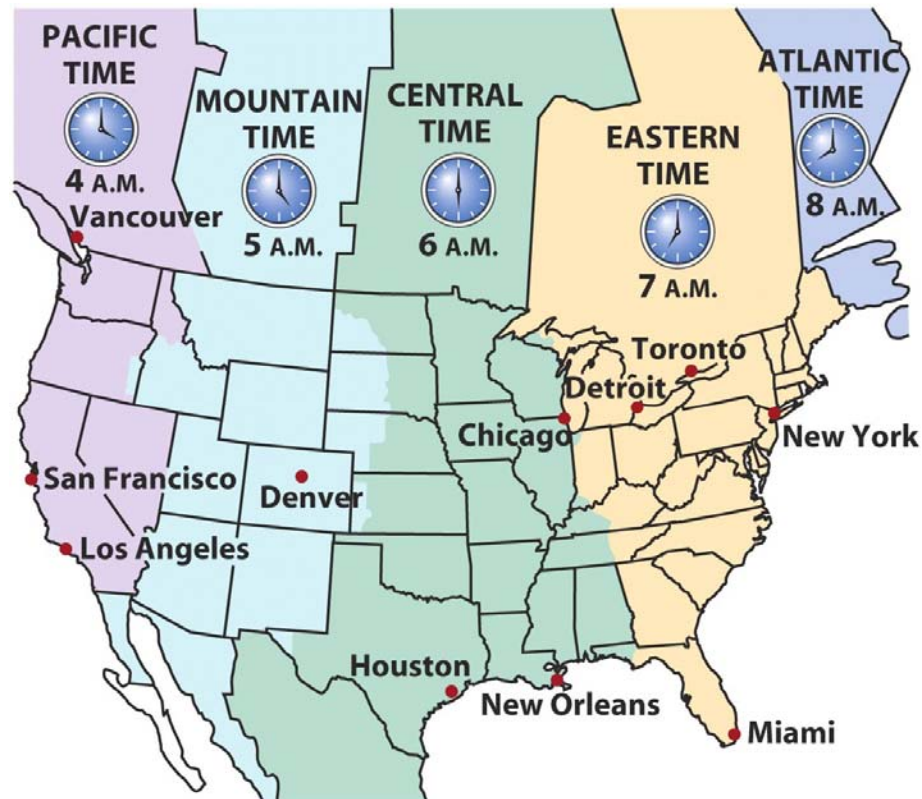
- **A “modern” day is the mean solar day**, defined by the interval between successive upper meridian transit of the **mean sun**
  - A mean solar day is exactly 24 hours long
- An apparent solar day varies over the course of the year
  - Because the Earth’s orbit is not a perfect circle
    - Earth moves faster when it is near the Sun, making the day longer
- Mean Sun is the imaginary sun that travels at a uniform rate (the average of the apparent days over one year) along the celestial equator
  - Mean Sun produces a uniform mean solar day of 24 hours
- Ordinary watches and clocks measure mean solar time

# Timekeeping

- **A “modern” day is the mean solar day**, defined by the interval between successive upper meridian transit of the **mean sun**
  - A mean solar day is exactly 24 hours long throughout the year
- An apparent solar day varies over the course of the year
  - Because the Earth’s orbit is not a perfect circle
    - Earth moves faster when it is near the Sun, making the day longer
- Mean solar time is based on the motion of an imaginary mean sun along the celestial equator, which produces a uniform mean solar day of 24 hours
- Ordinary watches and clocks measure mean solar time

# Time Zone and Universal Time

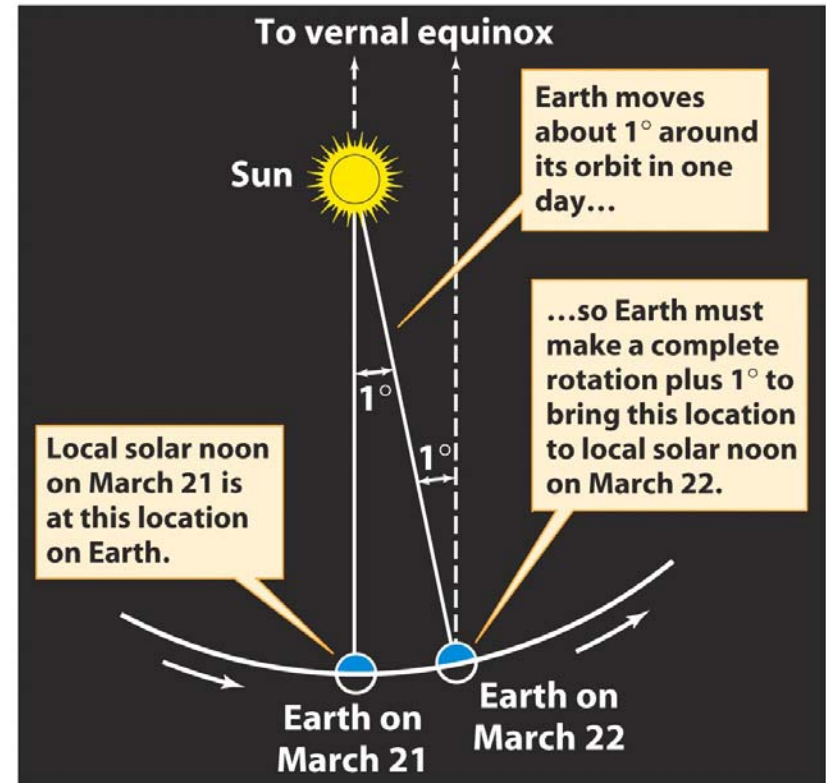
- For convenience of most people, the Earth is divided into 24 time zones, centered on  $15^\circ$  intervals of longitude around the globe
- UT (universal time): for convenience of aviator and sailors, who regularly travel across time zones.
  - It is always the time in the zone that includes Greenwich, England.





# Sidereal Time (tools in Box 2-2)

- **Sidereal time:** a preferred time by astronomers
- It is based on the position of the star, not the Sun.
- It makes easier to track astronomical objects
- **A sidereal day is the time between successive upper meridian passages of the vernal equinox (23h 56m)**
- **A sidereal day:** the time takes the Earth rotate exactly  $360^\circ$
- A solar day: the time takes the Earth rotate  $360^\circ$ , plus  $\sim 1^\circ$  (or 4 more min of rotation) to make up the Sun's shift caused by orbital motion.



# Calendar and Leap Years

- In modern calendar, a year is 365 whole days, and 366 whole days in leap years (one more day on Feb. 29).
- The reason is that the more accurate year, the tropic year, defined by the interval of successive vernal equinox transit of the Sun, is not a whole number. It is 365.2422 days.
- Julius Caesar's calendar: assuming year=365.25 days
  - The offset of 0.25 day/year adds one more day in every 4 years
  - Leap year: the year can be evenly divided by 4, e.g., 2004, 2008
- Gregory Calendar (Pope Gregory XIII), current calendar
  - Dropped ten days from Oct. 4, 1582 to Oct. 15, 1582; brought the spring (Sun passes the vernal equinox) back to March 21.
  - Because a tropic year is 11 minute offset from 365.25 days
  - This error adds up about three days in every four centuries
  - Only century years evenly divisible by 400 should be leap years.

# Final Notes on Chap. 2

- By default, the content in the tool boxes are not taught, with the exception of the following
  - Box 2-1 (page 27) on celestial coordinate should be studied
  - Box 2-2 (page 35) on sidereal time
- Section 2.6 (on Earth precession) is not taught
- But I encourage students who need challenge to study these tools and sections by your own. I will be happy to answer any questions.