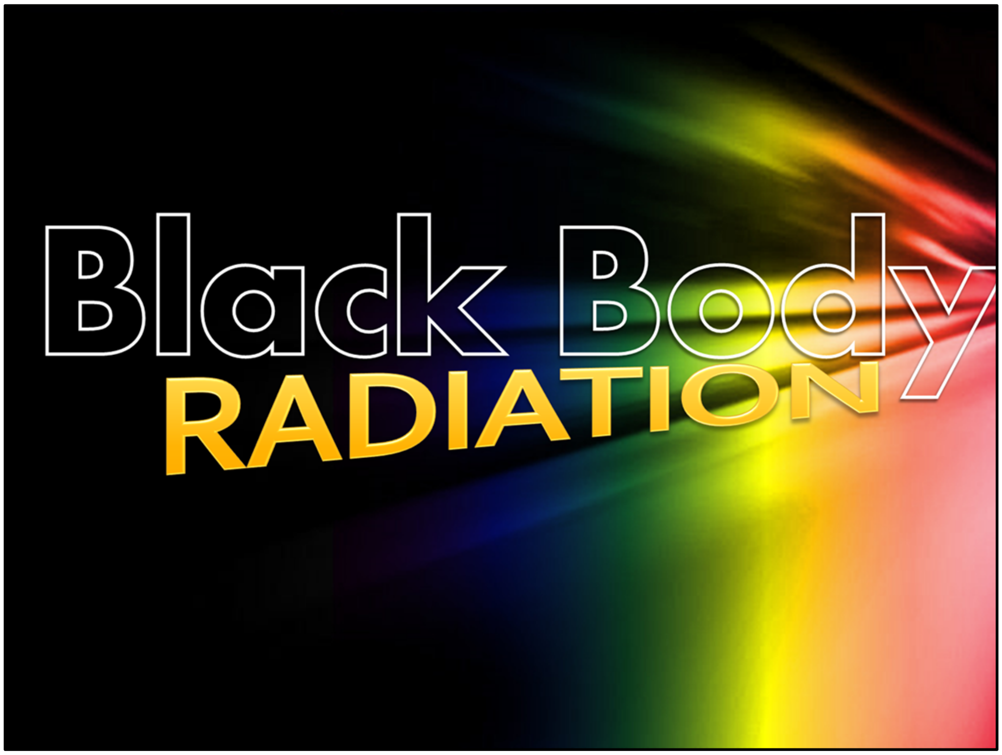
Module 4: Radiation and the Electromagnetic Spectrum

Topic 3: Black Body Radiation



Black Body Radiation

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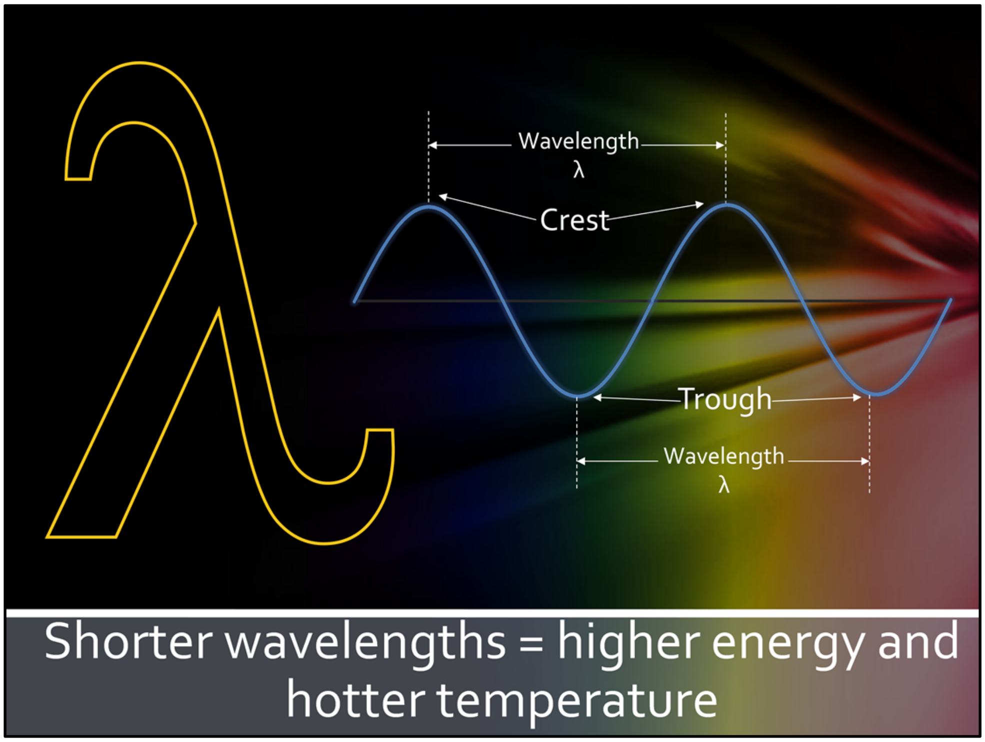
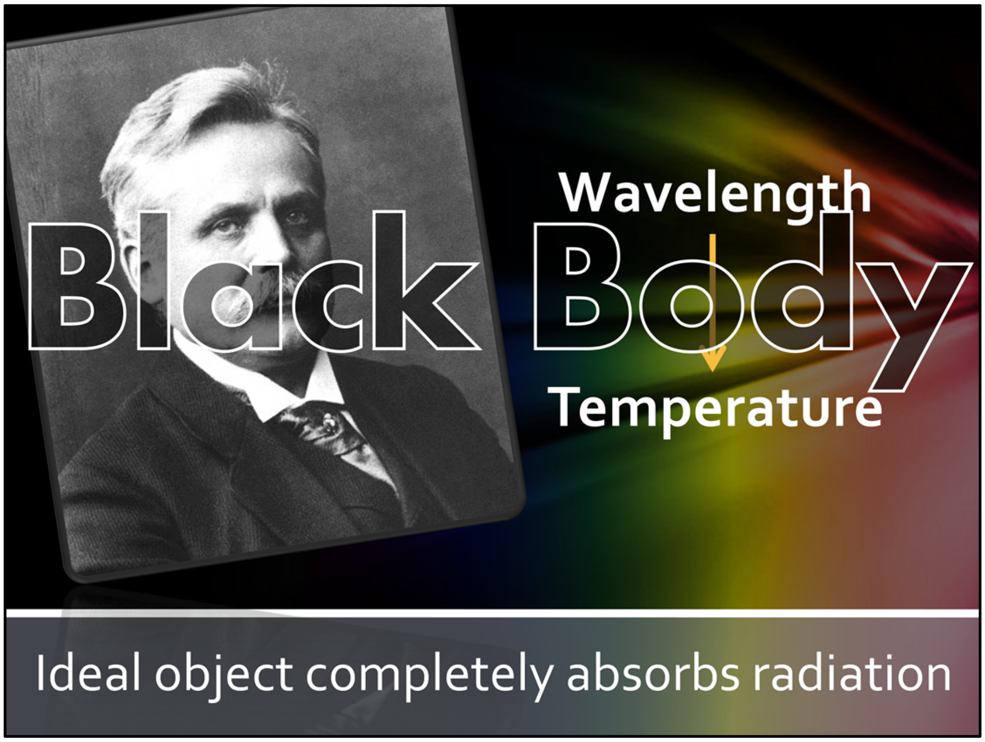


Shorter wavelengths = higher energy and hotter temperature

Objects appear different colors because they emit energy at different wavelengths. Represented by the Greek letter lambda, the wavelength of a wave is the distance from the same point on one crest of a wave to the same point on the crest of the next wave, or from the same point on one trough to the next trough. Shorter wavelengths produce higher energy and are hotter in temperature.



Wavelength

Black Body

Temperature

Ideal object completely absorbs radiation

This means that wavelength is directly related to temperature. This was first discovered by Wilhelm Wien. In doing so, he found that an ideal object would completely absorb all radiation. He called this object a black body.

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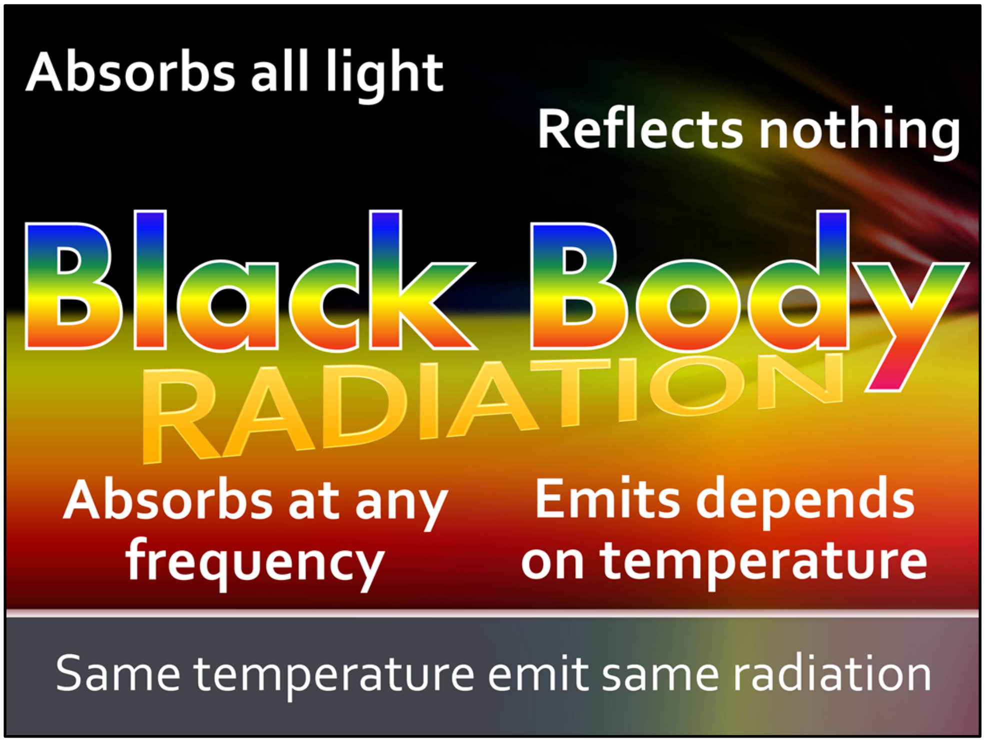

Absorbs all light

Reflects nothing

Black Body RADIATION

Absorbs at any frequency

Emits depends on temperature

Same temperature emit same radiation

A black body absorbs all light and reflects nothing, therefore, appearing black. If the object were heated, it would produce a near perfect spectrum. Objects in space, like stars, asteroids, or planets, are near enough black bodies that they could produce perfect spectra. This means that a black body is an ideal object that can completely absorb any radiation that can fall upon it at any frequency, and emits radiation in a way that depends only on its temperature. All black bodies with the same temperature emit the same radiation, which is called black body radiation, or thermal radiation.

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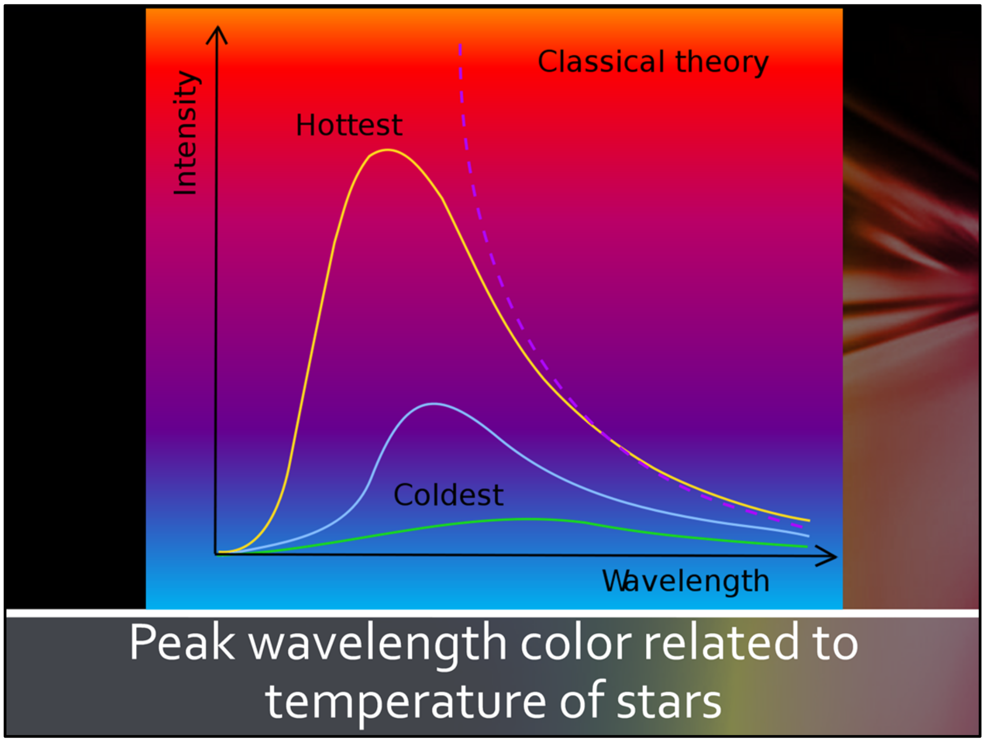

Peak wavelength color related to temperature of stars

In astronomy, the color of the peak wavelength is directly related to the temperature of stars. This is how astronomers answer the question, “How hot are the surfaces of stars?” A plot of the intensity of light versus wavelength or frequency is called the black body curve. Almost all objects of interest in astronomy can be described as black bodies. In the curve, the steeper side is found in the shortest wavelength, with the peak of it on the brightest color of the black body. The brightest color is known as the highest intensity of light and is viewed with the human eye as a specific colored star, if found within the visible spectrum.

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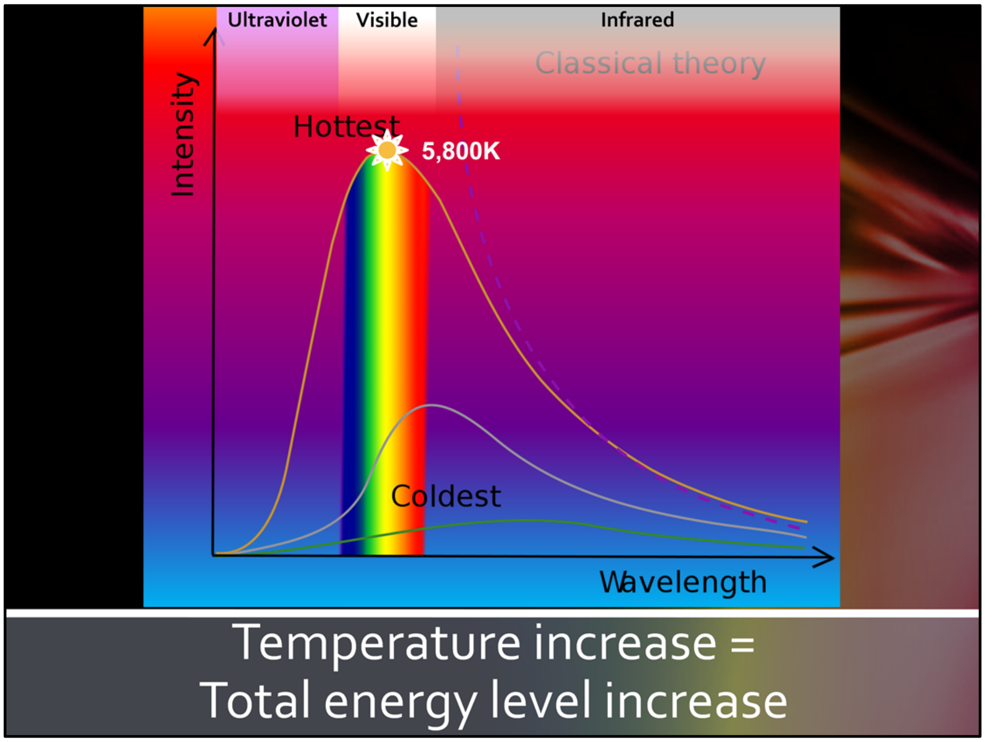

The sun appears yellow because its peak wavelength is in the green-yellow portion of the visible spectrum. Astronomers know the surface temperature because of this curve being at 5800 Kelvin. Because of how human eyes view light, you see yellow to white light, which falls in the visible portion of the electromagnetic spectrum. Hotter stars emit in the ultraviolet part of the electromagnetic spectrum. Objects, like humans, also give off light as radiation, but not in the visible part of the spectrum, rather in the infrared part of the spectrum. As the temperature of an object increases, it emits an increased total energy level, which can be seen when objects heat up and begin to glow. The hotter the object, the bluer its radiation.

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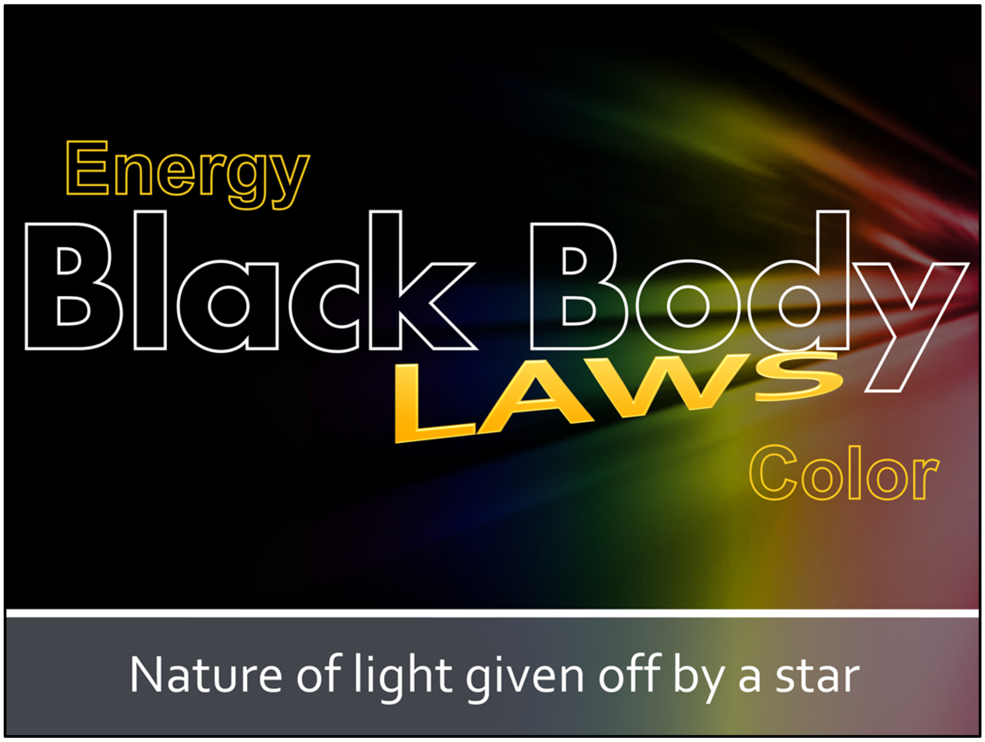


Energy

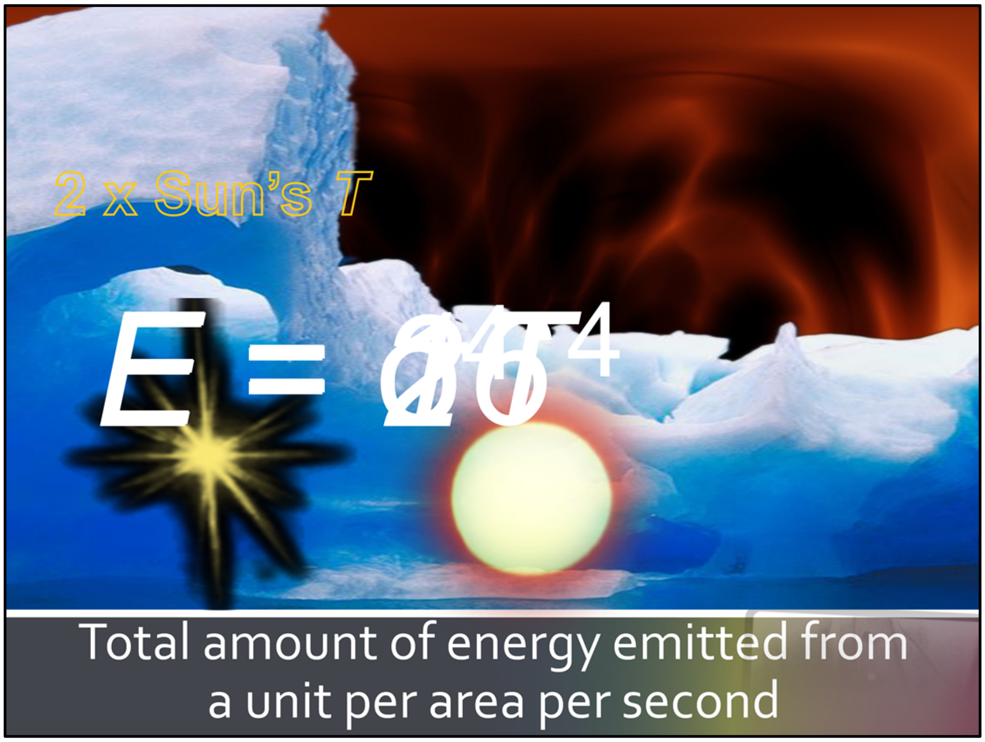
Black Body

LAWS

Color

Nature of light given off by a star

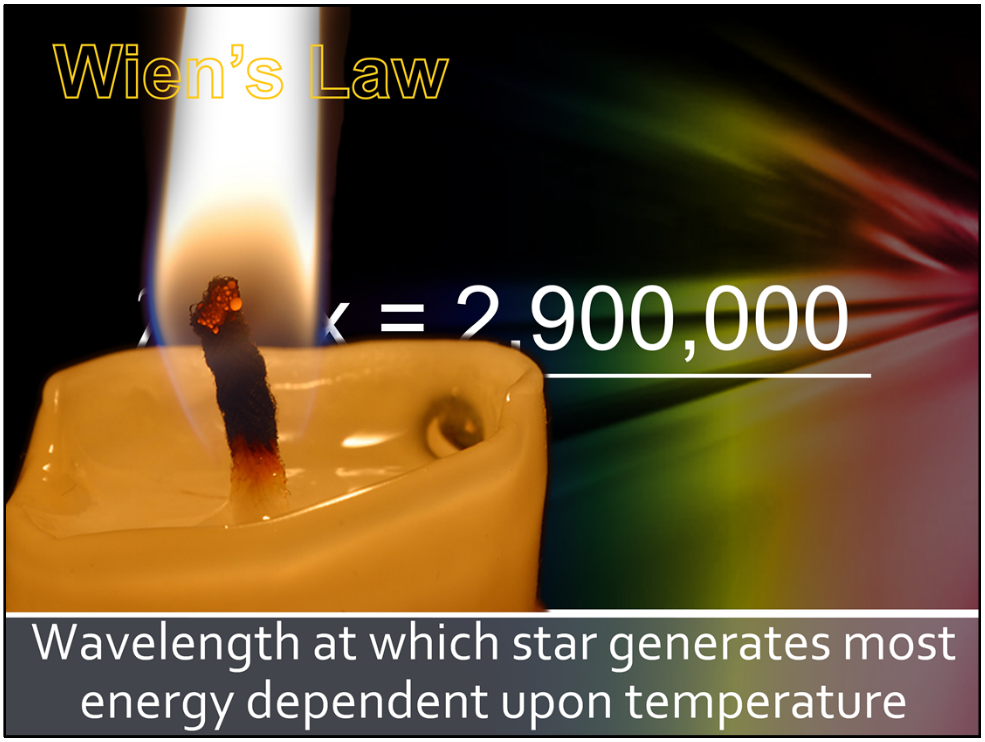
There are two radiation laws that deal with black bodies. These laws will help you understand the nature of the light given off by a star. The first law is related to energy and the second law is related to color.



Total amount of energy emitted from a unit per area per second

Which gives off more black body radiation, a hot surface or a cool one? Hopefully, you said a hot surface. After the discovery made by Wien, two scientists, Josef Stefan and one of his students, Ludwig Boltzmann, studied the total amount of energy emitted by an object per square meter per second. The relationship they came up with is called the Stefan-Boltzmann Law: E =sigma T to the fourth power.

How will this help you understand stars? Say you were observing two stars. One star that was the same size as the Sun had a surface temperature that was double the Sun's temperature. How much more energy would that star generate? By using the Stefan-Boltzmann equation, you would find that the star generated roughly sixteen times as much energy. It would not have been twice as much. Remember, it would have been E equals two to the fourth power or sixteen times as much energy!



Wien's Law

x = 2,900,000

Wavelength at which star generates most energy dependent upon temperature

The second law is called Wien's law. This law is related to the color of stars. You could relate this law to the heat of a flame. What part of a flame is the hottest? Hopefully, you said the blue part. What part of the flame is the coolest? If you said red, you are correct again. Just like the colors of the flame, you can also tell a star's relative temperature by its color. Blue stars are hotter than red stars. Wien's law tells you that the wavelength of light at which the star radiates the most energy is only dependent upon one thing, its temperature. Wien's law uses the equation lambda max equals two million nine hundred thousand divided by T.

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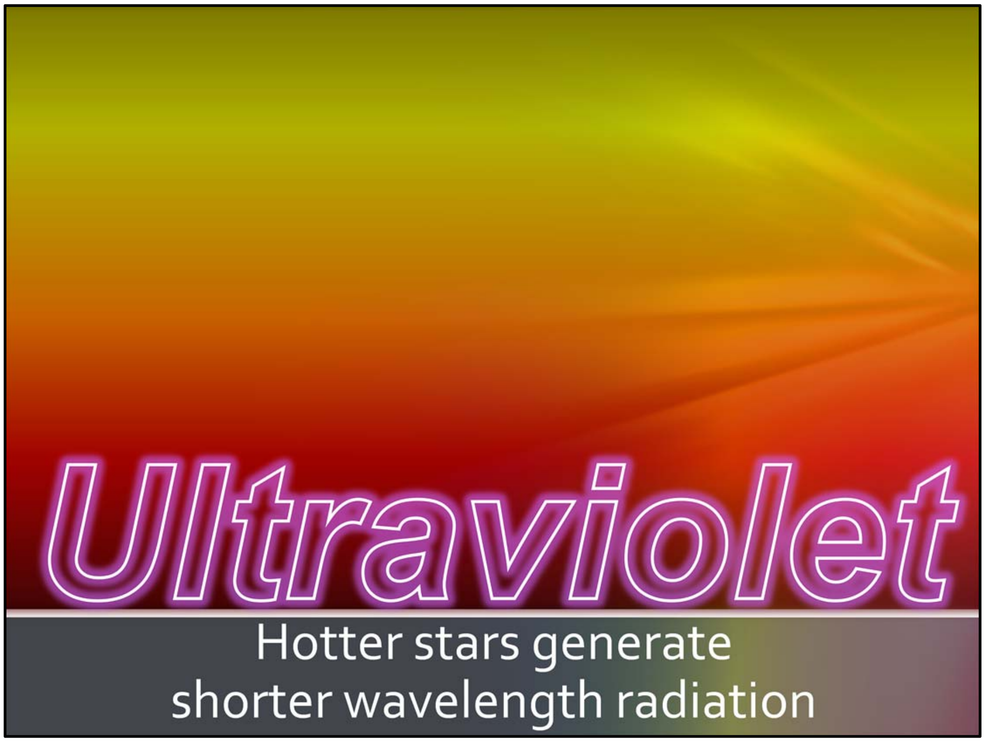
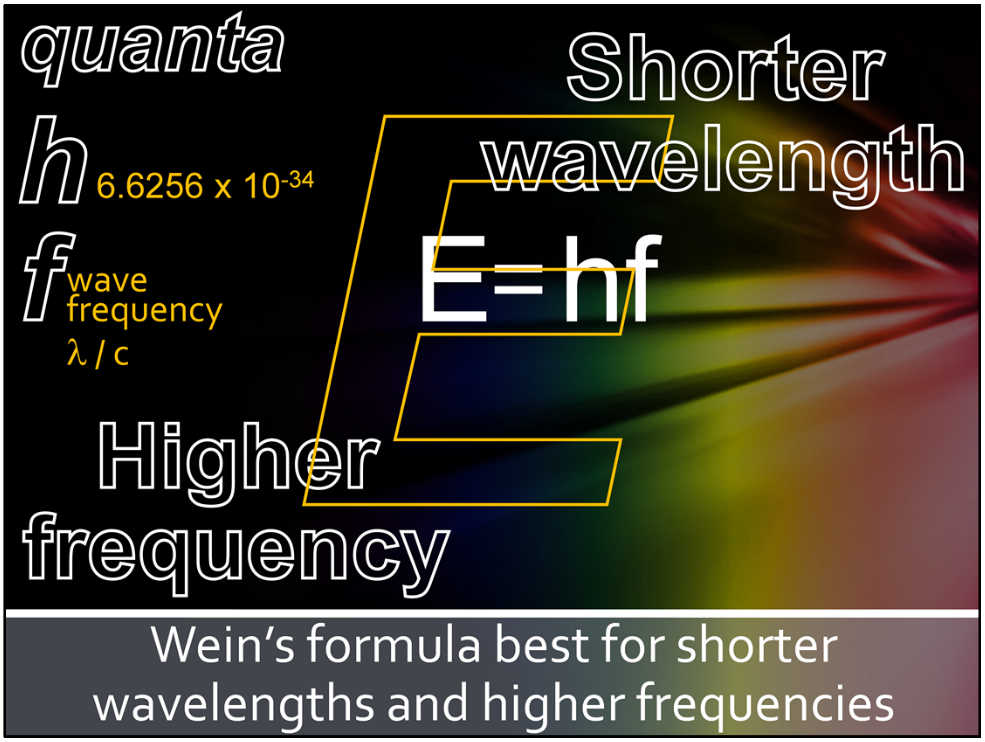


Ultraviolet

Hotter stars generate shorter wavelength radiation

This becomes a great tool for astronomers because it helps them make one major inference. As stars become hotter, they generate shorter wavelength radiation. The hottest stars will give off mostly ultraviolet radiation. As you can see from these two laws, studying the energy emitted from a object can tell astronomers a lot about that object.



Wein's formula best for shorter wavelengths and higher frequencies

The relationship between temperature and energy emitted is helpful in understanding stars, but it does not predict the spectral distribution of the energy of the radiation. It was proven that Wien's formula worked best for the shorter wavelengths and higher frequencies. Max Planck found that electromagnetic energy is emitted in discrete units, or "quanta", with the energy being equal to *hf, written in the equation E equals h f.* The *h* is Planck's constant 6.6256 x 10^{-34} joule-second and the *f* is the frequency of the wave. Frequency can also be stated as the wavelength divided by the speed of light or lambda divided by *c*. The speed of light is a constant at 3 x 10^{8} kilometers per second. Planck found that an intensity wavelength graph, or the *thermal spectrum*, of an object emitting electromagnetic radiation can be used to detect its temperature. The higher the frequency and shorter the wavelength, the greater the energy.