Key concepts for Nov 10, 2011 ASTR 100 exam

Note: as before, *everything* in the class since the last exam is fair game, as are basic concepts from before such as gravity. Thus anything in lecture, discussion, homeworks, or our textbook could be used. The following are key concepts to help you focus your studies.

- Content of the Solar System: small, rocky planets close; big, gaseous planets far away; rocky asteroids close-ish; icy comets farther away.
- Formation of the Solar System: originally a diffuse nebula came together by gravity (spinning faster as it contracted, because of angular momentum conservation). The spin flattened the matter, which is why all the major planets orbit in the same direction and in the same plane. Small grains within the nebula came together to form bigger grains, pebbles, boulders, up to the planetesimals whose collisions finally made the planets. A major late collision formed our Moon. Inside the *frost line* no ices can form, so the inner planets could only form grains out of metallic and rocky elements. Outside this line, water ices and other ices could form. There is much more hydrogen than rocky or metallic elements, so the outer planets had a bigger supply of mass and grew larger.
- More than 1,000 planets have now been detected around other stars. These are seen either by the motion their gravity induces on their host star, or by the periodic dimming of light when the planet passes in front of the star. It is much easier to see large, massive planets that are close to their star than small or distant planets; this is an example of a *selection effect*.
- Light is more than what is visible to our eyes; indeed, more generally electromagnetic radiation comes in all wavelengths and provides us with almost all our information about the universe. Shorter wavelength light has more energy per photon (a light "particle") than longer wavelength light. Light interacts with matter in various ways. It can be emitted by matter; absorbed by matter; transmitted by matter; or scattered by matter.
- Dense matter emits *thermal* radiation: this extends over all wavelengths (equivalently, over all frequencies), and hotter things emit more energy *per area* per time than cooler things at *all* wavelengths. In addition, the thermal spectra of hotter things peak at shorter wavelengths than the thermal spectra of cooler things: this is quantified by Wien's Law $\lambda_p T = 2.9 \times 10^6$ nm K, where "nm" means nanometer (10^{-9} of a meter) and K is Kelvin. A spherical object of radius R and temperature T emits a total luminosity L (energy per time) of $L = 4\pi R^2 \sigma T^4$, where σ is a constant. This is the Stefan-Boltzmann Law.

- Light spreads out from its source. At a distance d from a source of luminosity L that emits equally in all directions, the brightness b we see (energy per area per time) is given by $b = L/(4\pi d^2)$.
- There are three basic types of spectra, and a given spectrum is usually a combination of the types. Continuous spectra extend over all wavelengths. Emission spectra show sharp peaks above the continuum, and are typically produced by hot, tenuous gas. Absorption spectra show sharp dips below the continuum, and are typically produced by cold, tenuous gas in front of a continuum source. The particular wavelengths of the peaks are the same as the corresponding dips if the material is the same. In both cases, the specific wavelengths correspond to the energy transitions allowed in the atoms or molecules of the substance. Each type of atom, and each type of molecule, has unique energy levels, hence there are unique wavelengths of the photons that can jump between those levels. The particular levels we see depend on which electrons are around, if we are looking at atomic lines; in a hot environment, some electrons can be stripped. Molecules can vibrate or rotate as well as having the electron transitions in atoms; these vibrations or rotations also produce lines, but at longer wavelength (hence lower energy) than electron transitions.
- An object moving towards or away from us presents lines that are shifted compared to their wavelengths with no motion. If the object moves towards us, the wavelengths are shorter and this is called a *blueshift*. If away from us, the wavelengths are longer and this is called a *redshift*. These shifts, also called Doppler shifts, have been used to discover hundreds of extrasolar planets.
- Telescopes augment our eyes in many ways: (1) they are much bigger, so they collect more light, (2) they have better angular resolution, meaning that they can distinguish objects that blend to our eyes, (3) they can see other wavelengths than our eyes, and (4) they can record what they see, for later analysis. Telescopes on the ground are hampered by our atmosphere; for many wavelengths (e.g., X-ray and gamma-ray) the atmosphere completely blocks the radiation, but even for optical wavelengths there is distortion.
- Our Sun is powered by nuclear fusion in its core, which has a temperature of about 15,000,000 degrees Kelvin. This energy moves outward, mainly in the form of photons in the inner part, but by convection (gas motion) in the outer part. The Sun is held up against gravity by pressure forces, and is thus in *hydrostatic equilibrium*. The part of the Sun we see is the *photosphere*. Parts that are farther out are the chromosphere and corona (very hot, but tenuous), and the Sun sends out a tenuous flow of charged particles called the *solar wind*.
- Stars spend most of their lives on the *main sequence*, which is seen as a track on the *Hertzsprung-Russell* or H-R diagram, which plots luminosity (increasing upward)

against temperature (increasing to the left). Stars on the main sequence are fusing hydrogen to helium in their cores. These stars have a wide range of properties: masses from 0.08 to ∼100 times our Sun's mass, temperatures from ∼3,000 to ∼50,000 K, luminosities from $\sim 10^{-4}$ to 10^{6} times our Sun's, and radii from ~ 0.1 to ~ 10 times our Sun's. The spectral types of stars, running from hottest to coolest, are O B A F G K M (Oh, Be A Fine Girl/Guy, Kiss Me, or whatever your best mnemonic is!). The H-R diagram is extremely useful: it shows the temperature, color, spectral type, luminosity, and radius of stars, and is a key to understanding the evolution of stars and the ages of star clusters. A star's mass at birth is its destiny! More mass means bigger, brighter, hotter, and shorter-living.

- Most stars are in *binaries*, where they are in a mutual orbit with one other star, or in multiple star systems, where they have more than one companion. Types of binary system are *visual* (you can see two stars), *eclipsing* (each star passes in front of the other during their orbit), and/or *spectroscopic* (the spectral lines shift because of their motion and the Doppler effect). Binary systems allow us to determine stellar masses.
- When stars that start their lives with less than about eight times the mass of our Sun run out of core hydrogen, they move off the main sequence and become large, cool, but luminous objects called *red giants*. This stage lasts a comparatively short time, then the star settles down to become a small, hot, but low-luminosity object roughly the size of Earth called a *white dwarf*. These are very dense objects that are held up by *degeneracy pressure* rather than generation of energy in their interiors; they may stay in that state, cooling gradually, forever.