

ASTRONOMY 12 WINTER 2010
MID-TERM SYNOPSIS

I. Descriptive Astronomy

Celestial Equator - projection of earth's equator into sky

Ecliptic - path of sun in the sky

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
Meridian

Vernal and Autumnal equinoxes

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

Paths of stars in sky - due to Earth's rotation, precession, and motion
around the sun.

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 (eg., South pole -90 deg) lat (SC) = 37

Highest sun is in summer = $90 \text{ deg} - |\text{lat}| + 23.5 \text{ deg} = 76.5$ in SC

Where is sun ever directly overhead? where can you see all stars
sometime each day?

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

Your latitude = angular distance of the north rotational axis

(approximately Polaris) above the northern horizon.

The celestial equator passes through due east and due all of the time.

Its highest altitude above the horizon (south from Santa Cruz) varies with the season.

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 active in 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 is 4.57 billion years old. Know this.

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.

Stars lighter than 8 times the mass of the sun will end their lives as white dwarfs. Heavier stars will end their lives as supernovae.

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.

Stars over 8 times the mass of the sun end their lives as supernovae and make neutron stars and black holes. Essentially all the elements except for hydrogen and helium have been made in stars with the bulk of the synthesis occurring in supernovae.

Because of this ongoing synthesis the metal content of the galaxy gradually rises.

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

I	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

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

velocity of sun around GC inferred by 21 cm - 220 km/s

II. Fundamental astrophysics

Force

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

Strong	bind nuclei
Electric*	chemistry
Weak	$n \rightarrow p + e + \nu$
Gravity*	falling down

Kepler's three laws

Planetary orbits are ellipses sun - at one focus
Equal areas in equal times swept out by line connecting
 P^{**2} proportional to a^{**3}

Meaning of centrifugal force

Kepler's Third Law

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

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 - v outside sun's orbit does not decline like $1/\sqrt{r}$

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, rotational, thermal

Definition of temperature - measures random kinetic energy

Objects falling freely from infinity impact at the escape velocity
 $\sqrt{2GM/r}$

Definition of Gravitational binding energy (about $3/5 GM^2/r$)

Definition of the Kelvin Helmholtz time scale 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 = $1/\text{parallax angle in arc sec}$

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. Very bright stars. Once calibrated can use for large distances - up to Mpc and more. Historical problem with calibration.

Flux, luminosity, and standard candles

Flux is $L/(4\pi d^2)$

Measured using magnitudes (m)

5 magnitudes is a factor of 100 in flux

6th magnitude is faintest 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

$$M = m + 5 - 5 \log d(\text{in pc})$$

to get actual luminosity from measured M, apply corrections

bolometric (BC)

reddening (RC)

Once know M_{bol} can get L (don't need to remember eqn)

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 M_{bol} 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) \rightarrow 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

Other standard candles

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.

Tully Fisher relation

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

thus

are more luminous

Hubble's Law and the age of the universe

$v = H_0 d$ -- 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_0 is not a

constant.

By looking at the evolution of H_0 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 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.

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 of 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 300,000 years after the universe when the temperature declined to about 6000 K and the universe became transparent to radiation.

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. $E = h \cdot \nu$
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 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 $\lambda_{\max} = 0.289 \text{ cm}/T$ (Wien's law)

A blackbody emits radiation at a rate per cm^2 of σT_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 $\lambda = h/\text{momentum}$. 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.

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 Å.

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.

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
- H₂ 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 ($\lambda_{\text{max}} = 0.289 \text{ cm/T}$)

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.

$P^2 \propto (Total\ separation)^3 / (M_1 + M_2)$
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.

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
0.08 Msun (threshold for nuclear ignition)