ASTRONOMY 12 - FALL QUARTER 2012
MID-TERM SYNOPSIS

I. Descriptive Astronomy

Celestial Equator - projection of earth's equator into sky
                rises due east sets due west everywhere
                always. Overhead only at the equator.
                In the Northern hemisphere, the highest the
                CE rises above the horizon is
                90 degrees – your latitude
Ecliptic - path of sun in the sky. The ecliptic intersects the
                Celestial Equator at the two equinoxes.
Right Ascension - measured in hr, min, sec eastward of the vernal
                equinox along the celestial equator
Declination - angle (deg, min, sec) above or below the Celestial Equator
On the Vernal and Autumnal equinoxes, sun is on the CE.
Siderial time - time with respect to the distant stars
Solar time - time with respect to the sun
        (solar day is longer than the siderial day by about 4 min)
Earth's Precession - 26,000 years. The location of "north" varies
            in the sky during this period and Polaris is not always
            the north star.
The earth's rotational axis is inclined by 23.5 degrees to the plane
            of the ecliptic (i.e., the plane of its orbit around the sun).
            As a result the declination of the sun varies from -23.5 degrees
            (on the winter solstice) to +23.5 degrees (on the summer solstice).

 Paths of stars in sky - due to Earth's rotation, precession, and motion
                around the sun. Some stars are visible all the time, some
                are never visible from a certain latitude on the earth.

 What stars are visible -
        (for N. hemisphere)

            some time   declination > lat - 90 deg
            all the time   declination > 90 deg - lat
            never   declination < lat - 90 deg

    e.g., stars of declination less than -53 deg are never visible from
                Santa Cruz which has a latitude of 37 degrees

    Highest the sun is in summer = 90 deg - llatl + 23.5 deg = 76.5 in SC

    Where is sun ever directly overhead? Within the tropics sometime during
            the year. At the equator on the equinoxes

    During summer in the northern hemisphere the sun rises north of east
     and sets north of west. In the winter, the sun rises south of east.

Your longitude = difference between sidereal time in Greenwich and RA of stars on your Celestial Meridian. Convert time into degrees using 1 hour = 15 degrees.

Your latitude = angular distance of the north rotational axis (approximately Polaris) above the northern horizon (for northern hemisphere only).

The celestial equator's highest altitude above the horizon (south from Santa Cruz) does not vary with the season but the sun's declination above it or below it does vary. This is in fact the cause of the seasons.

Properties of the Milky Way Galaxy

Composition - H, He, O, C, N (know ordered by abundance)
Components

Disk - where the sun is found
Bulge - the central nearly spherical part
Halo - an extended region roughly spherical where e.g., globular clusters are found

These properties reflect the galaxy's formation from a rotating cloud of gas.

The Milky Way is a spiral galaxy. Interior to the sun's orbit about 90% of the (baryonic) mass is stars and 10% is gas and dust.

There are also elliptical and irregular galaxies. Ellipticals have ceased star formation. Spirals and irregulars contain gas and are still actively forming stars.

Stars

There are many more low mass, faint, red main sequence stars than any other kind.

There are more low mass stars than high mass stars.

The sun is a moderate mass main sequence star, a bit on the heavy side of average.

Open clusters of stars like the Pleiades and Hyades are groups of stars all born at about the same time and recently. They are not gravitationally bound and will gradually drift apart.

Globular clusters are also (larger) clusters of stars (up to a million stars) all born a long time ago. Globular clusters are bound by gravity. Globular clusters are found out in the Galactic halo on orbits that take them far above and below the disk.

The sun and earth are 4.56 billion years old.

All true stars get their energy from nuclear reactions. This
   requires a mass at least 8% that of the sun

"Main sequence" stars are burning hydrogen to helium in their
 centers. The lifetime of a star on the main sequence is
 approximately 10 billion years divided by the square of its mass
 in solar masses.

If nuclear reactions went out in the sun's interior it would
 continue to shine at its present luminosity for the Kelvin-Helmholtz
 time scale - about 20 million years.

When stars radiate for long periods of time, they contract and
 become hotter in their interiors (unless they become
 degenerate). The Virial Theorem says that half of the radiation
 released in gravitational contraction goes into heating and the
 other half is radiated away.

Stellar populations - relate to how the galaxy was born, or perhaps
        to galactic mergers.

        Population   I   Population   II

          Young   Old
         High and low mass   Low mass
         Luminous and faint   Faint
          In disk   In halo and thick disk
         Low v perp disk   High v perp disk
       Large metal abundance (1-2%)   Low metal abundance (<<2%)
          Sun, Pleiades   Globular clusters

   The distance from sun to the Galactic center = 8.5 kpc - about 30,000 ly

   The velocity of sun around Galactic center as inferred by the 21 cm radio
        emission of hydrogen is 250 km/s

II. Basic (astro)physics

Force:

  Four forces in order of decreasing strength, examples, and
   which are 1/r**2 (indicated with "*") are

        Strong   bind nuclei
        Electric*   chemistry
         Weak   n -> p + e + nu
        Gravity*   falling down

Kepler's three laws

   Planetary orbits are ellipses with the sun at one focus
   Equal areas in equal times swept out by line connecting
   P**2 proportional to a**3 where a is the radius of the
    orbit (or semi-major axis if an ellipse)

The sun and the moon contribute comparably in producing tides
 on the earth. A tidal force is not the same as a gravitational
 force but is proportional to its derivative. It thus depends on $1/r^3$

Meaning of centrifugal force   - mv^2/r

Kepler's Third Law P^2 proportional to R^3

Review use of Kepler's Third Law to get the AU

Review use of Kepler's Third Law to get masses

Approximate mass of the MW galaxy
      about 10**11 Msun (interior to solar orbit)
      about 10**12 Msun total - much of it "dark matter"

Differential rotation of the galaxy, not rigid. Inner parts go
  round faster (as do the inner planets in our solar system)

Evidence for dark matter in the Galaxy and other spiral galaxies- v outside
     sun's orbit does not decline like 1/sqrt(r) but stays constant

Age of the MW galaxy about 12 billion years inferred from
 ages of oldest stars and must be less than the age of the universe,
 13.7 billion years

Energy

Three kinds of kinetic energy – translational ($\frac{1}{2} mv^2$), rotational, thermal (kT)

Definition of temperature - measures random kinetic energy

Objects falling freely from infinity impact at the escape velocity
                 sqrt(2 G M/r)

Definition of Gravitational binding energy - what it means
       (numerically about 3/5 G M**2/r)

Definition of the Kelvin Helmholtz time scale - what it means
        and how long it is for the sun (20 My)

III. Distances

First get the AU (Kepler's 3rd; Radar, Mars)

Measure distances to nearby stars using ordinary parallax
   (out to about 1000 pc from space, 100 pc from ground)

   d in pc = 1/parallax angle in arc sec (1 pc = 3.26 light years)

Flux, luminosity, and standard candles

   Flux is L/(4 pi d**2)
   e.g. A given star twice as far away is 4 times fainter
   Flux is measured using magnitudes (m)
   5 magnitudes is a factor of 100 in flux
   6th magnitude is the faintest the eye can see
   Larger m means a fainter star

   Luminosity is the power of the star in electromagnetic radiation
   Measured using absolute magnitudes (M)
   M = m at 10 pc
   M = m + 5 - 5 log d(in pc)
   to get actual luminosity from measured M, apply corrections
       bolometric (BC)
       reddening (RC)
   Once know Mbol can get L (don't need to remember eqn)

A standard candle is a celestial source whose luminosity is always
        the same. These may be calibrated, in some cases by seeing
        examples nearby and using parallax to get their distance.

Examples are:

Cepheid variables - stars whose regular change of luminosity has a
        period which is correlated with average luminosity. L varies
        because star pulses. Two types of Cepheids with two different
        P-L relations. Type I is massive and young; Type II is low mass and old.
        Very bright stars. Once calibrated can use for large distances - up to
        20 Mpc and more. Historical problem with calibration led to confusion
        about the size and age of the universe

Main sequence stars and the Hertzsprung Russell (HR) diagram

        Temperature can be measured approximately by the color index
           obtained by measuring the magnitude with two filters
           on the telescope, e.g. , B and V
           B - V is smaller or more negative for hotter stars
           When plot B-V against Mbol or M for a large number
               of stars, find a well defined strip where most
               stars lie called the main sequence

Thus either the HR diagram for a cluster or the color of an
        individual main sequence star can be used to get distance

(B-V) -> M measure m and calculate d

We can tell the luminosity class of a star (class V is main
sequence; I is supergiants) by looking at its spectrum
main sequence stars have broader lines than red giants
becuase the pressure at the photosphere is greater

Type Ia supernovae

calibrated to be standard candles using the
"width-luminosity relation". Gives the currently favored
Hubble constant and shows evidence for an accelerating expansion of the
universe.

Tully Fisher relation

(Spiral) galaxies that rotate more rapidly have higher mass and thus
are more luminous

Beyond standard candles:

Hubble's Law and the age of the universe

$v = H_o d$ -- Tells how fast widely separated galaxies and
clusters of galaxies are moving apart
(strictly speaking this is not the
motion of anything but a measure of the
rate at which space is expanding locally).
At very great distances H_o is not a constant.

The redshift z is defined by the ratio of the size of the
universe (i.e., the distance between widely separated
objects) at time t, which is R, and now, whch is R_o
$(1+z) = R/R_o$

By looking at the evolution of $H = 1/R(dR/dt)$ we can tell what kind
of universe we live in

Current observational evidence indicates that the
expansion of the universe is *accelerating". A model
consistent with this is a universe in which over 70% of the
mass energy is "dark energy" also called by Einstein
the "cosmological constant". In this model, and
according to recent measurements of the structure of
the microwave background radiation, the universe is
13.7 +- 0.1 billion years old.

IV. Cosmology (brief)

On large spaces - greater than a few hundred Mpc - the

distribution of matter in the universe is smooth and isotropic.

The Universe is expanding (Hubble's Law) and the expansion is accelerating

The expansion can only be seen on the largest scales. Tightly bound systems like atoms, the solar system, and even individual galaxies do not participate in this expansion, but very large collections of galaxies do.

Besides the expansion of the universe other evidence for a hot Big Bang is the abundances of helium and deuterium and the cosmic microwave background radiation at 2.73 K

This universe has an age of 13.7 billion years consistent with the ages of the oldest stars in globular clusters

Most of the matter is non-baryonic dark matter (not neutrons, protons, and electrons, and probably not neutrinos).

Most of the baryonic matter is also dark and could be dwarf stars black holes, or other forms on non-luminous matter. The rotation curves of spiral galaxies show evidence for this.

Cosmological redshifts are not Doppler shifts but come about due to the expansion of the space through which the light travels

Our "observable universe" contains all the matter upon which we can make measurements. It is limited by how far light can travel in the time since the Big Bang

The cosmic microwave background radiation, which we see coming from all directions, originated about 380,000 years after the universe when the temperature declined to about 3000 K and the universe became transparent to radiation. The redshift then was $z = 1100$

V. Electromagnetic Radiation

Produced when charge is accelerated

Classically a wave - quantum mechanically a particle called the photon

The energy of a photon is proportional to its frequency. $E = h\nu$
   red photons are less energetic than blue ones (red light has a
   lower frequency)

Photoelectric effect - shine light on a metal and get some electric current, but no current unless the light is shorter than a certain wavelength, no matter how intense the light.

Earth's atmosphere transparent to visible light, (some) infrared, and radio

x-rays, gamma-rays, uv radiation, and most infrared must be studied
from balloons, rockets, or satellites

Blackbody radiation

characterized by just the temperature. Emitted by material
having emission properties independent of wavelength.
Must start out from region that is very optically thick (opaque)
so that the radiation comes into equilibrium with the
temperature of its surroundings.

The radiation diffusion time for sun is thousands of years
Radiation has temperature equal to matter until it escapes.
This defines the "photosphere" of a star.

For T_e the effective temperature at the photosphere --

A blackbody spectrum peaks at a wavelength inversely proportional
to its temperature lambda_max = 0.289 cm K / T (Wien's law)

A blackbody emits radiation at a rate per cm^2 of $\sigma(T_e)^4$
for a spherical star L = $4\pi R^2 \sigma(T_e)^4$

The latter implies that cool luminous stars will have large radii
(red giants) and hot compact stars will have small radius
(white dwarfs). The HR diagram may also be interpreted as
a relation between L and T_eff (or M and B-V). The main
sequence is the location of stars which, as it turns out, are
burning hydrogen in their centers, and for which the radius
varies slowly (increases) with mass of the star being considered.

The same expression allows us to evaluate stellar radii if we know
the luminosity and temperature

Planetary temperatures

Set by blackbody radiation theory
energy in = energy out. Sunlight comes in
easily. Earth emits at about 10 microns (IR)
light may have trouble getting out if concentration
of greenhouse gases is high.
Temperature of a planet is independent of its radius

Neglecting the greenhouse effect, two planets will have
the same temperature if they receive the same FLUX from
their star. e.g., the habitable zone of a star 4 times
the luminosity of the sun would be at 2 AU.

The greenhouse effect causes major modifications to the
temperatures of the Earth and especially Venus. The amount
of light reaching the ground for Venus is less than for
the Earth but Venus is enormously hotter.

VI. Atomic spectral radiation

The Rutherford atom (planetary like electron orbits) is unstable

Particles cannot be localized to a region smaller than their
wavelength lambda = h/momentum. Thus the product of
momentum and confinement length must always exceed h

Confining an electron to a smaller volume actually makes it
move faster - even if it has no temperature. This is an effect
of the uncertainty principle. Electrons that are as crowded as
the uncertainty principle allows are "degenerate".

Electrons can occupy only certain energy levels in atoms
these levels must be consistent with the electron's quantum
mechanical properties.

The ground states of atoms are perfectly stable because the electric
force provides inadequate energy to squeeze the electron into a
smaller volume. In the smaller volume the electron's wavelength
would be smaller and it would therefore move faster.

Other higher energy levels are unstable and can be formed by
absorbing radiation from a blackbody source or by collisional
excitation. If absorption, light of a specific wavelength is
subtracted. These levels can return to lower states by emitting
radiation of characteristic wavelength.

The most energetic lines of hydrogen involve transitions into or
out of the ground state. They are the Lyman series. Next most
energetic are the lines in and out of the $n = 2$ state (first
excited state). These are the Balmer series. They are the
prominent optical lines of hydrogen. H-alpha is 6563 A.

Absorption lines are seen when a source of continuous radiation
(e.g., a blackbody) lies behind a cooler gas, e.g., the atmosphere
of a star. Radiation is subtracted out and re-emitted in
a different direction. The atom may also be collisionally
de-excited.

Emission lines are seen if a gas is illuminated from the side.
Emission lines are also seen in low density regions where
the atoms have been ionized and are recombining - e.g. H II
regions and nebulae.

Different elements have different thresholds for atomic excitation
and ionization. The ions seen are a sensitive function of the
temperature.

Nomenclature -
        H I neutral hydrogen
            H II ionized hydrogen
            He I neutral helium
            O V oxygen that has had four electrons removed

H_2 molecular hydrogen

Stars may be grouped into groups having similar spectra and therefore similar temperature. The temperature sequence from hot to cold is OBAFGKM. The hottest O stars are around 40,000 K, The coolest M stars around 2500 K.

O stars have strong absorption lines of He II and, to a lesser extent, He I. No H lines

A stars have hydrogen lines at their strongest

G stars have hydrogen lines but Ca II and Fe I are stronger

M stars have weak hydrogen lines but show bands of absorption due to TiO and other refractory molecules.

The series OBAFGKM (on the main sequence is also a series of decreasing mass, luminosity, radius, and temperature

Spectral lines may be broadened owing to:

Stellar rotation
Temperature

Temperature and rotation have different dependences on atomic mass and are distinguishable

Things we can learn from the spectrum and how:

Temperature

Wien's law (Lambda_max = 0.289 cm/T)
Spectral line widths (thermal broadening)
Ionization states that are present

Rotation

Doppler broadening - more massive stars rotate faster

Radius

L = 4 pi r**2 sigma T**4

Composition

strengths of lines

Pressure and whether the star is a MS star

higher gravity -> higher density
higher density decreases the ionization stage
of a given element and also gives broader lines

Velocity

Doppler shift

Mass

If in an eclipsing spectroscopic binary

Doppler shift - classically

$\Delta\lambda / \lambda = v/c$.
wavelengths get larger if v is away from you.
shorter if v is toward you.

21 cm is a special spectral line due to a spin flip transition
in the neutral (H I) atom. It is seen by radio telescopes and
used to map the distribution of gas and its velocity in galaxies.

VII. Getting stellar masses

Use a variation of Kepler's third law.

P^2 is proportional to (Total separation)^3/(M_1 + M_2)
ratio of masses is the inverse of the ratio of their
distances from the center of mass or, equivalently, their
orbital speeds. If mass is in solar masses, separation in AUs,
and period in years, this proportionality becomes an equality.

The product of mass times distance to center of mass in a binary
star system is a constant. The heavier star thus lies closer
to the center of mass and the lighter one is farther away

If know the separation of two stars from the center of mass
of the system and the period, you can get the masses of both stars.

Visual binaries - measure P, separation, and inclination directly.

Spectroscopic binaries - measure P and radial velocities
can get actual masses if the binary has eclipses. Otherwise
the masses determined (M Sin i) are lower limits.

Find there is a correlation between mass and luminosity on the
main sequence. L approximately proportional to M**3.
This implies that more massive stars have shorter lives, indeed
scaling approximately as M**(-2). The lifetime of the sun on the
MS is 10 billion years. Other stars scale accordingly. Thus we
can date the ages of stellar clusters by the "turn off" mass.

Age of a cluster = 10^{10} yr /(turn off mass in solar masses)^2
(actually between **2 and **3 is appropriate)

The most massive stars are about 100 Msun. The very lightest is 0.08 Msun