Astronomy 350: Lecture 1 - Positional Astronomy

- Time
  - Basics of astronomical time is the rotation of the Earth on its axis. This is what casues objects to rise in the east, move across the sky and set in the west.
  - One sidereal day is a full rotation of the Earth relative to a fixed distant reference point such as a star (ie. the time it takes the star to return to the meridian (see later) after a full rotation of the Earth. This rotation of 360° takes 24 Sidereal hours or 15° degrees per hour.
  - A Solar day is the time it takes the Sun to come back to its position on the meridian after a full rotation of the Earth. This rotation of 360° takes 24 solar hours at a rate of 15° degrees per hour.
  - The orbital motion of the Earth around the Sun makes for a difference between the Solar day and the Sidereal day.
  - While rotating on its axis, the Earth is also revolving around the Sun. Since the Earth has moved about one degree in its orbit in one day, it needs to rotate one additional degree to bring the Sun back into transit (see later). This takes about 4 minutes.
  - Thus a sidereal day is shorter than a solar day by about 4 minutes. So whilst there are about 365.25 solar days in a year, there are about 366.25 sidereal days in a year.
  - Time and angles are equivalent.
  - $360°/hr$, $15°/hr$, $15'/perminute$, $15''/persecond$.
  - 24 hours per 360 degrees, 4 minutes/degree, 4 seconds/arcminute, 0.067 seconds/arcsecond.
  - Apparent solar time or solar time is the hour angle of the Sun (see later). Apparent solar time 00:00 means noon and 12:00 means midnight. Noon solar time means the Sun is on your meridian. If the local apparent solar time is 9.00pm, that means that the Sun is 9 hours past the meridian.
  - But the length of the solar day varies throughout the year. The Earth's orbit around the Sun is not a circle but an ellipse: the Earth moves faster at closest approach to the Sun (perihelion) than when it is furthest away (aphelion) due to the conservation of angular momentum. Also due to the earth's axis tilt, the earth moves along the ecliptic which is tilted to Earth's celestial equator. As the Earth moves around the Sun, its NS axis always points in the same direction in space.
  - Equinoxes and solstices.

- At the equinoxes, the Sun is moving at an angle to the Celestial equator, hence the projection of its motion onto the Celestial equator results in a slower motion than its actual motion. At the solstices, when it is furthest from the equator, it is actually moving parallel to it and closer to the polar axis, so the projection of its mean motion on the Celestial equator is faster than its actial motion.
- Apparent solar days are shorter at solstices (March 26-27, September 12-13) and longer at equinixes (June 18-19, December 20-21).
- Define the mean Sun: Moves along the ecliptic at a constant speed and occupies the same position as the real Sun at perihelion and aphelion. Mean solar time is the hour angle of the mean Sun. The length of the mean solar day does not change during the year.
- The length of the mean solar day is increasing though, by about 1.4 milliseconds per century, due to tidal acceleration of the Moon by the earth and the tidal deceleration of the earth by the Moon.
- In 1820, the mean solar day was 86,400 SI seconds. Now its 86400.002 SI seconds.
- Apparent solar day may be as much as 22 seconds shorter to 29 seconds longer than the mean solar day. These are cyclical and dont accumalate.
- Mean solar day starts at noon (00:00) and midnight is (12:00). Civil time is defined as mean solar time minus 12 hours.
- Difference between apparent solar time and mean solar time is the equation of time or analemma.
- Mean Solar Time at Greenwich Meridian ($0° longitude$) is called Greenwich Mean Time (GMT) or Universal Time (UT).
- Because the Earth rotates West to East, when the Sun is crossing the meridian at noon at Greenwich, it will be before noon at points west of Greenwich and after noon at points east of Greenwich. Thus Local Mean Solar Time (LMT) is such that $LMT = GMT + L$, where L is the longitude of the location.
- Civil time at longitude L also depends on the time zone and is the LMT of that zone's standard
- Sidereal Time: time kept relative to stars instead of relative to the Sun: this reflects the actual rotation of the earth on its axis. Local Sidereal time (LST) is the right ascension crossing the local meridian at a given instant. Greenwich Sidereal time (GST) is local sidereal time on the Greenwich meridian. $LST = GST + L$, where L is the longitude and points east/west of Greenwich have positive/negative longitude.

- Precession: the Earth is not spherically symmetric, thus the gravitational attraction of the Sun and Moon causes the Earth's axis to change direction slowly, or precess just like a spinning top. This is also a rotataton and takes about 26,000 years. Thus the position of the vernal equinox changes and moves westwards at about 50 arcseconds/year. The "true" sidereal year is 86164.100 seconds, the rotation relative to the vernal equinox (ie. relative to 0 hours RA) is 86164.092 seconds.
- Thus astronomical positions given in terms of RA and dec (see later) change and must be given relative to a current epoch.
- Universal time (UT0) is the same as GMT.
- Changes in the distribution of the Earth's mass, perhaps due to changes in the Earth's atmosphere, result in small changes in the location of the poles. GMT corrected for this is UT1. It is the main form of Universal time. UT1 is the same everywhere on Earth. There exists some others, $UT2, UT2R, UT1R, UTC$ etc.
- The SI unit of 1 second is independent of astronomical observations: The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Cesium 133 atom.
- The Julian Day Number (JDN) is a count of days since January 1, 4713 BC, noon UT. This numnber is referred to as JD. Can have fractional parts to it.
- For example the Julian date for 2008 August 10 02:30:32.2 UT is JD 2454688.60454. Many astronomical observations are given times using the JD number.
- Standard time is the mean solar time in the center of the time zone you ar elocated in with the Earth being divided into 24 timezones, each roughly 15 degrees wide.
- Basics
    * On Earth, position is measured with respect to fixed circles on the Earth. The first is the equator. Position north or south of the equator is measured by latitude ($-90° < lat < +90°$). Longitude is measured east west with respect to the crossing of the Greenwich prime meridian (see later) and the equator. Postivie longitude is east and negative longitude is west.
    * 360° is a circle. One degree is divided into 60 minutes and each minute is divided into 60 seconds. So there are 60×60 seconds in a degree. How are these related to minutes and seconds we are used. They are similar since we tell time by how fast the Earth

takes to spin around, that is complete 360°. So an hour of time is also 360/24 degrees.

* So measures of time like hours, minutes and seconds are equivalent to mesures of angle.
* The observer is located at the center of his "celestial sphere" with the zenith, Z, above his head. The horizon is N-E-S-W.
* A circle on the celestial sphere that divides it into two equal hemispheres is called a great circle.
* Then any celestial body can be identified by two coordinates, altitude h and azimuth, α.
* Altitude is the angular distance above the horizon and azimuth is the angular distance, measured along the horizon, westwards from the S (in astronomy). In navigation, its eastwards from N.
* $0 < h, 90^\circ$ and $0 < \alpha < 360^\circ$.
* Celestial objects at a given location rise and set: this arises from the rotation of the Earth on its axisa Celestial objects appear to rise in the east and set in the west because of the west to east rotation of the Earth.
* The observers meridian or local meridian is the imaginary circle on the Celestial sphere starting due North, up to the Zenith and then the North Celestial Pole and then through to the horizon due South. Its perpendicular to the horizon.
* A Celestial object during the course of its nightly path through the sky will cross the local meridian: this is called transit or culmination.
* The hour circle of an object is the great circle through the object and north celestial pole. horizon.
* Altitude and Azimuth are horizontal coordinates and depend on the location of the observer on Earth and on time.
* Equatorial coordinates give the coordinates of an object on the Celestial sphere. These coords are based on the Celestial equator: the projection of the Earth's equator on the Celestial Sphere. An important reference point is the Vernal Equinox: the point where the ecliptic crosses the celestial equator with the sun moving towards the summer solstice.
* Note also the Fall Equinox and the winter and summer solstices.
* The equatorial system can be a local system centered on the observer (hour angle and declination).
* The declination, δ measures the angular distance north or south of the celestial equator. Thus $-90 < \delta < +90$.

* The right ascension, RA, is a longitude type coordinate mesured from the vernal equinox increasing in the direction of the Sun's motion: $0 < RA < 24 hours$. RA increases to the east from the vernal equinox.
* For example, Vega has dec=$+38°44'$, RA=18^h35^m. The positive declination tells us its north of the celestial equator and the RA tells us by how much this star is east of the vernal equinox.
* All objects with a particular RA cross the meridian at the same time. The RA of any object tells us how long after the spring equinox the object crosses the meridian. Note Vega crosses the meridian 18h35m of sidereal time after the vernal equinox crosses the meridian.
* The RA and dec of a star do not change. But the RA and dec of the Sun does change as it moves along the ecliptic.
* The hour angle, τ or HA is the angle measured at the pole or the angular distance measured along the horizon from the meridian of the observer to the hour circle of the Celestial body. The number of hours since the object crossed the meridian is hour angle of the object, increasing toward the west: if a star is crossing the meridian, its hour angle is 0^h. If a star crossed the meridian 3 hours ago, its hour angle is 3^h. If a star will cross the meridian 1 hour from now, its hour angle is -1^h or 23^h.
* An observer has a meridian running overhead from north to south. Objects rise in the east, transit the meridian and set in the west. An object at declination $0°$, that is its on the equator, takes 12 hours to cross the sky from the east to the west.
* Thus an object setting due west is at an hour angle of $+6H$ and an object rising due east is at an hour angle of $-6H$.
* If an object that is transiting the meridian has an RA of 12H, then an object rising due east has an RA of $18H$ and an object setting due west has an RA of $6H$.
* Thus Local Sidereal Time (LST, time relative to the local stars) can be defined as $LST = HA + RA$. This is usually written as $LST - RA = HA$. Or $LST = HA_{springequinox}$.
* Motion of Stars in the local sky
  - Consider the sky at the North Pole.
  - A star's altitude is equal to its declination and all stars are cicumpolar. The celestial equator circles the horizon.
  - At the equator, all stars rise and set. The north celestial pole is on the horizon. Stars with dec=0 lie on the celestial equator

which is your local meridian here. These stars rise due east, cross the meridian at the zenith and set due west.

  · Stars with positive declination rise north of due east reach their highest points in the north and set north of due west. These stars cross the meridian at an altitude of $90° - dec$.
  · Stars with negative declinations rise south of due east, each their highest points in the south and set south of due west. These stars cross the meridian at an altitude of $90° - dec$.
  · Now consider the sky at a latitude of say $40°N$.
  · Here the celestial equator extends from due east on your horizon to due west on your horizon crossing the meridian at an altitude of 90° minus your latitude.

* Stars with dec=0° lie on the celestial equator so at latitude 40° these stars rise due east, cross the meridian at an altitude of $90 - 40 = 50°$ in the south and set due west.
* Stars with $dec > (90 - lat)°$ are circumpolar.
* The remainins stars rise north of due east and set north of due west and cross the meridian north of the place where the celestial equator crosses it by an amount equal to their declination.
* Stars with $dec < (-90 + lat)°$ never rise above the horizon.
* Stars with $dec < 0°$ but which are sometimes visible follow paths parallel to but south of the celetial equator: they rise south of due east and set south of due west and cross the meridian south of the place where the the celestial equator crosses it by an amount equal to their declination.
* Fraction of time a star's "daily circle" is above the horizon depends on its declination.