Wien's Law

What is it?
Wien's Law tells us where (meaning at what wavelength) the star's brightness is at a maximum. See the picture below – the red dot under the word "visible" is the peak for the 6000 K object. In other words, Wien's law tells us what color the object is brightest at. As the surface temperature rises, this peak intensity (brightness) shifts toward the bluer end of the spectrum. As the surface temperature decreases, the peak intensity/brightness will shift more towards the redder end of the spectrum as shown by the red dot in the picture below.

Official Definition: Wien's Law (also called Wien's Displacement Law) is defined as so: For a blackbody (or star), the wavelength of maximum emission of any body is inversely proportional to its absolute temperature (measured in Kelvin). As a result, as the temperature rises, the maximum (peak) of the radiant energy shifts toward the shorter wavelength (higher frequency and energy) end of the spectrum (bluer). This is what the equation looks like:

Peak Intensity (Max Brightness) occurs at this Wavelength $\lambda_{(max)}$ (in meters) = $\frac{0.0029\ meters \cdot K}{T\ (in\ Kelvin)}$

The wavelength lambda$_{(max)}$ is where the intensity is a maximum; T is the star's average surface temperature measured in Kelvin; and the 0.0029 meters x Kelvin is known as Wien's constant:.

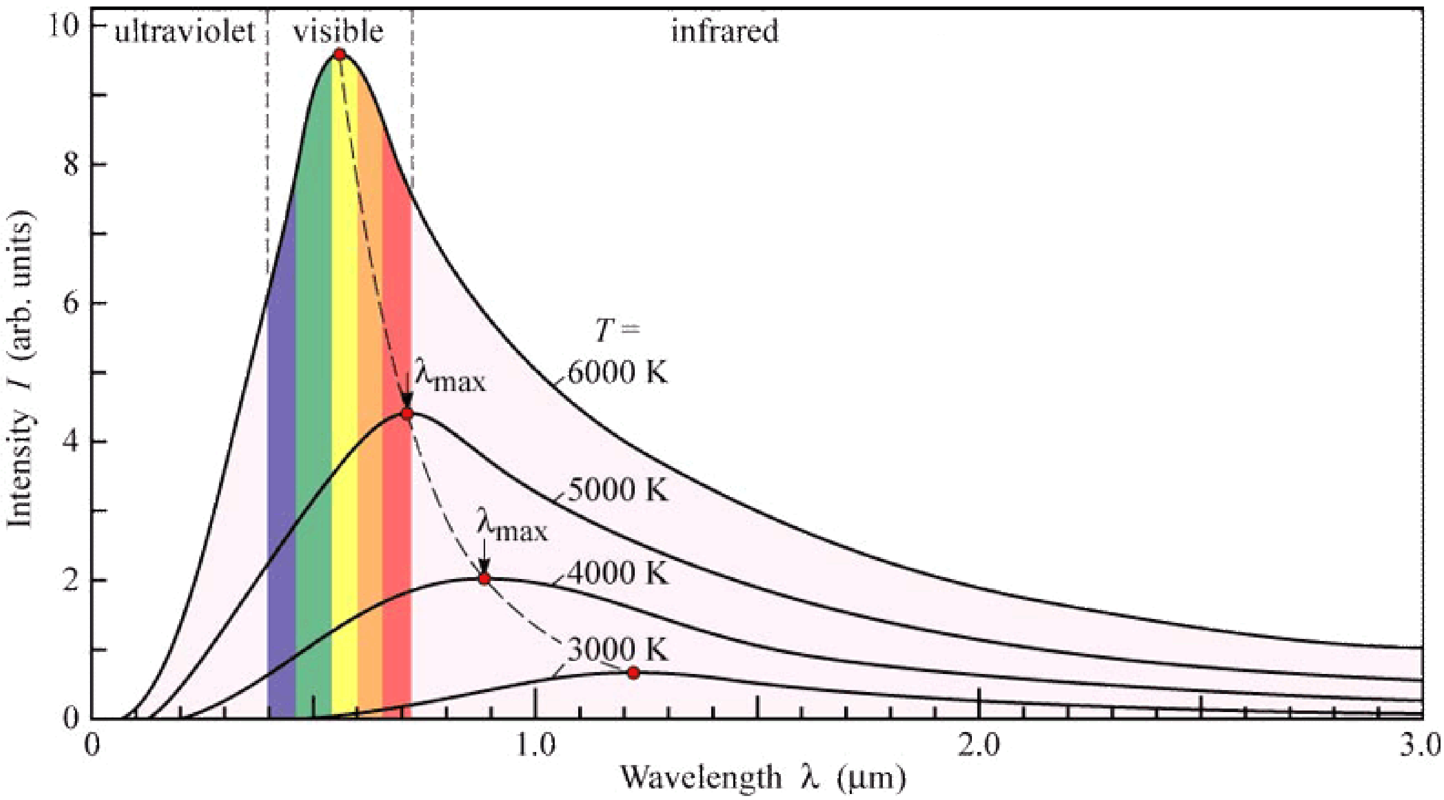

Image Credit: http://chriscolose.wordpress.com/2010/02/18/greenhouse-effect-revisited/

The curves above are Planck curves for objects at different temperatures. Planck's law tells us how intense the thermal emission is at **each** wavelength. The peak of this Planck curve (the red dot) is what Wien's Law tells us.

Wien's Law tells us that objects of different temperature emit spectra that peak at different wavelengths.

- Hotter objects emit most of their radiation at **shorter** wavelengths; hence they will appear to be **bluer**.
- Cooler objects emit most of their radiation at **longer** wavelengths; hence they will appear to be **redder**.

Remember, at any wavelength, a hotter object radiates more energy (is more luminous or brighter) at all wavelengths than a cooler one.

<u>Practice:</u> Now let's try a few out on your own.

<u>Example 1</u>: What wavelength (in nanometers) is the peak intensity of the light coming from a star whose surface temperature is 11,000 Kelvin? (Note: This is about twice the temperature of our Sun's surface.)

Let's plug the numbers into our Wien's Law equation: Wavelength $\lambda_{(max)}$ in meters = $\frac{0.0029\, meters \cdot K}{11{,}000\, K}$

We divide, the Kelvin cancels out and we are left with: $\lambda_{(max)}$ = 0.000000263 (which in scientific notation is 2.63 x 10^{-7}) meters. Since we know that there are 1,000,000,000 (one billion) nanometers in a meter, we simply multiply our answer by one billion to convert it from meters to nanometers: 0.000000263 x 1,000,000,000 = **<u>263 nm.</u>**

What color would we see with our eyes? Would we even be able to see it?
The answer to both of these questions is that a wavelength of 263 nanometers is in the ultraviolet (UV) part of the electromagnetic spectrum. Our eyes can't really see any wavelengths smaller than about 380nanometers so we wouldn't even be able to see this star's peak light . (If we lived close to it, we would probably adapt to it in a few million years ☺…)

<u>Example 2:</u> What is the wavelength of the brightest part of the light from our next closest star, Proxima Centauri? Proxima Centauri is a red dwarf star about 4.2 light years away from us with an average surface temperature of 3,042 Kelvin.

We don't really need the distance to solve this. All we need is the surface temperature to plug into our Wien's Law equation:

Wavelength $\lambda_{(max)}$ in meters = $\frac{0.0029\, meters \cdot K}{3{,}042\, K}$ which is 0.000000953 meters. We can convert this to nanometers as we did in Example 1 above and we get a peak wavelength of **<u>953 nm</u>**.

So would we be able to see the peak wave of this star?
Nope! Our eyes can only see wavelengths roughly between 380-750 nanometers. At 953 nm, this star's peak wavelength is in the infrared (IR) part of the spectrum so we are completely missing it.

<u>Example 3:</u> Determine the surface temperature of a star whose maximum intensity is at 400nm.

This is a little different but don't let it confuse you. Since we already have the wavelength, we just put it into our Wien's Law equation and solve for the surface temperature. This looks like:

Wavelength of the peak is at 400 nanometers = $\frac{0.0029\, meters \cdot K}{Temperature\ (K)}$

Let's convert our numerator to nanometers by multiplying it by one billion. This gives us:

Wavelength 400 nanometers = $\frac{2{,}900{,}000\, nm \cdot K}{Temperature\ (K)}$

We algebraically convert this to: Temperature (K) = $\frac{2{,}900{,}000\ nm \cdot K}{400\ nm}$ and solve for Temperature. The *nm* units cancel out and we get a surface temperature of **7,250 Kelvin**.

How do we know this is correct?

This is a little hotter than our Sun and the wavelength of 400 nanometers would be at the violet end of the visual spectrum. As we have learned, the hotter the star, the smaller the wavelength in nanometers which translates to a color towards the violet or ultraviolet end of the visible spectrum. Conversely, the cooler the star, the larger the wavelength in nanometers which translates into a color that is more towards the red or infrared end of the spectrum.
Since our Sun burns at around 5,778 Kelvin and is in the greenish yellow band of the spectrum, it makes sense that a hotter star at 7,250 Kelvin would translate as a smaller wavelength and a color more towards the violet end of the spectrum.

Here is a “map” of the electromagnetic spectrum, showing the small part that is visible to our eyes.

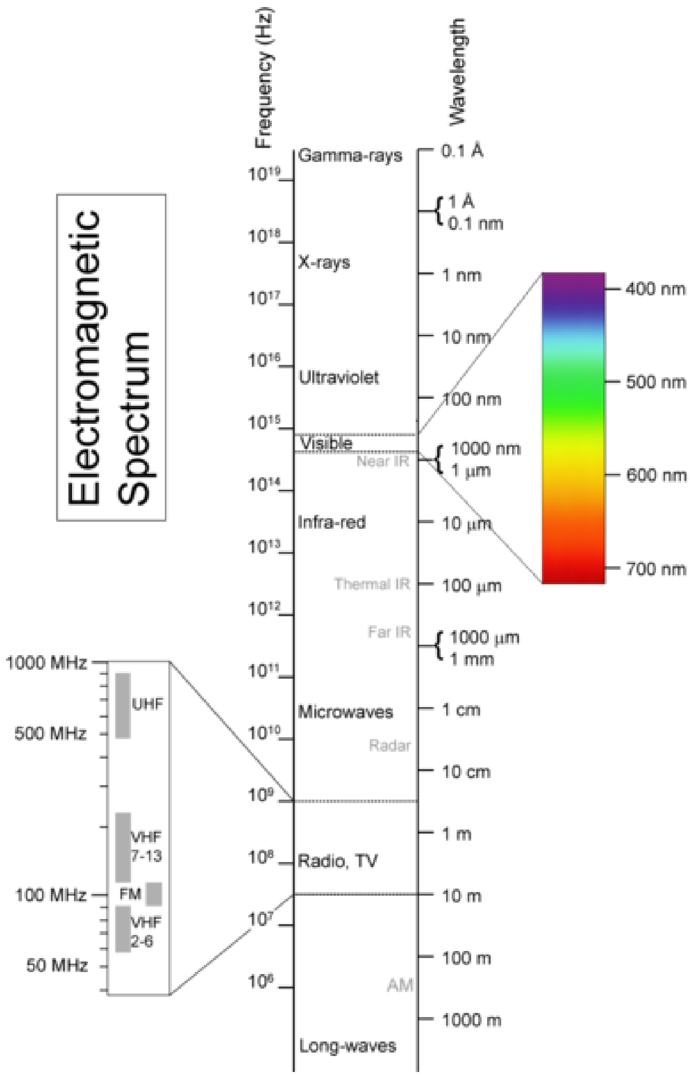

Image Credit: http://en.wikipedia.org/wiki/File:Electromagnetic-Spectrum.png