Astronomy 10 **Spring 2006**

Emission and Absorption and Scattering, Oh My!

1. Stars and clouds

In much of the local part of our galaxy there are two major types of objects that we detect: stars and clouds. We already talked about the different types of stars and different stages of a star's life, but for today's discussion we'll lump all those together and just consider main sequence stars.

As for the spectral type of the stars, it won't really make a difference. However, to make our lives a little easier we'll consider just two stars, a hot one and a cool one. Let's call them Star B (with a surface temperature around 10,000K) and Star G (with a surface temperature around 5000K). Why did I choose these names?

Plot the intensity versus wavelength of both stars on the same axes (you don't have to be ridiculously accurate but recall that stars are blackbodies and that we have specified the temperatures of our two stars). Also label which curve goes with which star. You should easily be able to figure out where the two blackbody curves peak (that is if you remember Wien's Law, look it up if you don't). Also, be sure to label the wavelength axis of your plot with actual numbers (the intensity axis does not need labels). These should be **blackbody curves**.

As for the clouds, they can be made of dust or hydrogen gas, they are usually relatively thin (low density), they are relatively cool (usually cooler than stars, but not necessarily so), and they do not create their own light (they would be completely dark if not for the light of a nearby star).

Let's take two different clouds and assume they're both made of mostly hydrogen. One we will call Cloud H, the hotter one (with an average temperature of about 7000K), and the other one we'll call Cloud C, the cooler one of course (with an average temperature of about 3000K). Since these clouds don't create their own light, they must be getting their temperatures from the light given off by some nearby star.

If the nearby star and cloud aren't both aligned along our line of sight, we don't observe anything like a blackbody spectrum from the cloud. However, since both clouds are mostly made up of an element we all know and love and they have a non-zero temperature we expect to see "hydrogen lines" in the clouds' spectra. The important lines that fall into the visible part of the spectrum are at wavelengths of: 656nm, 486nm, 434nm, and 410nm. The other important fact to realize is that these spectral lines will look brighter if they're coming from a hotter object.[1]

[1] In reality the exact temperature dictates what spectral lines are present and which ones are missing, as well as how bright they appear, but for the purpose of this worksheet let's assume that both clouds will be able to show the four spectral lines listed and that they will be brighter with higher temperatures.

Draw a (simple) schematic picture of our setup where you label where we're observing from, the cloud itself, and the nearby star that is heating up the cloud. Why do I keep referring to these things as lines? Plot the intensity versus wavelength of both clouds on the same axes and label which set of spikes goes with which star. Again, be sure to label the wavelength axis of your plot with actual numbers (the intensity axis does not need labels). Why did I use the phrase 'set of spikes' as opposed to 'curve' or 'line'? These are **emission nebulae**.

If the hydrogen line at 656nm is by far the strongest hydrogen line in most emission nebulae clouds, what do you expect the usual color of emission nebulae to be?

Now here's where it can get tricky. If the nearby star and cloud *do* both lie along our line of sight, we will see the blackbody spectrum of the star, but it will be modified by the cloud that is between our telescope and the star itself. We learned that the luminosity (intensity) of a blackbody is related to both its temperature and radius. What is this relationship?

At this point we will ignore the difference in size between Star B and Star G (one is bigger, but not by all that much, which one?) and we will assume that Cloud H and Cloud C are also about the same size as our stars. With these assumptions, which is the brighter star? Which cloud has brighter spectral lines?

Draw a (simple) schematic picture of our setup where you label where we're observing from, the cloud itself, and the nearby star that is heating up the cloud. Draw all four possible combinations of star and cloud.

Plot the intensity versus wavelength of the setup where Star G is behind Cloud H. Again, be sure to label the wavelength axis of your plot with actual numbers (the intensity axis does not need labels). This is also known as an **emission nebula** (however this one has a blackbody continuum background). Where does this name come from?

Plot the intensity versus wavelength of the setup where Star B is behind Cloud C. Again, be sure to label the wavelength axis of your plot with actual numbers (the intensity axis does not need labels). This is an **absorption nebula**. Where does this name come from?

Label your four schematic diagrams at the end of the last page as either an **absorption** or **emission nebula**.

2. The Return of Rayleigh Scattering

Now we will consider a cloud like the ones above, but instead of being made of mostly hydrogen we will make it mostly consist of dust (grains of rock or ice about the size of the particles in cigarette smoke). The dust will *not* give off spectral lines like the hydrogen.[2] However, the dust *does* interact with the starlight that shines on these clouds. We can get a good idea about how the dust interacts with light using a very powerful, yet relatively simple analogy.

Light can be thought of as a wave, and like other types of waves, it interacts with obstacles that get in its way. Imagine you are on a small rowboat in the middle of the Bay, away from other boats or islands or the shore, and that the water is flat as a board calm (yes I realize this rarely happens, but hey, use your imagination). Now if a stupid seagull flies near your boat and poops, the poop drops into the water and causes little ripples (small water waves) to move outward along the water's surface in all directions. When the ripples (waves) get to your boat what happens (to both your boat as well as the part of the wave that hit your boat)?

Now imagine a blue whale suddenly appears in the sky right near you boat (anyone read *Hitchhiker's Guide to the Galaxy*?) and falls into the water. Again, this causes ripples (water waves) to move outward along the water's surface in all directions, albeit much

[2] Mainly due to the fact that the electrons that cause the hydrogen lines are all wrapped up in chemical bonds in the dust particles, but this is a minor detail you shouldn't really worry about.

larger waves. When the ripples (waves) get to your boat what happens (to both your boat as well as the part of the wave that hit your boat)?

Being the good scientist that you are, you realize that the first wave had a relatively small wavelength whereas the second wave had a fairly large wavelength (this second wavelength being about the size of the rowboat itself or even larger)! Now this isn't an exact analogy, but it always helps me to remember this basic physics result (called Rayleigh scattering): **shorter wavelength waves scatter more than longer wavelength waves**.

Now back to our cloud (Remember? Before the whole boat deal?). Here we're of course talking about light waves (as opposed to water waves), but the principle still holds.

A nearby star will shine light onto a thin cloud of dust and some of the light will be scattered (get bounced in all directions) by the dust particles and some of the light will travel straight though the cloud unimpeded. From our analogy, what color of the visible spectrum of light will be mostly bounced in all directions (scattered) and what color will travel mostly unimpeded straight through the cloud (transmitted)?

If we have a star sitting near a cloud of dust (but not directly behind it from our point of view). What color will the cloud appear to us? This is called a **reflection nebula**.

Use this result to explain why the sunny sky is blue and the sun at sunset is reddish. Use a diagram. (If you remember, we actually talked about this in section a month or so ago).

Milk Demo: What color do you see when there's no milk in the water?

After a little milk is added, what color do you see when the light is behind the water? To the side of the water?

After a lot of milk is added, what color do you see?

Again use Rayleigh scattering to explain your observations. Use a diagram.