Lecture Outline: Spectroscopy (Ch. 4 + sec. 3.5)

Please note that these are just an outline of the lectures and a guide to the textbook. The material will be covered in much more detail in class. Also, this is a little tentative, being put online so that you can have already have them before you attend lectures and then "fill them in' during class.

We will cover most of the material, but in a somewhat different order than the textbook.

First, we consider a property of wave motion, the Doppler effect, that allows us to determine how fast something is moving.

Doppler Effect (sec. 3.5): one of most useful and important techniques used in all of astronomy. We will encounter it again and again—it is part of how we determine the speeds and masses of objects in the universe, it is the primary method by which planets outside our solar system have been found, and it is the key to discovering the expansion of our universe and probing its early history.

Wavelength (or frequency) of a wave depends on the relative *radial* speed of the source and observer.

Radial motion means: motion towards or away; along the line of sight. The Doppler effect involves *only* this component of motion.

Moving away: wavelengths increase ("redshift")
Moving toward: wavelengths decrease ("blueshift")

Shift in $\lambda \propto$ radial velocity ⇒ this is how we get speeds of cosmic objects, stars, galaxies, even expansion of universe.

Actual formula is:

$$\lambda(\text{apparent})/\lambda(\text{true}) = 1 + (\text{vel./speed of light})$$

For most objects in the universe, this relative shift is tiny, so we can't detect it using the "shift" of the whole spectrum. But we *can* use places in the spectrum whose wavelengths are precisely known ⇒ spectral lines (the subject of Chapter 4).

<u>Spectral lines</u>—very narrow, well-defined wavelength/frequency regions in the spectrum where excess photon energy appears (<u>emission lines</u>) or else where photons are missing (<u>absorption lines</u>).

Often these lines are superimposed on a smooth, "continuous" spectrum, which is the near-blackbody emission of a heated object that we discussed in connection with Ch. 3.

Illustrated on board in class and in textbook.

The wavelengths, shapes, and strengths of these "spectral lines" are the keys to understanding many of the physical properties of planets, stars and galaxies.

<u>Your goal</u>: to understand physically how these spectral lines come about due to the internal structure of atoms and molecules, and how they can be used to learn about many physical properties of astronomical objects, like their temperature, radial velocity, composition, even rotation speed and (in a few cases) magnetic field strength.

Most important thing to understand: <u>atomic structure</u> and how photons can interact with atoms.

- ➨ ***Quantized* electron orbits (see Figs. 4-8 to 4-10)**

- ➨ **Ground state**

- ➨ **Excited states**

- ➨ **Ionization**

Emission and absorption lines explained (class discussion). This material is covered in sec. 4.1, 4.2. Before the causes of these "lines" were understood, they were described by "Kirchoff's laws"; but you don't have to memorize these "laws," only understand why they come about. I will show you more pictures to illustrate this.

The most basic idea is that electrons can be "excited" to higher levels (after which they decay back to a lower level, emitting a photon of a *well-defined energy that corresponds to the change in energy of the electron) either* by collisions (e.g. in a hot tenuous gas—these are emission lines) or by absorbing photons (e.g. in the atmospheres of stars—these are absorption lines).

We will discuss hydrogen (see p. 93-94) because of its simplicity, but the same principles apply to all atoms. They just have more electrons, and so have many more complicated possibilities for spectral lines. (Example: iron shows something like 100 thousand absorption lines in the Sun's spectrum.)

(You will not need to understand the *specifics* of "More Precisely 4-1" on pp. 90-91 for the exam, but I do expect you to get the basic idea. Read Discovery 4-1, but I will not test you on it.)

I think you should be able to understand and explain the relation between the different electron transitions that can occur in hydrogen (e.g. Lyman series, Balmer series, …) and the patterns of spectral lines that are seen in the spectrum.

Lyman series: spectral lines that correspond to all electgron transitions that begin or end on the lowest electron orbital.

Balmer series: same, but begins or ends on next-highest (in energy) orbital.

Molecules—can only exist at relatively low temperatures (less than roughly 3000 ^{O}K); at higher temperatures their bonds are broken by collisions with other particles. So we see spectral lines of molecules in the coolest stars (Sun = 6000K, so only very weak molecular lines), planets (surface temperatures ~ few hundred K), and in the gas clouds between the stars where stars form (temperatures ~ 10 to 100 K).

Besides electron transitions (like in atoms), molecules also vibrate and rotate (see Fig. 4.13).

The energies of these motions are also quantized, leading to more kinds of spectral lines in different wavelength ranges.

Vibrational transitions—usually in the infrared part of the spectrum.

Rotational transitions—usually in the radio part of the spectrum.

Why do electronic, vibrational, and rotational molecular spectral lines occur in such different spectral regions?

What can be learned from a spectral line?

First: the identity of the element (or molecule) giving rise to it.

Each chemical element has a particular, recognizable spectral line signature at particular wavelengths. This pattern of wavelengths is like a map of the possible transitions of electrons within atoms corresponding to each chemical element. These wavelengths are known by heating gases of all the different elements in the laboratory and recording the spectra.

So it is *easy* to identify the chemical element causing a given spectral line, just from the line's central, or peak, wavelength.

Spectral line analysis:

Wavelength—besides the identity of the atom or molecule, get radial velocity from Doppler effect. (Review this if it is not clear; notice that without spectral lines we would not be able to get the speeds at which most objects in the universe move! Later you will see that most of our current understanding of the beginnings of the universe comes from using spectral lines to get speeds from the Doppler effect.)

Intensity (or "strength")—gives composition (or "abundance") of emitting gas, and its temperature. An important thing to understand is why the intensities of spectral lines are usually more sensitive to the temperature than the abundances of the elements that cause the lines.

<u>Width and shape</u> ("line profile")—a number of effects broaden spectral lines:

Thermal motions (see. Fig.4-17)

Turbulent motions

Rotation (see Fig. 4-18)

Atomic collisions

Magnetic fields

Notice that many (not all) of these are directly due to the Doppler effect.