ASTRONOMY 12 – WINTER QUARTER, 2016
MID-TERM SYNOPSIS

I. Descriptive Astronomy

Celestial Equator - projection of earth's equator into sky
rises due east sets due west everywhere
on the earth. Overhead only at the equator.
In the Northern hemisphere, the highest the
CE rises above the horizon is
90 degrees – your latitude. CE is at 53 degrees in SCruz
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. 0 is vernal equinox
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 - |lat| + 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 (½ 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 for constant density)

Definition of the Kelvin Helmholtz time scale - what it means
and how long it is for the sun (3/5 GM**2/2RL ~ 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 because 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 and this equation breaks down – i.e., as “v” approaches c.

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 R(t) we can tell what kind of universe we live in. This requires measuring z and the distance for a standard candle that is very far away – eg., Type Ia SN
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 “e” stands for “emission”
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