

Knowing the Heavens

- **Goals:**
 - To see how the sky changes during a night and from night to night.
 - To measure the positions of stars in celestial coordinates.
 - To understand the cause of the seasons.
- **Constellations in the Sky**
 - 6000 stars visible by eye in the night sky. Ancient civilizations traced the patterns of these stars into figures - constellations (groups of stars).
 - 88 constellations in the sky (e.g. Ursa Major - big dipper, Orion).
 - Stars in constellations are generally not physically close to each other (e.g. Orion).

The changing night sky

- **Positions change during a night.**
 - During the night the positions of stars and moon change “Diurnal Motion”.
 - Earth rotates from West to East so stars appear to rise in the east and set in the west (e.g. a rotating chair).
see Figure 2-4
 - Earth rotates 360° in 24 hours: $15^\circ/\text{hr}$
 - This is a rapid rotation.
- **Positions change night to night.**
 - The earth orbits the Sun in 365.25 days ($0.986^\circ/\text{day}$).
see Figure 2-5
 - The positions of the constellations change slowly during the year.
 - Sky rotates at about 30° or 2 hours a month.
 - This is a slow rotation.

Star names and Catalogs

- **Early Catalogs**
 - Mapping and cataloging the stars has been in business for 1000s of years.
 - Positions of stars have been used to tell the season and navigation.
- **“Modern” Catalogs**
 - **Johann Bayer (1603)**
 - used constellations and added Greek letters e.g. α -Lyrae is the brightest star (Vega).
 - 24 x 88 (constellations) possible names.
 - **Bonner Durchmusterung (1850s)**
 - compiled by FW Argelander (many years)
 - 324,188 stars, e.g. BD+5° 1668
 - **Henry Draper (1911)**
 - 225,300 stars, e.g. HD87901

Star names and catalogs

- **Current Catalogs**
 - **New technologies**
 - Photographic plates or CCD imaging surveys enable millions of stars to be cataloged.
 - **HST Guide star Catalog (Version 1)**
 - 15,169,873 stars (accurate positions)
 - names are celestial coordinates.
 - **HST Guide star Catalog (Version 2)**
 - >100,000,000 stars cataloged
 - positions accurate to < 1 arcsec (in 1500s positions were measured to 1 arcmin)
- **Catalogue names**
 - **Stars can have many names in many different catalogs.**

The Celestial Sphere

- **No absolute reference frame**
 - A person on earth can be described by 2 angles (longitude and latitude).
 - Stars and galaxies appear to be on the surface of a sphere “celestial sphere” with the earth at the center.
 - Any star can then be described by 2 angles/coordinates (RA and Dec).
- **Orientation of the celestial sphere**
 - Poles are the axes of the Earth’s rotation.
 - Directly over head is call the “zenith”.
see Figure 2-10
 - A person can only see 90° in any direction (one hemisphere).
 - A person at 35° north can see the pole star all year and never see the south pole.

Coordinate Systems

- **Longitude and latitude**
 - **On the sky we call these angles Right Ascension and Declination.**
see Box 2-2
 - **Declination (Latitude)**
 - Measured in degrees
 - (North) $90^\circ < \text{Dec} < -90^\circ$ (South)
 - **Right Ascension (Longitude)**
 - Measured in hours (15° per hour) .
 - Starting point is defined as the vernal equinox (March).
 - RA is the angular distance eastward along the celestial equator.
 - **Example:**
 - If a star overhead (zenith) has an RA 8hr30m0s then 2.5 hours later a star at 10hr0m0s will be overhead.
 - Using time (not angles) makes it easy to know when a star is visible.

The Seasons

- **Rotation of the Earth around the sun causes the seasons**

- **The distance to the Sun does NOT cause seasons**

- The seasons are opposite in the Northern and Southern Hemispheres.
- The Earth's distance from the Sun changes by only 3%.
- The Earth is closest to the Sun in January.

- **Seasons are caused by the tilt of the Earth's axis of rotation.**

see Figure 2-11

- The earth is tilted 23.5° from the perpendicular.
- When the Northern hemisphere is tilted towards the Sun it is summer.
- When the Northern hemisphere is tilted away from the sun it is winter .

The Seasons

- **Summer**

- During the summer a point on the Earth has more than 12 hours of day light.
- Its is hotter due to the length of the day and the angle that the sun makes
see **Figure 2-12**
- 1/2 a year later the Northern hemisphere tilts away from the sun (winter).

- **Apparent motion of the Sun**

- The Suns position on the sky changes over the year.
- It appears to trace a circular path - the “Ecliptic”.
 - The Sun moves at 1° per day around the ecliptic (west to east).
 - The ecliptic is inclined to the celestial equator by 23.5° (due to the earths tilt).

The Equinoxes and Solstices

- **The ecliptic is inclined at 23.5°**
 - **The Sun revolves around the Earth at an angle to the Celestial Sphere**
see Figure 2-13
 - **The points where the orbit crosses the celestial equator are the equinoxes.**
 - **The sun appears to be directly over the equator.**
 - **Day and Night are of equal length**
 - **Spring equinox occurs around 21st of March.**
 - **The points when the Sun reaches the farthest North/South are “solstices”.**
 - **solstice = “standstill”**
 - **represents the longest day (and of the midnight sun).**
 - **Usually around 21st of June.**
 - **The movement of the Sun means it follows different tracks across the sky and the length of the day varies.**

Precession of the Earth's Tilt

- **Rotation of moon around the earth**
 - **Moon rotates around the Earth every 4 weeks.**
 - moves at 0.5° per hour.
 - complicated orbit.
 - **The moon and the Sun's rotation are almost on the same plane.**
 - The moon's plane of rotation is tilted by about 5° to the Sun.
 - the moon sweeps out a band ± 8 degrees either side of Ecliptic called the Zodiac.
 - The moon is north of the celestial equator for 2 weeks and then south of the equator .
 - **Moon and Sun "pull" at the Earth**
see Figure 2-15
 - The earth is not completely spherical (43 km larger at the equator).
 - The Sun and Moon cause a gravitational pull (trying the "straighten" the rotation axes).
 - The spin of the earth opposes this pull.

Precession of the Earth's Tilt

– This pull causes a gyroscope effect

- The “spinning bicycle” wheel opposes a change in the motion.
- This rotation is called “precession”.
- As with the bicycle wheel the axes of the the Earth’s rotation precesses.

– A slow precession of the pole

- The pole rotates at 23.5° to the perpendicular of the ecliptic.
- This rotation is the slowest change (taking 26,000 years to complete).
- The result is a change in where the celestial pole points relative to the stars.
- 5000 years ago Thuban in Draco would have been the “Pole Star”.

– Precession causes RA, Dec to change

- Precession of the pole means the equator also precesses.
- The equinoxes precess so the coordinates of the stars change slowly with time.
- Coordinates are only good for a particular time (epoch). Most catalogs refer to J2000.

Keeping Time

- **A solar day**
 - **Local noon is defined as when the sun crosses a meridian.**
 - meridian is a circle passing through the celestial poles and through the zenith.
 - a solar day is the time between 2 crossings of the meridian.
 - the earth revolves around the sun (so the earth must rotate more than 360° between crossings).
 - **The length of a solar day varies**
 - The earth's orbit is not perfectly circular (Chapter 4). The earth moves more rapidly near the sun so solar days are longer in January.
 - The 23.5° angle to the ecliptic means that during the equinoxes (spring/summer) the sun appears to move north-south (day is longer in March/September)
 - not good for time keeping.

Keeping Time

– Mean Solar Day

- Path the Sun would take if its orbit was circular around the celestial equator (average Sun).
- Successive transits of the “mean sun” are 24 hours long.
- good for time keeping (though no longer used).

– Time Zones

- We want time relative to our daytime - the Earth has approximately 24 time zones.
- Time differs by about 1 hour from one zone to the next.
- Each zone is define so that the apparent noon occurs at about 12pm in each zone.
- Time in each zone called Standard Time.

– Universal Time

- So we have a common reference point
Universal time is the time zone covering Longitude 0 (Greenwich England)
- 24 hour system.

Sidereal Time

- **A time related to the stars**
 - **Astronomers want to know when a star (not the sun) is visible.**
 - The visibility of a star depends on its position (RA).
 - **Sidereal time is based on the position of the vernal equinox**
see Box 2-4
 - This is the same starting point for RA.
 - A Sidereal Day is about 4 minutes shorter than a Mean Solar Day (due to the rotation of the Earth round the Sun).
 - sidereal clocks tick at different rates from normal clocks.
 - **Why astronomers use Sidereal Time**
 - A star always rises at the same sidereal time.
 - When the Sidereal time equals an objects RA the object is on the meridian.

Calendars

- **Defining a calendar year**
 - **Earth rotates around the Sun every 365.25 days**
 - Assuming a year of 365 days will cause the seasons to slowly move out of sync with the months.
 - Leap years account for these changes.
 - **Sidereal year**
 - For the Sun to return to the same position as defined by the stars (365.3564 mean solar days).
 - **Tropical year**
 - Time for the Sun to return to vernal equinox (365.2422 days)
 - Tropical year is 20m24s shorter than a sidereal year (precession of the Equinoxes)
 - **Leap years**
 - Tropical year is not 365.25 days the year will lose 3 days every 4 centuries
 - To account for this only centuries divisible by 400 are leap years (Gregory XIII). The error is now 1 day every 3300 years.