Light: Properties

This is the most important and most difficult topic in the course. Trust me—you have no hope for doing well in the class if you don't get the basic ideas about light in Chapters 3 and 4.

Properties of Light (ch. 3 in text)

This is an extremely important topic, because the only things we can learn about objects and phenomena outside our solar system are learned by analyzing the light they send us. In a sense, *astronomy is all about how to collect, analyze, and interpret light.*

Can consider light as *waves* or as *particles*, depending on circumstance. (One of the "big mysteries" of physics.) Either way, it is common practice to call them "**photons**."

Light can be thought of as a wave that arises due to an oscillating (vibrating) electromagnetic field (see text). Unlike other kinds of waves, light does not require a material medium for its propagation (travel); light can propagate in a vacuum.

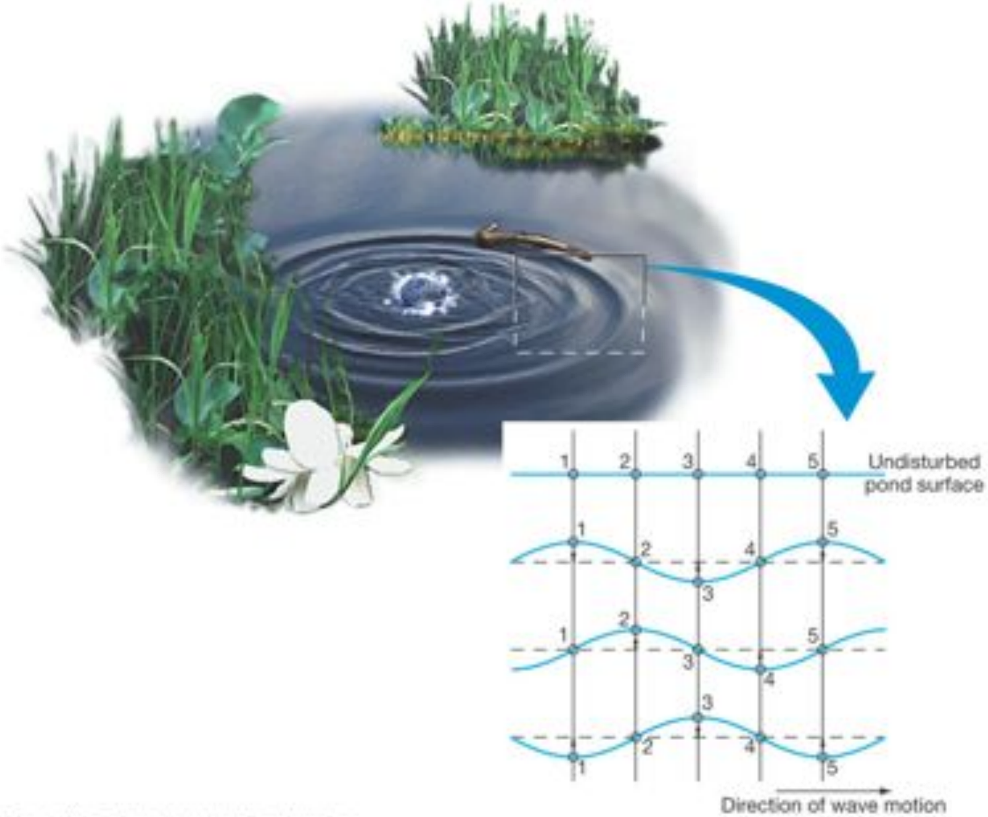
(Don't worry about "polarization" in text if it is confusing to you. It won't be on the exam.)

Waves: Need to understand and become familiar with the following properties of light (will discuss in class):

- **Wavelength**—Always denoted by Greek letter "λ" (lambda)
- **Frequency**—how many waves pass per second, denoted "f" or Greek "ν" (nu)
- **Speed**—All light waves travel at the same speed, the "speed of light", "c"(=$3x10^5$ km/sec = $2.86x10^5$ mi/sec (286,000 miles per second); no need to memorize these numbers!
- **Energy**--the energy of a photon is its frequency times its speed E = f x c

It is extremely important that students become familiar and comfortable with these terms and symbols--they will recur throughout the class. See pp. 65-66 of textbook, and illustration on next slide.

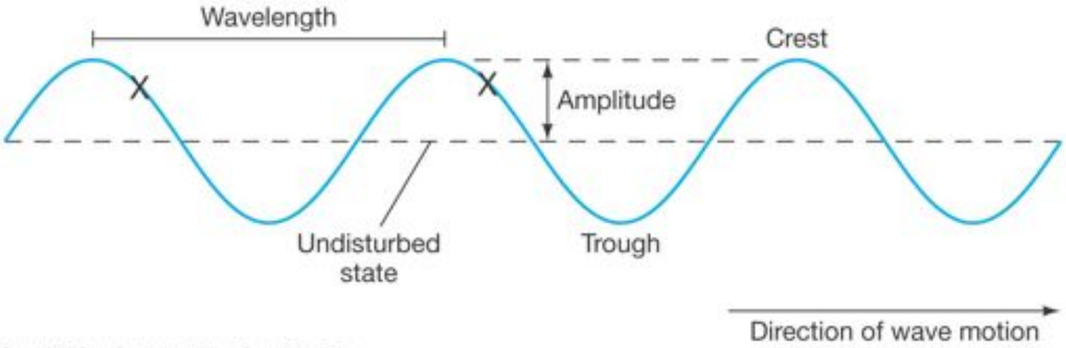
Illustrating wavelength, frequency



Imagine pebble dropped in pond: surface waves will appear to travel outward.

Distance between peaks or troughs = *wavelength*

How many peaks or troughs pass by you per second?
= *frequency*



→ The fact that light travels at a finite speed (“c”) means that we see distant objects as they were in the past.

Consider our neighbor, the Andromeda galaxy shown in Fig. 3.1 in your text—it is about 2 million light years away…

→ Later we will “look back” to times near the beginning of the universe (billions of years ago) using very distant galaxies.

Spectrum: → Possibly the most important term to understand in this course! It refers to the mixture of light of different wavelengths from a given source; best to remember it as a graph of “intensity” (or brightness) of radiation in each wavelength (or frequency) interval. See illustrations in sec. 3.3. Will discuss in class.

(Note: much of rest of class is concerned with analyzing the spectra of different types of astronomical objects—so *get used to the concept now.*)

Light from all objects covers an extremely large range of wavelengths (or frequencies), from radio waves to gamma rays. Memorize this list, and study figs. 3.4 and 3.9 carefully:

radio, infrared (IR), visible, ultraviolet (UV), x-rays, gamma rays

It lists the regions of electromagnetic spectrum, i.e. the classes of light, from smallest frequency (largest wavelength) to largest frequency (smallest wavelength). It also goes from *smallest energy* to *highest energy*.

The restriction of human wavelength sensitivity

Human vision is only sensitive to a very tiny fraction of all this radiation, the “visible” or “optical” part of the spectrum—astronomy in the last 50 years has been mostly concerned with getting *out* of this region. That is probably the single most important technical revolution in astronomy-- for most of this radiation you have to be above the Earth’s atmosphere.

Atmospheric absorption and “windows”

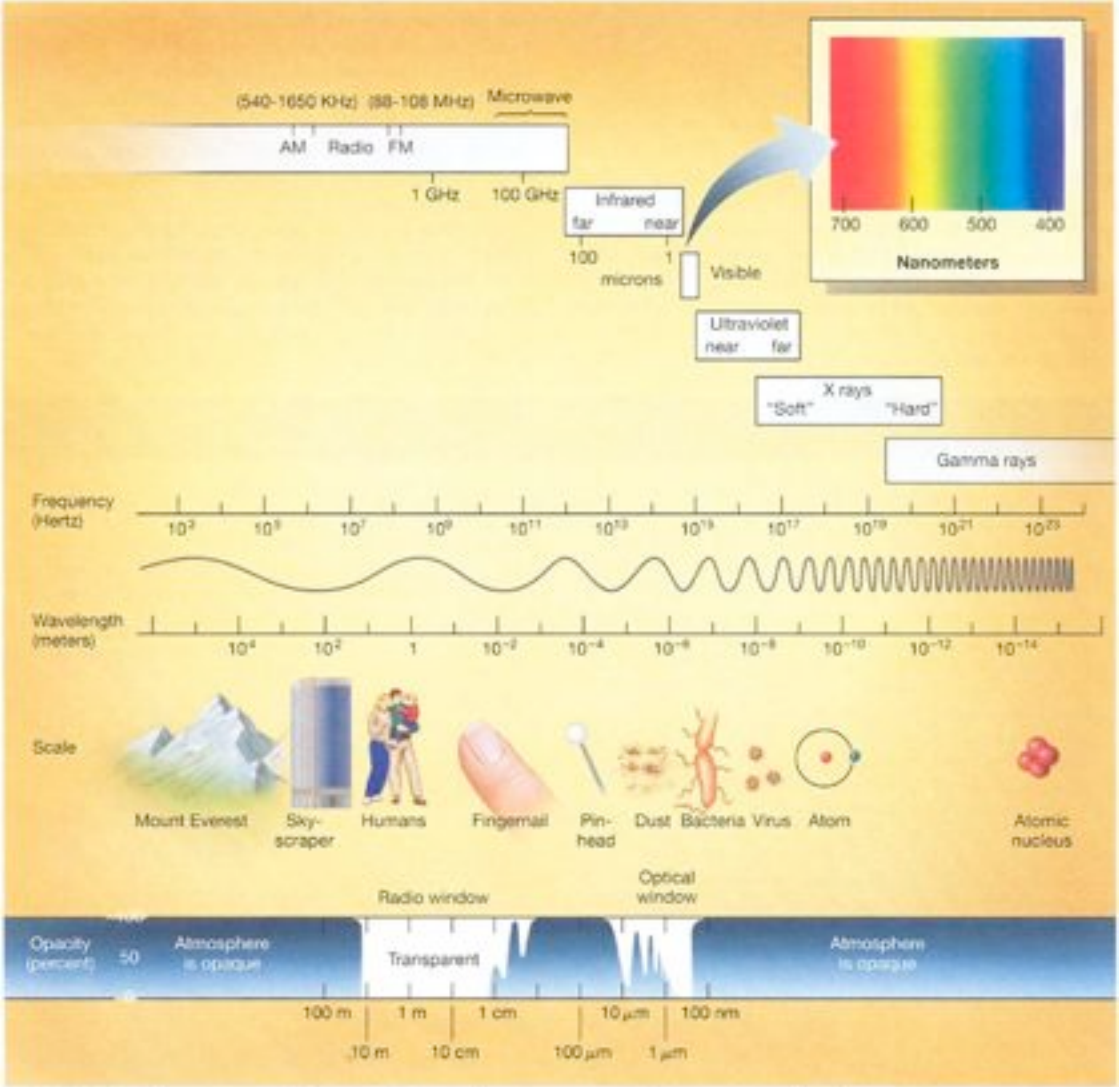
Earth’s atmosphere is very *opaque* (light can’t get through) except in the visible (also called “optical”) and radio parts of the spectrum (the so-called optical and radio “windows”). That’s why much of recent astronomy is done from satellites. See p. 70 of textbook on “atmospheric opacity” and get used to the word “opacity.”

Illustrations of the various wavelength regions

The illustration (from your text) on the next slide illustrates the different categories of light--please note that they are just historical conventions that are useful. But there is no definite “boundary” between, say, ultraviolet and x-rays, or infrared and radio. The next illustration is just an alternative presentation of the same information.

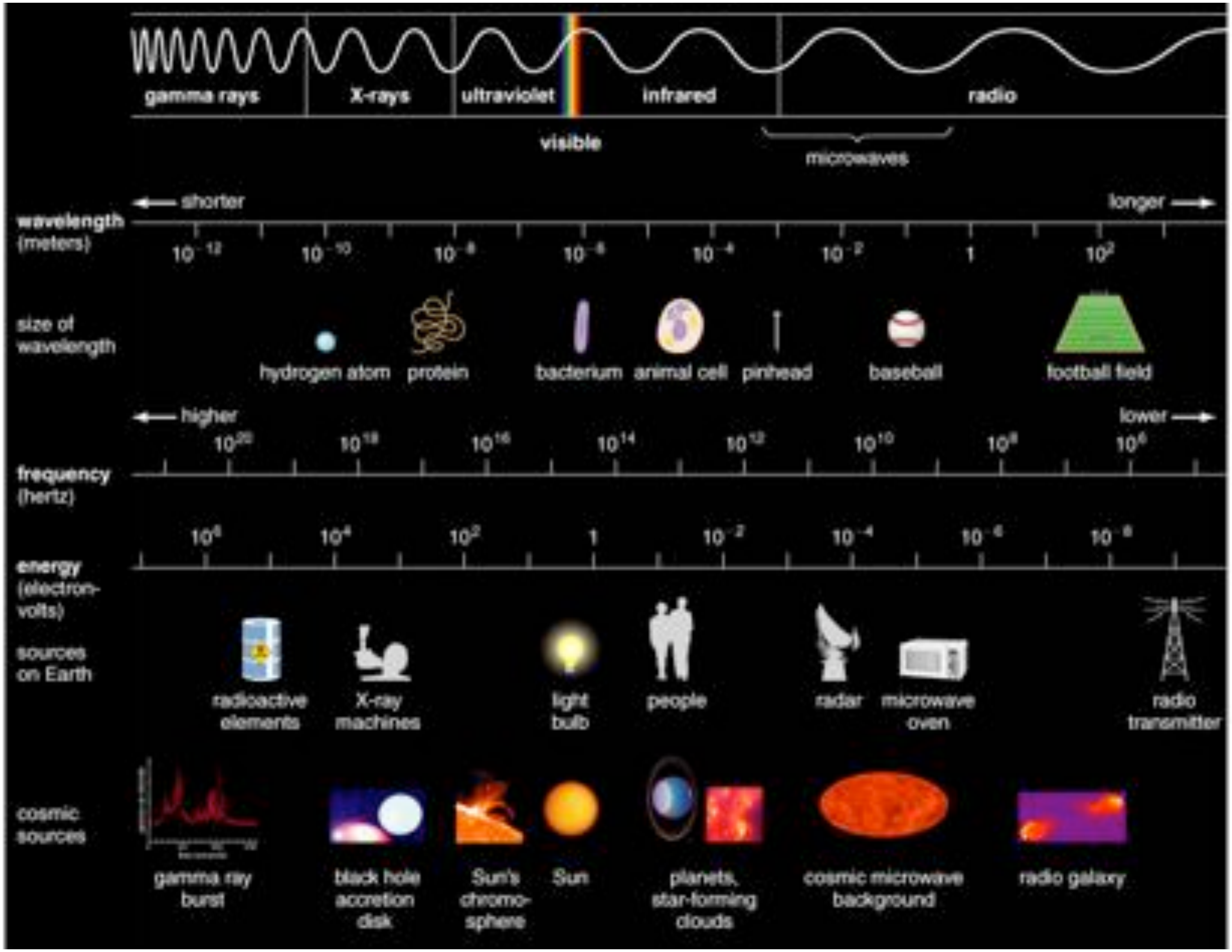
★The third illustration is worth studying: *Earth’s atmospheric windows*.

NOTE: The **units** of wavelength (e.g. Angstroms, nanometers, microns) and frequency (Hertz, MHz, GHz) are just something you have to get used to in order to understand the text and the lectures, but you will not be asked to manipulate or memorize them on exams. *However* do not ignore them either, or you’ll have much trouble reading the text or understanding lectures.



▲ **FIGURE 3.9 Electromagnetic Spectrum** The entire electromagnetic spectrum, running from long-wavelength, low-frequency radio waves to short-wavelength, high-frequency gamma rays.

The electromagnetic spectrum again



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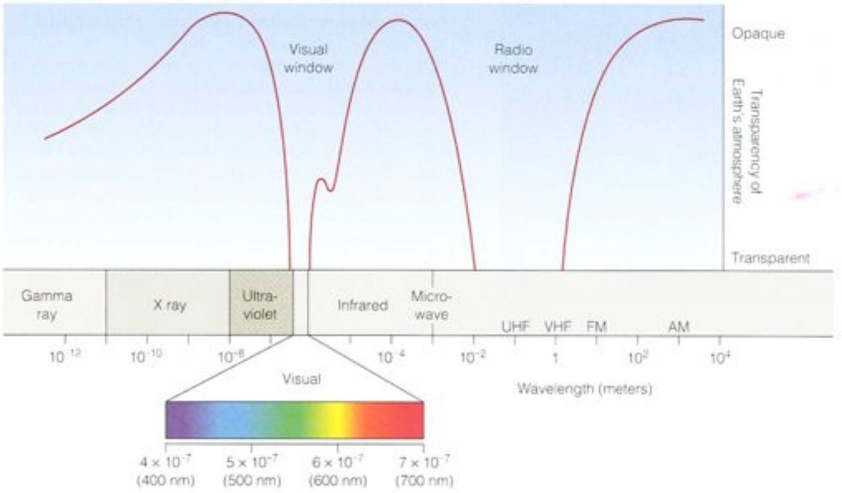
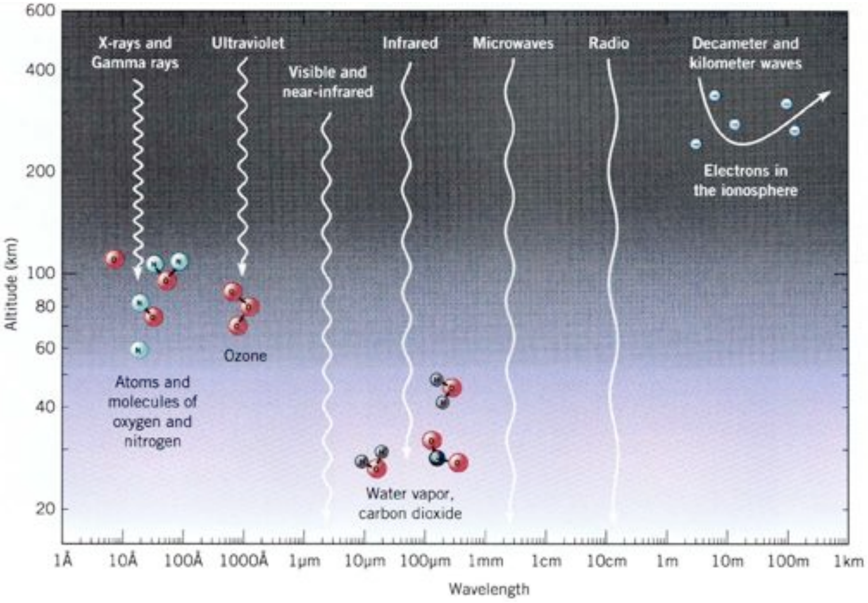




Spectra: what they are, why they are useful

(note-this is the beginning of a very long list of uses)

The ideas on the next few slides are indispensible for understanding nearly every astronomical phenomena, and so nearly every topic to be covered in this course.

Spectra of lemons and car tail lights

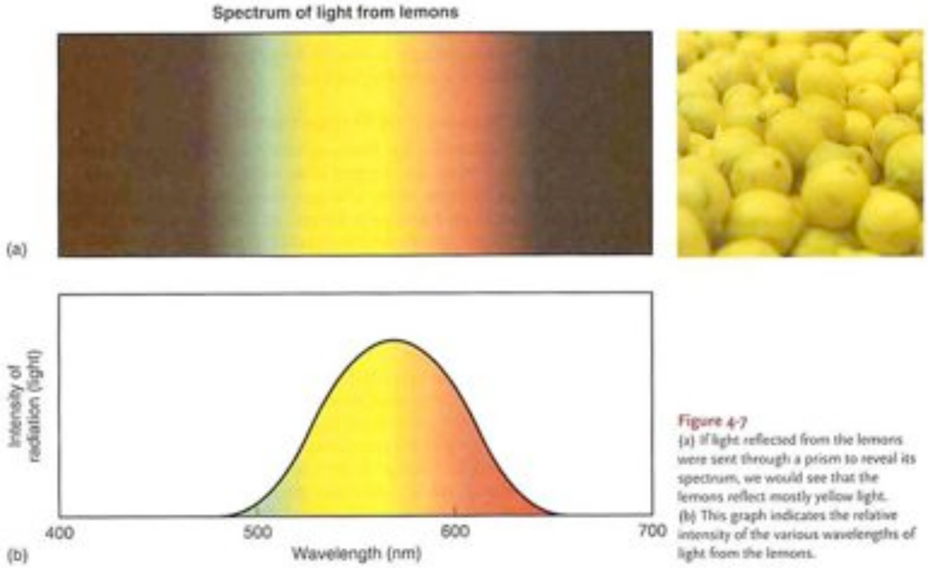


Figure 4-7
(a) If light reflected from the lemons were sent through a prism to reveal its spectrum, we would see that the lemons reflect mostly yellow light.
(b) This graph indicates the relative intensity of the various wavelengths of light from the lemons.

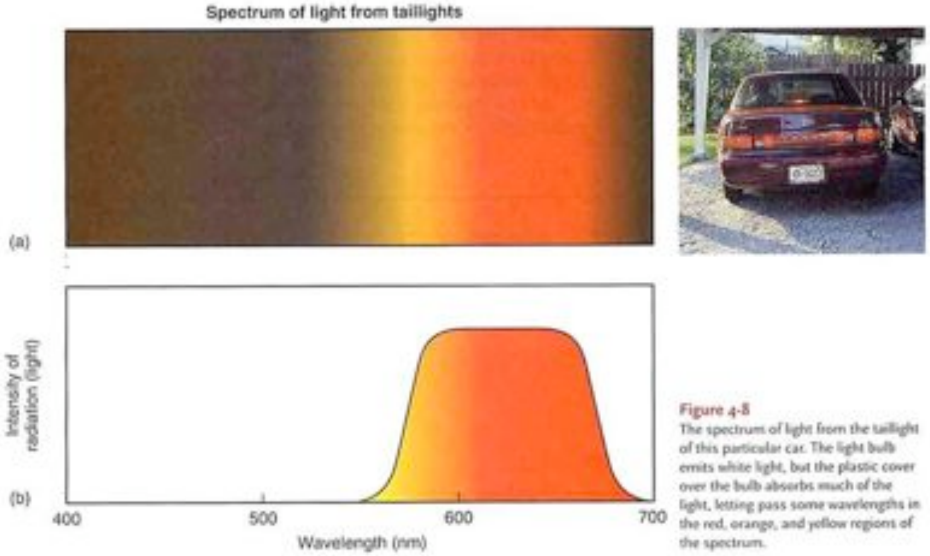


Figure 4-8
The spectrum of light from the taillight of this particular car. The light bulb emits white light, but the plastic cover over the bulb absorbs much of the light, letting pass some wavelengths in the red, orange, and yellow regions of the spectrum.

In each case the top picture shows how the spectrum appear in a *spectrometer*; *the bottom picture is a graph of the spectrum as intensity versus wavelength, which is how the idea should be understood.*

The first representation has vertical “bands” only because of the design of the instrument. You will see lots of these in your reading: Always try to think of them in terms of intensity vs. wavelength (or frequency) instead.

You will need to keep this in mind:
A “spectrum” is a graph showing the relative amount of light emitted as a function of wavelength.

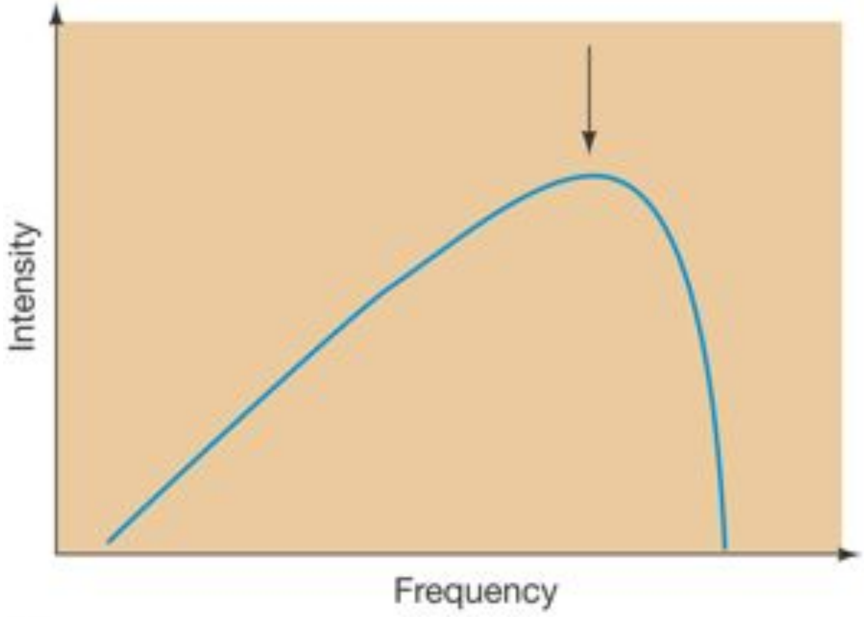
Black-Body Spectrum

A "black-body" (BB) is only a simplified mathematical model, but works surprisingly well for the continuous (smooth) spectra of objects. See Fig. 3.10 and graphs after this page.
The model predicts an equation for the *continuous* **spectrum** (intensity vs. wavelength or frequency--be sure you understand this word!) of such an ideal object, for any temperature.

"Continuous" means it is a smooth curve (compared to the "spectral lines" that real objects exhibit, and which we will study later, in Ch. 4).

The graph to the right is an example of a blackbody spectrum. It is smooth (continuous), with a peak at some definite frequency (wavelength). Understand it as showing the number of photons that are emitted by this object at each interval of frequency (wavelength)

This is the wavelength of peak emission that is called λ_{max}. Wien's law says that λ_{max} increases with decreasing temperature. Which direction is this on the graph below?



Two ways in which a BB can be related to temperature:

1. Wien's law: relates wavelength at which most energy is emitted in the spectrum ("wavelength of peak emission") to the temperature:

$$\lambda_{max} \sim 1/(\text{temperature of object})$$

So

hotter object → bluer, cooler object → redder.

You'll be surprised how often this simple result is used in astronomy.

→ *So we can get an object's surface temperature from the spectrum.* (See fig.3.11 in text)

2. Stefan's law: TOTAL energy E radiated at *all* wavelengths (*per unit surface area*, meaning per square inch, or per square meter, or per square anything) is related to the temperature by:

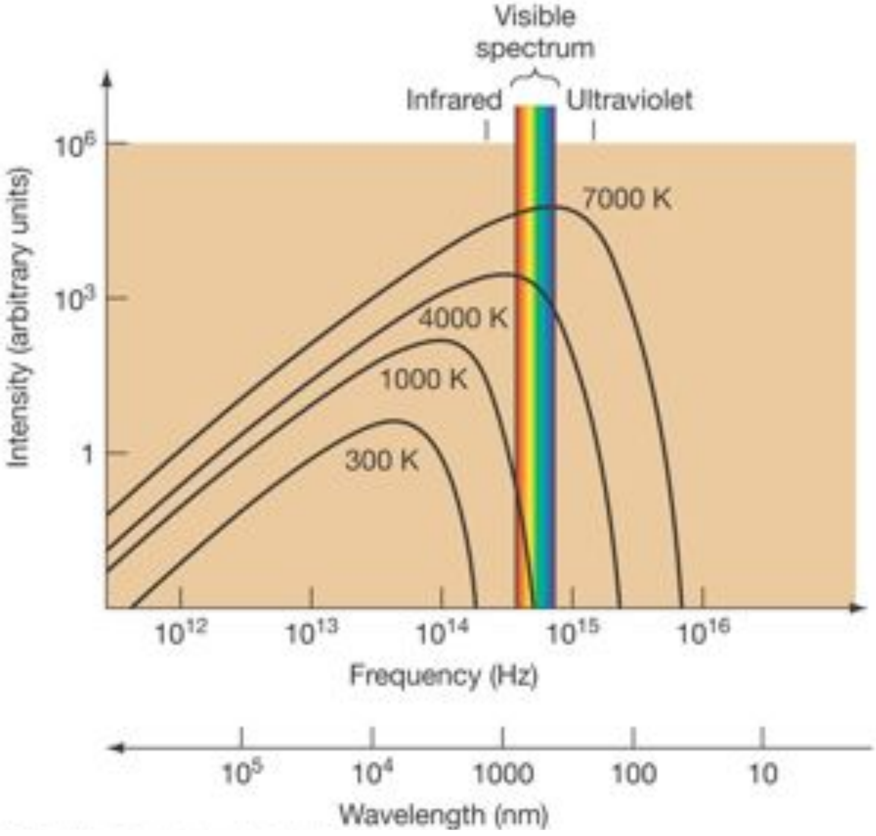
$E \sim (\text{temperature})^4$ → hotter objects will be brighter (per unit area)

Notice the steep temperature dependence!

→ *Make something a little hotter and it will become much brighter!* *(If it behaves like a BB.) Study Fig. 3.12 (BB curves for 4 cosmic objects) on next page.*

You have to know the two radiation laws listed above. I'll give you samples of how you may need to use them on an exam.

This graph shows blackbodies with four temperatures T. As T increases, λ_{max} decreases (Wien), and the total energy under each curve *increases* (Stefan-Boltzmann)

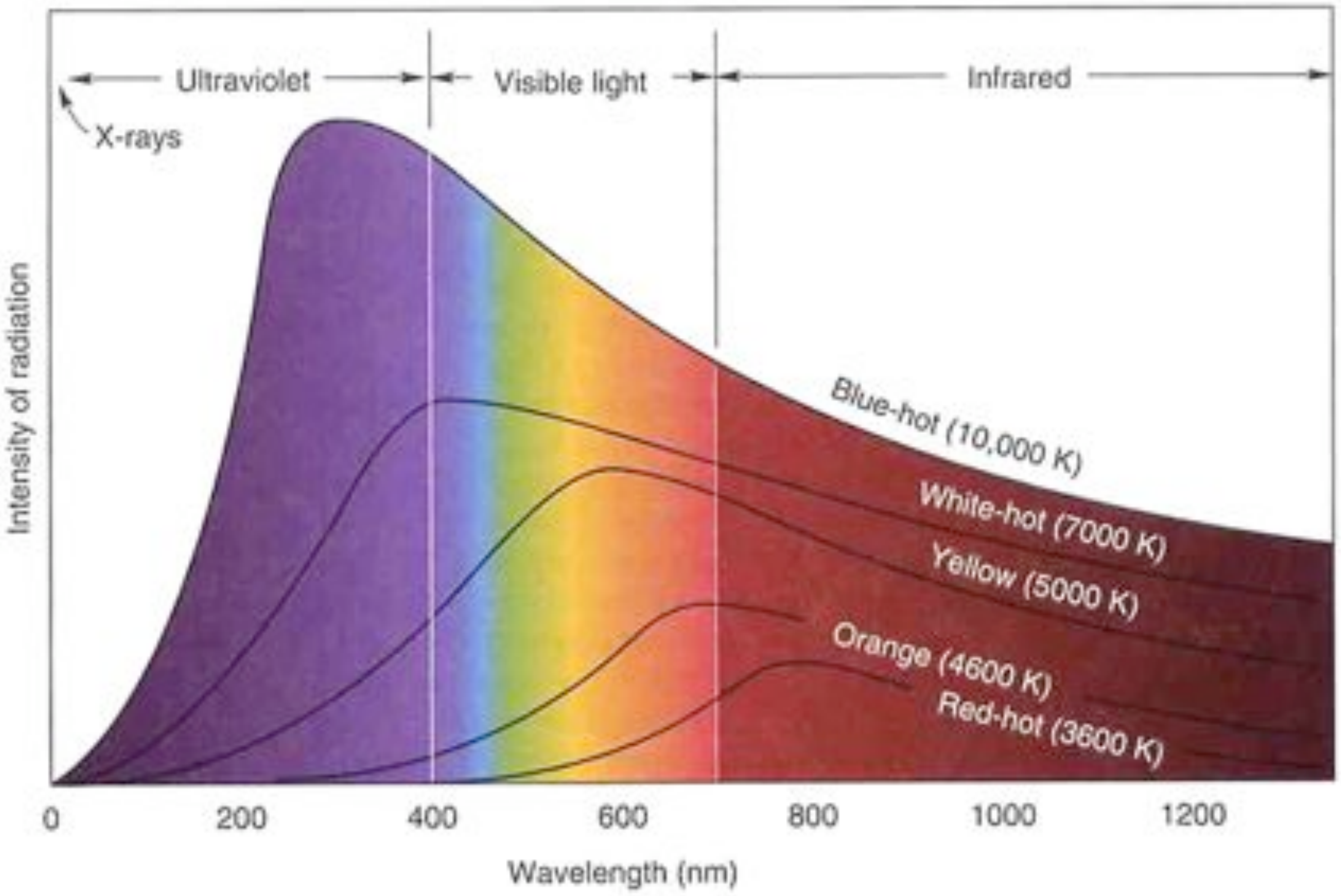


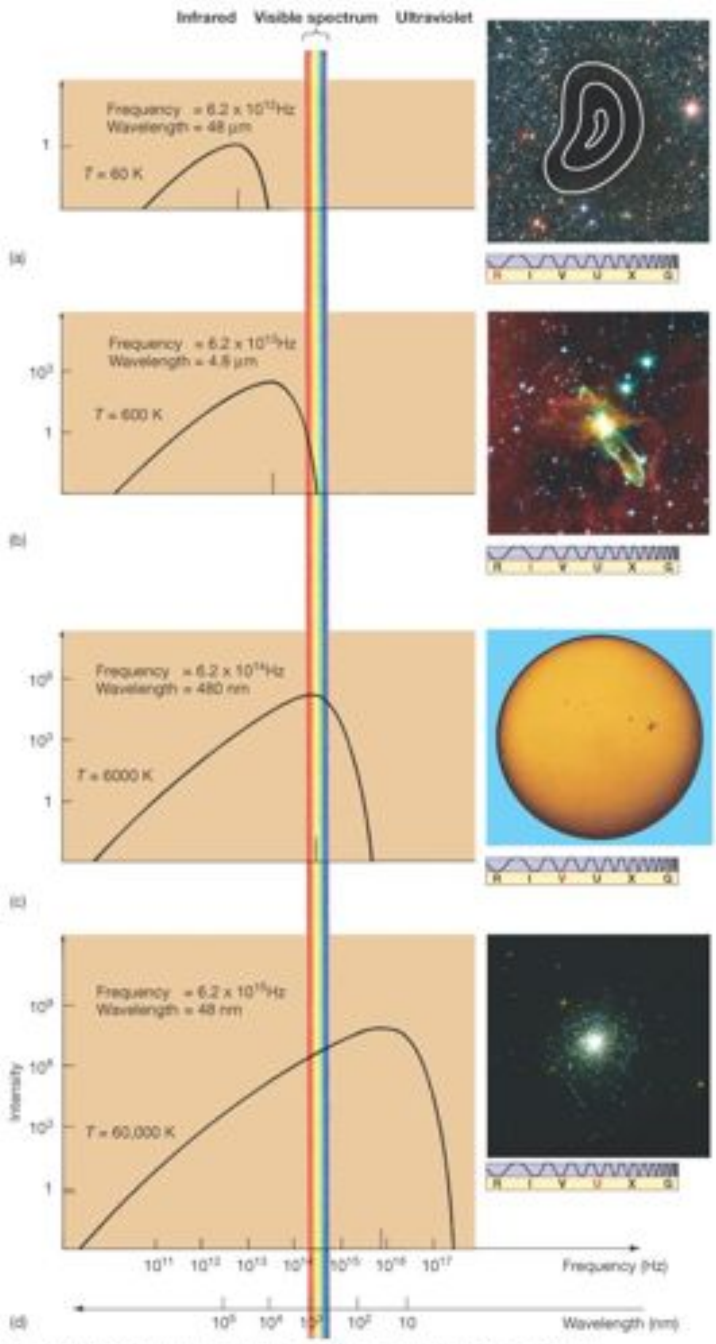
→ Which spectrum above could be the spectrum of an object at room temperature?

→ Which could be a star?

Blackbody Spectrum: figure below illustrates Wien's law and Stefan–Boltzmann law (again)

Rather than explaining how this figure illustrates those laws, thisis the place where you should see if you understand what we are talking about: Try to explain it yourself…





Blackbody spectra at the temperatures of four astronomical objects

Carefully compare the graphs with the temperatures given for each object.

Notice that the coolest of these is only 60 degrees above absolute zero, while the hottest is ten times hotter than the Sun’s surface.

At this point you should stop to see if you understand that the importance of “black bodies” is that it gives us a simple way to estimate the temperatures of things.

Then you should be asking yourself:
Why would we want to know the temperatures of stars, or anything, except out of pure curiosity?

We may SKIP THIS until exam 2

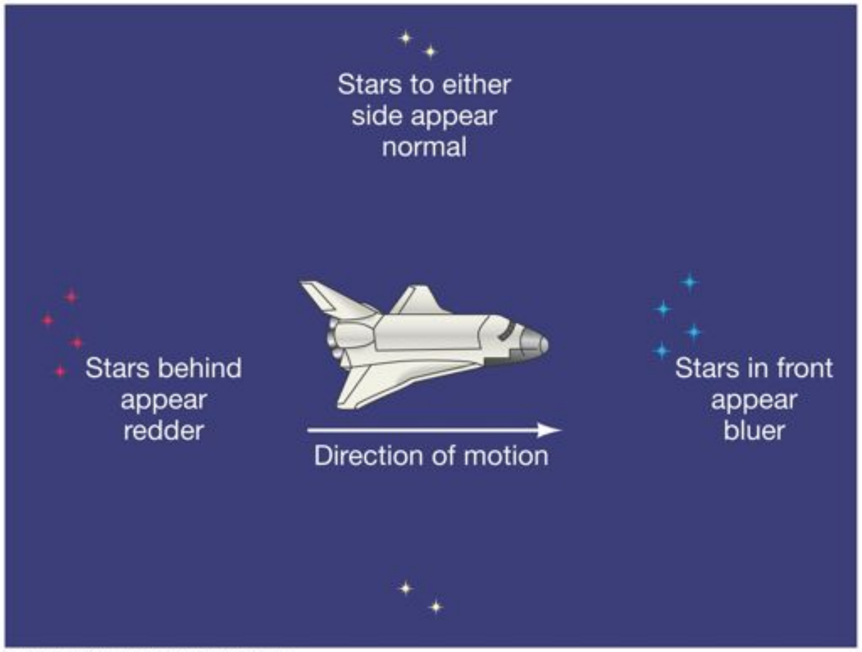
Doppler Effect : one of most useful and important techniques used in all of astronomy. We will encounter it again and again.

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, the *radial velocity.*

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



How the Doppler effect allows you to calculate how fast things are moving, and why you can't use it for a continuous spectrum?

Shift in wavelength gives radial velocity. This is how we get speeds of cosmic objects, stars, galaxies, even expansion of universe.

Actual formula is: λ(apparent)/ λ(true) = 1 ± (vel./speed of light)

where the ± sign means it is + if it is moving away from us (redshift, longer wavelength), - if it is moving toward us (blueshift, shorter wavelength)

Look at this formula: If velocity of object away or toward us is much less than the speed of light (true for almost all objects in the universe), the apparent wavelength will be only slightly different from the "laboratory" or "rest" wavelength.

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

End of material for exam 1