Lecture 2: Measuring time, angle and distance

- Time - solar, universal and sidereal
- Angle - degrees and radians
- Distance - Astronomical Units, light years and parsecs

Astronomy and the passage of time

Local astronomical timescales dominate our lives, and form the basis for our measurement of time:

- The day is based on the Earth's rotation
- The year is based on the Earth's orbit
- The month is based on the lunar cycle
- However, these astronomical cycles are imperfect in various respects - for example the length of the day varies due to ellipticity of the Earth's orbit, and one year is not an integral number of days
- Refinements such as the mean day and leap seconds and years are employed to keep the calendar and time consistent

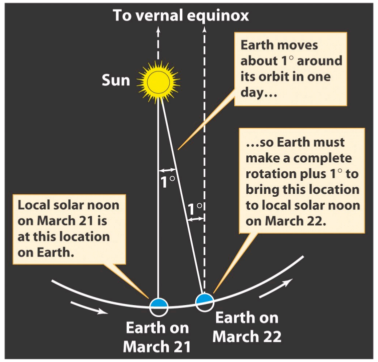
The length of the day

- A day is defined as the time that it takes the Earth to rotate on its axis.
- However, there is more than one way to define a day:
  - A solar day is the time that it takes to rotate with respect to the Sun.
  - A sidereal day is the time that it takes for the Earth to rotate with respect to the distant stars.
- A solar day is slightly longer than a sidereal day.
  - A sidereal day is 23h 56m 4.091s in length.

- Astronomers use sidereal time because we are mostly interested in distant celestial objects.

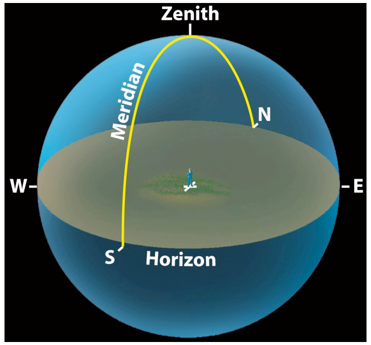
Why should a solar day be longer than a sidereal day?

- The Earth orbits in the same sense as it rotates (i.e. the spin and orbital angular momentum vectors both point to the N)
- Hence, due to the motion of the sun relative to the stars, it takes a little longer to bring the sun back to the same point in the sky, compared to a star.
- The extra time required is approximately 24hr/365, or roughly 4 minutes.
- Hence a sidereal day is roughly 23hr 56min long



The meridian and its crossings

- An observer's meridian is a great circle on the sky which passes through his zenith and the celestial poles. The upper meridian is the half-circle above the horizon.
- The apparent solar day is the time between crossings of the upper meridian by the sun.
- The sidereal day is the time between meridian crossings by the vernal equinox (or by any fixed point on the sky which rises and sets).



Mean solar time

The apparent solar day is not a very good time measure, since the time between solar crossings of the meridian varies from day to day. This occurs primarily because the sun's motion in right ascension is variable, for two reasons:

a) The Earth is slightly closer to the sun in the northern winter, and hence the sun appears to more more quickly relative to the stars
b) The tilt of the ecliptic means that the sun moves faster <u>parallel</u> to the celestial equator (i.e. in RA) near the solstices

To avoid this irregularity in the length of the day, one can define a fictitious mean sun, which moves along the celestial equator in one year at a <u>constant</u> rate.

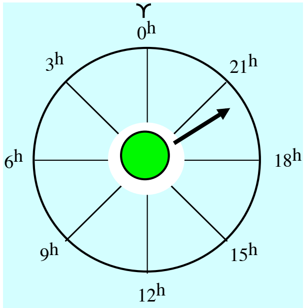
The mean solar day is then the time between upper meridian crossings of this mean sun.

Universal time - UT and UTC

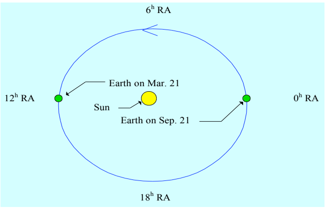
- The Greenwich meridian was adopted as the prime meridian for the measurement of longitude and time in 1884.
- Universal time is similar to mean solar time on this prime meridian. In practice, UT is now defined using GPS satellites, and can be corrected to allow for a variety of small effects, giving several different flavours of UT, known as UT0, UT1 etc.
- However, the key point is that all these UT timescales are based on the rotation of the Earth, and as such they are not perfectly steady and regular. For example, the Earth's rate of rotation is gradually slowing down, due to tidal friction.
- The advent of modern atomic clocks allowed scientists to establish a clock more reliable than the rotation of the Earth, and the average of about 200 atomic clocks in national laboratories is used to define international atomic time (TAI).
- However, TAI gets progressively out of step with the position of the sun in the sky. Universal coordinated time (UTC) is defined to establish a time system which is as regular as TAI, but is kept close to UT (and hence solar motion) by adding leap seconds. UTC is the basis for civil times worldwide.

Sidereal Time

- Local Sidereal Time (LST) is based on the movements of stars at a given location (e.g. an observatory).
- A sidereal clock ticks slightly faster than a normal (solar) one.
- The right ascension of the local meridian defines LST.
- E.g. if the star overhead has RA 4h, then the local sidereal time is 4 o'clock.
- In Northern hemisphere can use the Northern Sky as a Sidereal clock face.
- Use any circumpolar star having RA near 0h as hour hand (eg: β Cassiopeia).
  - hour hand rotates counterclockwise
  - clock has 24 hour face



Relating Sidereal and Solar Time



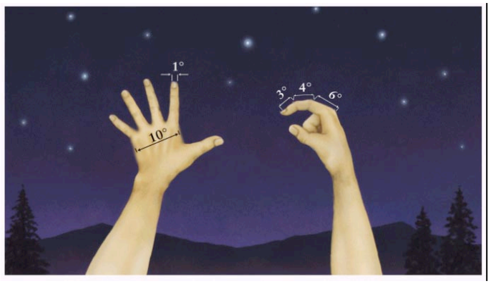
- At Solar Noon the Meridian points toward:
  - RA 0^h on Mar. 21; RA 6^h on Jun. 21;
  - RA 12^h on Sep. 21; RA 18^h on Dec. 21;
- To get Solar Time from Sidereal Time add:
  - 12 hours on Mar. 21; 6 hours on Jun. 21;
  - 0 hours on Sep. 21; 18 hours on Dec. 21.

Planning an observing trip

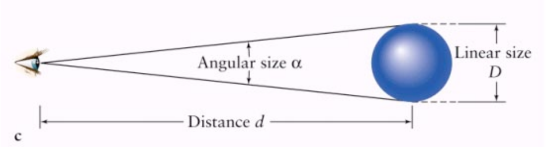
- I'd like to observe the cataclysmic variable IP Peg, at RA 23^h20^m, Dec +18°08'
- Where?
  - Declination > 0°, so any northern hemisphere observatory will do.
- When?
  - RA of sun should be 23^h-12^h=11^h (5.5 months after 21st March) - i.e. September is ideal
  - Best LST=23^h,when star crosses meridian

Angular measure - degrees

- Basic unit of angular measure is the degree (º), which can be subdivided into arcminutes (´) and arcseconds (´´)
- 1º=60´ ; 1´=60´´
- The moon is about 0.5º in diameter



Radians and the small angle formula



D = αd , where α is in radians

Example: On November 28, 2000, the planet Jupiter was 609 million kilometers from Earth and had an angular diameter of 48.6″ . Using the small-angle formula, determine Jupiter's actual diameter.

D =

Astronomical distances - astronomical units, parsecs and light years

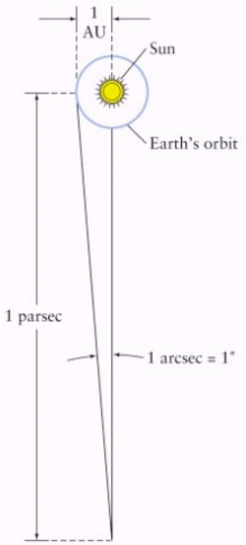
Astronomical Unit (AU): One AU is the average distance between Earth and the Sun (1.496×10^8 km or 92.96 million miles).

Light Year (ly): One ly is the distance light can travel in one year at a speed of about 3×10^5 km/s or 186,000 miles/s (9.46×10^{12} km or 63,240 AU).

Parsec (pc): One pc is the distance from which Earth would appear to be one arcsecond from the Sun.

$$1 \text{ pc} = 3.085 \times 10^{16} \text{ m}$$

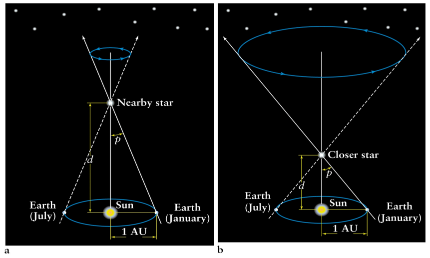
Kiloparsecs (1 kpc=1000 pc) and megaparsecs (1 Mpc=10^6 pc) are also widely used by astronomers.



One parsec (pc) is the distance from which Earth would appear to be one arcsecond from the Sun. Or equivalently, the distance at which a star would appear to move by 1 arcsec on the sky relative to the stars, as the Earth moves by 1AU perpendicular to the vector to the star - we say that the star has a parallax of 1 arcsecond.

i.e. using the formula $D = \alpha d$, with α in radians, the distance d corresponding to 1 pc is $d = D/\alpha = 1\text{AU}/(\pi/180 \times 60 \times 60)$.
Hence
$1 \text{ pc} = 1.496 \times 10^{11} \times 180 \times 3600/\pi$ m
$= 3.086 \times 10^{16}$ m

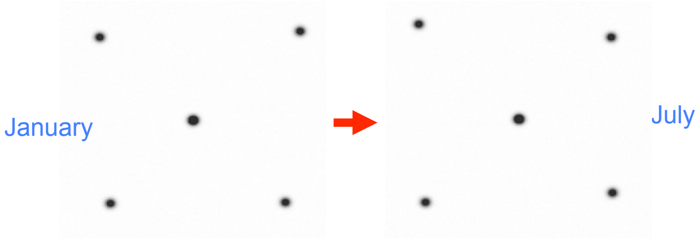
Stellar Parallax



The distance of a star in parsecs is just the inverse of its parallax in arcsec. i.e $d=1/p$

Example: Alpha Centauri has a parallax of p=0.76", what is its distance?
Ans: d=

Measuring parallax is difficult



1. Parallax shifts are small (<1 arcsec)
2. Atmosphere blurs images ("seeing" ~1 arcsec)
3. Nearby stars can have significant angular motion as a result of real movements in space (proper motion)
4. From the ground, can reach 0.01 arcsec accuracy at best - much higher accuracy can be attained by space missions