happens? What happens if you throw it even faster? What happens if you throw it so fast that it travels a large distance compared to the size of the Earth?
-Newton cannon applet. https://physics.weber.edu/schroeder/software/NewtonsCannon.html
Keeping this up eventually we get to the point where the cannonball is "falling" just as fast as the surface of the Earth is curving away from it (run applet to full circle)

The circular path around the earth occurs at a speed when the gravitational force is just what's needed to make them cannonball travel around in circular motion at constant speed.

For a small mass (cannonball) orbiting a much larger one (earth):

$$v_{circ} = \sqrt{\frac{GM_{earth}}{r}}$$

Where r is the distance from the earth's center

This is an approximation, but is accurate for any small mass orbiting any big mass, just substitute the big mass for Mearth

What if we keep increasing the speed? (show on applet)
-orbit gets elliptical
-slows down on way out, speeds up on way in (=Kepler II)
if launched fast enough, Fgrav can't turn it around→escape speed

$$v_{escape} = \sqrt{\frac{2GM_{earth}}{R}}$$

R= starting separation center to center (again, for escaping objects other than earth put in that mass for Mearth).

We can easily get a modified form of Kepler's third law from the circular velocity: there's an extra bit that comes in:

$$P^2 = \frac{4\pi^2 a^3}{G(m_1+m_2)}$$

for two objects m1 and m2 *orbiting each other*
Note: this is in SI/MKS units (not a.u.'s, not years, not solar masses). This is a purely metric relationship P=sec, M's=kg, a=meters

This also shows us that it's the total mass of the system that matters. For Kepler, he was dealing with the sun which is so much more massive than any of the planets that Msun+Mplanet is approximately Msun. But what if the two masses are nearly equal?
-air pucks tied with string
-binary star applet http://www.astro.ucla.edu/undergrad/astro3/orbits.html
-you can see that they are orbiting on ellipses with their common center of mass at the focus. This is like two figure skaters spinning around each other (explore effects of changing mass ratios in applet)

We will see that this form of Kepler's 3^{rd} law will help us determine the masses of stars other than the sun since we can often measure the period of binary star orbits and using our angular measure techniques can figure out what the semi-major axis is.

10/23/19

2/13/09

- Set up review
- Read Ch 2 through 2.3
- recap Newton's laws of motion and the relationship to Kepler's laws
    final form of modified Kepler's third law using years and a.u.'s and solar masses.
    $P^2=a^3/(M1+M2)$ M's in multiples of Msun
- Use binary star applet to show center of mass behavior.

- A related concept to the forces we've been talking about is the concept of energy.

We will talk about several different forms of energy during this course, here's an introduction to two:
1)Roll a ball into (pile of cups etc.)
-did the ball have energy?
-what kind of energy?
-$KE=1/2\ m\ v^2$
How does KE scale with m, v? (example m =5kg, v=10m/s)
Note: unit of energy in MKS system is Joule
Energy of motion (often referred to as kinetic energy)
2) roll the ball up the hill

- It started out with kinetic energy, did it have any kinetic energy at the top of its motion? (ke→0).
- Then what happened? (ke increases on the way back down).

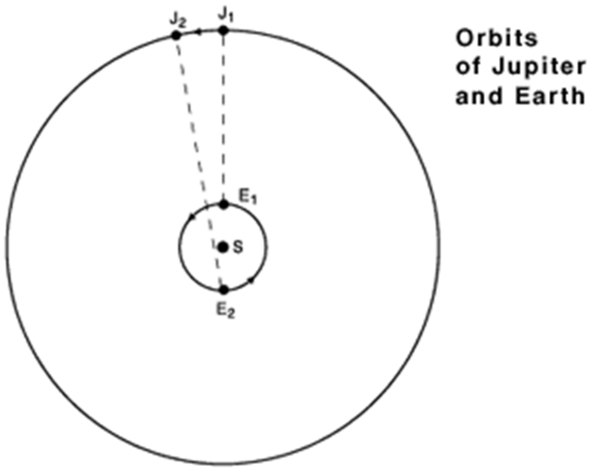
→This process represents a transformation of kinetic energy into stored energy and back to kinetic.
We call this stored energy potential energy.

This stored energy is due to the gravitational interaction between the Earth and the ball.
Rolling the ball up the hill increases the separation between the Earth and the ball.
The Earth plus ball system has potential energy.
Not all forces are associated with potential energy, but many are (gravity, electric forces, magnetic forces, spring forces). If these are the only forces acting (for example with no friction) sum of kinetic plus potential energy for a system is constant. We call this the conservation of mechanical energy.

Ch 2

Light and Matter
The primary way we know things about things in general is from seeing them. This is even more so in astronomy where, as we pointed out early on, we don't have a lot that we can investigate through controlled experiments. We can't remake the sun with a slightly different chemical composition etc.

So one obvious question is: what is this light stuff that we see by anyway?
That question has been asked for a long time.
People eventually decided that it was <u>something</u>. And that it traveled from place to place.
This made people wonder how fast it travels.
Really fast is the answer.
So fast that it took until about 1670 for anyone to get a decent measure of its speed. (Picture of Roemers method https://www.amnh.org/learn-teach/curriculum-collections/cosmic-horizons-book/ole-roemer-speed-of-light)



Roemer measured the speed of light by timing eclipses of Jupiter's moon Io. In this figure, S is the Sun, E1 is the Earth when closest to Jupiter (J1) and E2 is the Earth about six months later, on the opposite side of the Sun from Jupiter (J2). When the Earth is at E2, the light from the Jupiter system has to travel an extra distance represented by the diameter of the Earth's orbit. This causes a delay in the timing of the eclipses. Roemer measured the delay and, knowing approximately the diameter of the Earth's orbit, made the first good estimate of the speed of light. Illustration by Diana Kline. (from link above)

Modern measurements put the speed of light at 299,792,458 m/s ($3x10^8$ m/s for our purposes)

So… what is it was moving so fast?
Historically some thought it was particles, but in 1873 Maxwell came up with a successful (at the time) description of light as an electromagnetic wave.
We're fairly familiar with a magnetic field (magnet, iron filings, acetate on overhead/camera) we are less familiar with an electric field but here we can see its effects (electrostatic generator)

So Maxwell described light as a set of oscillating electric and magnetic fields that travel through space. Specifically he showed that a changing electric field can create a changing magnetic field and vice versa. Together they form a wave (def: travelling disturbance).

We're familiar with lots of mechanical waves: waves on a string or rope, waves on a spring, waves on water.

There are two main classes of waves
transverse in which the disturbance is perpendicular to the direction of travel
longitudinal in which the disturbance is parallel to the direction of travel
(examples of both on big slinky)

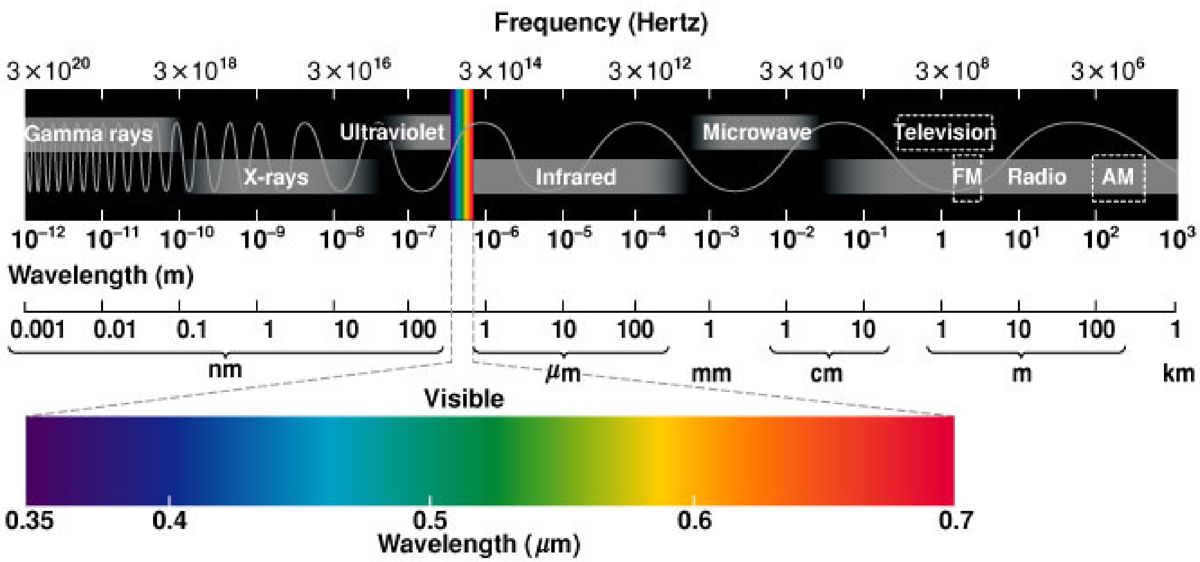
Maxwell's description was of light as a transverse wave-a propagating collection of electric and magnetic fields (show plane wave applet)

How do you make electro-magnetic wave?
By accelerating some electric charge!
→Physlet, Phet applet

What characterizes an electromagnetic wave?
Amplitude: size of fields
Frequency (f): how many oscillations per second=1/(time for one oscillation)=1/(Period of wave)
Related: wavelength distance in space it takes for the wave to repeat (lambda)

10/23/19
v=f*λ
v= wave speed=c for light

Electro-magnetic waves come in lots of wavelengths (in principle from zero to infinity)
→more than just visible light is electromagnetic waves. Also included are radio, infrared, visible, ultraviolet, x-rays, gamma rays.
Electro-magnetic spectrum



February 20, 2009

So we saw that light is an electromagnetic wave and that's caused by accelerating electric charges.

In the case of radio waves we talked about producing them by wiggling charges up and down in an antenna.

So how about visible light? What sorts of things do we experience every day giving off light of its own? (Look for anything thermal: (stove element, incandescent bulb, coals in a fire). Obviously in these cases we are not running an electric current up-and-down something. But if light is an electromagnetic wave some charges must be accelerating.

10/23/19

Another way to accelerate charges is by banging them together. To bang them together at least one of them must be moving. What do all of these sources of light have in common? They all correspond to objects we consider to have high temperatures.

What does temperature really mean?

At the microscopic level temperature can be considered to be a measure of the average energy of motion (kinetic energy) of the atoms/molecules of the substance. The hotter something is, the faster on average the molecules of it are moving. In the case of a solid or liquid, this motion is sort of like a mass on a spring bouncing around some average position. They are sort of held in place by the interactions with the surrounding atoms or molecules. In the case of the gas atoms and molecules are free to wander around anywhere.

So you've got these atoms, banging into each other and their electrons are banging around-- accelerating! These accelerating electrons emit electromagnetic radiation. Since they are banging around at random with quite a range of energies, all sorts of sizes of accelerations take place and we get a distribution of frequencies/wavelengths of light out.

Another hot thing that gives off light that we're familiar with is an incandescent lightbulb.

How do we make it hot? We pass an electric current through it. The electric current (which is really a flow of electrons) bangs into the atoms and electrons of the filament material and transfers energy from the orderly flow of electrons in the current into thermal energy of motion of the atoms of the filament. (Turn on light).

Many people have heard of something described as “red hot”? What does it imply about the object? What would you expect to see? How would something cooler than red-hot look? Would it be emitting light? Does anyone know of a similar phrase to describe something that's even hotter than “red hot”? (white hot)?

This implies some relationship between the color of a thermally emitting object and its temperature.

→variac/incandescent light demo-- when you can just barely see the light from the filaments how does it color compare to a situation where of turned up the current through the filaments higher?

Let's look at the colors from the lightbulb in some more detail using Newton's prism technique for breaking up colors: Light bulb+prism demo+camera. You can see that we get all kinds of colors, and how much of what color changes with temperature.

Since Newton's time, we have developed something that can spread the light out even more making this even clearer. It's called a diffraction grating, and it's really just a piece of plastic with a bunch of scratches on it but they carefully made, and very close together. Light bulb + grating demo+camera.

Try it yourself with the gratings I'm passing around…

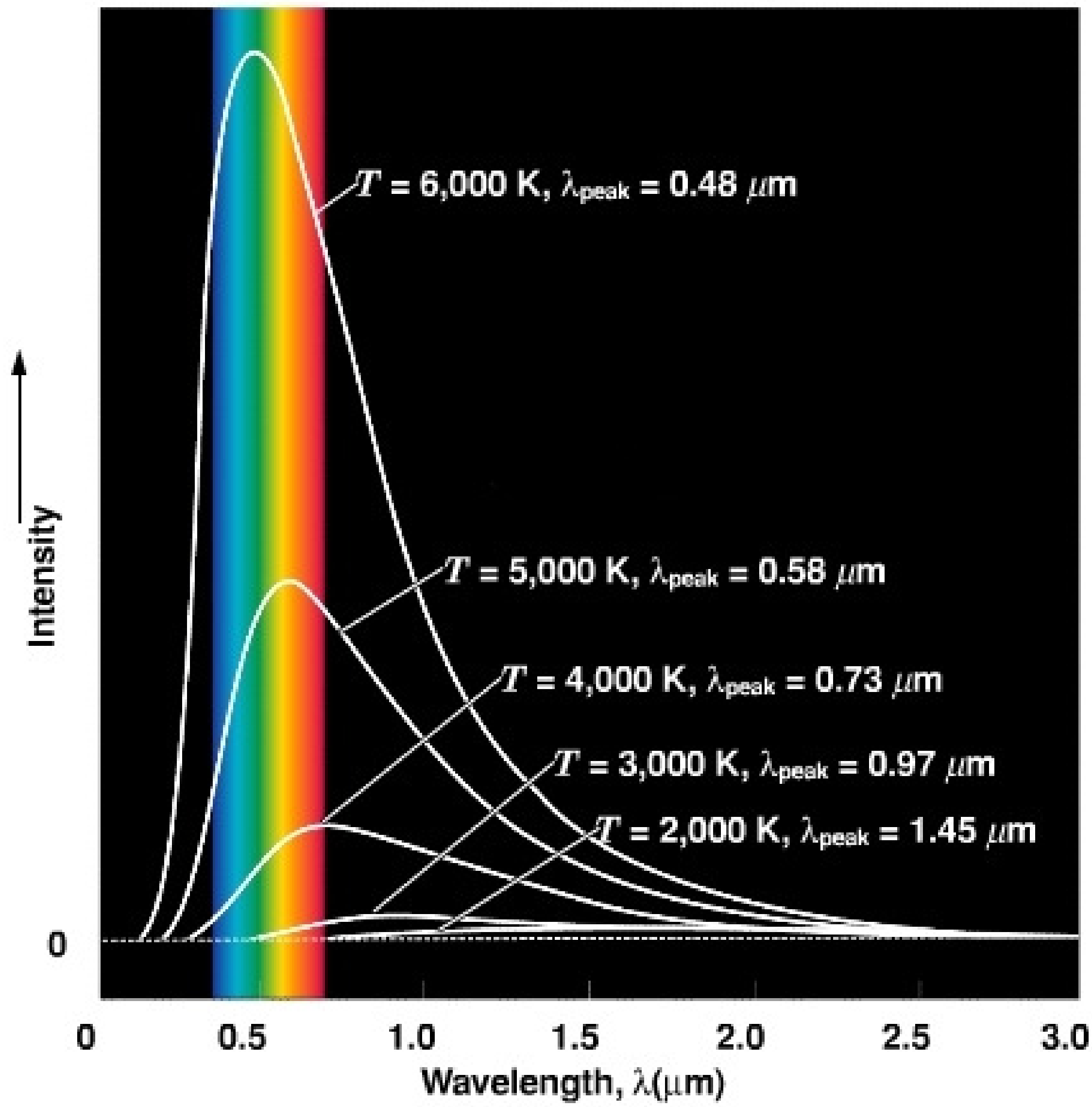
If available use Ocean optics spectrometer to graph spectrum.

Rough plot of the intensity (energy per time) of the light admitted from the lightbulb at various wavelengths look something like this when cooler:

Objects which emit a continuous source smooth range of colors of light by virtue of being hot are called blackbody radiators and this intensity versus wavelength profile is called a black body spectrum.

And this when hotter:

Notice that the wavelength at which most of the light comes out changes with temperature. The hotter it is, the more the peak shifts to the blue.



It turns out that the location of that peak (that is the wavelength at which the peak occurs) follows a very simple relationship with temperature:

$\lambda_{I_{max}} = \frac{0.29cm}{T_{Kelvin}}$ (Wien's law). So λ_{I_max} is the wavelength with the highest (maximum) intensity, and T_{Kelvin} is the temperature of the object measured on the Kelvin temperature scale.

Does anybody know what the Kelvin temperature scale is?

We are most familiar with the Fahrenheit scale (water freezes at 32, water boils at 212).

Next most commonly known is the Celsius or centigrade scale (water freezes at zero, water boils at 100).

Remember we talked about temperature being a measure of the average energy of the atoms?

That means there's a temperature that would correspond to zero average energy. We call this absolute zero. As in you can't get any colder.

The Kelvin scale has the same size degree as the Celsius scale, but is shifted so that zero Kelvin is absolute zero. This means $T_{Kelvin}=T_{Celcius}+273$. So water freezes at 273K and boils at 373K

So how does Wien's law work? This says that if I measure how much light comes out at each wavelength from a blackbody and locate the wavelength where it has the most, I can tell the temperature. Or vice versa.

10/23/19

Example: It turns out our sun is pretty well described as a blackbody. It's spectrum peaks at a wavelength of 500 nm (in what we would see by itself as yellow). What temperature would it have to be?

Let's look at another property of the hot filament. Overall, does the filament look brighter when it's hotter? Sure does! In fact, the total amount of electromagnetic radiation per unit time from an object (called its luminosity, L) increases rapidly with temperature. (L proportional to T^4) Units of L? Energy per time=power. Joule/sec=Watt (W). So Watt is the rate at which energy moves around/is radiated/is consumed etc. Incandescent lightbulbs: 100W; Hairdryer 1500W etc.

If I have 2 identical filaments at same temp, how much power would you say they radiate compared to just one? (2x). It turns out that what matters is how much surface area there is that is emitting. In other words, every square meter of surface area that's at a given temp emits the same power.

What does all this per unit area mean? Well let's say I've got a sphere with a surface area of two square meters. If you measure its total rate of emission of energy per second to be 10 J Watts, its flux would be $10W/(2m^2)=5\ W/m^2$. This really is just a way of taking out the size dependence of the amount emitted energy. Take two objects one with twice the area as the other both at the same temperature. Each square meter of either object emits the same flux, but the one with larger surface area will emit twice the _total_ power just because it has more surface area that's emitting.

The amount of electromagnetic energy that each square meter of surface area that's emitting it (Joules/sec)/m*m is called the flux.
$F=\sigma T^4$ where σ =Stefan's constant=$5.67x10^{-8}\ W/(m^2K^4)$
(Stefan's law/Stefan-Boltzman equation)

Example:
Back to the sun...we know its temperature is about 5800 Kelvin. So what is its flux?
Given its flux, what's its total luminosity?
How do I find that?
The flux tells us how much power each square meter of area emits, so given any particular object, how would I find the total power? So what information do I need? assuming it's a sphere with radius 7x10^8 meters,

$L_{sun}=3.9x10^{26}$ W!!!!

Light has other interesting properties.
In spite of the success of Maxwell's wave theory of light, in the early 1900s some problems were found with that description.
It could not explain some of the interactions between light and atoms. In particular, light from a low-pressure gas discharge lamp was not like a blackbody, but gave off only particular colors (wavelengths).
Look at this hydrogen discharge lamp with your gratings.

What was realized was that this was explainable if light had both wave and particle properties.

This introduced the concept of the particle of light or the "photon".

A photon behaves as a massless particle with an energy related to its frequency.
$E=hf=hc/\lambda$ where $h=6.63x10^{-34}$ joule-sec (Planck's constant after Max Planck-- note joule is the unit of energy

in the metric system)

This odd situation with light is part of the general description of the world given by quantum mechanics.

The flipside is that things we thought of as particles (atoms, protons, electrons) also have wavelike properties.

Another aspect of quantum mechanics describes an electron in an atom as only having particular energies available to it.

We talked about energy before (kinetic, potential).

Think about two objects interacting via gravity. If they start at 1 m apart at rest, what will happen if you let them go? Does the kinetic energy increase?
If the kinetic energy plus the potential energy is constant, does that mean the potential energy has increased or decreased in the process?

So, objects closer together have lower gravitational potential energy, and each position has a unique energy (we're used to thinking about position has been a continuous variable so the energy should change smoothly with separation).
Similar behavior occurs between the positive charge of an atomic nucleus and the negative electrons around it.

But what quantum mechanics says is that the electrons around atoms can only have certain energies, not any arbitrary value.
(atom_bookshelf.swf) 21st century: swf 4.16
(quantum_h_atom_fig219.jpg) aabgu
Dead: Best: http://www.colorado.edu/physics/2000/quantumzone/bohr.html

For an atom to move from one energy level to another, energy must be added or taken away.
Photons can manage that.
(absorb_emit_fig220.jpg) aabgu

Demo showing them hydrogen, helium, neon discharge tubes with diffraction gratings.

Since the energy levels for each atom are different because you have different numbers of electrons interacting with a different target nucleus and with each other, the energy levels and therefore the energies of the photons making transitions between them represent a unique signature for each element. Therefore a spectrum for annulment is essentially a fingerprint. If you see the spectrum, you can look for the pattern of colors (since each energy of photon corresponds to a given frequency and therefore wavelength) and identify the elements involved in a emitting that electro-magnetic radiation.
→Atlas of spectra applet online

<u>Spectral line formation:</u>
We've seen now for continuous blackbody spectrum where we get a continuous distribution of wavelengths (e.g. a smooth rainbow)

If we send that light through a low-pressure cool gas, the atoms in the gas can absorb the colors (energies) of photons that correspond to energy differences between the energy levels of the atoms. This removes some of the intensity of light at those particular wavelengths, and we see a dip in the spectrum at that color. This corresponds to an absorption line spectrum. Of course once the atom is in an excited state, it can jump down to the lower energy state and we get a photon of that energy, but a photon has no memory of the direction of the original photon and therefore it is emitted with equal probability in all directions. Because of this, very little of that reradiated energy would make it into my eye and I still see a dip (that is the dip does not completely fill in with the photons from de-excitation of the atom).

If instead, we look at that cold gas without a blackbody emitter behind it, but say from the side what we see is just the light given off by the atoms coming back down to the ground state. This means we just see the emission line spectrum of the atoms.
HST M42 spectrum (and Atlas of lines at same time?)

What more can we tell from this?
Another property of waves will let us determine whether an object is moving towards us are moving away from us. As shown in this video (laser disk video on Doppler effect in ripple tank) if the source of the waves is moving towards us how you can see that the waves get scrunched together, whereas if it's moving away from us they get stretched out, and if they are moving perpendicular to our line of sight nothing interesting happens. This is true of all waves, and light waves are no exception. This means that if we see the pattern of lines appropriate to hydrogen, but they are all shifted towards longer wavelengths (towards the red end of the spectrum therefore called red shifted) we can tell that the distance between us and the object is increasing-- the waves are being stretched out. Conversely, if there is a blueshift the object must be moving towards us, scrunching the waves together. Again, we're not restricted to just qualitative statements like this, there's a specific relationship. F=f'(1+v/c) where f' is the frequency of radiation we observe, f is what we would observe if the object were at rest with respect to us, and v is its speed relative to us (negative if the distance between us is getting smaller, positive if the distance between us is getting larger).

Binary star/Doppler shift applet

http://homepages.uc.edu/~hansonmm/ASTRO/LECTURENOTES/W04/Binaries/Page56.html

Clarify Luminosity, Flux
Luminosity=total power (nrg/time) (Joule/sec or watt)
Flux=power per area (watt/m^2)

If you're standing underneath a solitary streetlight, and start walking away what happens to the brightness of the light where you are as you walk away? (Decreases of course!)
1/r^2 intensity falloff—data with light sensor (try using motion detector sometime for distance data)
As we saw last time, the intensity of the measured light with a sensor was lower the further we got away from the light source. This agrees with our everyday experience. We were able to quantify it by saying that the output from the sensor gets smaller in a particular way: $I \propto 1/r^2$. Why should this be?

A things like this spherical lightbulb, and stars, tend to radiate equal amounts of light in all directions-- we call this an isotropic or a uniform distribution of radiation. If I imagine enclosing the lightbulb in a sphere centered on the lightbulb, how will the intensity appear at different locations on the inside of that sphere? (same)
So if the lightbulb is emitting a certain amount of power in the form of electromagnetic radiation, that light is uniformly distributed all over the inside area that sphere. We could write a relationship than that says that the power per area that hits the inside of the sphere is
Flux incident=Total power radiated in all directions/total area=P/4piR^2

Take the Sun as an example:
It has a temperature of about 5800 Kelvin and a radius of about 7e8 m. if we treat it as a blackbody, what flux is

emitted by the sun?
What is the total power emitted by the sun?
What is the flux of sunlight at the location of Earth's orbit?
What is the flux of sunlight at a distance of 4 light-years from the sun? (oh, and what’s a light year?)

Thermal equilibrium?
Let's take a look at the situation of something like a planet near a star. It receives energy from the star in the form of electromagnetic radiation. If it is at some temperature other than zero Kelvin, it will radiate according to Stefan’s law. If that's all that's going on, eventually what happens? Well imagine we start out with a cold planet; as it receives radiation from its star it warms up. As it warms up it radiates more. How much will it warm-up? Well, if the planet warms up to the point where it's radiating away as much energy as is shining on it from its star, its thermal energy will be increasing no more and it will be at a steady temperature. We call such a condition or state “thermal equilibrium”.

We can make an estimate of what this temperature should be knowing what we already know. How much power is incident on a planet around a star? Well, we know how to decide what the flux is at any distance, so if we can figure out what area intercepts that flux, then we should know the total power. From the point of view of the star, a planet looks like a circular disk and it’s the area of that circular disk that intercepts the light.

So the power incident is (Power from star/4pi*(distance from star)^2)*pi*rplanet^2.

What about the radiation from the planet? If we assume it's a blackbody radiating evenly in all directions we know that the power radiated by the entire surface area of the planet is the flux (sigma*T^4) times the area of the planet with radiating (4pi*r^2).

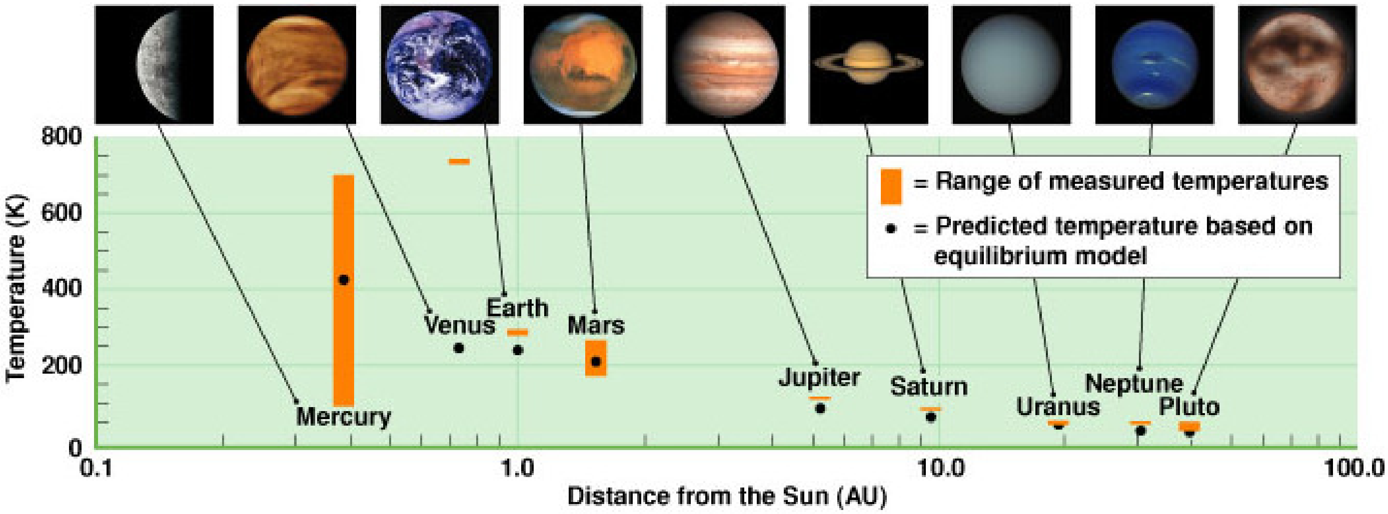
When these two powers are equal, the planet is in equilibrium (that is, its temperature is not changing any more).

$$\left(\frac{P_{star}}{4\pi d_{to\ planet}{}^2}\right) * \pi R^2{}_{planet} = \left(\sigma T_{planet}{}^4\right)\left(4\pi R^2{}_{planet}\right)$$

$$T_{planet} = \left(\frac{P_{star}}{16\pi\sigma d^2{}_{to\ planet}}\right)^{1/4}$$

Notice that it ends up not depending on size of planet!
let's consider specifically earth and our Sun.
We know that the Sun is emitting $3\text{x}10^{26}$ watts, we are about $1.5\text{x}10^{11}$ m from sun
This predicts a temperature of:
261K
Is that warm or cold? What are useful reference temps in Kelvin? (0 C=273K)
So what’s the deal?
Other planets?

10/23/19



(above Fig 4.27 from 21st Century Astronomy)

Other sources of energy? (leftover, radioactive decay)
Also—where are we measuring temperature? In side planet? Surface? Somewhere in the atmosphere? Energy balance in a planet is generally more complicated than this simple model predicts, but it is a useful first approximation.

2/26/09
Telescopes: Eyes on the Skies

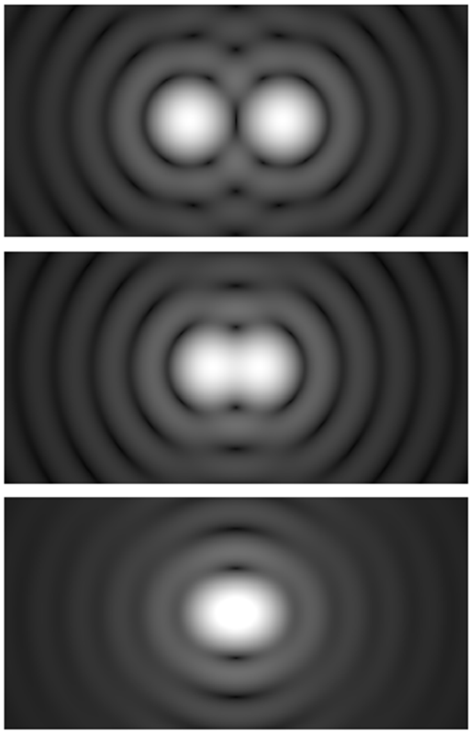
What's the first reason you think of for using a telescope? (Magnification?)

Why? Any time we look at an object, there's a limit to the amount of detail we can see. There are 2 sources of this, and to make sense out of them, we should look at how the eye works.

Draw Simple model of eye: lens which forms an image (focuses light) onto the retina at the back of the eye. The retina has cells that which respond to light and send out nerve impulses relating to the intensity of the light they receive. (http://universe-review.ca/I10-85-retina.jpg) (show applet?)

So if you imagine two objects close together, their images are close together on your retina. If they are too close together, that is if the angle between the incoming light rays is too small, they both end up getting the same cell (about 2 microns diameter--http://www.fz-juelich.de/isb/isb-1/datapool/page/24/Figure2.jpg) and you can't distinguish the two objects.

What's less obvious is that because light has wave properties, it turns out that any time part of the wave is blocked by something (an edge, or an aperture) the wave nature of light causes it to spread out or diffract. (ripple tank video: Disc 2 Side D 21, light: 14, aperture 24 or https://drc.ohiolink.edu/handle/2374.OX/59705). Because of this property, it turns out to be nearly impossible to focus a light that passes through an aperture down to a perfect point. Instead it is smeared out into a small disk. We call such a situation as being "diffraction limited". https://phet.colorado.edu/sims/html/wave-interference/latst/wave-interference_en.html This means that even if our retina had infinitely small sensors, we would not see infinite detail because of the smearing out caused by the light wave passing through the pupil of our eye. This similarly limits our resolution or ability to distinguish two objects which are very close together. If the two diffraction limited disks formed from two separate sources are too close together they will overlap and look like one big dot and we won't be able to tell the difference between an object and two. (Images of Rayleigh criterion?)



The extent to which we can focus light sharply depends on the ratio of the wavelength of the light to the size of the aperture (pupil for your eye). The smaller that ratio, the sharper an image one can get. The smallest angular separation between two objects of comparable brightness that can be resolved as two objects is roughly given by:
Smallest resolvable angular separation = wavelength/(aperture diameter)

$\theta_{resolvable} \approx \frac{\lambda}{D}$ (theta in radians, lambda, D in same length units)

Anyone remember the definition of a radian as angular measure? 360 degrees=all the way around a circle; 2π radians = all the way around a circle=> 180/π degrees per radian (~57.3 degrees/radian)

Quantitative Examples:
Eye with pupil of 5 mm at a wavelength of 500 nm. What is the angular separation of two distant lights that can just be resolved?
$500\text{x}10^{-9}$ m/0.005 m = $1\text{x}10^{-4}$ radians

Here's a telescope with a 10 inch diameter aperture. How about it?
10 inches =25.4 cm = 0.254 m. Compared to 0.005 m that is 0.254/.005 = 50.8 times larger diameter so theta_resolvable is 50.8 times smaller: So $1\text{x}10^{-4.}$ / 50.8 radians = $2\text{x}10^{-6}$ radians

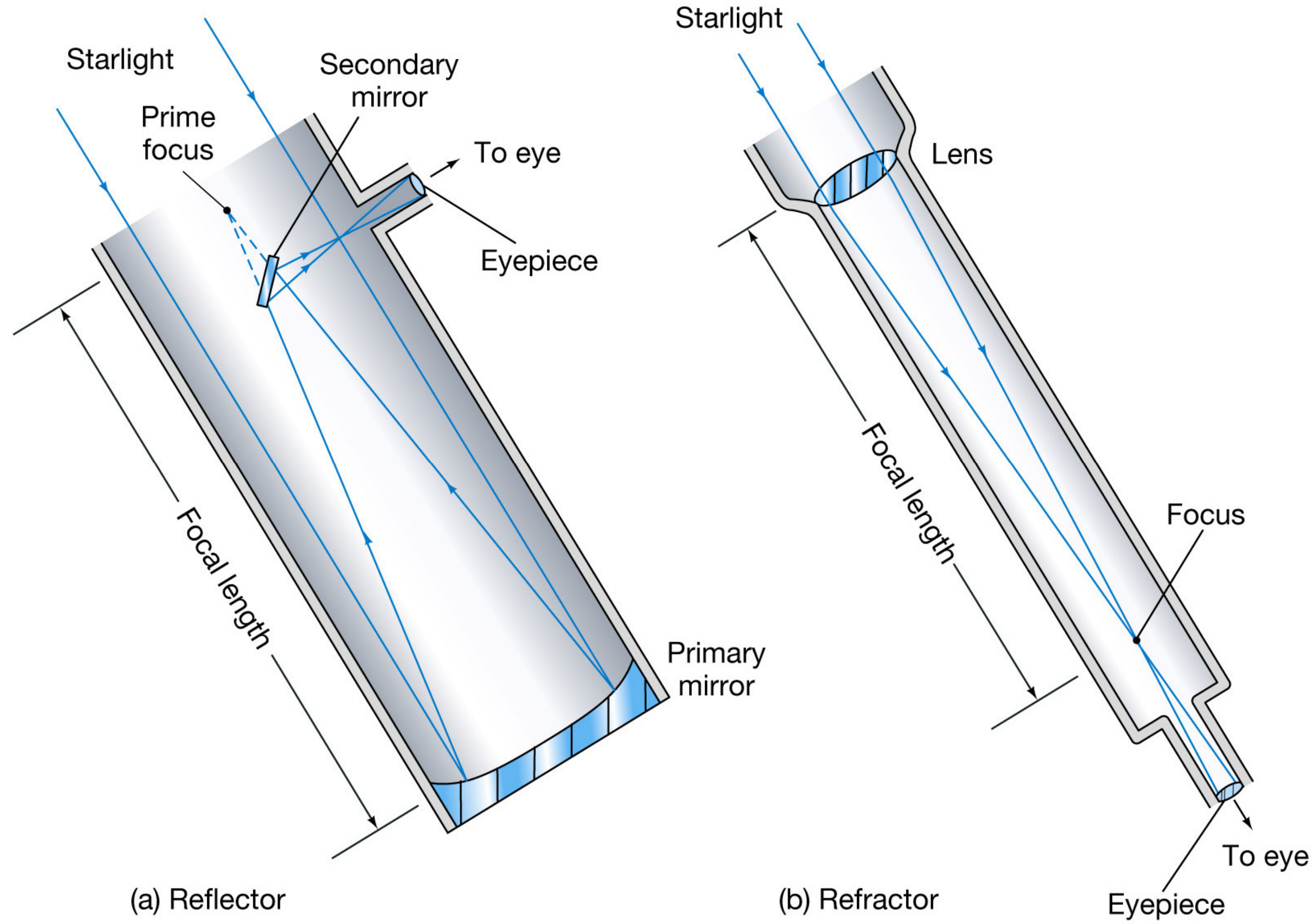
You could also imagine: I want to form an image at a given wavelength with some resolution and say "How large an aperture would I need to achieve that resolution?

The same is true of telescopes: the larger the diameter, the more detail there is in the image is formed because the diffraction limited spot is smaller.

Another important reason for making telescopes big (that is large diameter)? What is that? (More light!) See fainter things. Why necessary?

Your pupil never gets bigger than a few millimeters across and can only let in so much light. The sensors in your retina have some intensity threshold and if the amount of light is not over the threshold, you don't see anything! They also don't "store up" light signal the way a photograph of electronic sensor does. So the only solution is to stuff more light in which means a bigger hole. Telescope intercepts more light and directs all of it into your eye—presto! For scientific work, usually not in to the eye but onto an electronic sensor which can store up the signal over a long time---see much fainter things.

Types of telescopes

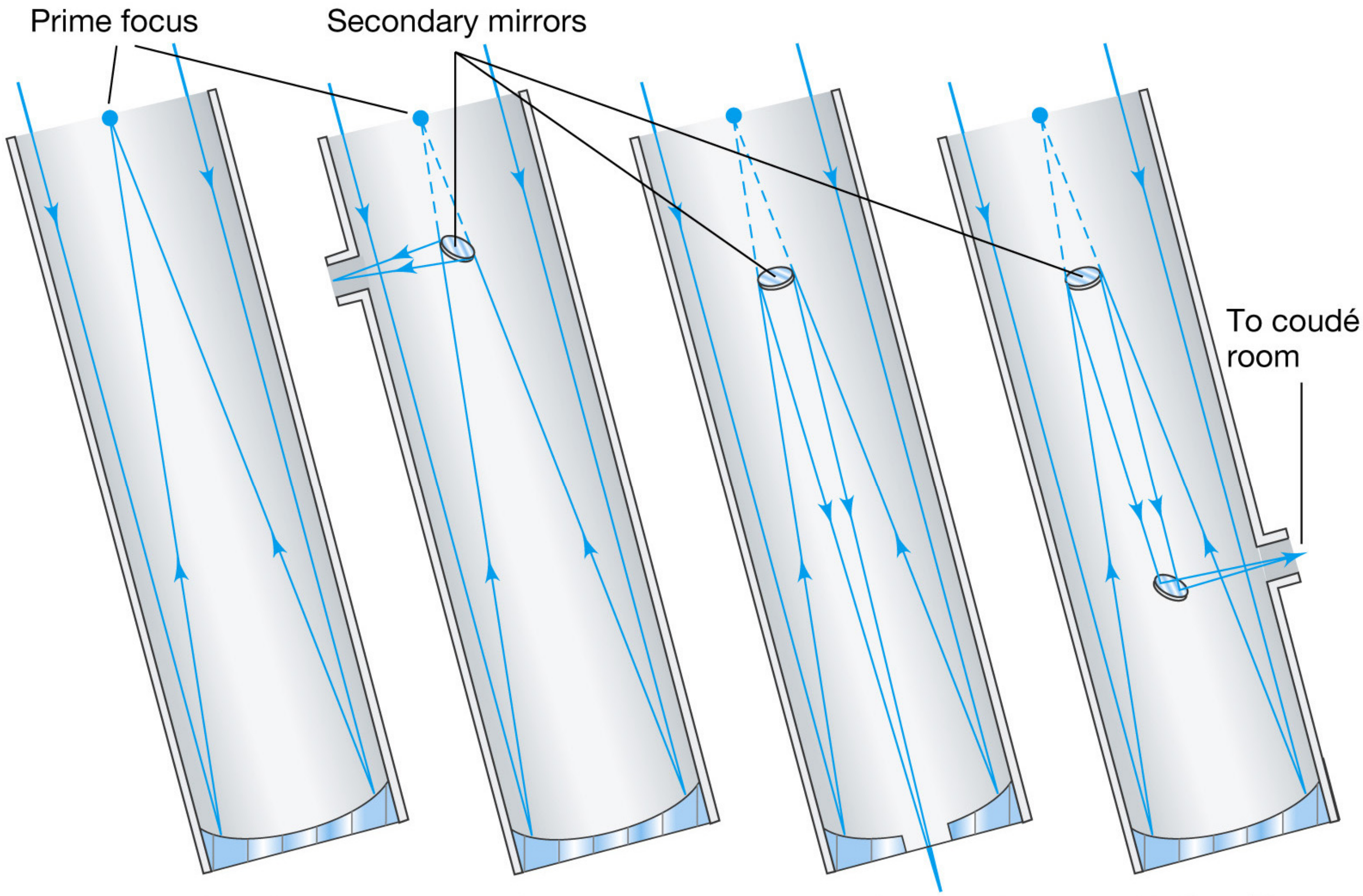


Refractor:
Historically older
Lenses
Work by refraction: speed of em wave different in different materials, changes direction of travel when going from one material to another.
Prism model (fig 3.2 ABGU)
Demo: big lens and lightbulb (lighted arrow?)(w. camera?)
Optics Applet
Only support around edge→limits to size w/o sagging a lot—largest functional one about 3feet in diameter.

10/23/19

Chromatic aberration—different wavelengths generally bend by different amounts (material dependent) like the prism separating white light into colors.

Reflector:
Mirrors
Applet, Demo w. Big Gold mirror and light bulb.
Can support from behind→can make almost any size
Many different designs (cost/benefit/application/aesthetics):



(a) Prime focus (b) Newtonian focus (c) Cassegrain focus (d) Coudé focus

Prime focus
Newtonian
SC
Coude'
Since rays not focused at obstruction (secondary, tertiary mirrors, etc), obstruction only makes image dimmer, doesn't take chunks out. (also true of refractor, but you don't have an obstruction in simple refractor). Demo?

Detectors
Not much scientific work is done by eye any more. Not as sensitive as electronic instruments, not quantitative at all, not even linear in its sensitivity. (More: your eye doesn't integrate/store up signal so looking for longer time doesn't help).
CCD—Charge Coupled Device: solid state light sensor, as in most digital cameras. Only bigger and better.

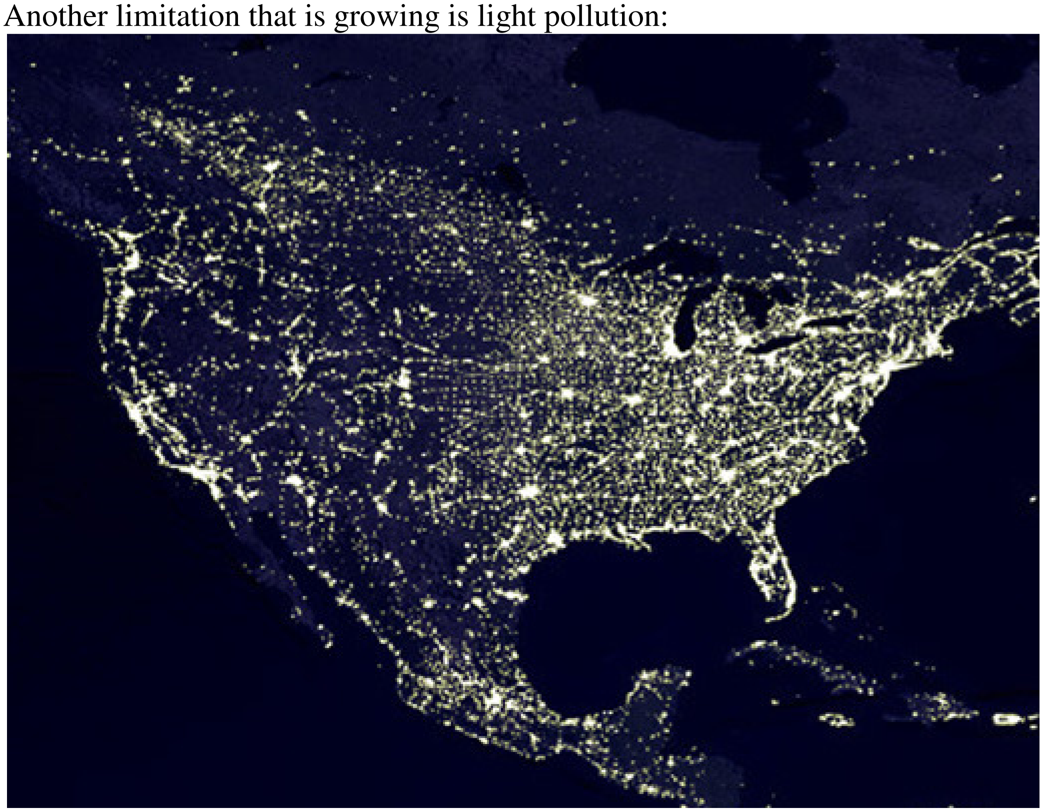
10/23/19
Describe basics: rectangular array of sensors (pixels) which produce electrical signals proportional to the total amount of light that has hit sensor.
Spectrometer—CCD
High-resolution astronomy
We've talked about diffraction and how that limits the angular resolution of images formed from light

Other things also limit the quality of images we can obtain.
-atmospheric blurring
-turbulence
-temperature gradients
demo: shine laser over burner? Wiggle?

Solutions:
Siting
-stable atmosphere/weather (typically desert or island mountaintops)
-in orbit

Active optics: actuators which finely adjust the position of the optics of the telescope to obtain optimal alignment. Rather than make something incredibly rigid (and heavy), make it lighter but give it active means to adjust the positions of the mirrors to compensate for sagging as a telescope points in different directions and so on. Typically updated every few seconds or so.

Adaptive optics: frequently (many times per second) measure the distortion caused by the atmosphere and rapidly compensate by distorting the surface of the optics in a complementary way. Requires flexible optics, fast measurement and actuators.

Another limitation that is growing is light pollution:


10/23/19

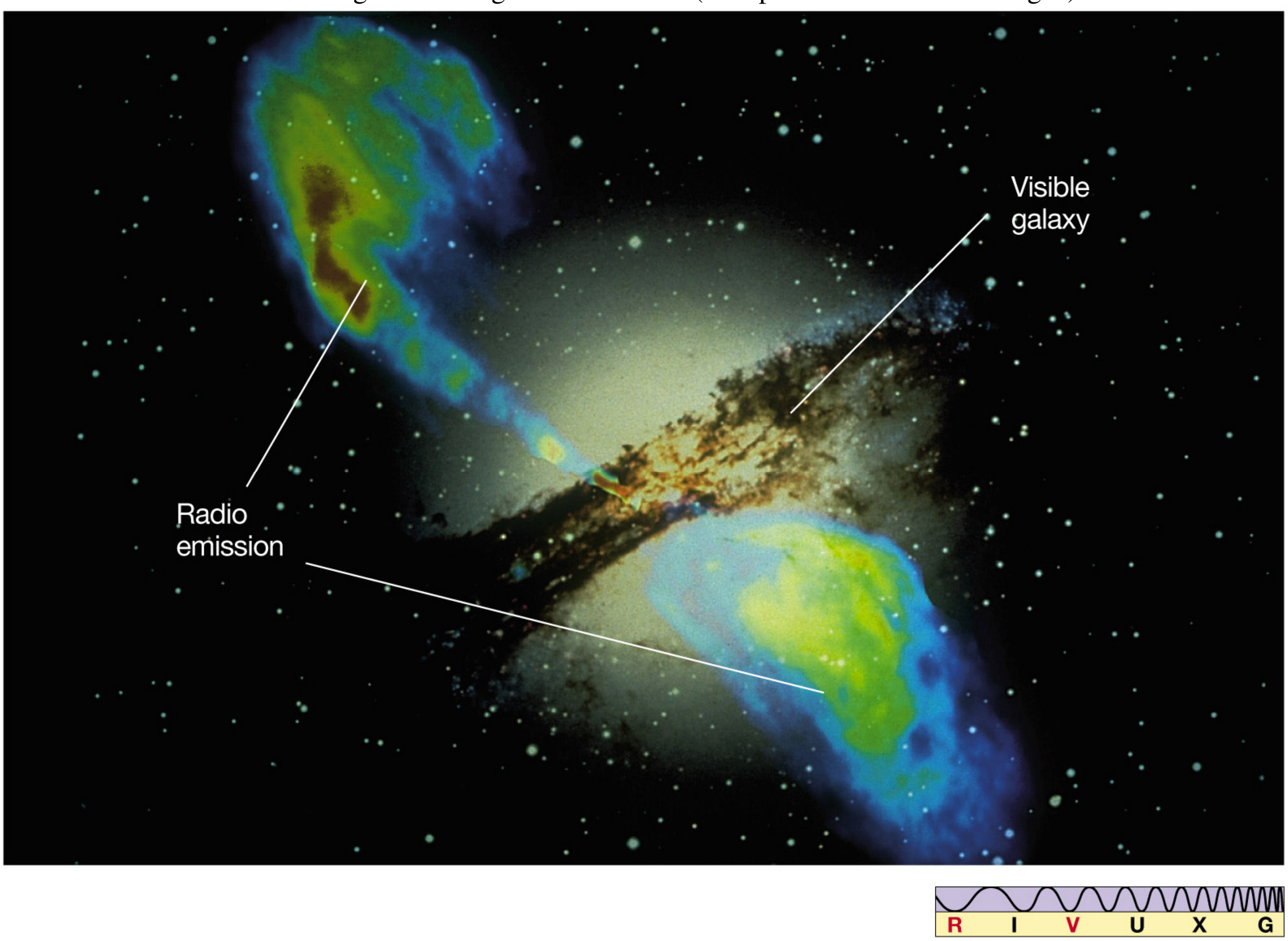
Other wavelengths or frequencies of electromagnetic radiation?
-typically come from different astronomical processes or reactions
-travel with more or less ease to us from the sources

Radio astronomy:
A radiotelescope typically looks like your basic dish network receiver: a curved reflector (a mirror for radio waves, typically metal), and a receiver which measures the intensity. (Fig)

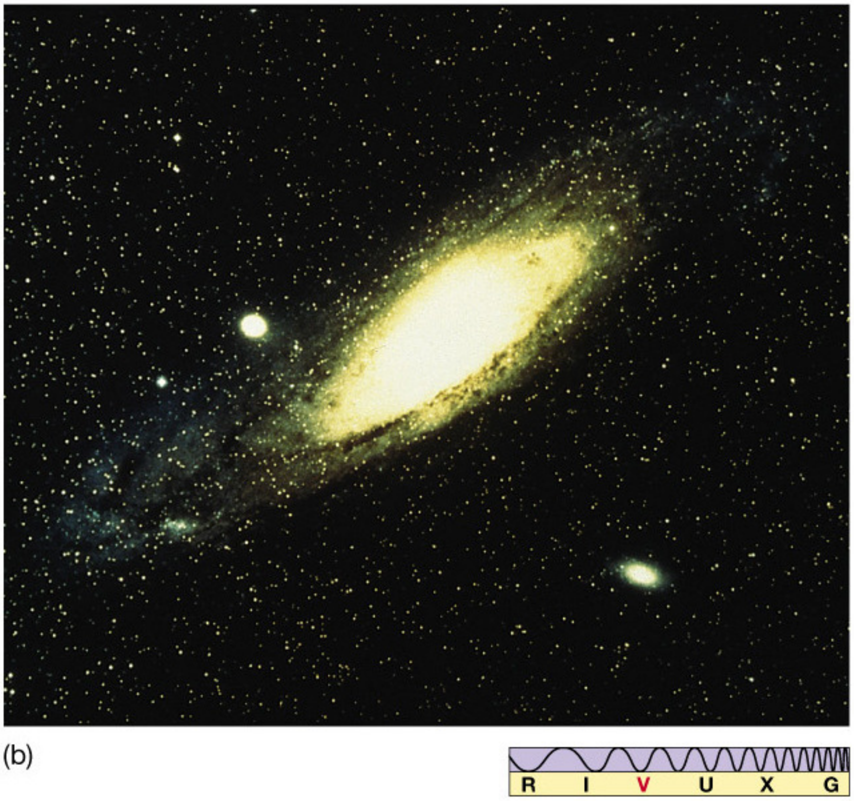
Radio telescopes do not form an image directly like an optical telescope, but just measure the overall amount of signal coming from the spot in the sky where it's pointed. To build up a picture it has to scan and measure the intensity at each point in the "image". Then you can make a 2D map showing intensity at points on the sky→"image".

Radio astronomy is sensitive to molecular energy levels (longer wavelength, lower frequency, lower energy—remember E=hf). It is therefore particularly useful for measuring clouds of molecular hydrogen and other similar gases.

Radio waves are also produced when charged particles interact with magnetic fields (synchrotron radiation) and therefore it's able to tell us things about magnetic structures. (Composite visible/radio image?)



10/23/19
At this point, point out the wavelength key on the images in the text



(b)

Interferometry
If I have a radio wave coming from a source and look at it with two different receivers then depending on how far the receivers each are from the source, they could be looking at the wave at the same point in the cycle (both crests, both troughs, etc.) if we add the signals together then we would get an extra large signal. If one receiver was looking at a crest while the other was looking at a trough and we add them together, the signal would be zero. Obviously we could have in between cases as well depending on where in the cycle the wave is at each receiver. (We call this “where in the cycle the wave is” the phase of the wave and the phase difference determines how big the combined signal is).

Whether the two waves are in phase or out of phase (or somewhere in between) also depends on the angle to the source from each antenna. Because of this, the angular resolution of an interferometer is better than the individual dishes could achieve, it's more like what an antenna with the diameter equal to the *spacing* of the antennas. This allows radio telescope to achieve very high angular resolution. Using the VLA (or even better, coordinating signals from telescopes on opposite sides of the world (VLBI)), we can achieve angular resolutions on the order of .001 arc seconds. http://www.vlba.nrao.edu/

Other astronomies:
infrared: (longer wavelength than visible, shorter than radio)
Remember from our discussion of diffraction, if the wavelength is much bigger than the size of an obstruction, the wave is hardly affected. This means that infrared radiation will let us see through dust that would absorb optical radiation. This lets us look inside starforming clouds of gas and dust. (Image?)
http://outreach.atnf.csiro.au/education/senior/astrophysics/stellarevolution_formation.html
http://news.bbc.co.uk/2/hi/science/nature/7864087.stm
http://www.gemini.edu/public/infrared.html

Ultraviolet, x-rays, gamma rays (higher frequencies, smaller wavelengths,

10/23/19
E=hf → larger energies
So these are sensitive to more energetic events, especially things like stars blowing up, starts crashing together, black holes crashing together, stuff falling into black holes, stuff falling onto neutron stars--all things we'll talk about a little bit more later.

Come up with some sort of spectroscopy exercise
Select bits of text relating to 1/r^2 intensity laws and assign for Wednesday