Summary of Lecture 15

Key points include:

1. Reminder: spectra of astronomical objects usually combine three types: (a) continuum spectrum (broad and smooth), (b) emission line spectrum (lines sticking above the broad smooth region), (c) absorption line spectrum (narrow lines dipping below the broad smooth region).

2. Reminder of Kirchoff's laws: (a) hot, dense objects emit a continuous spectrum, (b) hot, diffuse gas produces an emission line spectrum, (c) a cool gas obscuring a continuum source will absorb specific wavelengths and thus produce an absorption line spectrum.

3. A given atom or molecule has particular intrinsic wavelengths at which it emits or absorbs. These wavelengths act as a signature: you can learn about the composition of stars and other objects if you can identify those wavelengths.

4. Atoms are defined by the number of protons in their nucleus. For example, hydrogen has one proton, helium has two protons, and carbon has six protons. The number of protons is the *atomic number*. The *atomic mass* (or atomic mass number) is the total number of protons plus neutrons in an atom.

5. An *isotope* of an atom has a particular number of neutrons. For example, the normal isotope of hydrogen has no neutrons in addition to its one proton. Deuterium, which is an isotope of hydrogen, has a proton plus one neutron. The normal isotope of carbon has six neutrons in addition to its six protons. A rarer isotope of carbon has seven neutrons in addition to its six protons. The isotope is often indicated by a number up and to the left of the symbol for an atom. For example, normal hydrogen is ^{1}H, deuterium is ^{2}H (because the atomic mass is 2), normal carbon is ^{12}C, carbon with seven neutrons is ^{13}C, and so on.

6. Some nuclei are *unstable* and undergo spontaneous *radioactive decay*. For example, ^{14}C (carbon with eight neutrons; you would say this as "carbon 14") decays over thousands of years to ^{14}N (i.e., nitrogen 14). Decay is random for any given nucleus, but for a population of nuclei we talk about the *half-life*, which is the time over which we expect half of a large sample of the nuclei to decay. For instance, the half-life of ^{14}C is about 5700 years, which means that after 5700 years half of the ^{14}C in a given sample will have decayed; after $2 \times 5700 = 11400$ years, 3/4 of the original sample will have decayed; after $3 \times 5700 = 17100$ years, 7/8 of the original sample will have decayed; and so on. Note that the randomness of decay means that the probability of survival is independent of how long the nucleus has existed. That does not work, for example,

for human lifetimes; if half of people survive to 80 years old, that does not mean that a quarter will survive to 160 years and an eighth will survive to 240 years!

7. Finally, although a normal atom has the same number of electrons as protons (and is thus electrically neutral), atoms can have fewer electrons than protons, or more electrons than protons. All of these changes (more or fewer electrons than protons, more or fewer neutrons than normal for a given atom) change the signature wavelengths of emission or absorption.
8. Moreover, the signature wavelengths shift if the atom is coming toward us or moving away from us. This is called a *Doppler shift*. This happens by the same *factor* for every wavelength. For example, if a star is moving away from us such that one wavelength is 10% longer than normal, *all* wavelengths will be 10% longer than normal. Thus the same *pattern* of wavelengths is maintained when there is relative motion.
9. You can also have a blend of motions; for example, if the gas is hot, then some atoms will move toward us (decreasing the wavelength) and some will move away from us (increasing the wavelength). Combined, this means that although an emission or absorption line will be sharp if it is from one atom, from many atoms it can be smeared out, or broadened. This broadening can also happen if the emitting/absorbing matter has enough density that atoms bump into each other.
10. All of this combined means that you can tell an *enormous* amount about an astronomical system from its spectrum: the system's composition, temperature, density, relative motion from us, and other things. That's how we can learn so much about the universe even though (thankfully!) we're not close enough to experiment with stars and other things.