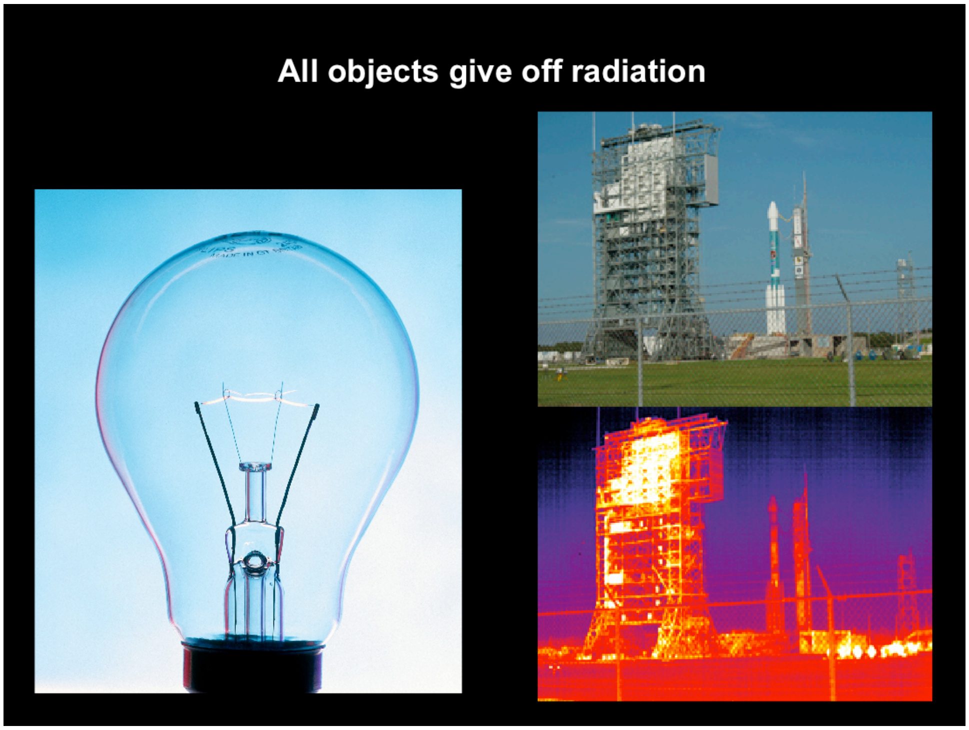
Blackbodies

Your eyes are stellar thermometers. Every time you look into the night sky and notice the color of a star you have taken the temperature of that distant, massive ball of cosmic gas! This is only possible through the power of Blackbody Radiation.

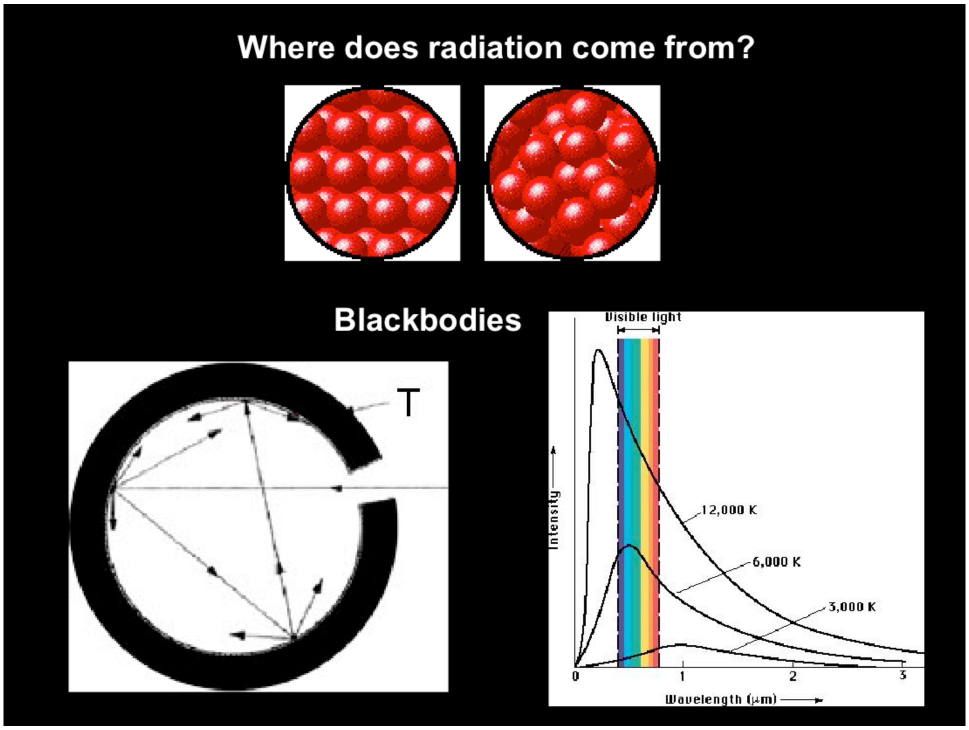
You can't take an astronomy course without learning about blackbody radiation. It's one of those ideas that form the cornerstone for what astronomers know and how they know it. But what, really, is a blackbody? How did astronomers (actually physicists) come up with that slightly misleading name? How do blackbodies end up being so important?



Use light bulb with dimmer switch and diffraction glasses.

All objects give off radiation. Some more, some less, different types of electromagnetic radiation (light).

Some we are familiar with (lightbulb, stove, fire) but others we are not so familiar with (launch pad)

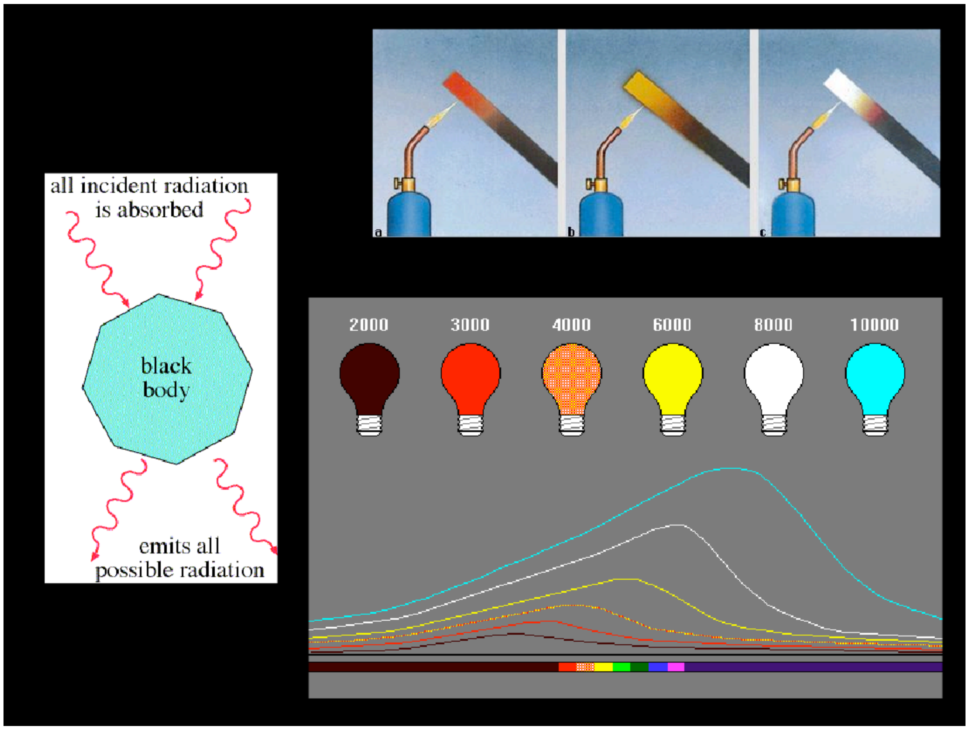


Why do things radiate?

Heat is molecules and atoms vibrating. From Maxwell's equations, we know that vibrating charges give off electromagnetic radiation (infrared heat and visible light). Temperature is a measure of the speed of the vibrating particles. We are used to atoms vibrating but charges do too.

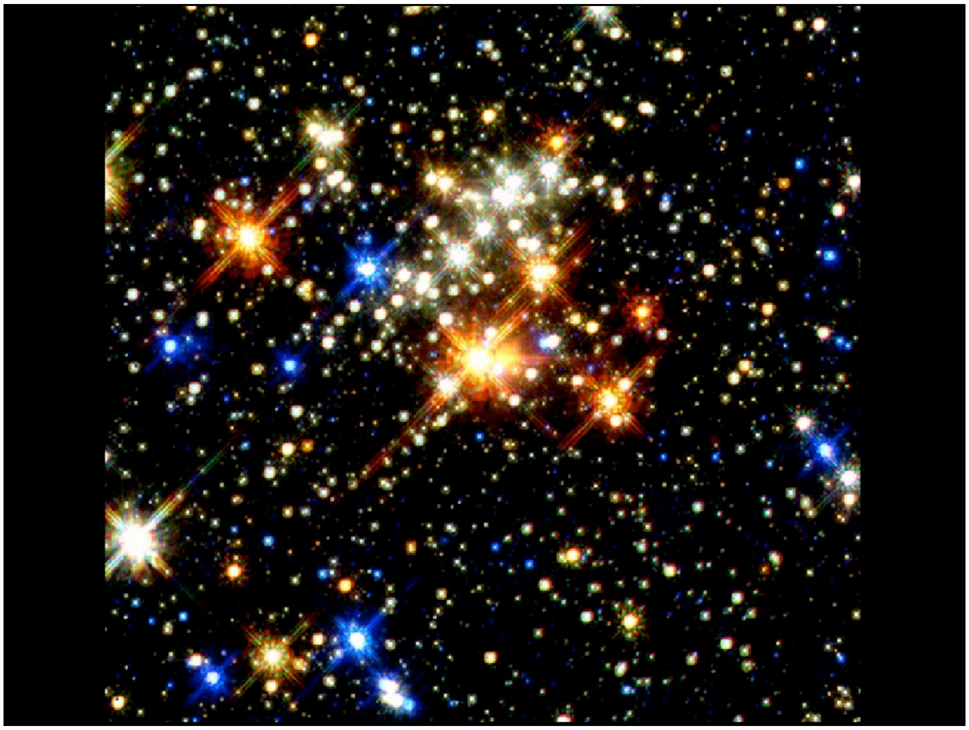
The simplest object to radiate is an opaque object – absorbs all radiation falling on it and emits radiation perfectly; perfect absorber and perfect emitter of radiation = a blackbody

A short definition of a blackbody might go like this: An object is a "blackbody" if the radiation it emits into space originates completely from its temperature. This means the radiation produced by the object comes from light waves mixing it up with the jiggling motions of all the zillions of atoms that make up the object. Inside a blackbody, radiation can not travel very far before it is absorbed by a jiggling atom. It is then quickly re-emitted, travels a short distance and then gets absorbed again by another atom. This happens zillions of times so there is a constant interplay between the matter and the radiation bouncing around in a blackbody. The one-to-one relation between the amount of jiggling heat motion of atoms and the spectral signature they produce make blackbodies unique, distinctive and of primary importance. Blackbody spectra do not depend on an object's chemical composition, its size or its age.

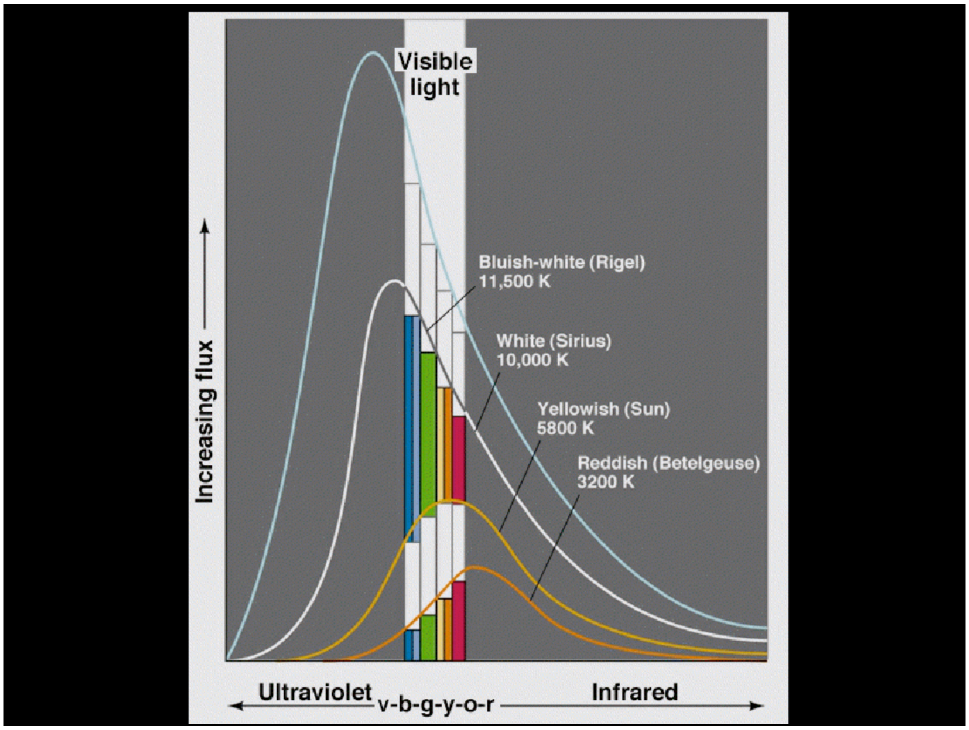


Don't let the name confuse you, blackbodies do not have to be black. They can be blue or red or yellow. So where does the name come from? Anything colored black absorbs all the wavelengths (colors) of light that fall onto it. Blackbodies do this as well and that is why physicists came up with the name "blackbody". How can blackbody appear blue or red? For now the important idea is that a blackbody pump radiation into space in a very special way. Anything which has heat and is dense enough will emit as a blackbody. That means you, the chair you're sitting on and the Earth on which the chair rests are all blackbodies.

Every blackbody emits light with an easily identified pattern, its "spectral" signature (also called a spectral energy distribution or more specifically the blackbody curve). The blackbody curve is the particular way the total light emitted by a blackbody varies with its frequency. The number of red photons, the number of green photons, the number of infrared and ultraviolet photons are all exactly specified by the blackbody curve. Now here is the killer point - the exact form of the curve depends only on the object's temperature. Every blackbody at 2000 degrees emits light with exactly the same curve. The spectral signature of a 2000 degree iron bar in a blast furnace is identical to a 2000 degree star a trillion, trillion miles away in deep space. That is what makes blackbodies so useful and that is why the color of a star is also a measure of its temperature.

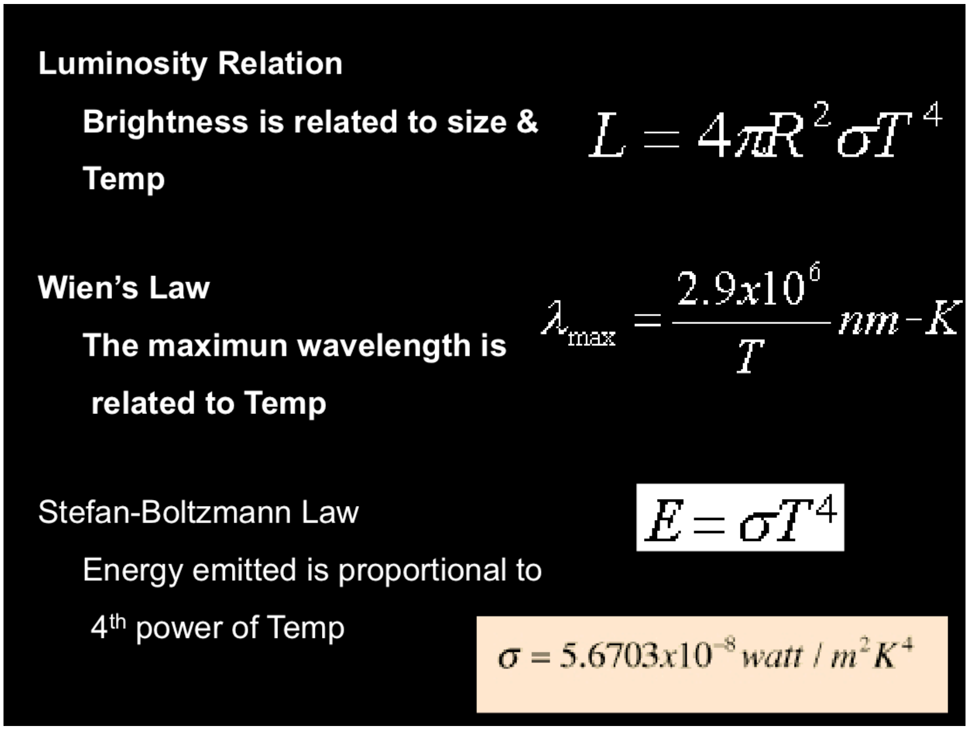


Stars are vast collections of hot gas. A star like the Sun is more than ten billion billion billion tons of matter crammed together under the force of its own gravity. The conditions in a star (dense and hot) make it a pretty nice example of a blackbody. The stellar atoms jiggle around absorbing and re-radiating radiation in just the right way so that light pouring out at the surface has just the mix of colors (wavelengths) predicted by the blackbody curve. This is good news for astronomers. By measuring the energy emitted by the star in different colors they can work backwards to figure out it’s temperature.



The highest point, or peak, of the blackbody curve shifts left or right at different wavelengths (notice the visual part of the spectrum is indicated by the rainbow of colors). Since the peak of the blackbody curve is where most of the radiation is emitted, you can see how changing the star's temperature changes it's color.

The peak wavelength doesn't tell the whole story since your eye will pick up a mix of colors in the visible band. Sometimes you will see more red or yellow or blue.



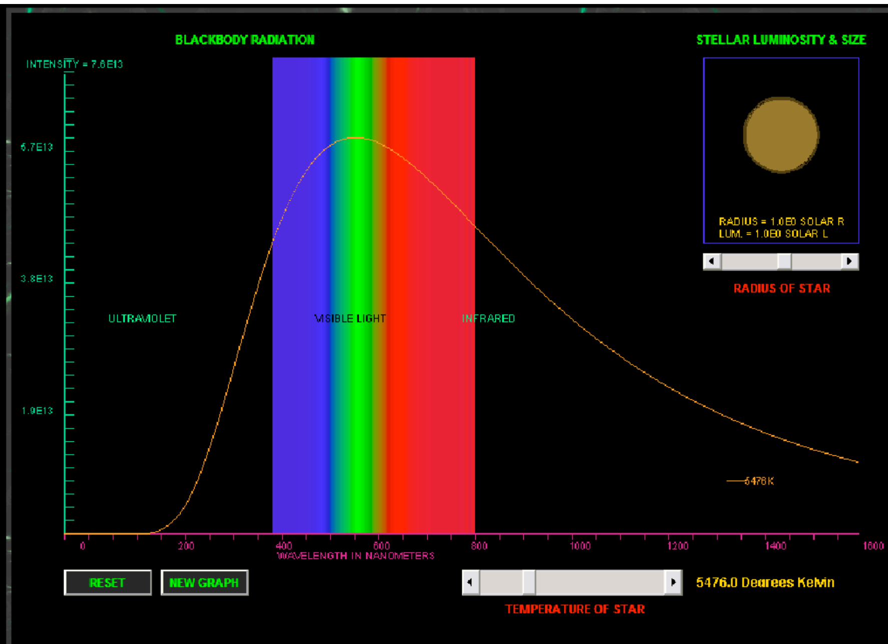
<u>Stellar Luminosity:</u> The brightness or luminosity of a star is also related to its temperature by the formula.

In this formula R is the radius of the star and σ (sigma) is the constant of nature called the Stefan-Boltzmann constant, (remember that **4pR2** is the surface area of a sphere). This formula tells you that the brightness of a star is very sensitive to both its temperature and its size (area). By changing the radius of the star on the applet you can see how the brightness of the star changes.

Wien's law gives the wavelength where the blackbody peaks as a function of temperature. Hot stars have a peak wavelength at shorter wavelengths and colder stars have a peak wavelength at longer wavelengths.

Stefan – Boltzman Law – This gives energy emitted per unit area. Sigma (σ) = constant;

hot blackbodies emit more energy/sec than cold blackbodies. The energy emitted is proportional to the 4^{th} power of T (T*T*T*T)



http://www.mhhe.com/physsci/astronomy/applets/Blackbody/applet_files/BlackBody.html

Give out worksheet for applet

To sum up . . .

1. How does Temperature affect peak wavelength?

2. What kind of stars emit more energy?
   A. Hotter or cooler stars?
   B. Larger or smaller stars?

3. What affect the Brightness of a star?

Summary

1. Temperature determines peak wavelength
    A. Cooler stars – longer peak wavelength
    B. Hotter stars – shorter peak wavelength

2. Energy coming from stars
    A. Hot stars emit more energy than cooler stars
    B. Larger stars emit more energy than smaller stars

3. Brightness is related to both size & temperature