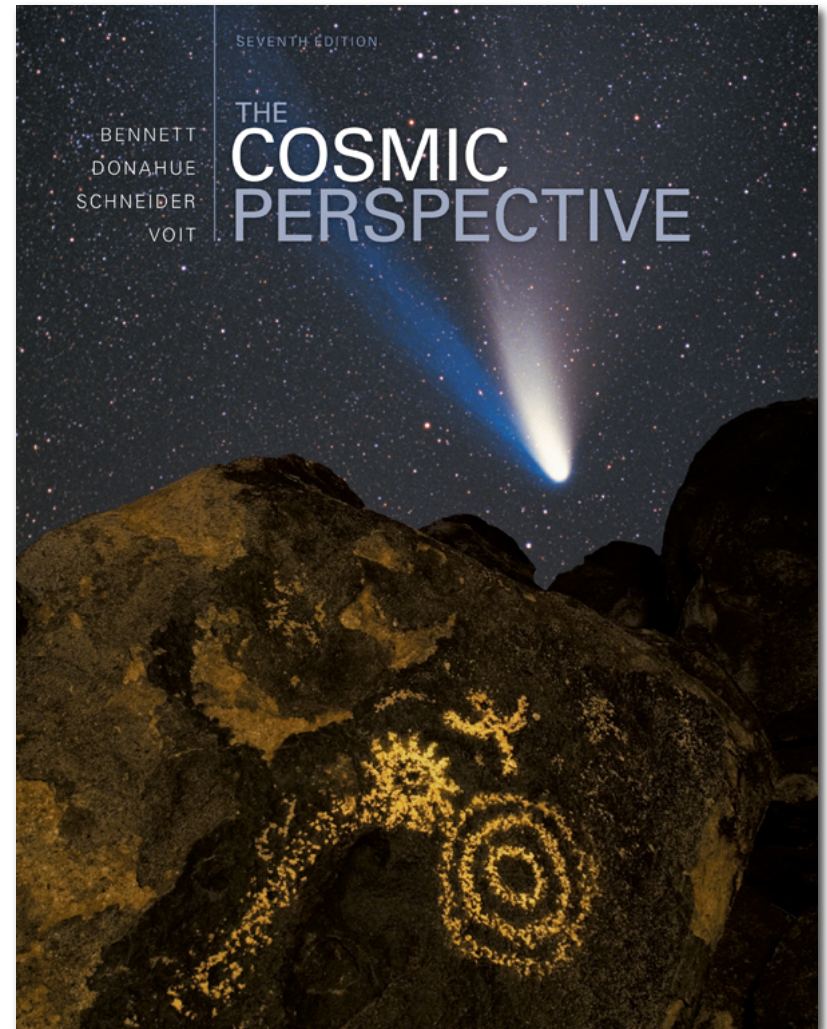


Chapter S1 Lecture

The Cosmic Perspective

Seventh Edition

Celestial Timekeeping and Navigation



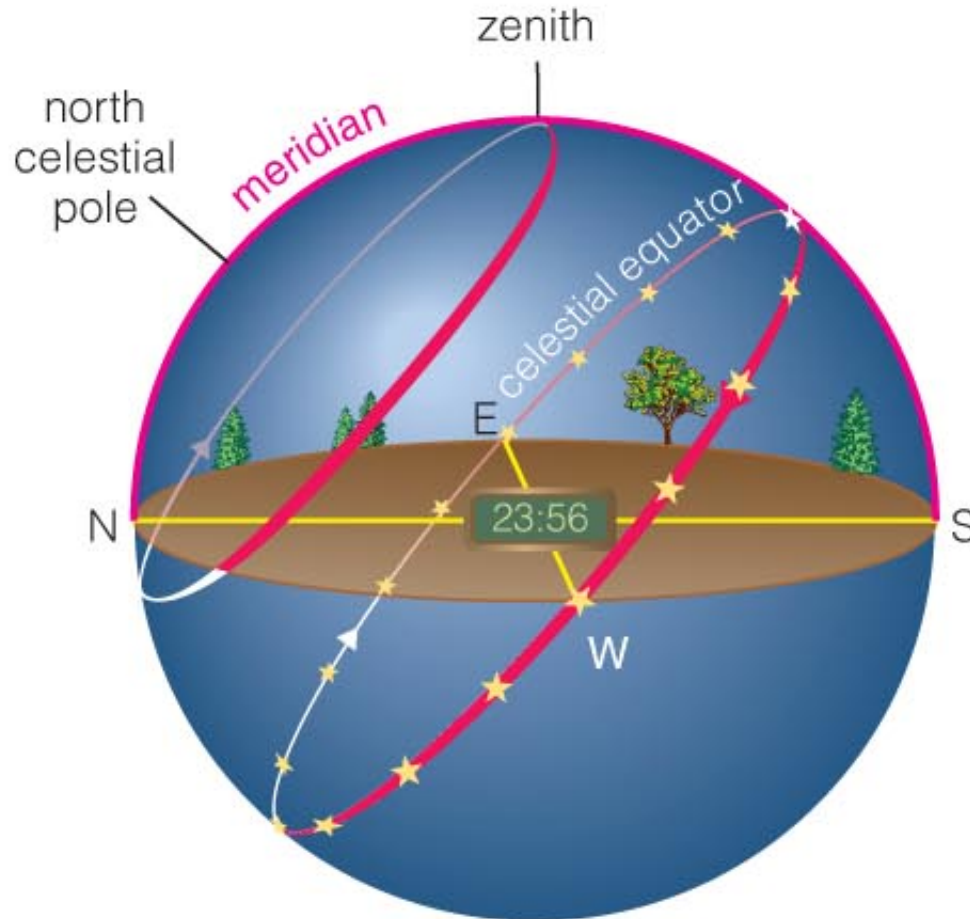
Celestial Timekeeping and Navigation



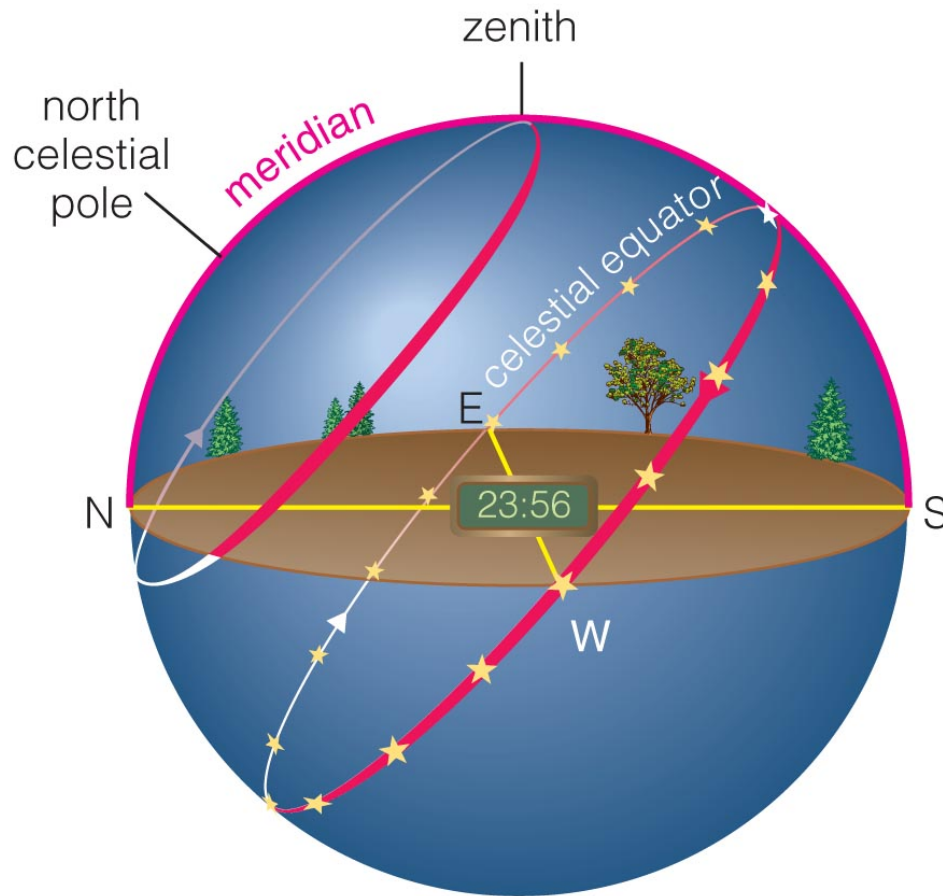
S1.1 Astronomical Time Periods

- Our goals for learning:
 - **How do we define the day, month, year, and planetary periods?**
 - **How do we tell the time of day?**
 - **When and why do we have leap years?**

How do we define the day, month, year, and planetary periods?

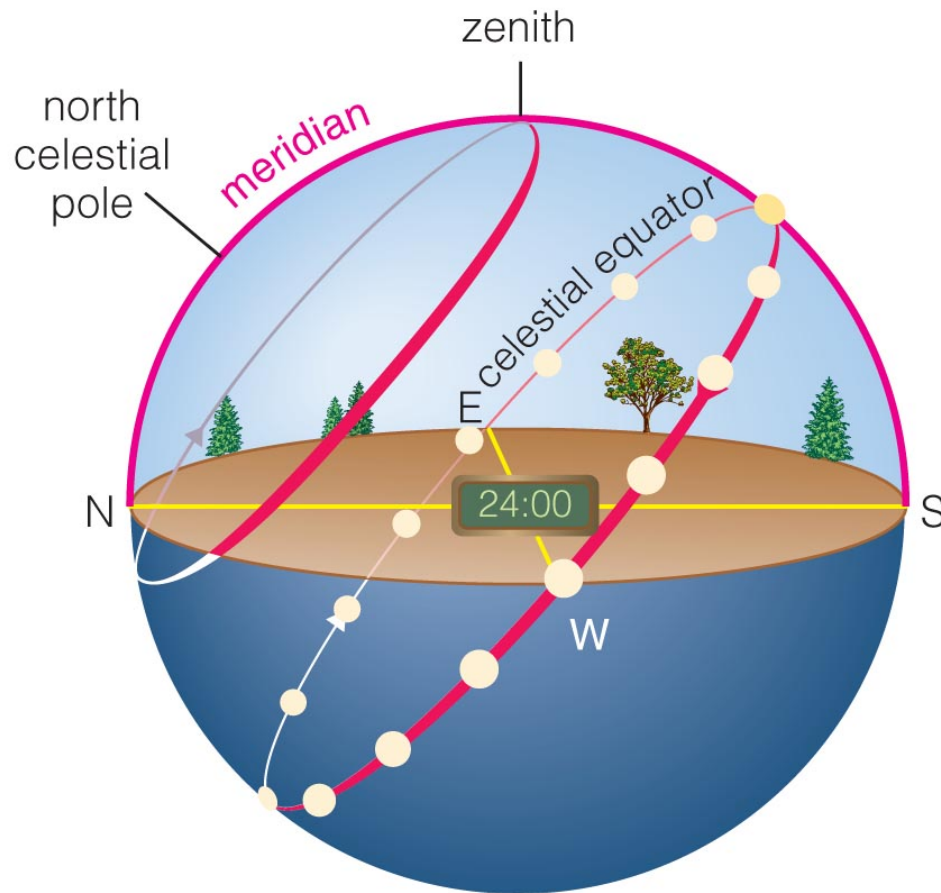


Length of a Day



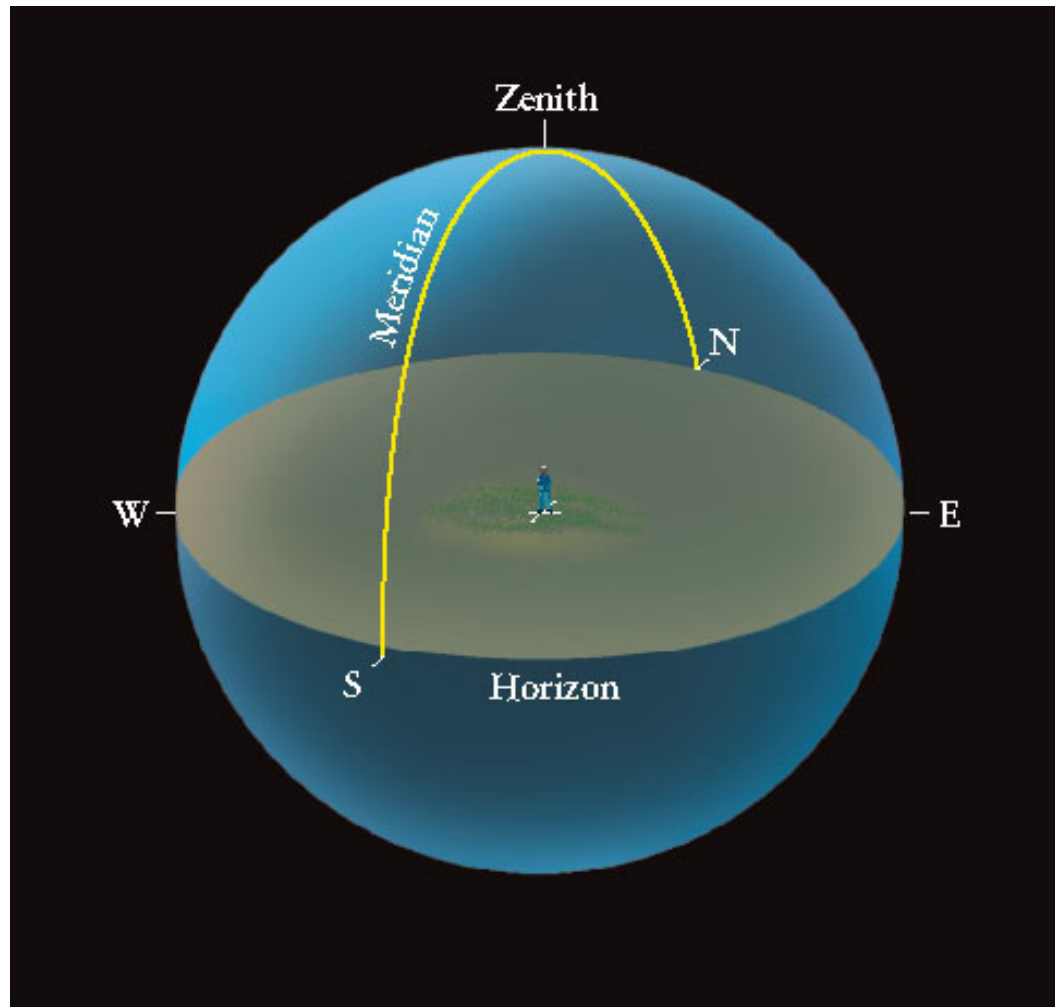
- **Sidereal day:**
Earth rotates once on its axis in 23 hours, 56 minutes, and 4.07 seconds.

Length of a Day



- **Solar day:** The Sun makes one circuit around the sky in 24 hours.

Apparent Solar Day



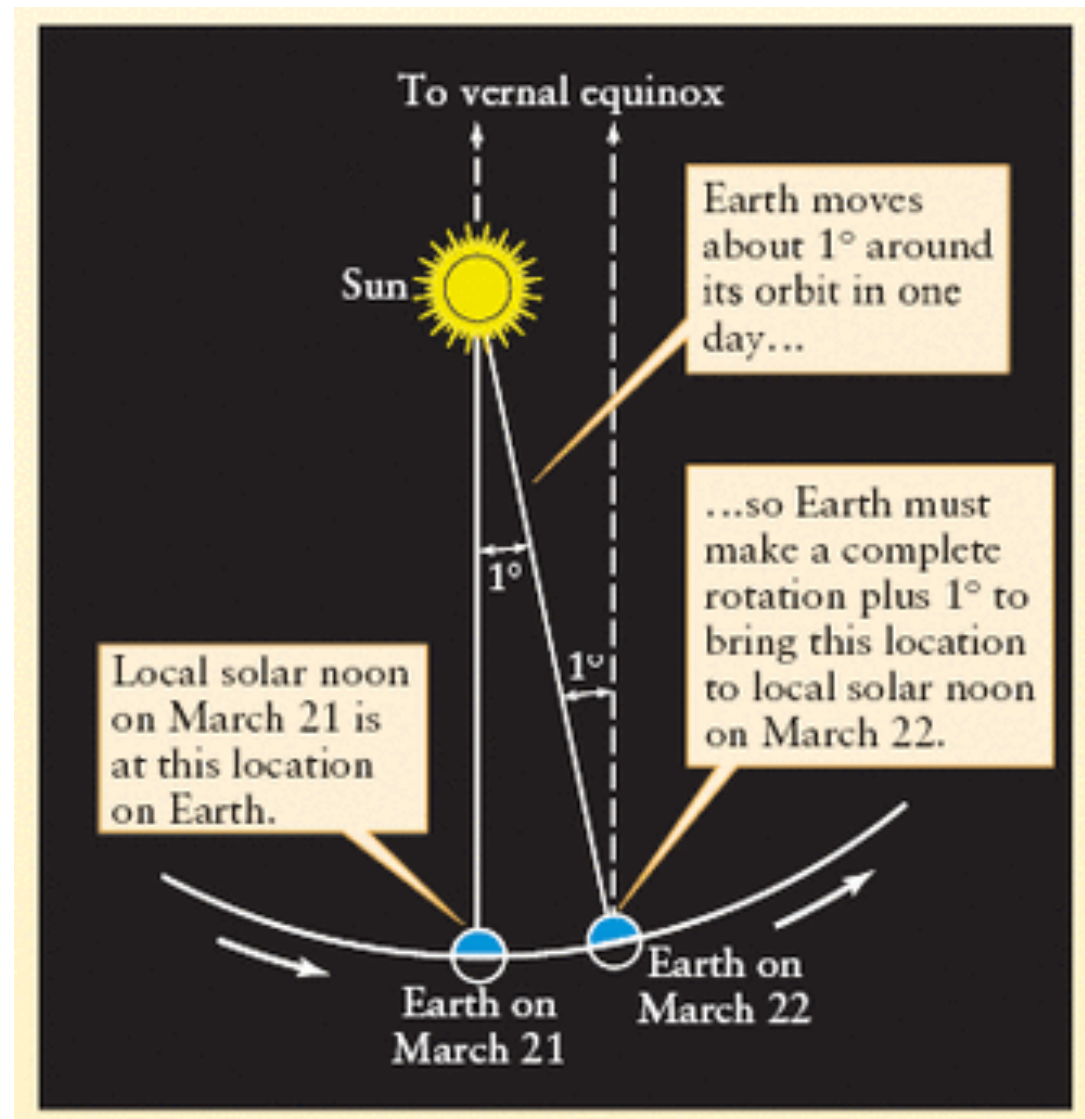
A apparent solar day is the time between two successive crossings of the Meridian by the sun.

Sidereal Day versus Solar Day

Solar Day = Time for one Earth rotation relative to the sun.

Sidereal Day = Time for one Earth rotation relative to the Vernal Equinox.

Which day is longer?



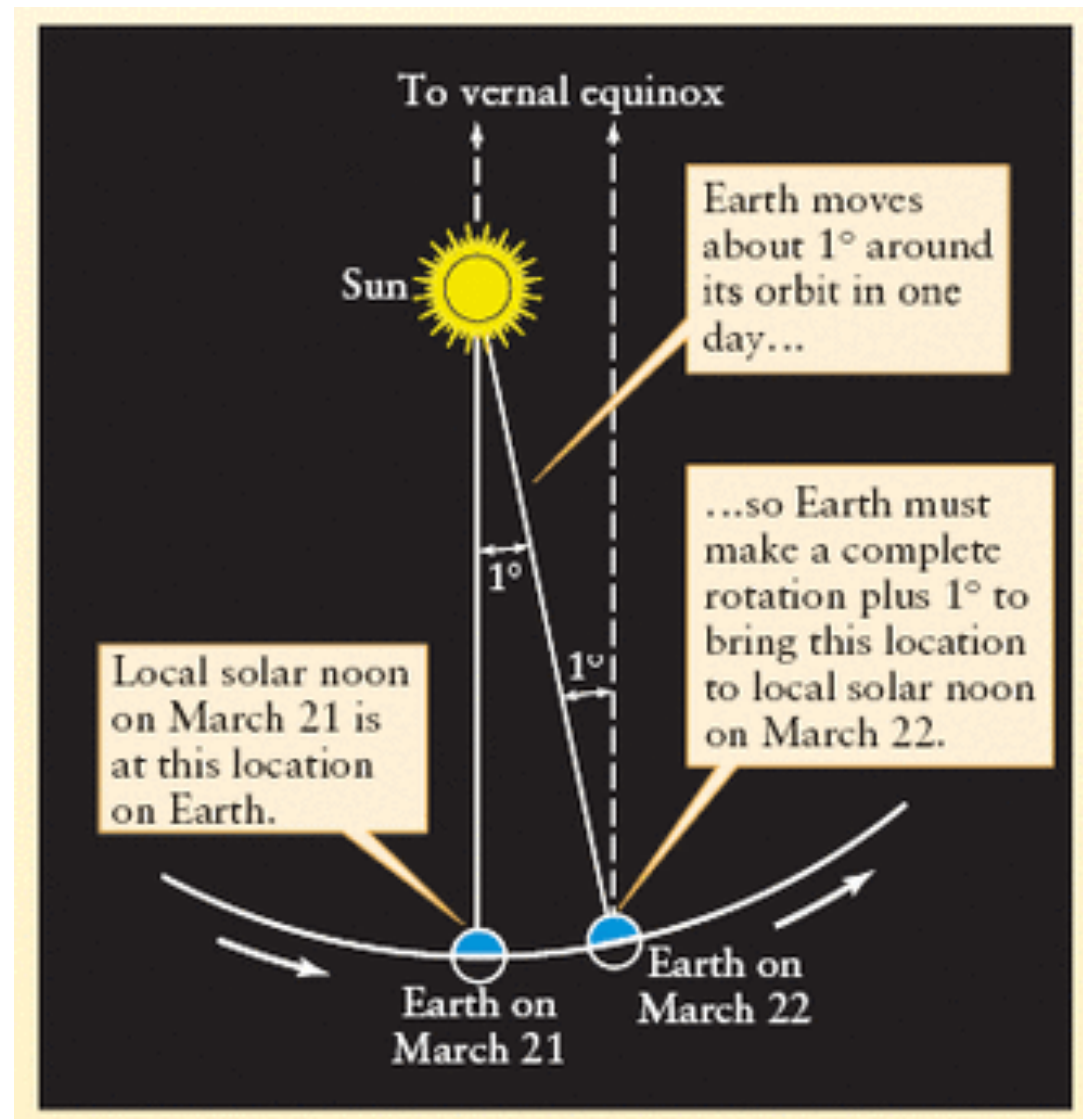
Sidereal Day versus Solar Day

Noon in **solar time** is the moment when the sun crosses the upper Meridian.

0:00h **Sidereal time** is defined as the moment the Vernal Equinox crosses the upper Meridian.

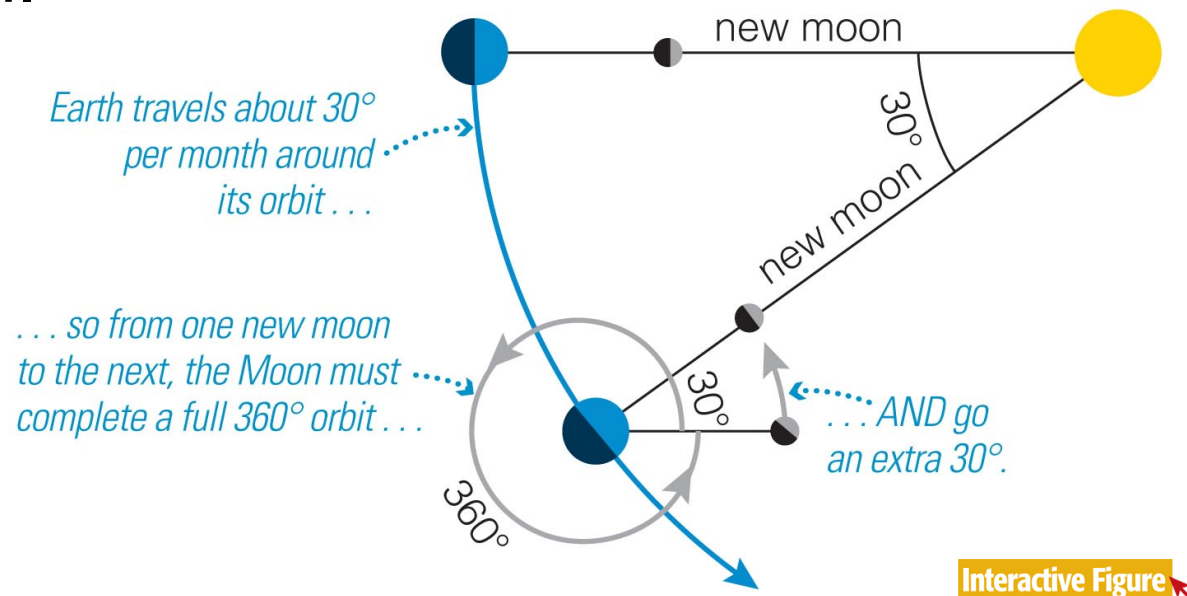
One Sidereal day =
 $23^{\text{h}} 56^{\text{m}} 4.091^{\text{s}}$

[Sidereal Day Animation](#)



Length of a Month

- **Sidereal month:** Moon orbits Earth in 27.3 days. Earth and Moon travel 30° around Sun during that time ($30^\circ/360^\circ = 1/12$).
- **Synodic month:** A cycle of lunar phases; takes about 29.5 days, $1/12$ longer than a sidereal month.

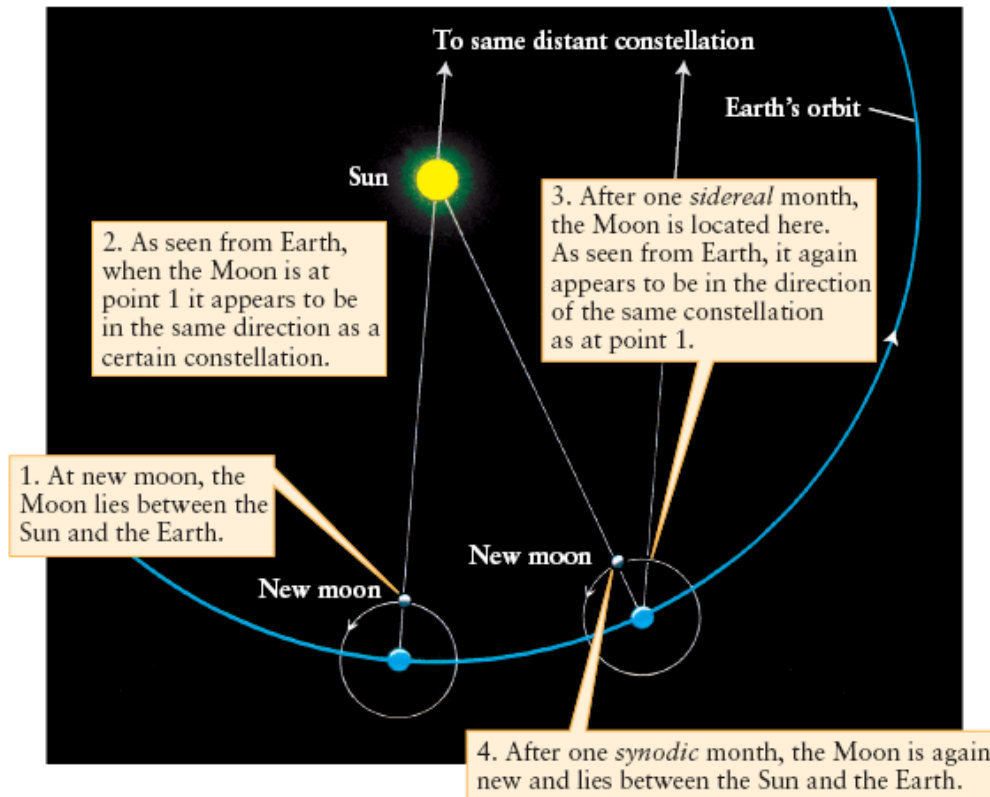


Sidereal and Synodic Month

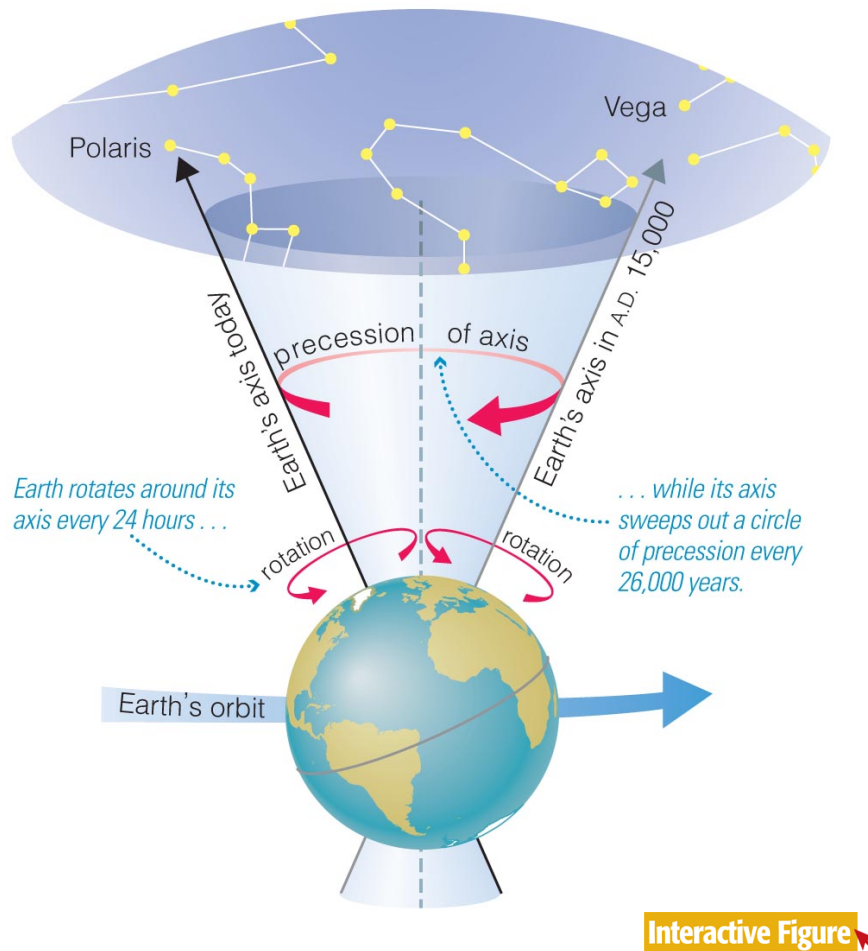
The Moon moves west-to-east on the celestial sphere (like the Sun), and takes about a month to circle the Earth.

But once again, there's a difference between the Moon's **sidereal** period with respect to the stars (27.32 days), and the **synodic** period with respect to the Sun (29.5 days).

[Animation of Sidereal and Synodic Months](#)

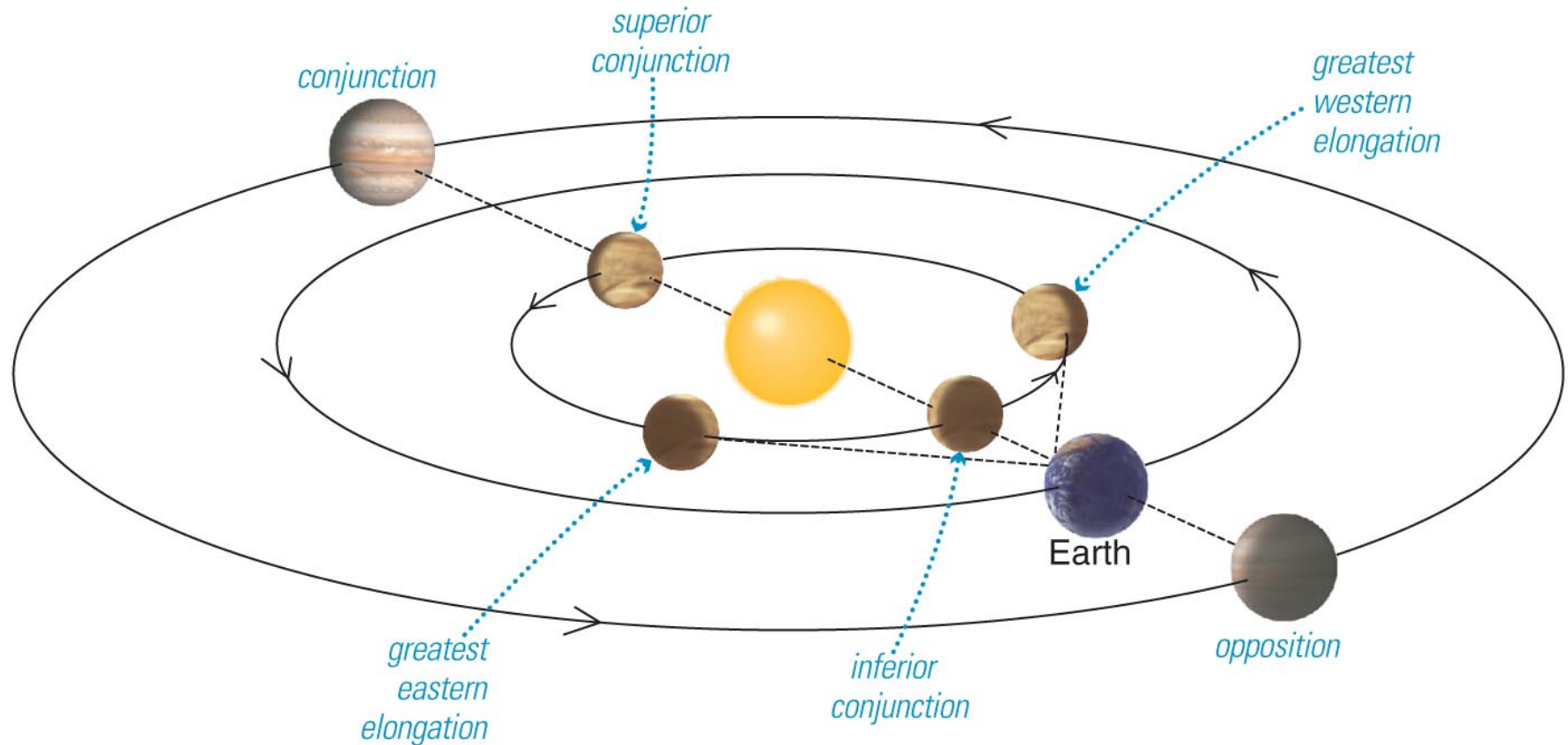


Length of a Year



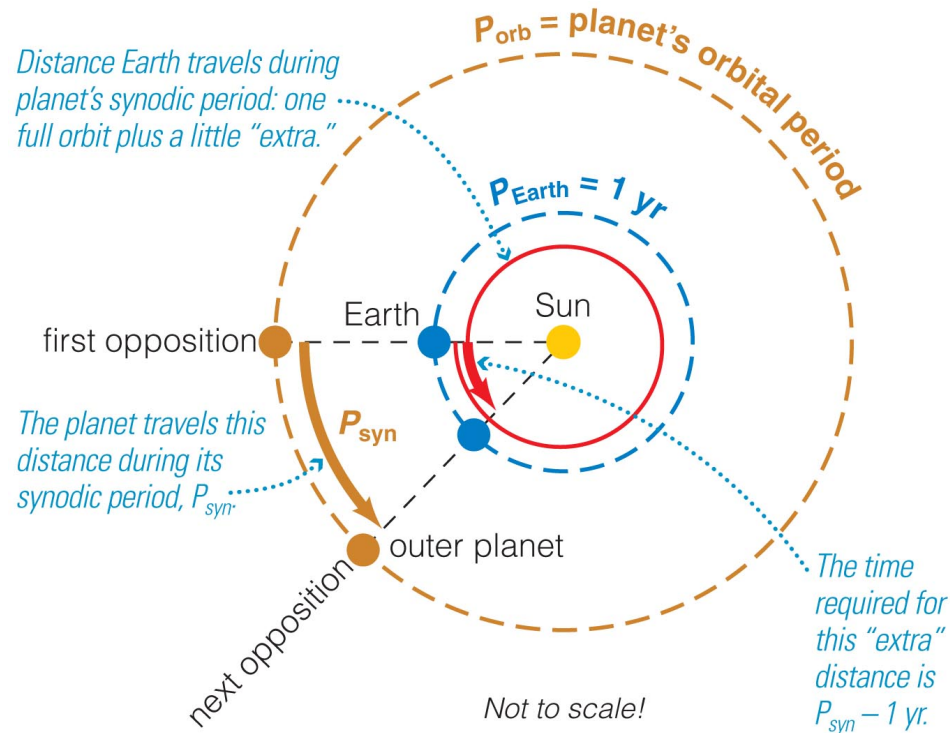
- **Sidereal year:** Time for Earth to complete one orbit of Sun = 365.2564 mean solar days
- **Tropical year:** Time for Earth to complete one cycle of seasons = 365.2422 mean solar days
- Tropical year is about 20 minutes ($1/26,000$) shorter than a sidereal year because of precession.

Planetary Periods



- Planetary periods can be measured with respect to stars (sidereal) or to apparent position of Sun (synodic).

Planetary Periods

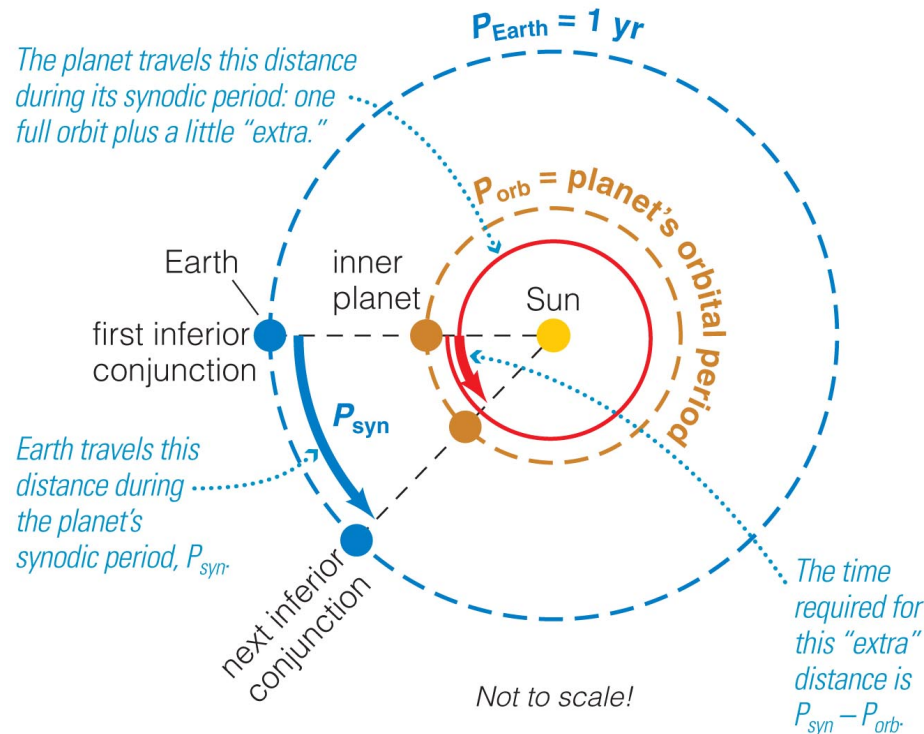


- Difference between a planet's orbital (sidereal) and synodic period depends on how far planet moves in 1 Earth year.

For outer planets

$$P_{\text{orb}} = P_{\text{syn}} \times \frac{1 \text{ yr}}{P_{\text{syn}} - 1 \text{ yr}}$$

Planetary Periods



- Difference between a planet's orbital (sidereal) and synodic period depends on how far planet moves in 1 Earth year.

For inner planets

$$P_{orb} = P_{syn} \times \frac{1 \text{ yr}}{P_{syn} + 1 \text{ yr}}$$

Transits



Transit of Venus: June 6, 2012

- On rare occasions, an inner planet will be perfectly aligned with Sun during inferior conjunction, causing a **transit** across Sun's surface.

How do we tell the time of day?



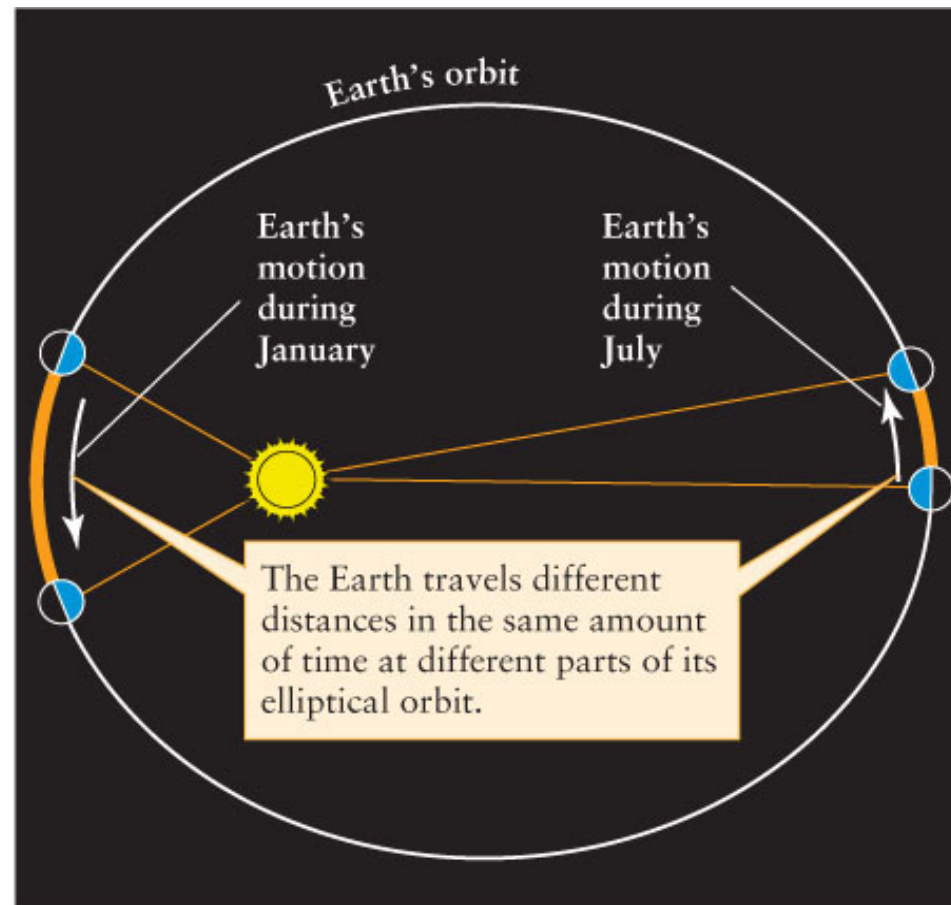
- **Apparent solar time** depends on the position of the Sun in the local sky.
- A sundial gives apparent solar time.

Mean Solar Time



- Length of an apparent solar day changes during the year because Earth's orbit is slightly elliptical.
- **Mean solar time** is based on the average length of a day.
- Noon is the average time at which the Sun crosses meridian.
- It is a *local* definition of time.

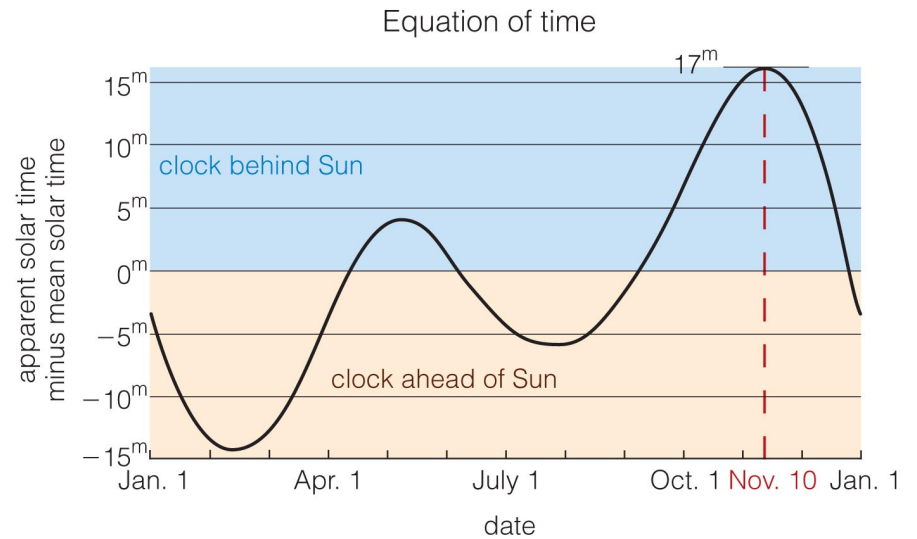
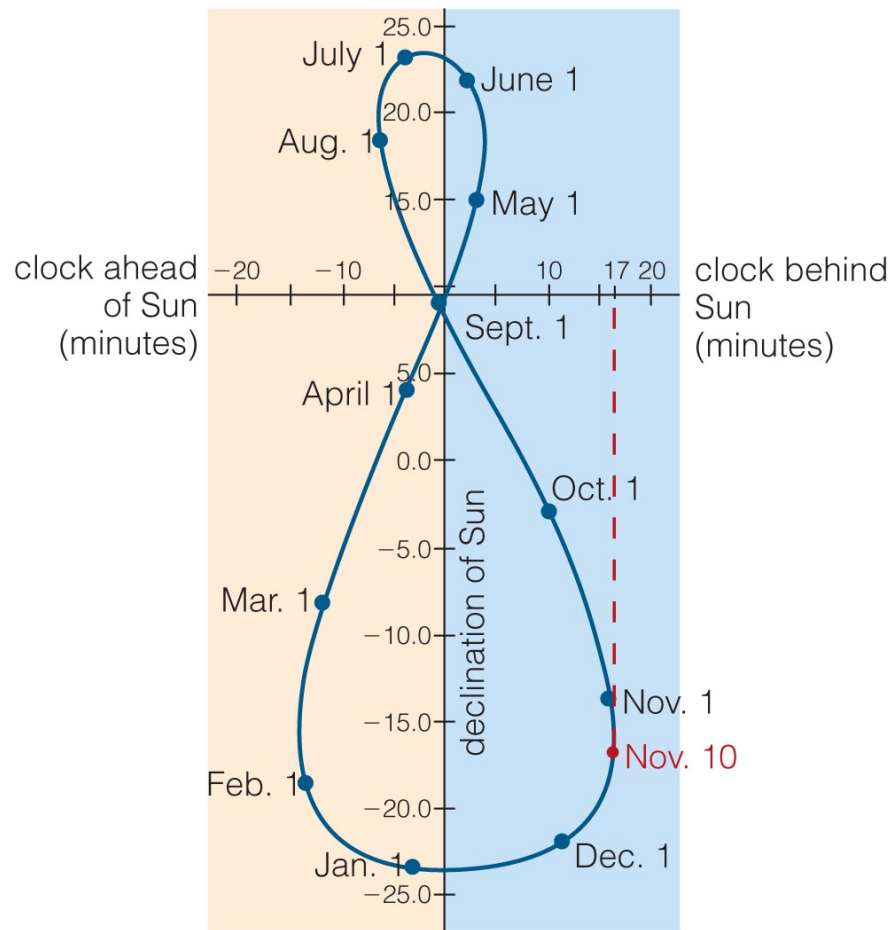
Mean Solar Time



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

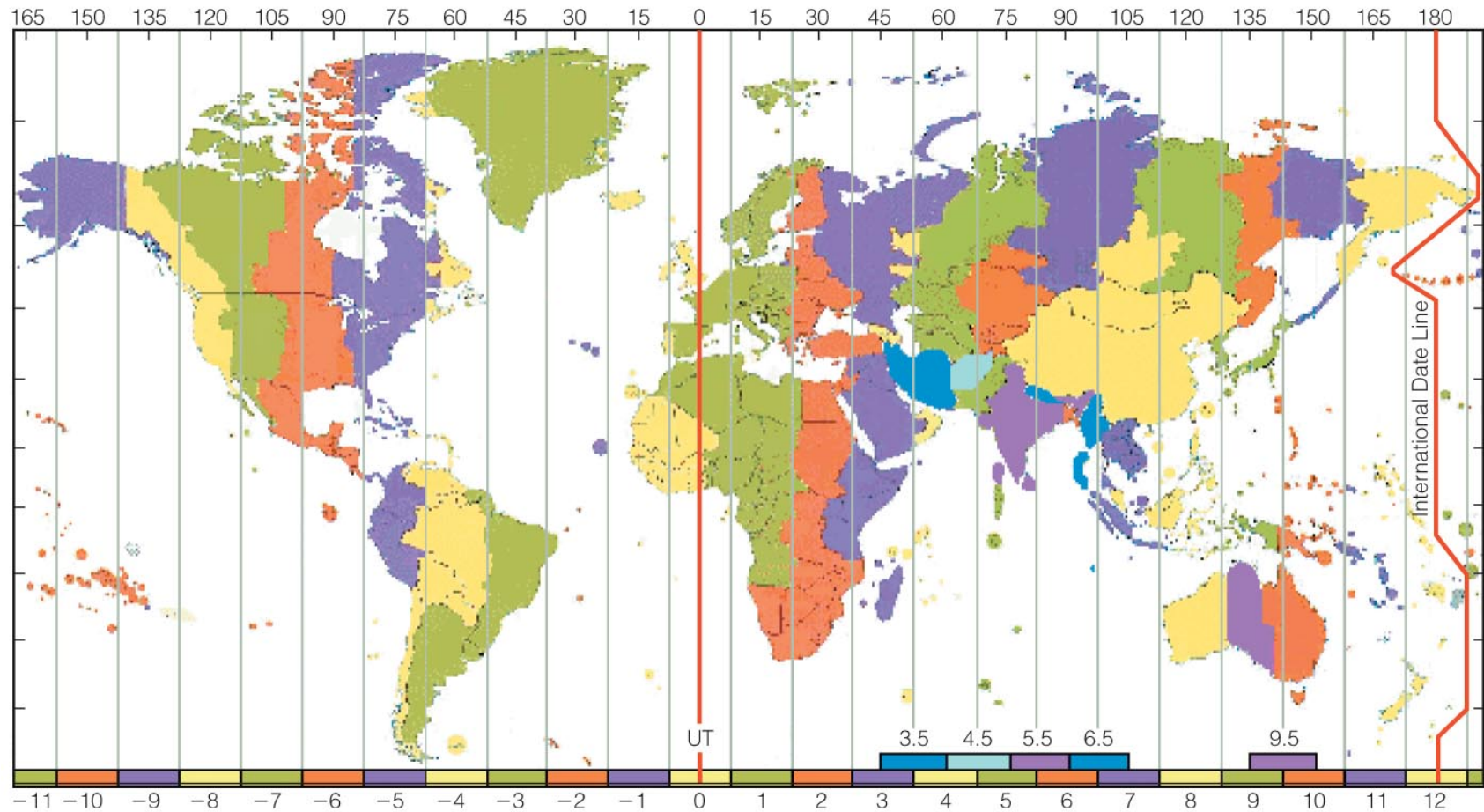
The length of an **apparent solar day** is not the same throughout the year. Astronomers thus came up with the **mean solar day** which is exactly 24 hours.

The Analemma



The **analemma** illustrates the position of the Sun with respect to the mean solar time.

Standard Time and Time Zones



- Rapid train travel required time to be standardized into time zones (time no longer local).

Universal Time

- **Universal time (UT)** is defined to be the mean solar time at 0° longitude.
- It is also known as Greenwich Mean Time (GMT) because 0° longitude is defined to pass through Greenwich, England.
- It is the standard time used for astronomy and navigation around the world.

Calendar



Julius Caesar: established the system of “leap years”



Pope Gregory XIII: Removed days October 4-15, 1582

1 **tropical year** = 365.2422 mean solar days (time needed for the Sun to return to the vernal equinox. Our calendar is based on the tropical year. This is not equal to the Siderial year because of precession).

1 **siderial year** = 365.2564 mean solar days (time needed for the Sun to return to the same position with respect to the stars).

Calendar



Julius Caesar: established the system of “leap years”



Gregory XIII: Removed days October 4-15, 1582

By adding an extra day to the calendar every four years, Julius Caesar hoped to ensure that seasonal astronomical events, would occur on the same date year after year.

Our current calendar is based on the **Gregorian system** that uses the tropical year and a modification of the leap year system.

When and why do we have leap years?

- The length of a tropical year is about 365.2422 days.
- In order to keep the calendar year synchronized with the seasons, we must add one day every 4 years (February 29).
- For precise synchronization, years divisible by 100 (e.g., 1900) are not leap years unless they are divisible by 400 (e.g., 2000).

What have we learned?

- **How do we define the day, month, year, and planetary time periods?**
 - Sidereal day (Earth's rotation with respect to stars) is 4 minutes shorter than a solar day.
 - Sidereal month (27.3 day orbit of moon) is shorter than synodic month (29.5 day cycle of phases).
 - Tropical year (cycle of seasons) is 20 minutes shorter than sidereal years (time to orbit Sun).

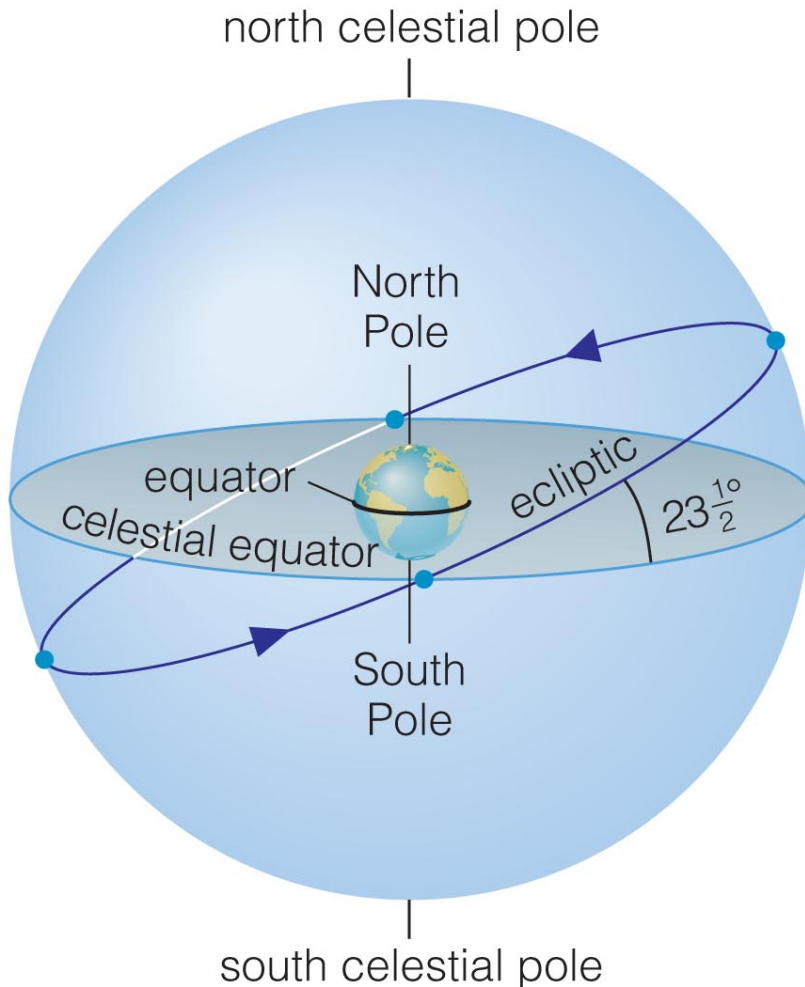
What have we learned?

- **How do we tell the time of day?**
 - Local solar time is based on the Sun's position.
 - Mean solar time is defined locally based on the average solar day.
 - Standard time is defined with respect to time zones.
- **When and why do we have leap years?**
 - Because a tropical year is 365.25 days, we need to add an extra day every 4 years so that the seasons remain synchronized with the calendar.

S1.2 Celestial Coordinates and Motion in the Sky

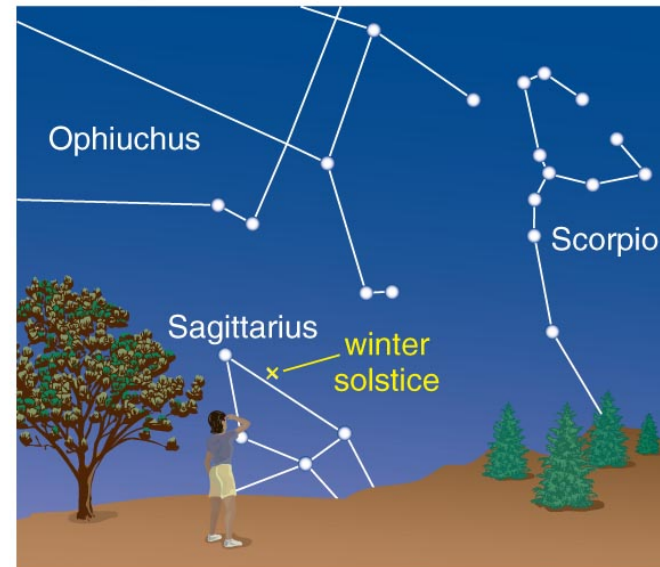
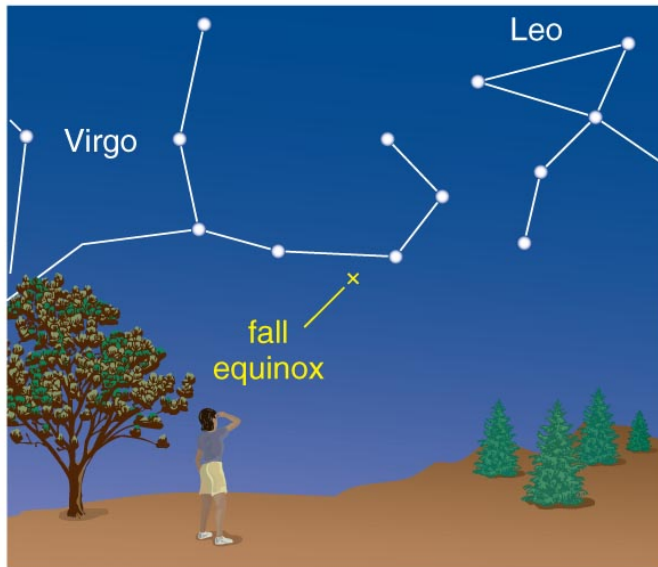
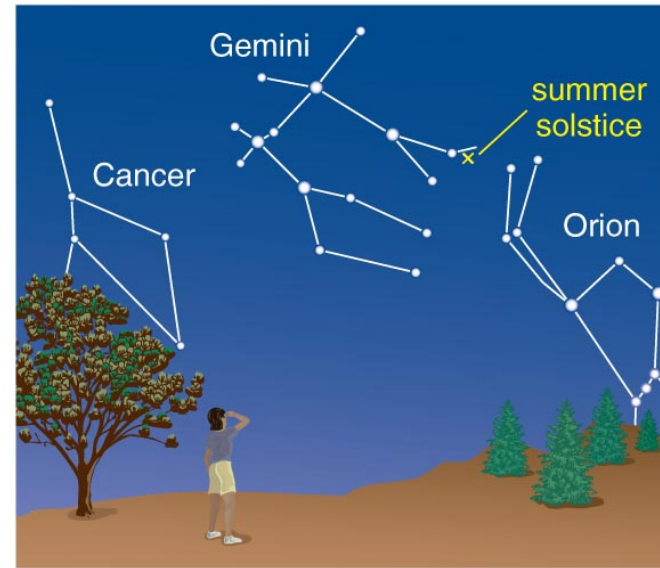
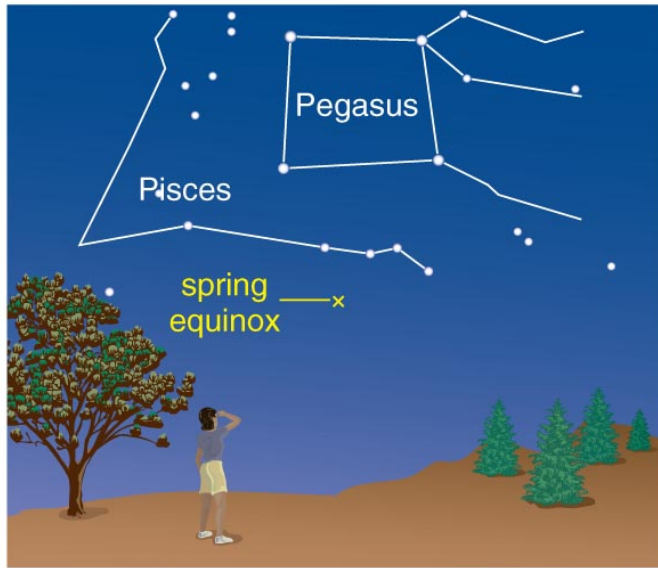
- Our goals for learning:
 - **How do we locate objects on the celestial sphere?**
 - **How do stars move through the local sky?**
 - **How does the Sun move through the local sky?**

How do we locate objects on the celestial sphere?

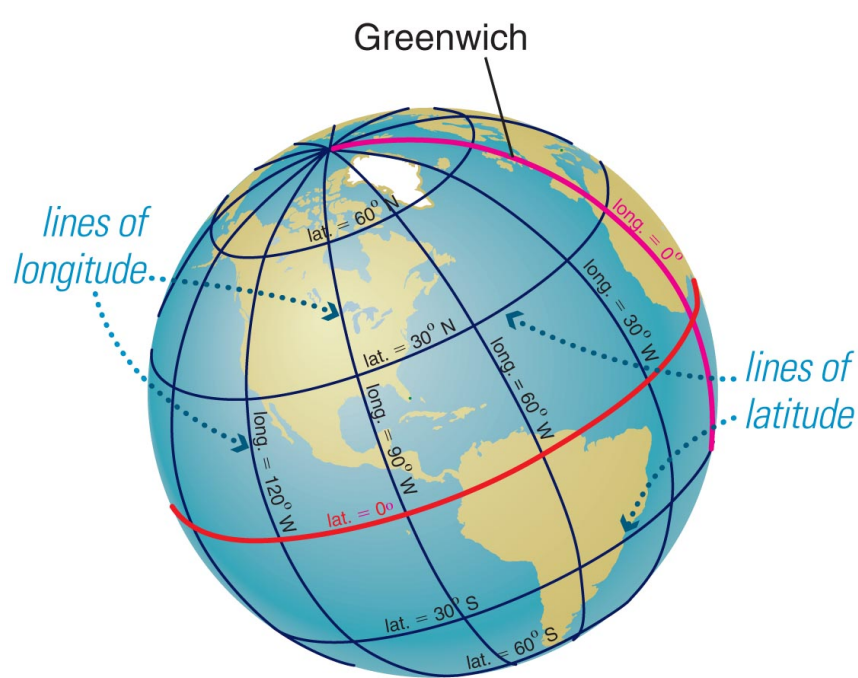


- Each point in the sky corresponds to a particular location on the celestial sphere.
- Equinoxes and solstices occur when Sun is at particular points on celestial sphere.

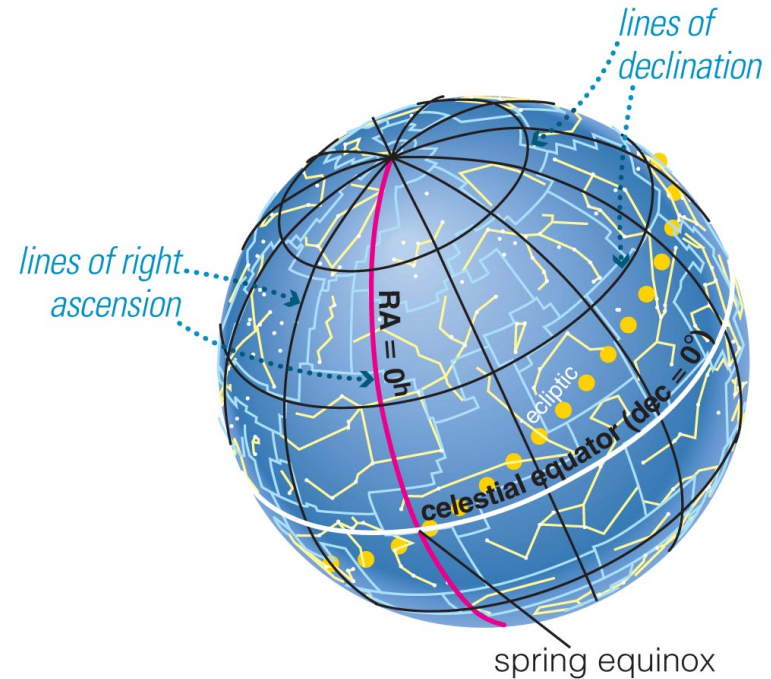
Solstices and Equinoxes



Celestial Coordinates



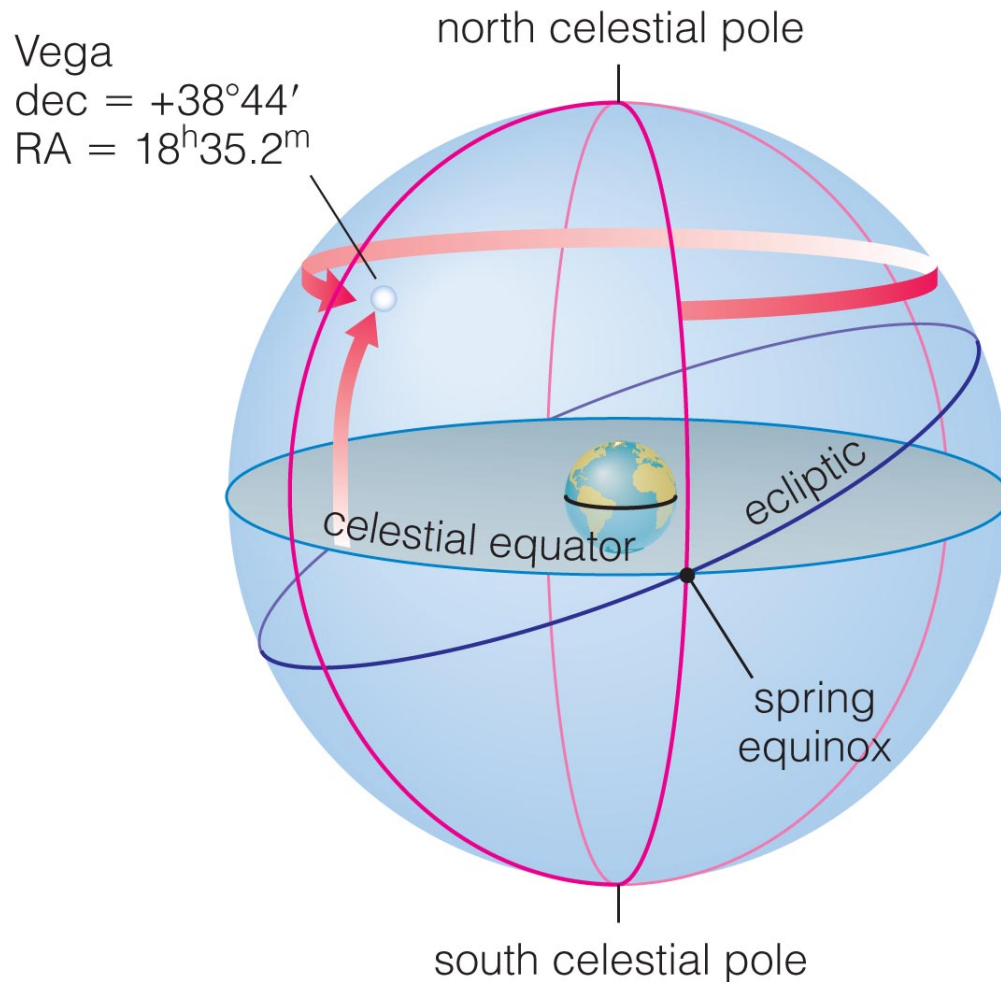
b We use latitude and longitude to pinpoint locations on Earth.



c We use declination and right ascension to pinpoint locations on the celestial sphere.

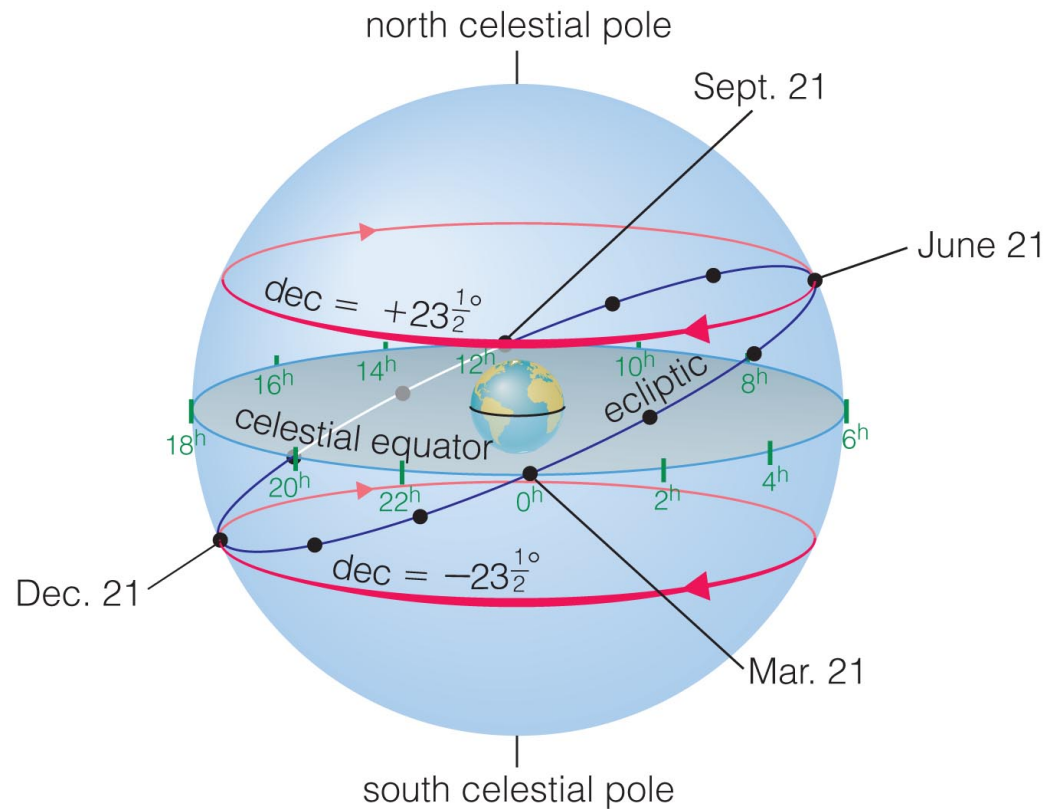
- **Right ascension:** like longitude on celestial sphere (measured in hours with respect to spring equinox)
- **Declination:** like latitude on celestial sphere (measured in degrees above celestial equator)

Celestial Coordinates of Vega



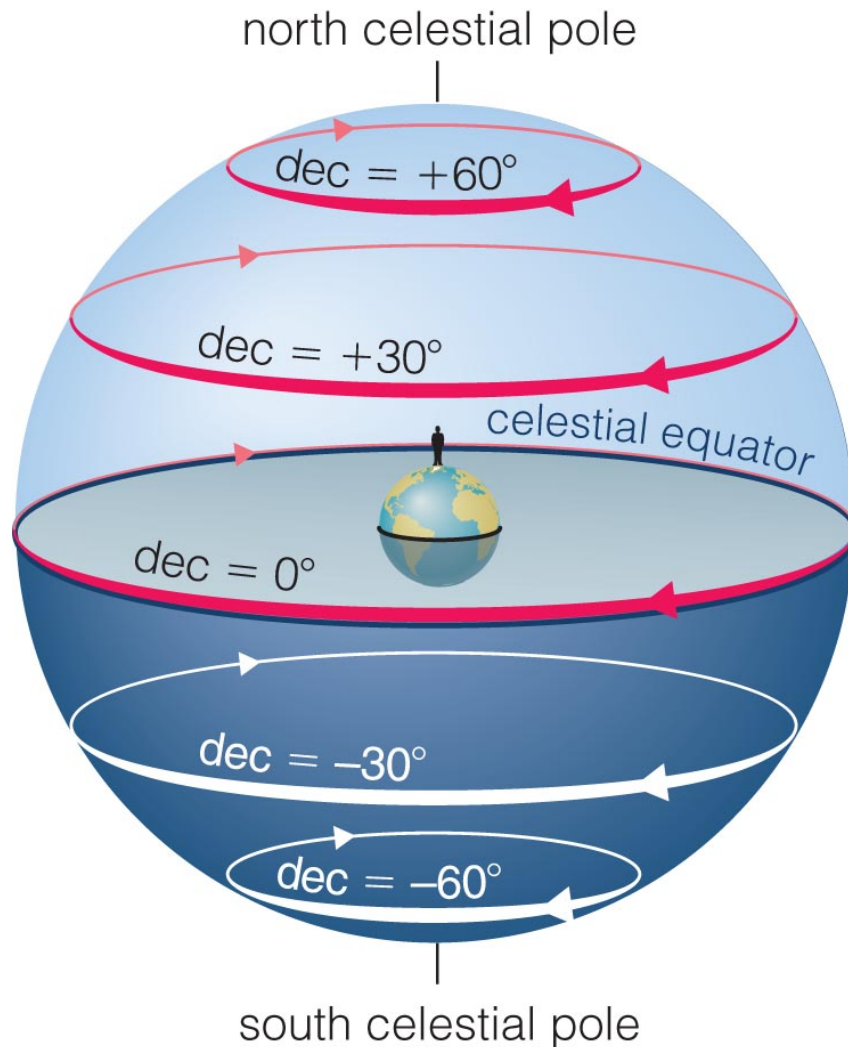
- **Right ascension:** Vega's RA of $18^{\text{h}} 35.2^{\text{m}}$ (out of 24^{h}) places it most of the way around celestial sphere from spring equinox.
- **Declination:** Vega's dec of $+38^\circ 44'$ puts it almost 39° north of celestial equator (negative dec would be south of equator).

Celestial Coordinates of Sun



- The Sun's RA and dec change along the ecliptic during the course of a year.
- Sun's declination is negative in fall and winter and positive in spring and summer.

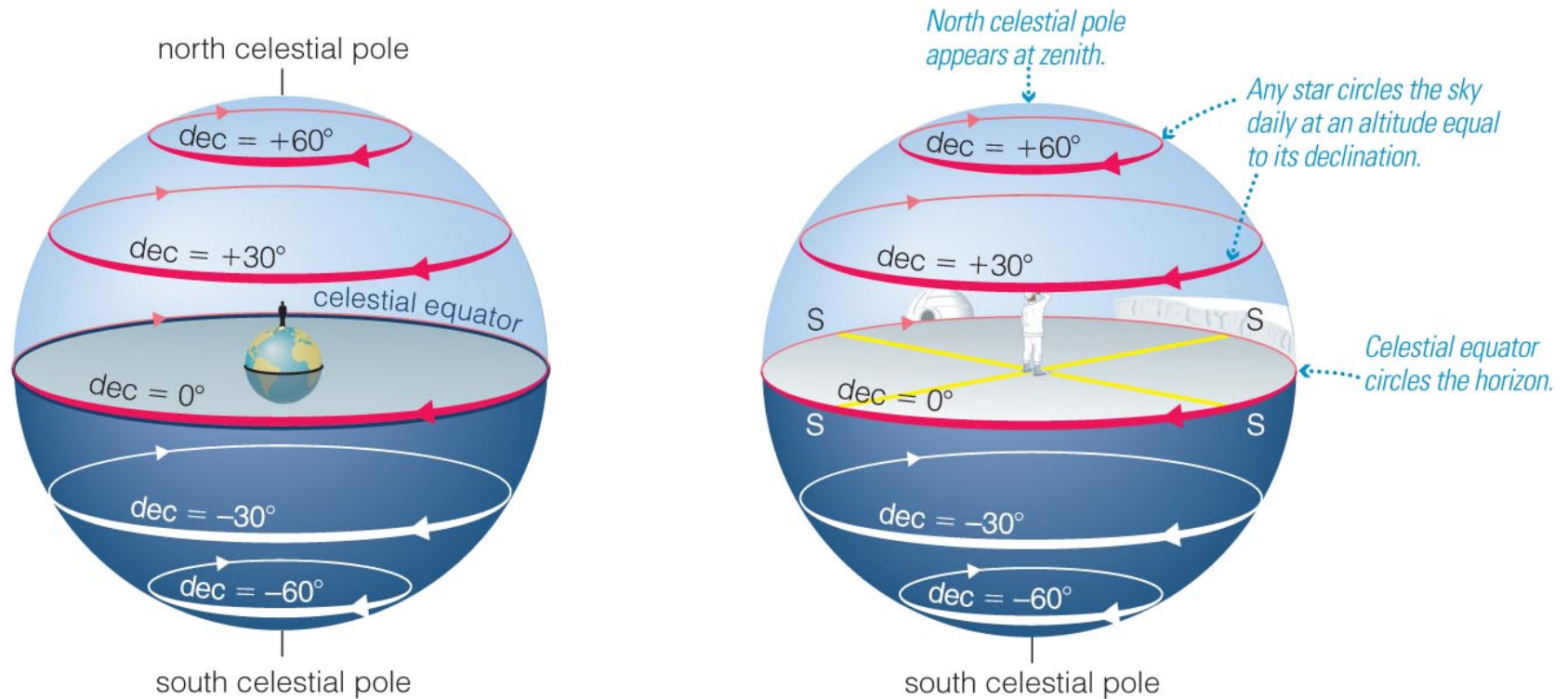
How do stars move through the local sky?



- A star's path depends on your latitude and the star's declination.

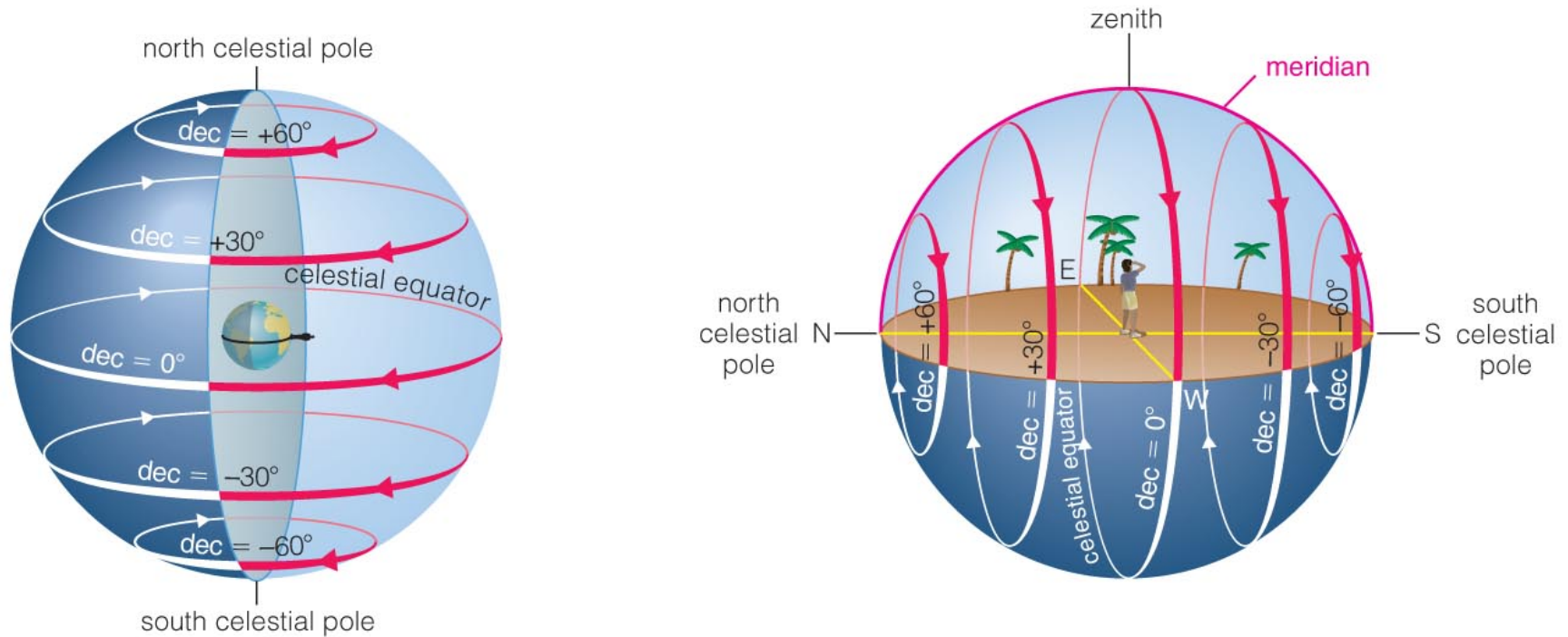
a The orientation of the local sky, relative to the celestial sphere, for an observer at the North Pole.

Star Paths at North Pole



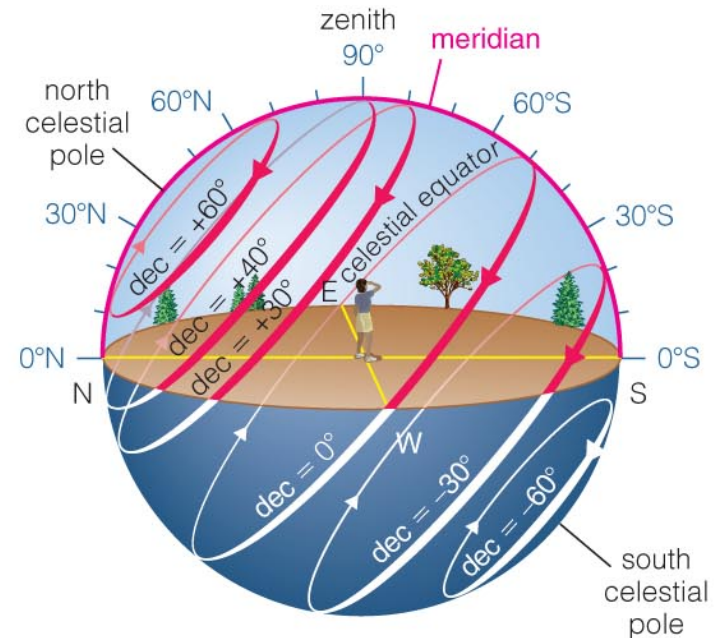
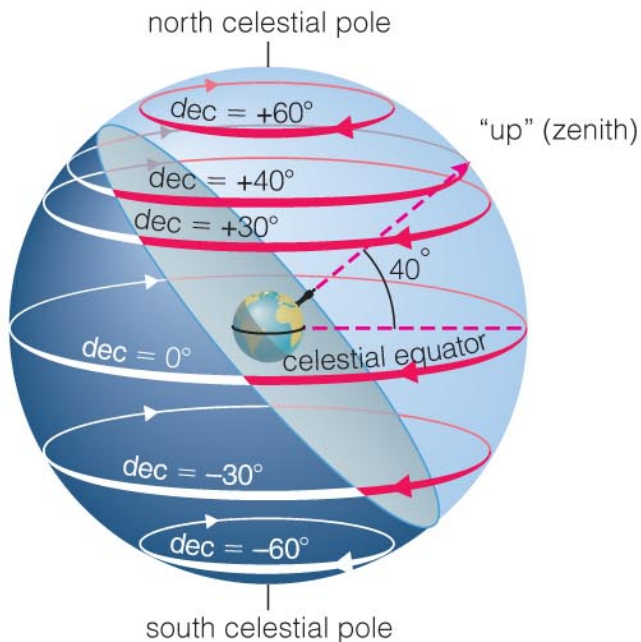
- At the North Pole stars remain at same altitude as Earth rotates.
- Star's altitude above horizon equals its declination.

Star Paths at Equator



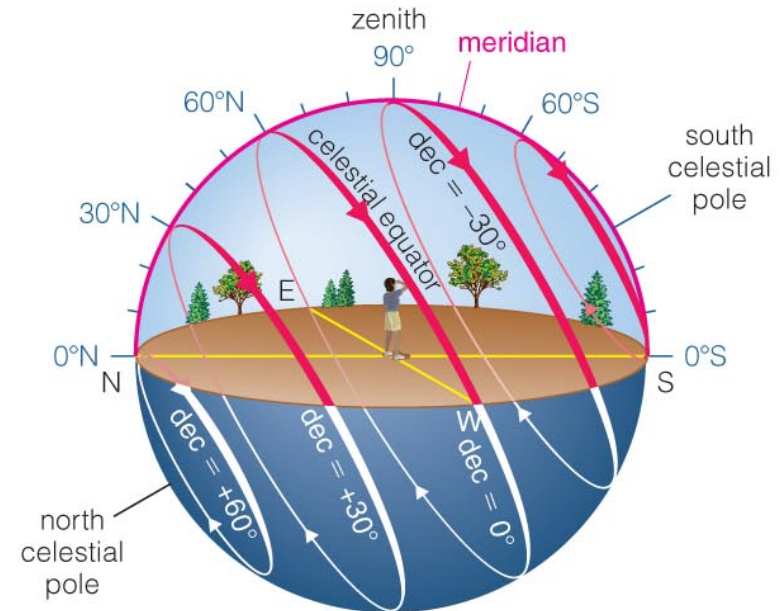
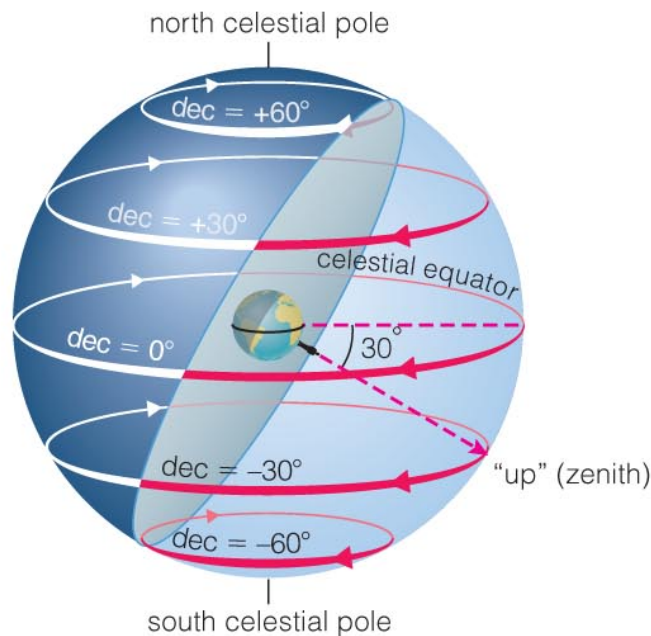
- At the equator, all stars remain above horizon for exactly 12 hours each day.
- Celestial equator passes overhead.

Star Paths in Northern Hemisphere



- In north, stars with $dec > (90^\circ - \text{your latitude})$ are circumpolar.
- Celestial equator is in south part of sky.

Star Paths in Southern Hemisphere

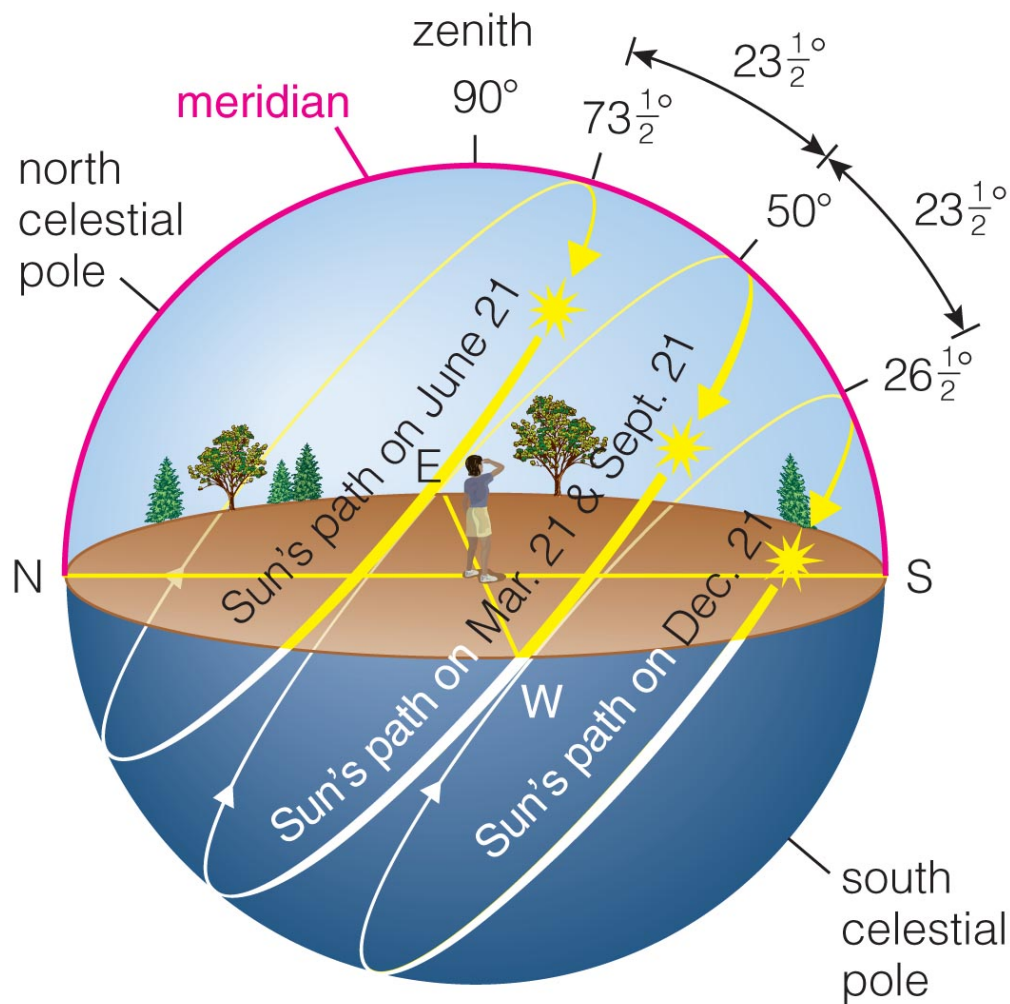


- In south, stars with $\text{dec} < (\text{your latitude} - 90^\circ)$ are circumpolar.
- Celestial equator is in north part of sky.

Time by the Stars

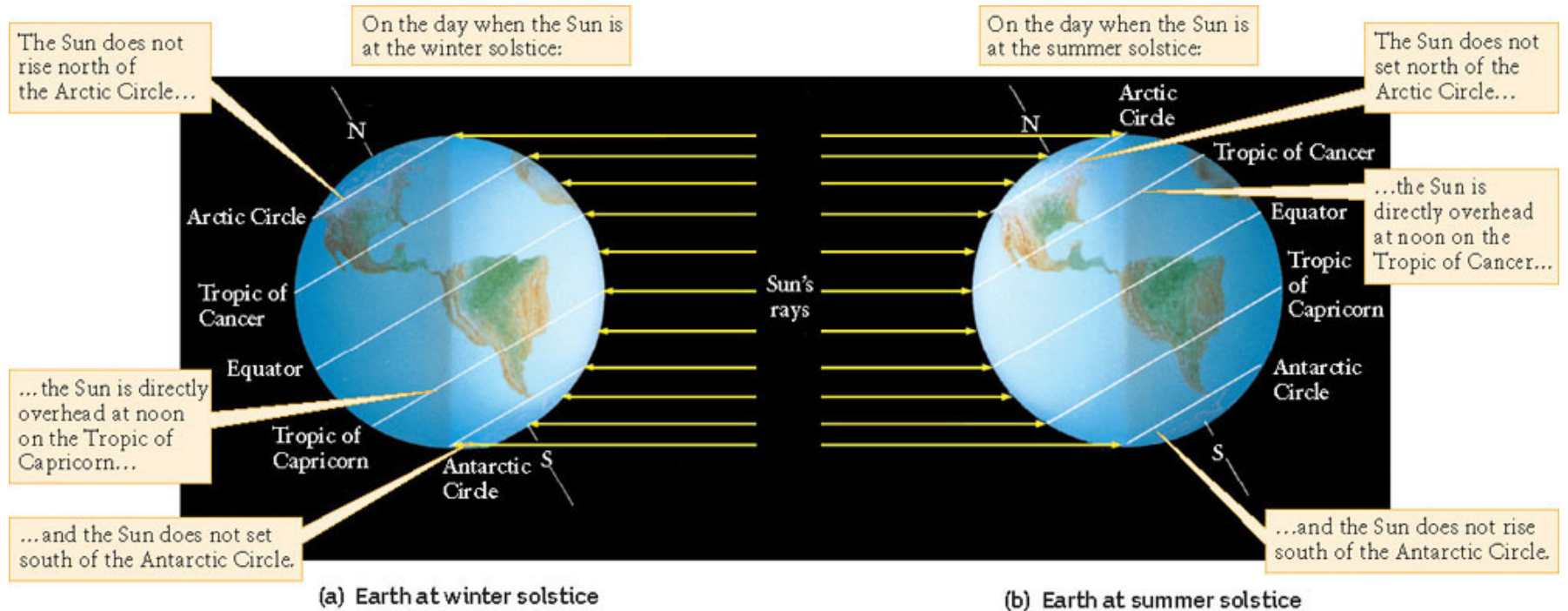
- **Sidereal time** is equal to right ascension that is passing through the meridian.
- The local siderial time is 0h0m when the spring equinox passes through the meridian.
- A star's **hour angle** is the time since it last passed through the meridian:
 - Local sidereal time = RA + hour angle

How does the Sun move through the local sky?



- Sun's path is like that of a star, except that its declination changes over the course of a year.

Tropics and Circles



Arctic Circle: $90^\circ - 23\frac{1}{2}^\circ = 66\frac{1}{2}^\circ$ North Latitude

Antarctic Circle: $90^\circ - 23\frac{1}{2}^\circ = 66\frac{1}{2}^\circ$ South Latitude

Tropic of Cancer: $23\frac{1}{2}^\circ$ North latitude

Tropic of Capricorn : $23\frac{1}{2}^\circ$ South Latitude

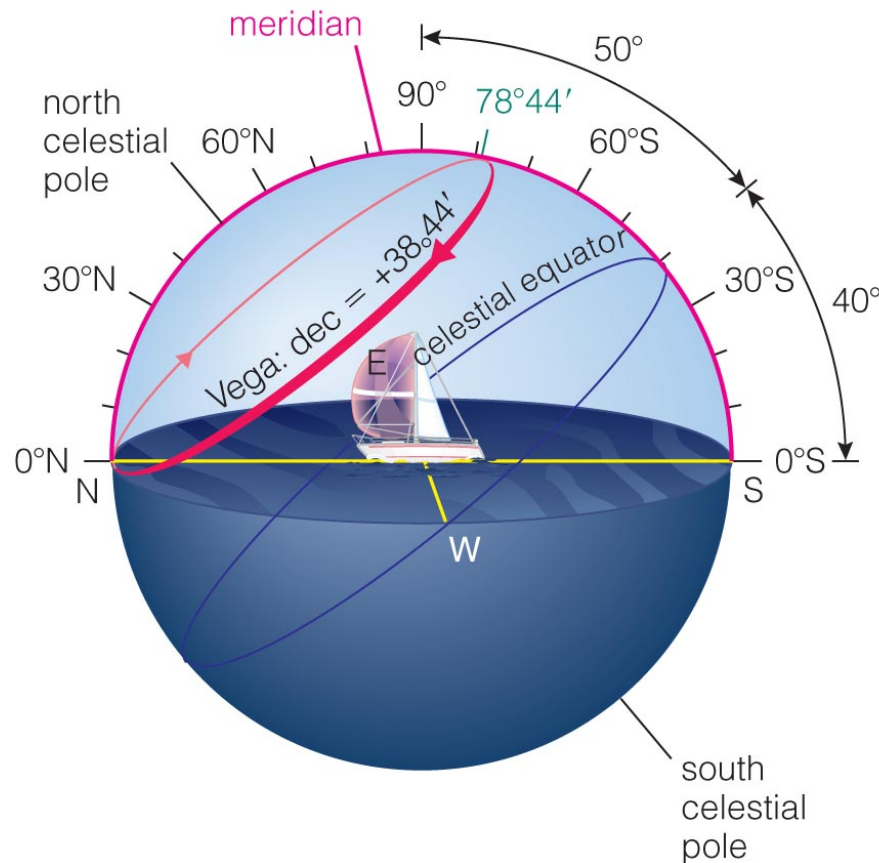
What have we learned?

- **How do we locate objects on the celestial sphere?**
 - Each point on the celestial sphere has a particular right ascension (like longitude) and declination (like latitude).
- **How do stars move through the local sky?**
 - Their paths depend on your latitude and the star's declination.
- **How does the Sun move through the local sky?**
 - Sun moves like a star except its declination depends on the time of year.

S1.3 Principles of Celestial Navigation

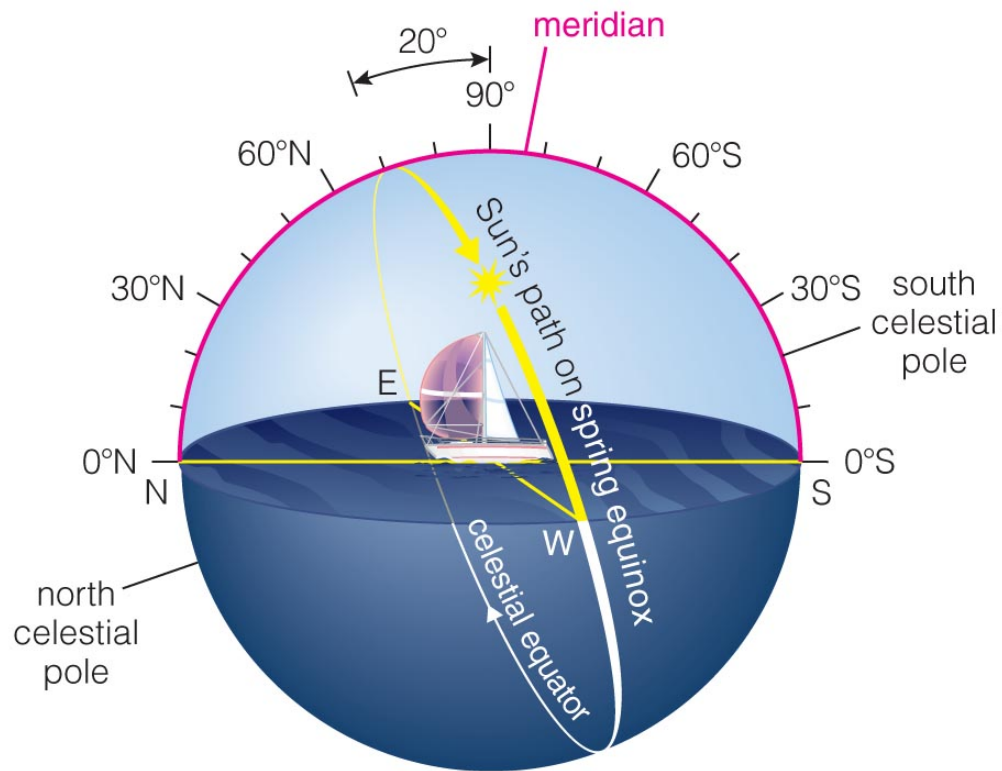
- Our goals for learning:
 - **How can you determine your latitude?**
 - **How can you determine your longitude?**

How can you determine your latitude?



- Latitude equals altitude of celestial pole.
- Altitude and declination of star crossing meridian also give latitude.

Latitude During Daytime



- You can determine the Sun's declination from the day of the year.
- Thus, measuring the Sun's altitude when it crosses meridian can tell you latitude.

How can you determine your longitude?

- In order to determine your longitude from the sky, you need to know time of day because of Earth's rotation.
- You also need to know day of year because of Earth's orbit.
- Accurate measurement of longitude requires an accurate clock.

Instruments for Navigation



a The faceplate of an astrolabe. Many astrolabes had sighting sticks on the back for measuring positions of bright stars.



b A copper engraving of Italian explorer Amerigo Vespucci (for whom America was named) using an astrolabe to sight the Southern Cross. The engraving by Philip Galle, from the book *Nova Reperta*, was based on an original by Joannes Stradanus in the early 1580s.

- An astrolabe can be used to measure star positions and to determine the time of day from them.

Instruments for Navigation



c A woodcutting of Ptolemy holding a cross-staff (artist unknown).



d A sextant.

- A cross-staff or sextant can be used to make accurate measurements of angles in the sky.

GPS Navigation

- The Global Positioning System (GPS) uses a set of satellites in Earth orbit as artificial stars.
- GPS devices use radio signals to determine your position relative to those satellites.

What have we learned?

- **How can you determine your latitude?**
 - The altitude of the celestial pole is equal to your latitude.
 - You can determine your latitude by measuring the altitude of a star crossing the meridian if you know the star's declination.
 - The Sun can be used if you determine its declination from the date.

What have we learned?

- **How can you determine your longitude?**
 - Because of Earth's motions (orbit and rotation) you need to know both the date and time of day to determine longitude.
 - Accurate determinations of longitude therefore require accurate clocks.
 - The GPS system uses a set of satellites as artificial stars.