

Introduction To Modern Astronomy I: Solar System

Introducing Astronomy
(chap. 1-6)

Planets and Moons
(chap. 7-15)

Chap. 16: Our Sun
Chap. 28: Search for
Extraterrestrial life

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 at night. The dome is illuminated from within, and the sky above it shows numerous concentric star trails, indicating the Earth's rotation. The dome is situated on a dark, rocky outcrop.

Knowing the Heavens

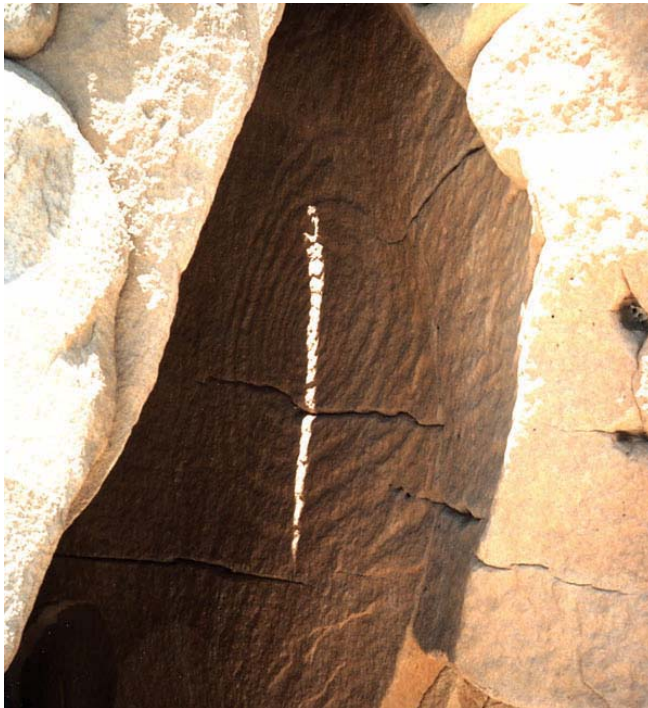
Chapter Two

Hawaii: N20°

Washington D.C.: N38°

Positional Astronomy

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



**The Sun Dagger
at Chaco Canyon,
New Mexico**

Positional Astronomy

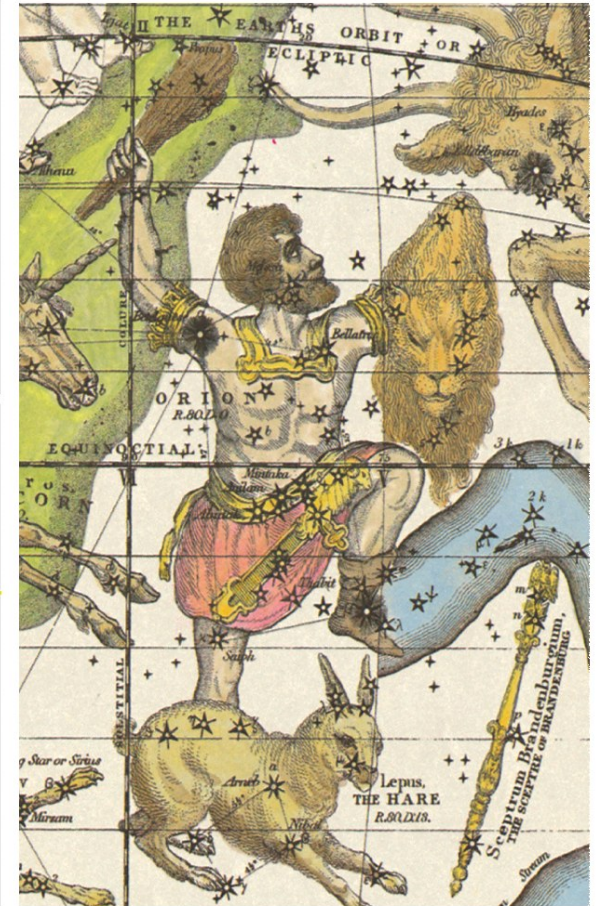
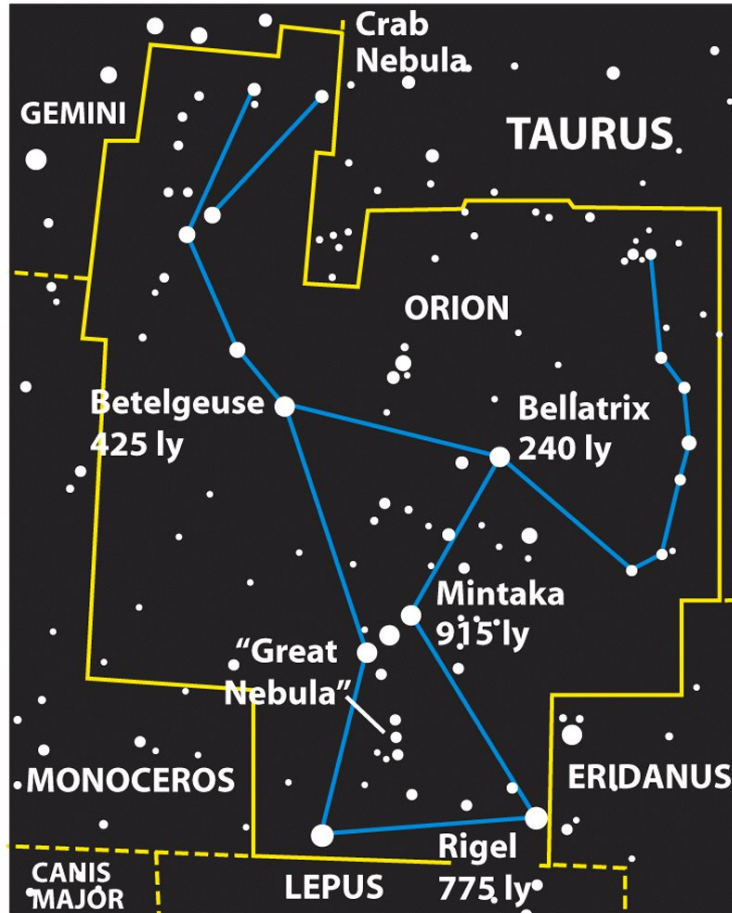
- Position of stars in the heaven; forming consternations
- Path of Sun, Moon and Planets; forming zodiac band



Heaven's Sphere
at
Purple Mountain
Observatory,
Nanjing,
China

Constellations

From the Latin for “group of stars”



ORION: Photograph

Modern Star Atlas

Ancient Star Atlas(1835)

ORION (the Hunter)

Betelgeuse: the armpit; Mintaka: the belt

Constellations

- Zodiac Constellations:
12 in total along the
ecliptic path

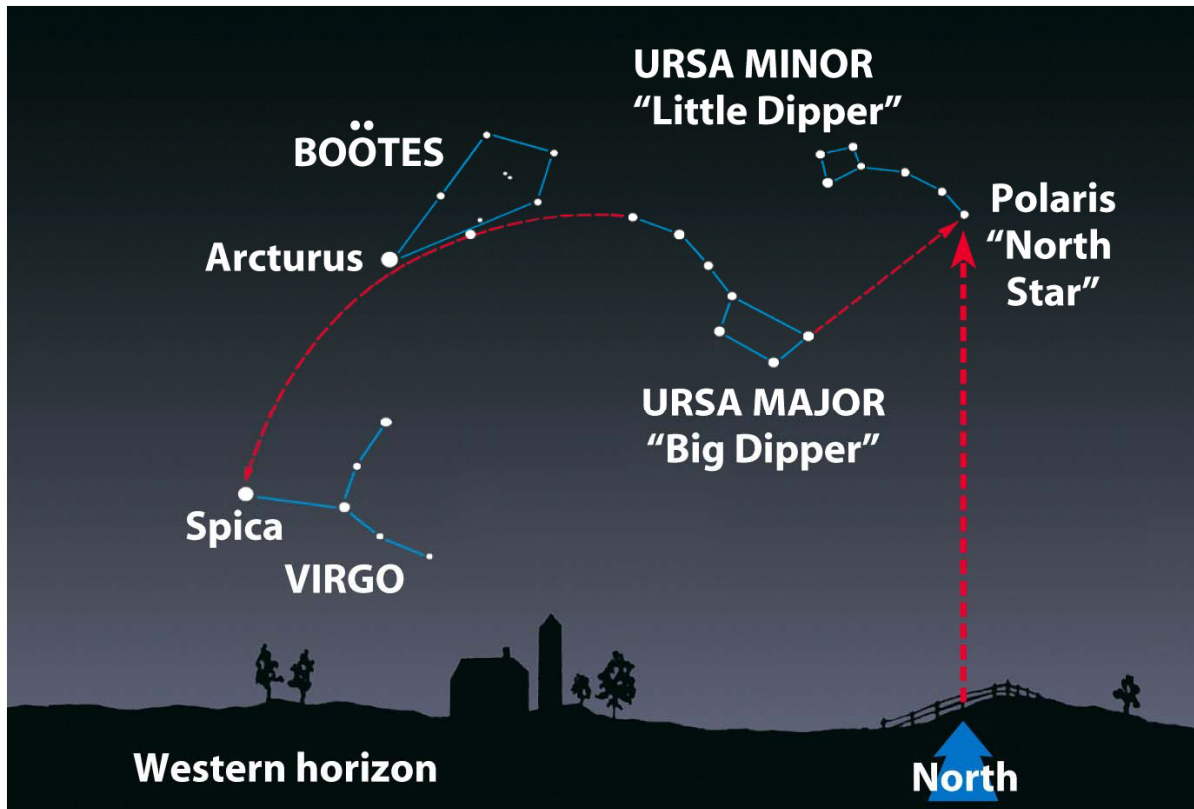
SIGNS OF THE ZODIAC			
NUMBER	NAME	SYMBOL	SUN ENTERS
1	Aries the Ram	♈	March 21
2	Taurus the Bull	♉	April 20
3	Gemini the Twins	♊	May 21
4	Cancer the Crab	♋	June 22
5	Leo the Lion	♌	July 23
6	Virgo the Virgin	♍	August 23
7	Libra the Balance	♎	September 23
8	Scorpio the Scorpion	♏	October 24
9	Sagittarius the Archer	♐	November 22
10	Capricorn the Goat	♑	December 22
11	Aquarius the Water Bearer	♒	January 20
12	Pisces the Fish	♓	February 19

Constellations

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

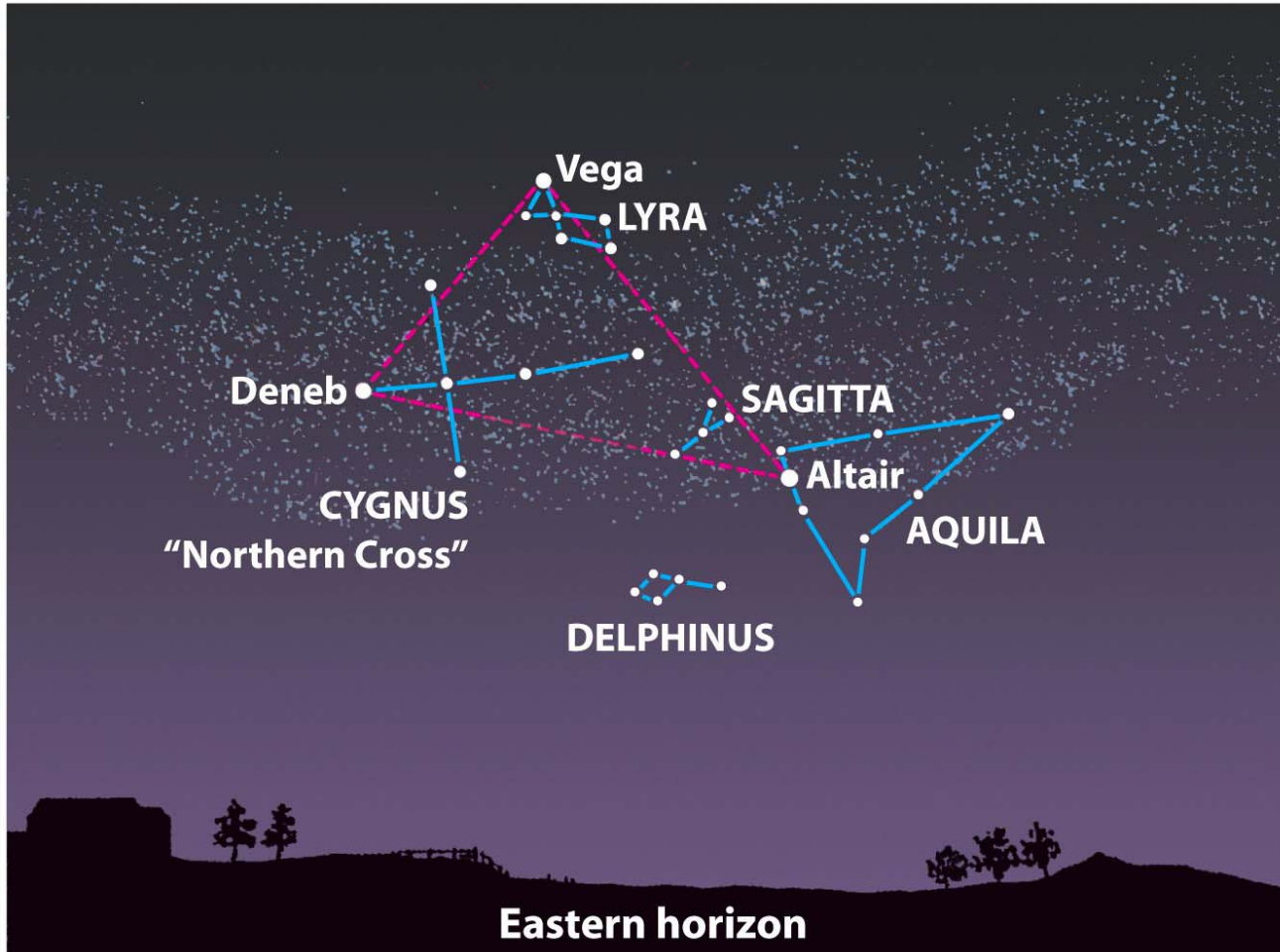
North Star: Polaris

- 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



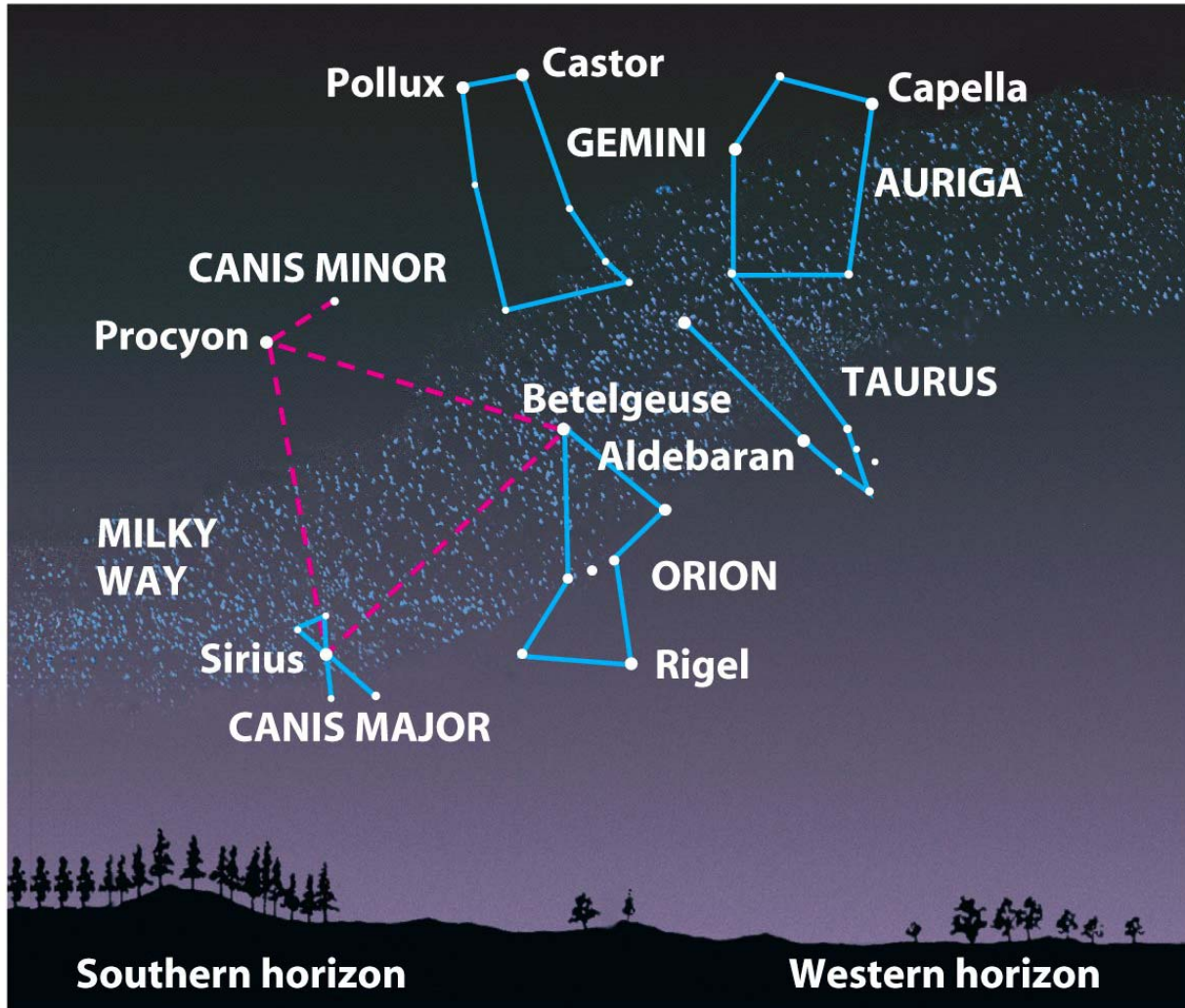
“Summer Triangle”

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



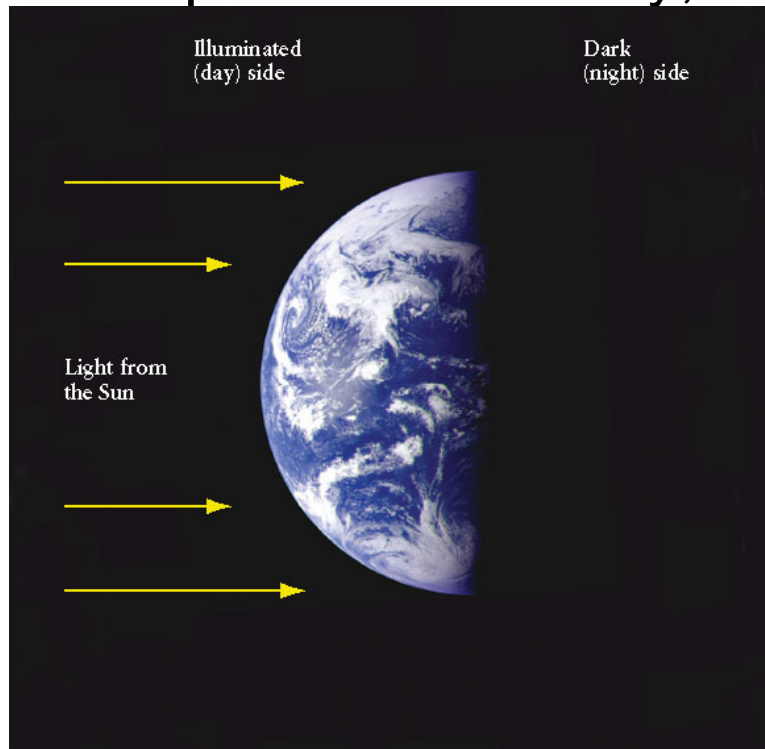
“Winter Triangle”

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



Diurnal Motion of Stars

- Stars appear to rise in the east, slowly rotate about the earth and set in the west over the night
- This diurnal or daily motion of the stars is actually caused by the rotation of the earth.
- It has a period of one day, exactly, 23 hr 56 min

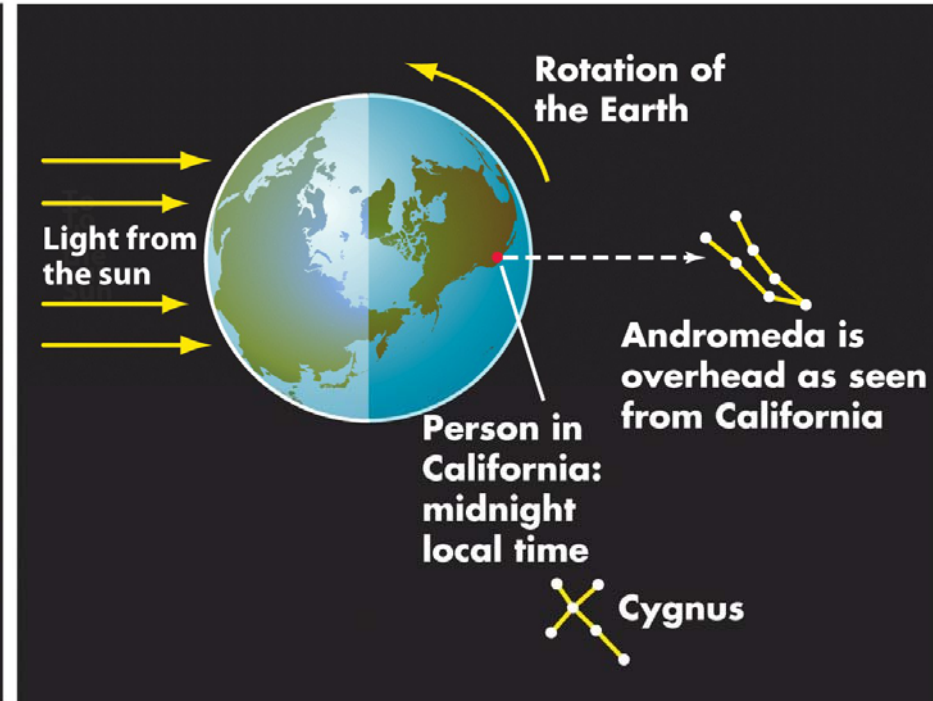
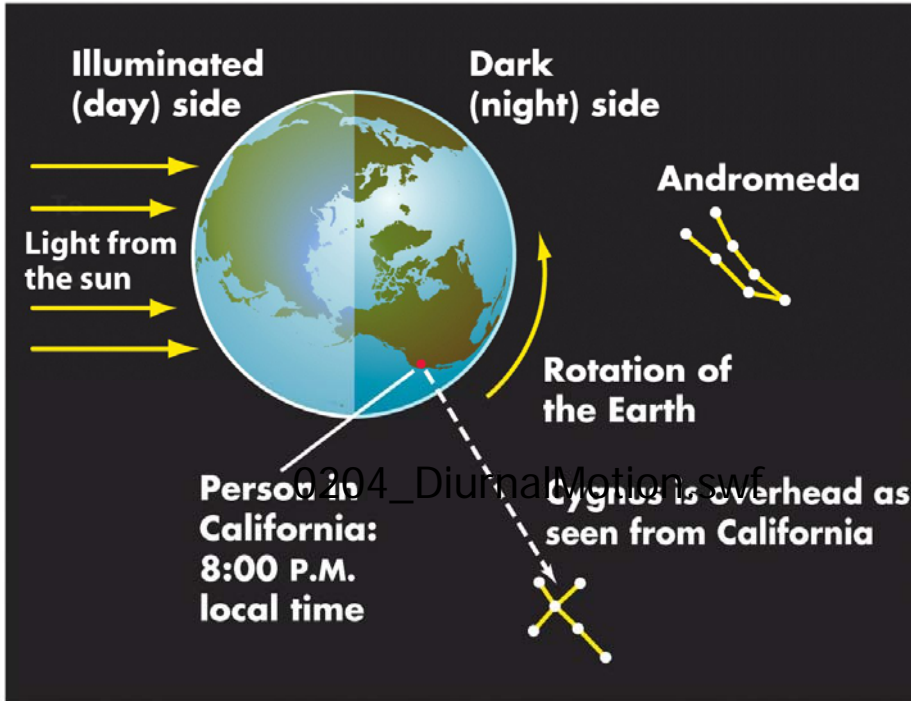


Earth is a rotating sphere illuminated by Sunlight

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0204_DiurnalMotion.swf

Diurnal Motion of Stars



(a) Earth as seen from above the North Pole (b) 4 hours (one-sixth of a complete rotation) later

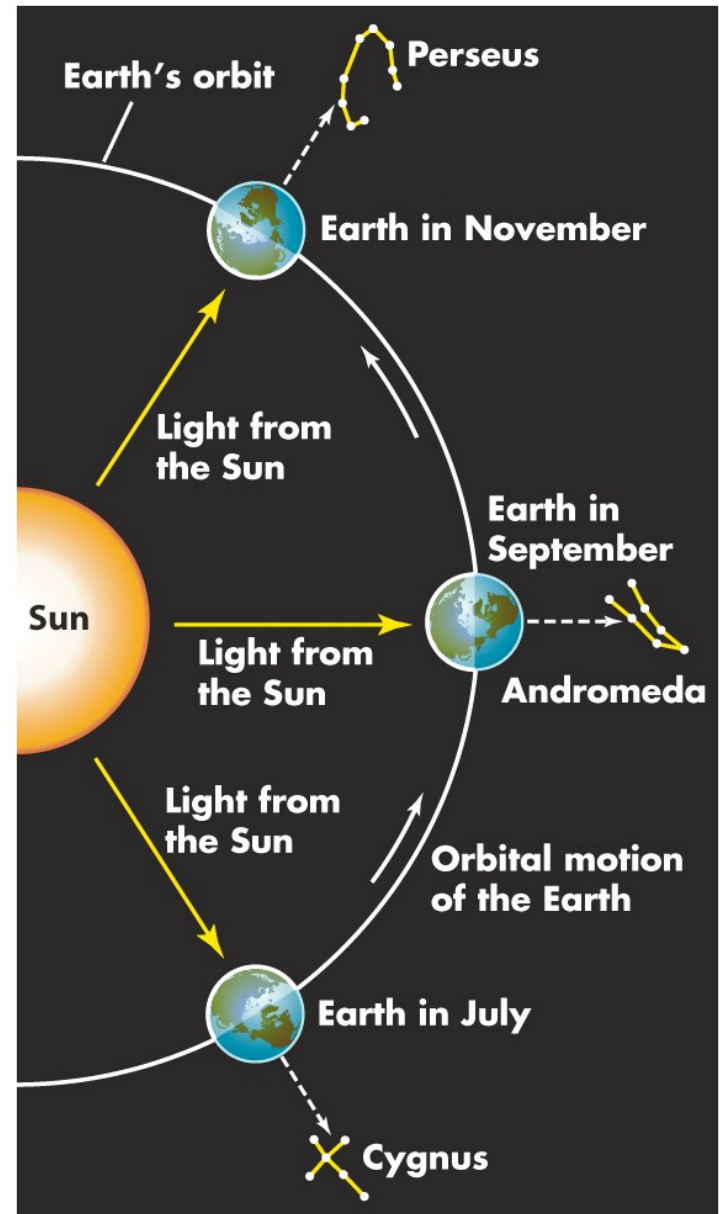
- View from the vantage point of above the North Pole
 - Earth rotates counter-clockwise, from west to east
- View from the Earth
 - Stars rotate from east to west

Yearly Motion of Stars

- when viewed at the same time (e.g., midnight) at the same location on the Earth, the stars appear to slowly shift in position throughout the year
- 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
- The star pattern in the evening (e.g, midnight) will be exactly the same after one year
- **The shift is due to the orbital motion of the Earth around the Sun**

Yearly Motion of Stars

- This shift motion has a period of exactly one year



Celestial Sphere

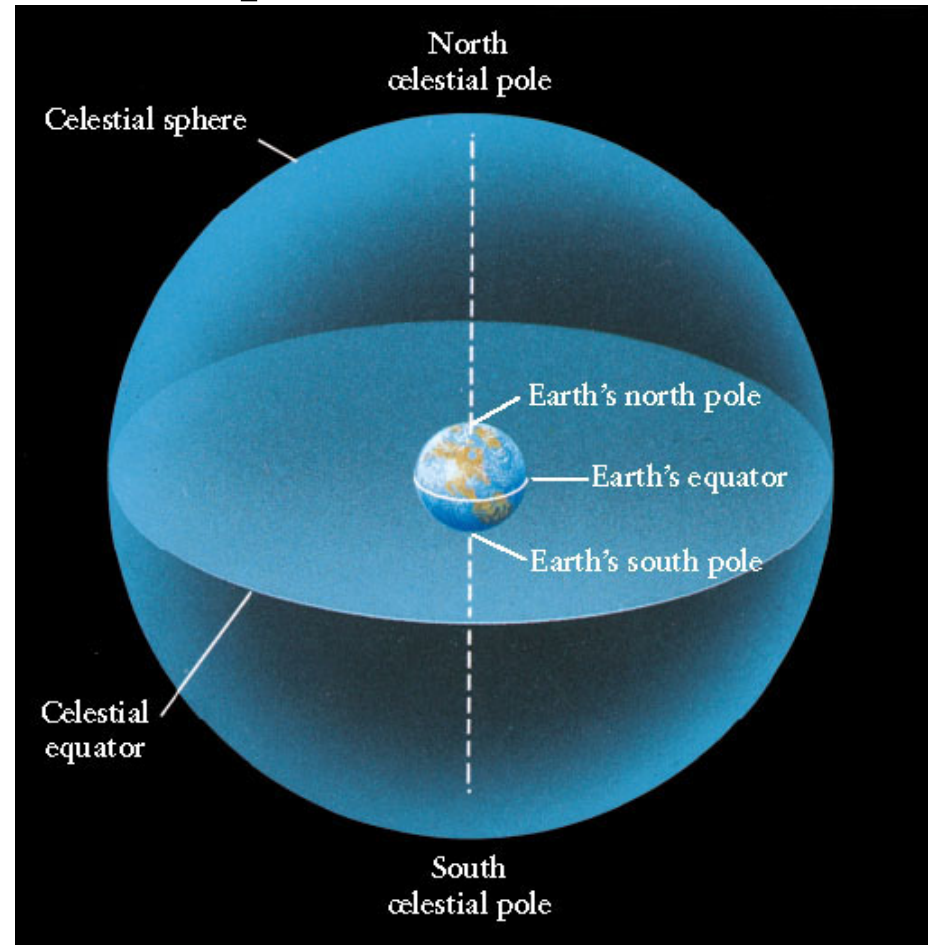
- **Celestial sphere: an imaginary sphere that all stars are fixed on its surface**
- In the sphere, all stars are assumed in the same distance
- The Earth is stationary and at the center of the sphere
- Note that it is an *imaginary object* that has no basis in physical reality
- However, it is a model that remains to be **very useful for positional astronomy**
- It **represents well the diurnal motion**, by assuming the whole sphere rotates in a daily basis.
- It also helps to track and visualize the patterns of motion of the Sun and planets across the sky background.

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**

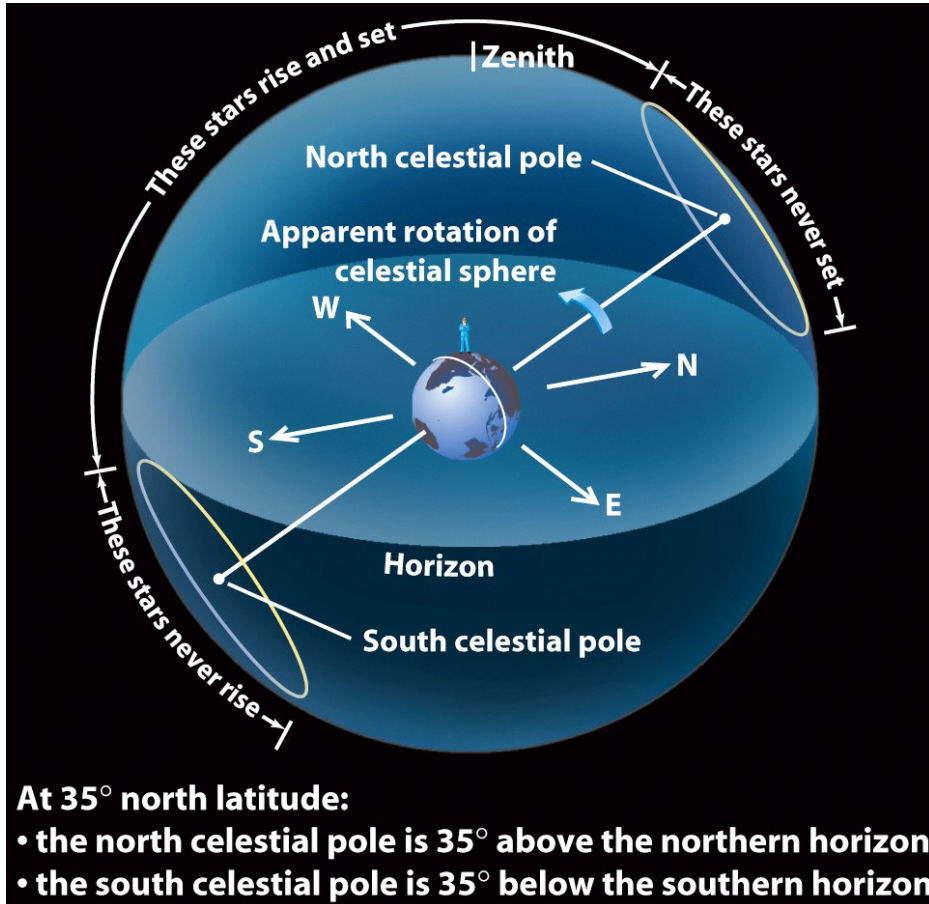
- Polaris is less than 1° away from the north celestial pole



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Celestial Sphere



- The celestial sphere appears “tipped” viewed by an observer
- **Zenith**
 - Point in the sky directly overhead
- At any time, observer can see only half of the celestial sphere, divided by the **local horizon**
- The stars close to north pole never sets

Celestial Sphere

- The tilt of the celestial sphere: the apparent motion of stars at different latitudes.

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(a) At middle northern latitudes

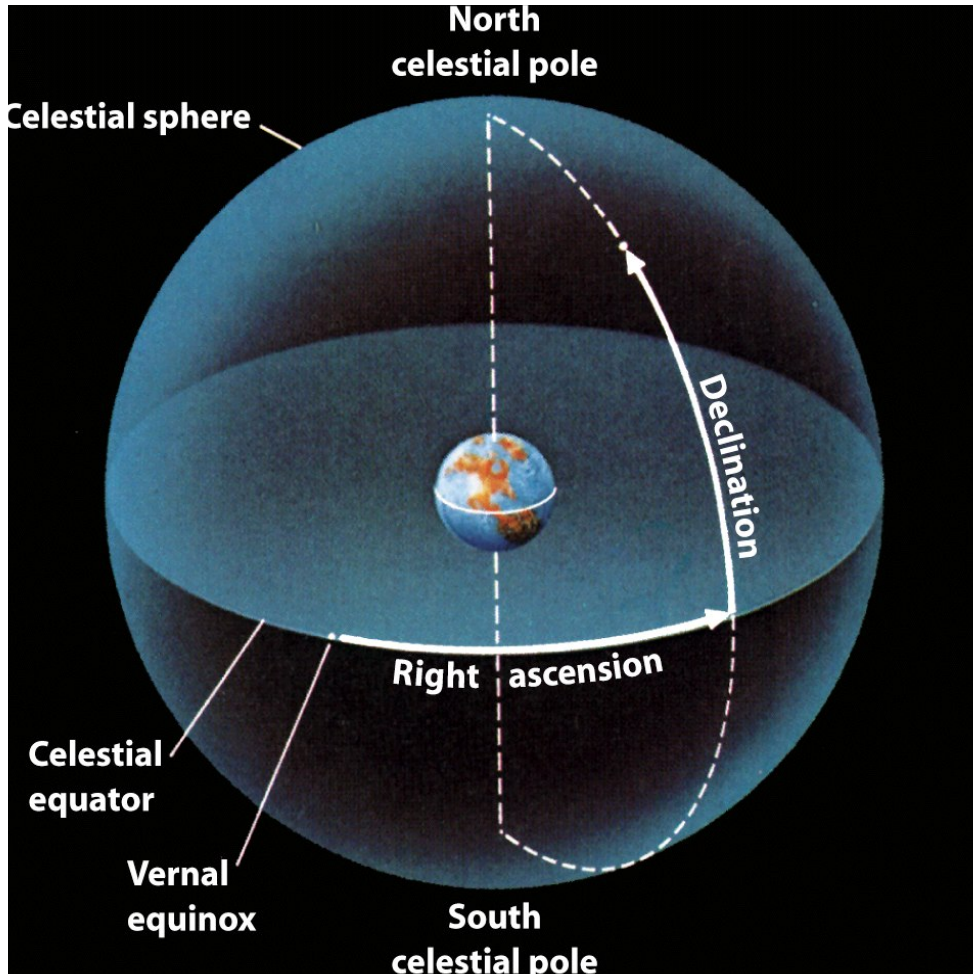


(b) At the north pole



(c) At the equator

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



- **Celestial coordinates:**
- Denote position of objects in the celestial sphere
- **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
 - Starting from the equator

Seasons

- Spring, Summer, Autumn, Winter
- A year, or 365 days, is the period

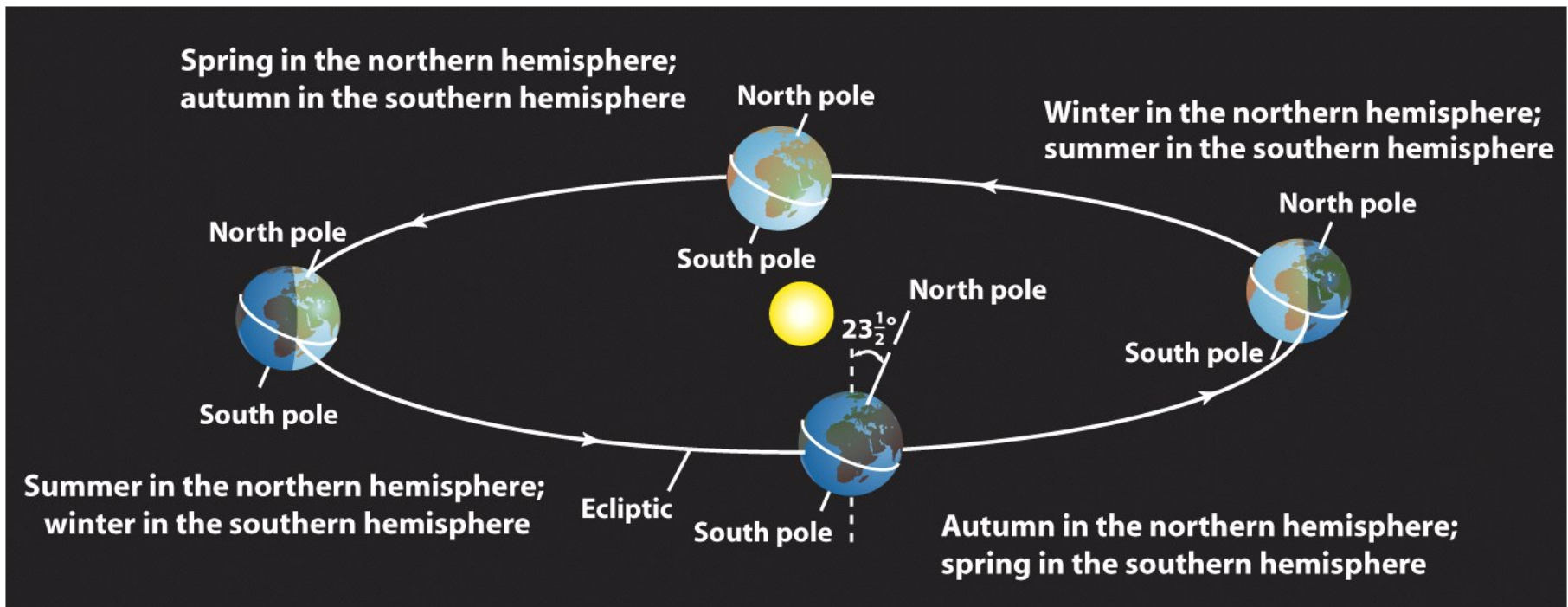
- Summer is hotter
- Winter is cooler

- In summer, the day time is longer than 12 hours
- In winter, the day time is shorter than 12 hours

- Seasons are opposite in the two hemispheres

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 perpendicular to the plane of the Earth's orbit
- The Earth maintains this tilt as it orbits the Sun



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Seasons: the Cause

Why is the summer hot? Because

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

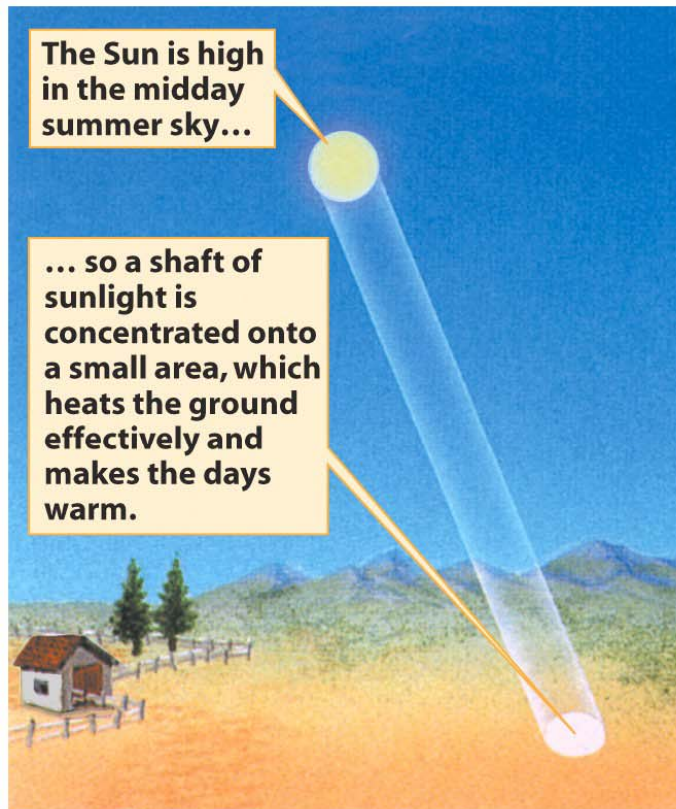
- the hemisphere is tilted toward the Sun
- As the Earth spins on its axis, the surface spends more than 12 hours in the sunlight
- The days are long and the nights are short

(2) The Sunlight heats the surface more efficiently

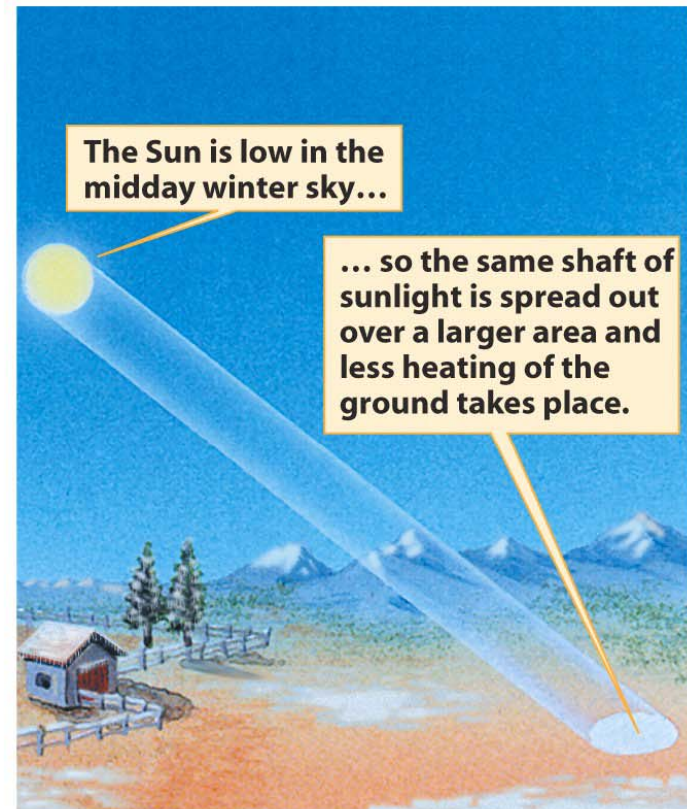
- the Sun is high in the sky
- sunlight strikes the ground at a nearly perpendicular angle that heats the ground efficiently

Seasons: the Cause (cont.)

- 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



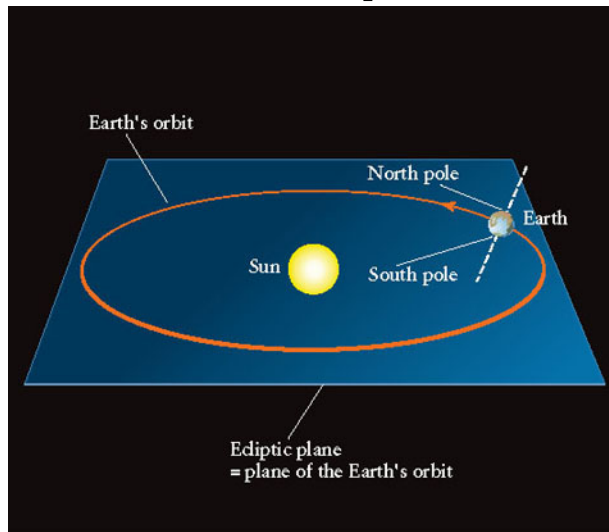
(a) The Sun in summer



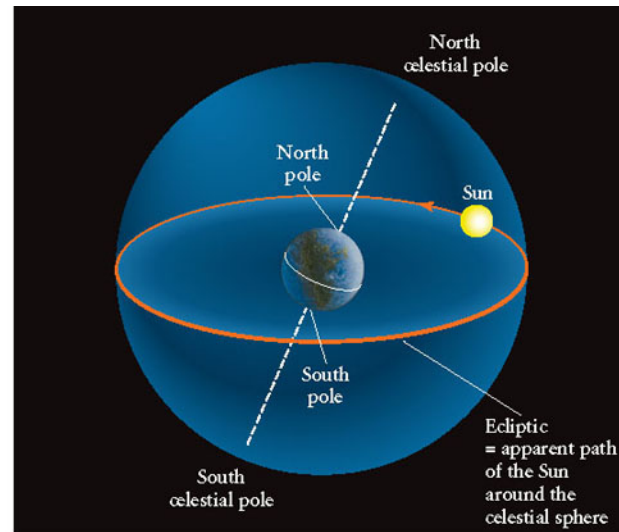
(b) The Sun in winter

The Sun's Path

- The seasons are formerly determined by the positions of the Sun in the celestial sphere.
- How to declare the beginning of a season?
- Why is spring always starting on March 21?
- **Ecliptic: the plane of the Earth annual orbit around the Sun; also the plane of the Sun's annual orbit in the celestial sphere**



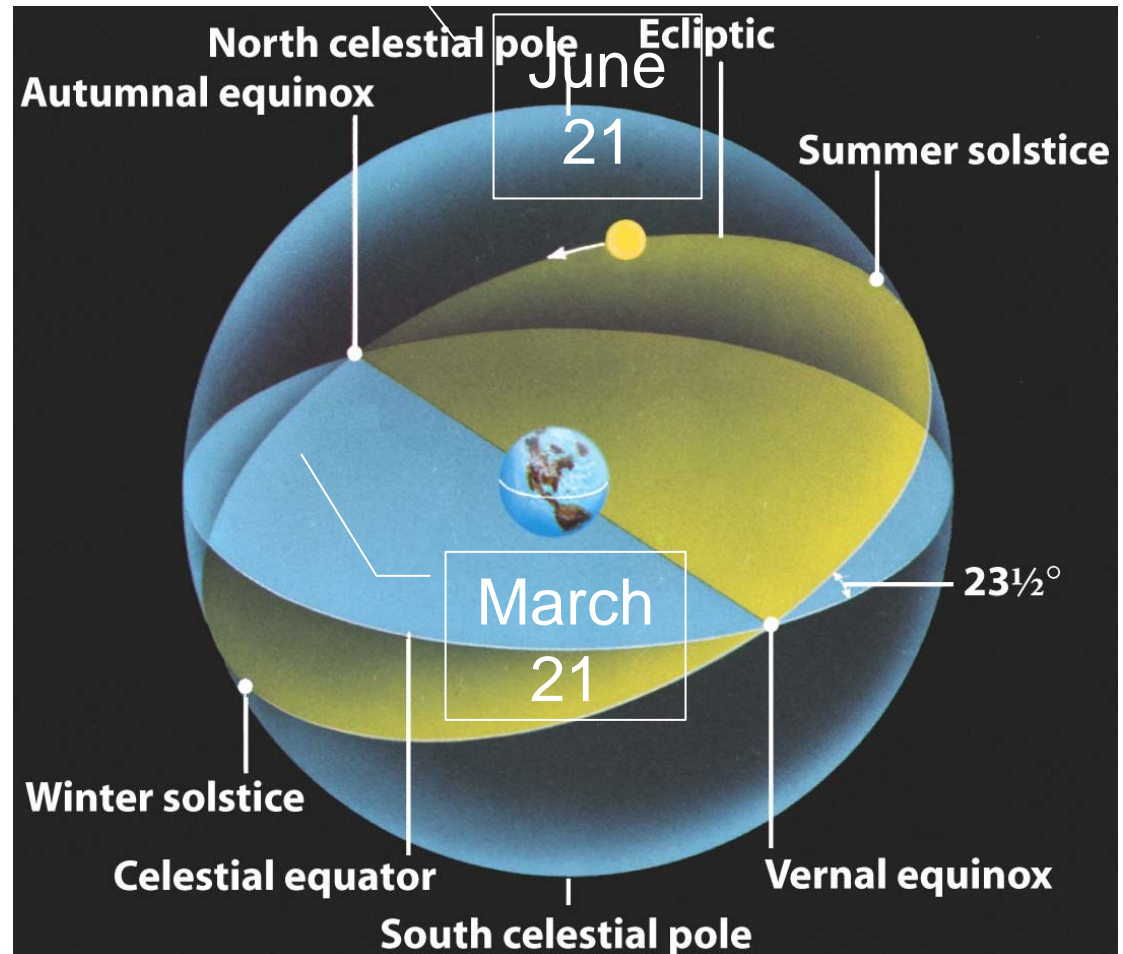
(a) In reality the Earth orbits the Sun once a year



(b) It appears to us that the Sun travels around the celestial sphere once a year

The Sun's Path

- The ecliptic plane is inclined to the equatorial plane in the celestial sphere by 23.5° , because of the tilt of the rotational axis of the Earth



The Sun's Path

- **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**

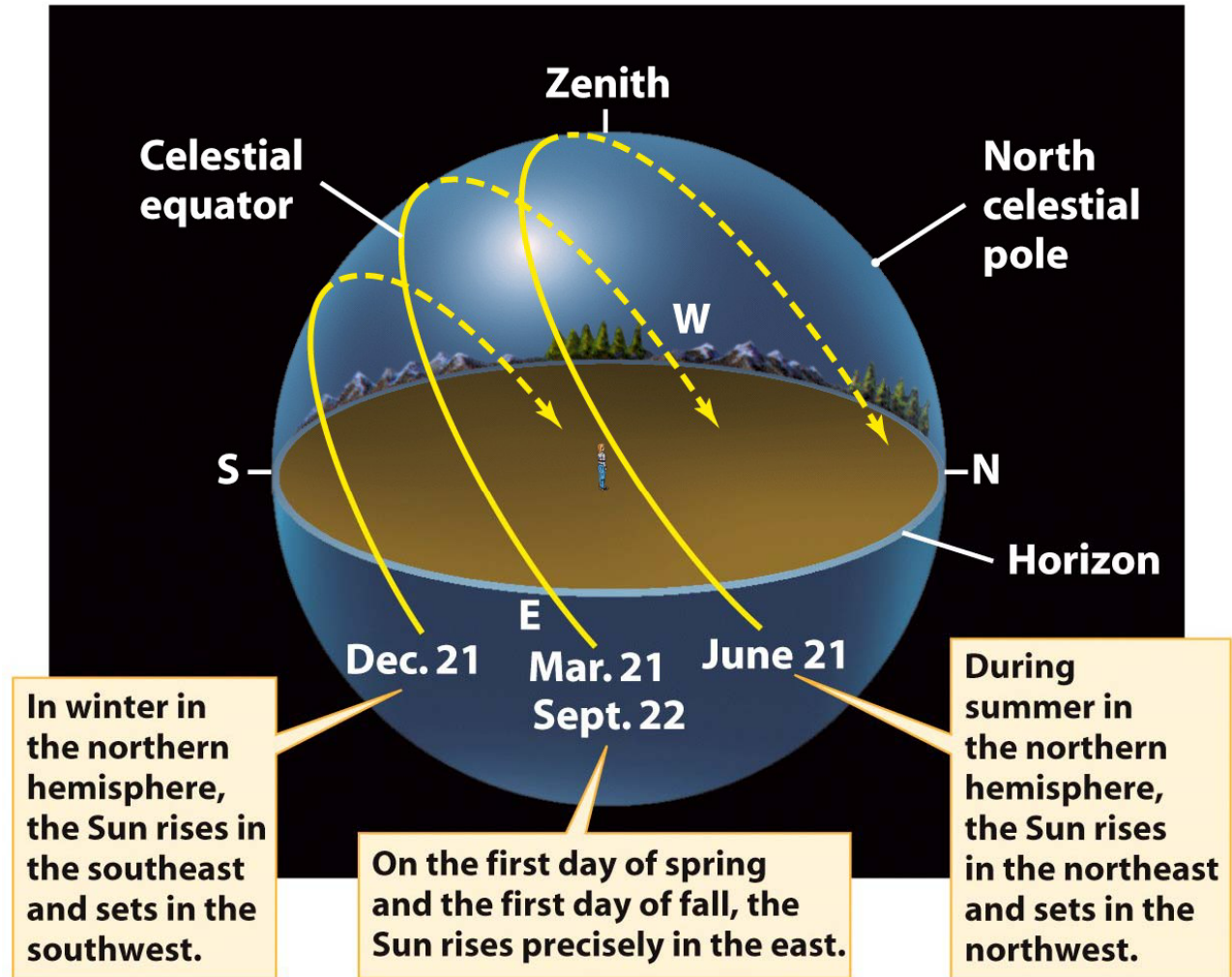
The Sun's Path

- **Summer Solstice:** the point on the ecliptic farthest north of the celestial equator
 - Occurs on about June 21
 - Marks 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 beginning of winter in the northern hemisphere
 - The day time is the shortest

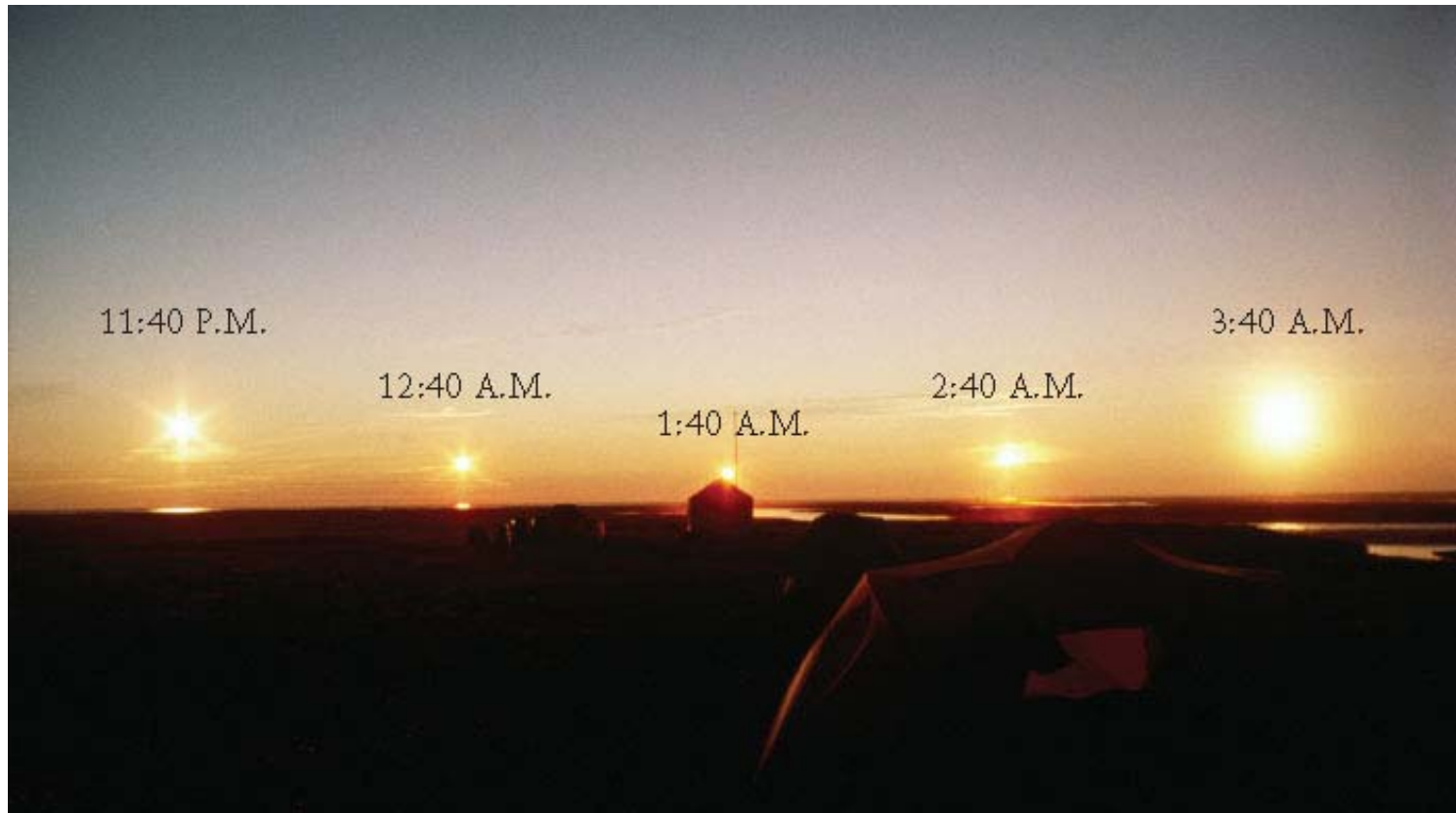
The Sun's Path

- The daily path in different days of the year
- In summer, more than 12 hours
- In winter, less than 12 hours



The Sun's Path

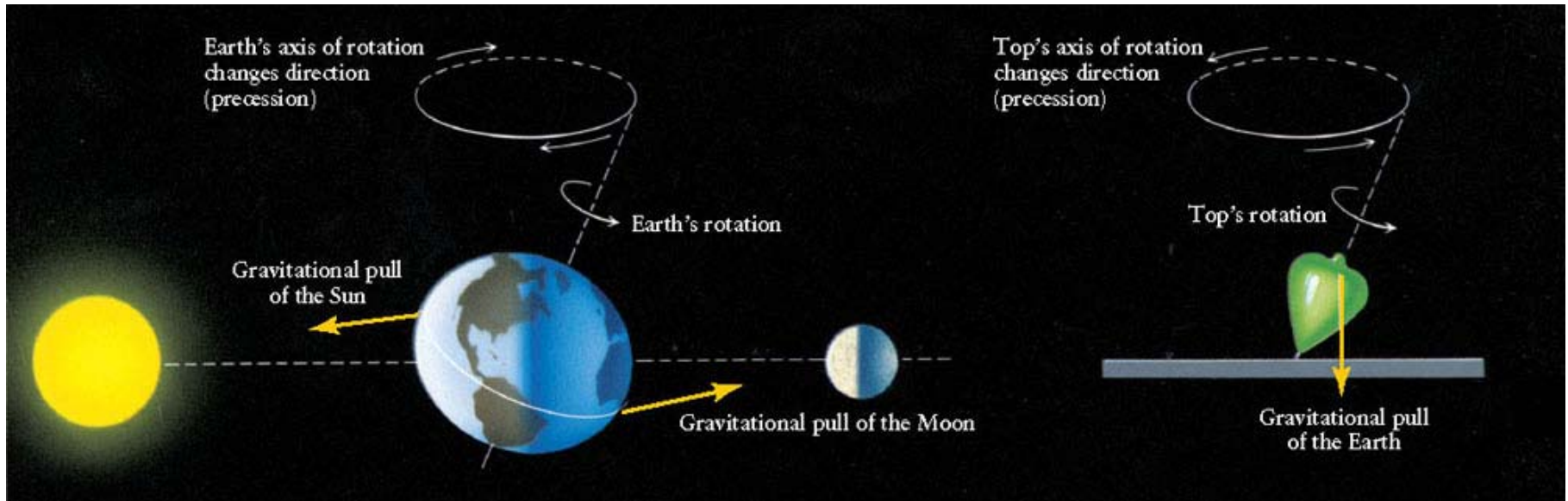
- The Sun is above the horizon continuously in the region close to the poles during the summer



Northeast Alaska, July 19, 1985

Precession

- Besides the daily rotation and yearly orbital motion, the Earth also undergoes a long term **precession**
- The precession is a slow, conical motion of the Earth's axis of rotation about the perpendicular to the plane of the orbit
- It is caused by the gravitational pull of the Sun and the Moon on the Earth's equatorial bulge.



Precession

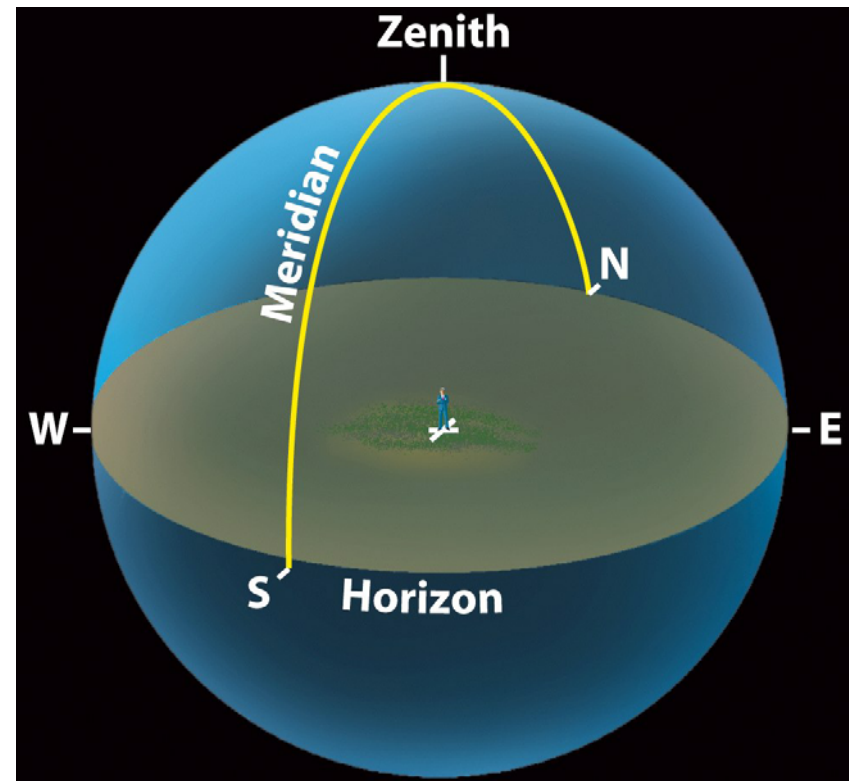
- The consequence is that the north celestial pole slowly changes and traces out a circle among the northern constellations.
- The circle has a radial size of 23.5°
- **The period is 26,000 years**
- After 12,000 years,
 - the north pole will be Vega



Timekeeping

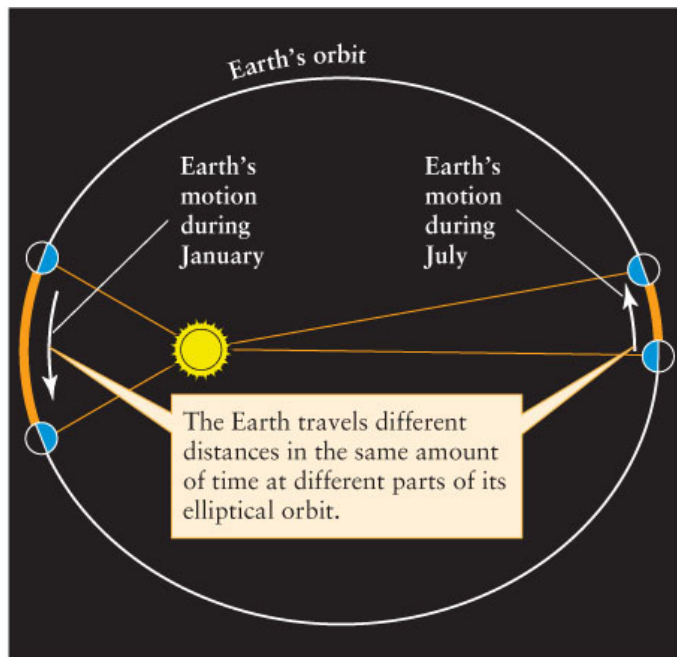
- A **day** is the interval between the successive upper **meridian** transits of the Sun
- **Meridian**: the north-south circle on the celestial sphere that passes through the local zenith and both celestial poles
- **Noon**: defined as the Sun crosses the upper **meridian**
- **Midnight**: cross the lower meridian

***Note: meridian circle, zenith and noon are all local; in other words, they depend on the location on the Earth**

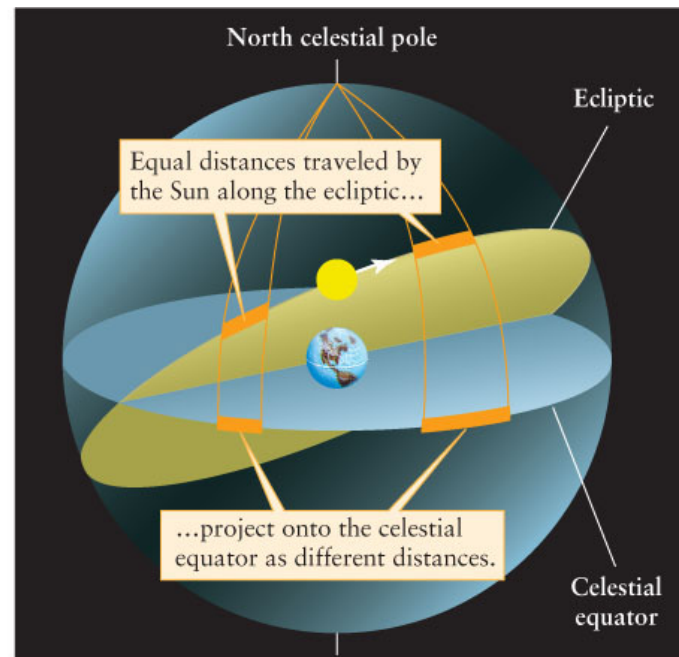


Timekeeping

- However, the Sun is a poor timekeeper
- An **apparent solar day** varies over the course of the year
 - The Earth's orbit is not a perfect circle. The Earth moves faster when it is near the Sun in January, making the day longer
 - The ecliptic path is tilted with respect to the celestial equator, making the projected progress along the equator varies during the year
 - The apparent solar day may vary up to 15 minutes.



(a) A month's motion of the Earth along its orbit



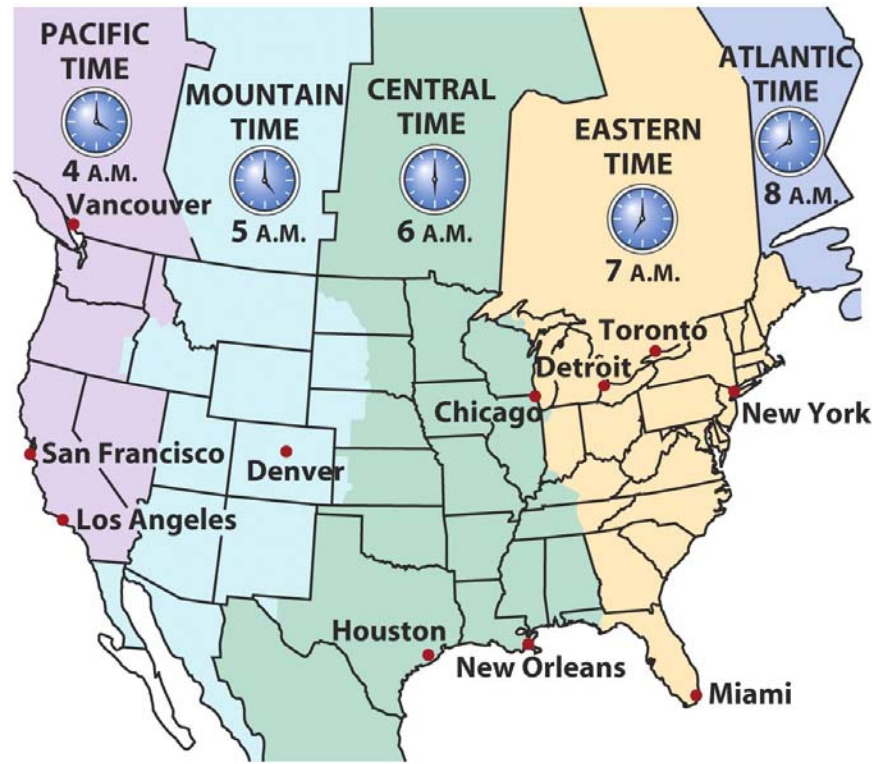
(b) A day's motion of the Sun along the ecliptic

Timekeeping

- A “**modern**” **day** is the **mean solar day**, defined by the interval between successive upper meridian transit of the **mean sun**
- **Mean Sun** is the imaginary sun that travels at a uniform rate (the average of all the apparent days over one year) along the celestial equator
 - Mean Sun produces a uniform mean solar day of exactly 24 hours
- Ordinary watches and clocks measure mean solar time

Time Zone and Universal Time

- For convenience of people and making the time meaningful, the Earth is divided into 24 time zones, centered on 15° 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.

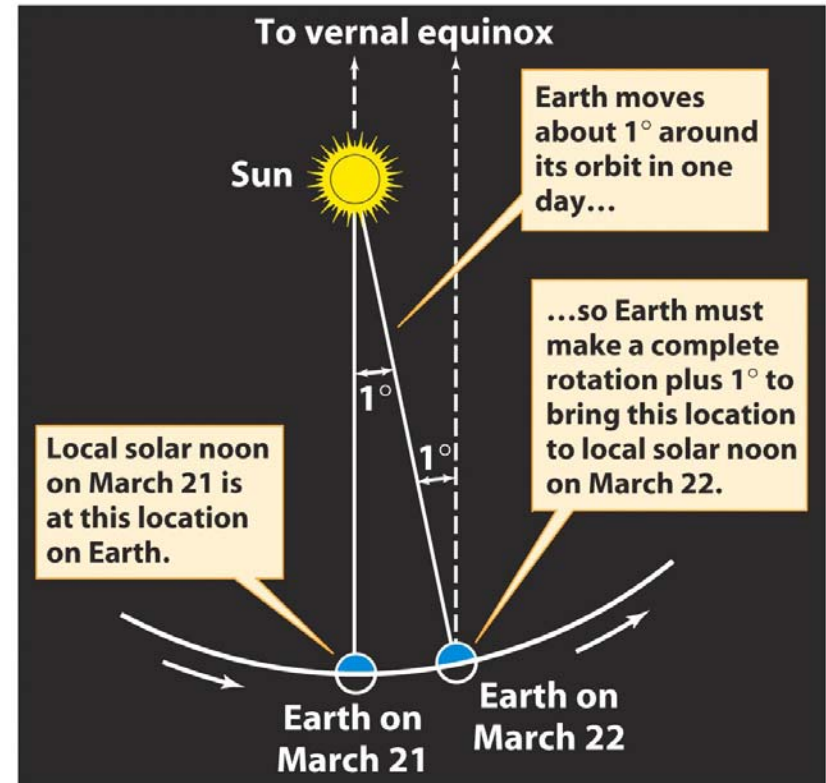


Calendar and Leap Years

- Calendar is required to be based on tropical year, which is equal to the time needed for the Sun to return to the vernal equinox on the celestial sphere, so that the first days of seasons fall on the same date each year.
- A **tropical year is 365.2422** (mean solar) day, or 365 d 5 h 48 m 46 s.
- **Julius Caesar's calendar**: assuming **year=365.25 days**
 - **Leap year**: the offset of 0.25 day/year adds one more day in every 4 years
 - However, the off of 11 m 14 s adds three days every four centuries
- **Gregory Calendar** (Pope Gregory XIII), current calendar: assuming **year = 365.2425 day**
 - Dropped ten days from Oct. 4, 1582 to Oct. 15, 1582; brought the spring (Sun passes the vernal equinox) back to March 21.
 - Leap year: every four years, and the year divisible by 4
 - Only century years divisible by 400 should be leap years.
 - The error is only one day in every 3300 years.

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°
- A solar day: the time takes the Earth rotate 360° , plus $\sim 1^\circ$ (or 4 more min of rotation) to make up the Sun's shift caused by orbital motion.



Final Notes on Chap. 2

- All sections, 2-1 to 2-8, are covered
- Two tool boxes, Box 2-1 and 2-2, are covered

Advanced Question

Chap. 2, Q28 in P28

On November 1 at 8:30 PM, you look toward the eastern horizon and see the bright star Bellatrix rising. At approximately what time will Bellatrix rise one week later on November 8?