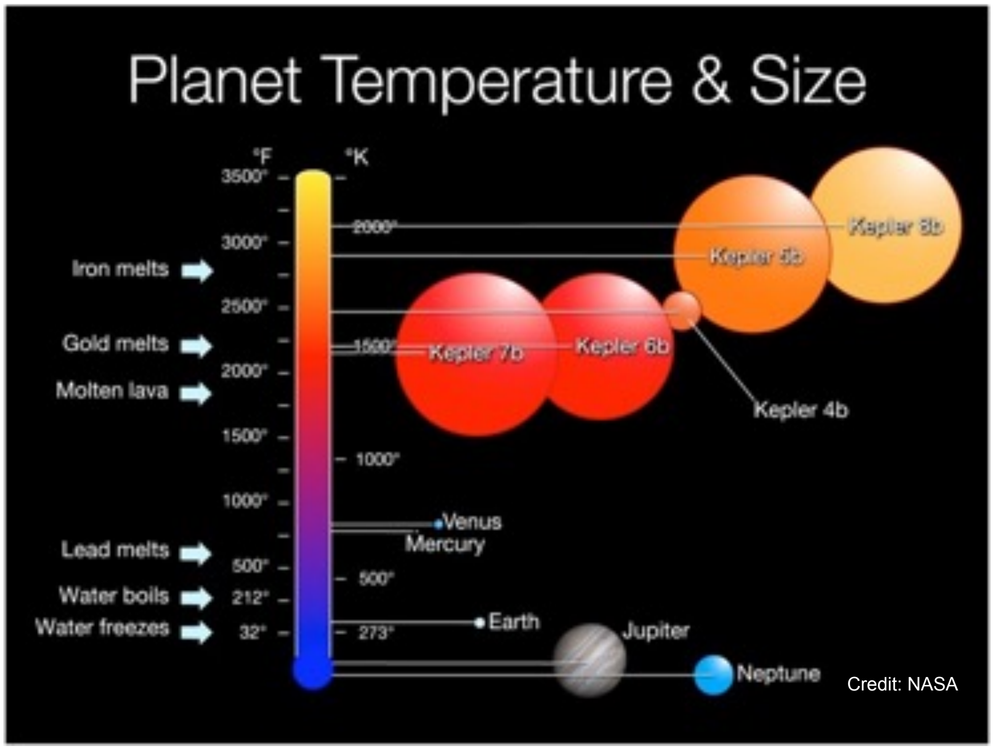
> Since, in the long run, every planetary civilization will be endangered by impacts from space, every surviving civilization is obliged to become spacefaring - not because of exploratory or romantic zeal, but for the most practical reason imaginable, staying alive. If our long-term survival is at stake, we have a basic responsibility to our species to venture to other worlds.
>
> Carl Sagan

The Hotter You Are, The More You Radiate

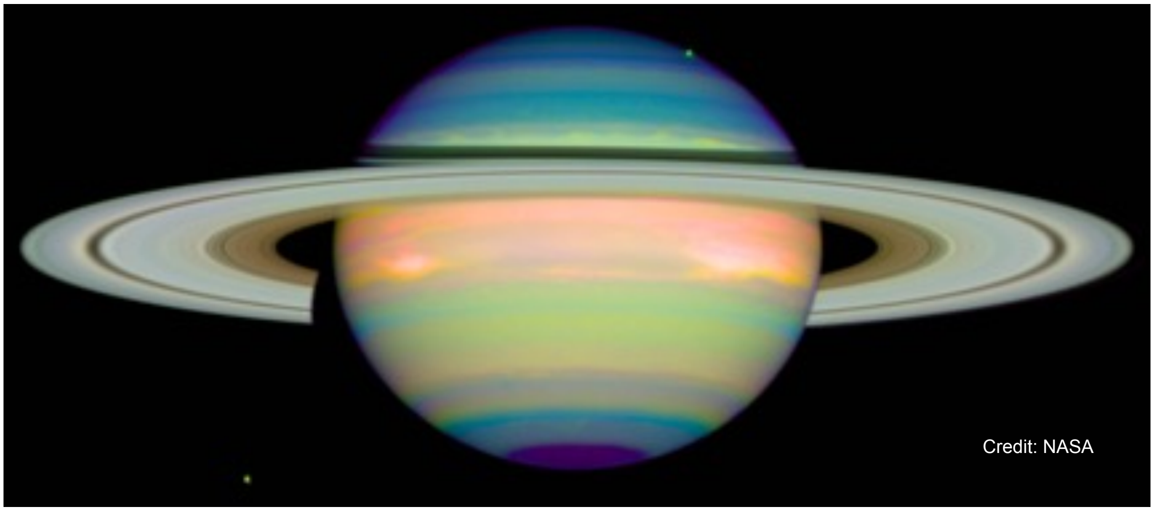
We're here! In this module we'll explore how light tells us the temperature of planets and other objects.

Let's not beat around the bush, most objects produce thermal radiation. This is the most common type of continuous spectra (rainbows). We can determine the temperature from these spectra because hotter objects emit more light per unit area and they emit photons with a higher average energy.



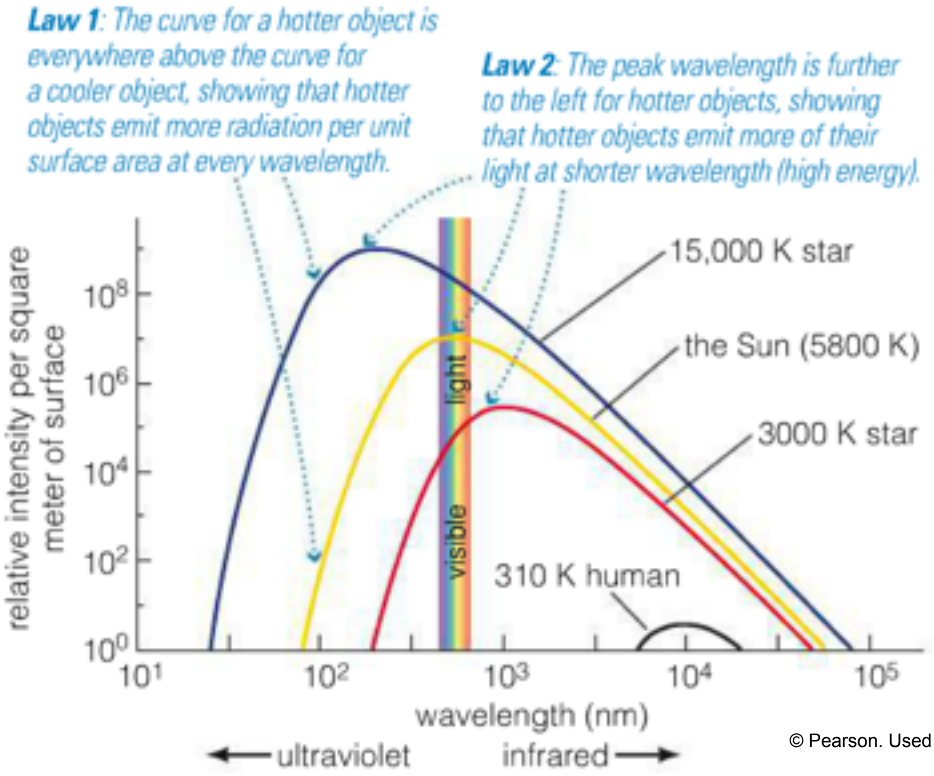
Credit: NASA

Above is a fun plot of how hot some planets and exoplanets are. Earth hovers between the freezing and boiling of water. Jupiter is colder, Neptune colder still. In some of the exoplanets, which orbit pretty close to their parent stars, they get hot enough where you can melt gold on them. Quite different planets than what we have. This is an example of how we can tell the temperatures (and other properties) of planets without ever going there to put up a thermometer.



Credit: NASA

Most objects in the universe, to a good order of approximation, are thermal radiators. You are a thermal radiator. The Sun is a thermal radiator. The stars are thermal radiators. Even the universe itself is a thermal radiator. That's because anything that has a temperature is going to emit a thermal spectrum, a continuous spectrum. Below is an image of Saturn in the infrared. It's cold there, but Saturn has a temperature. If something has a temperature, that something radiates.



© Pearson. Used with permission

What do I mean by a thermal radiator anyways? Well, a thermal radiator has a continuous spectrum. So all of the wavelengths, and all of the colors, are present. The plot above shows how bright each color is. The y-axis measures the brightness and the x-axis measures the wavelength or the color. You see a continuous, smooth spectra. Each curve is smooth.

The black curve is for us humans. Our body temperature is about 310 Kelvin. The curve peaks at wavelengths around 10,000 nanometers which is the infrared, hence night vision goggles which see in the infrared. We appear so bright with night vision goggles because we glow like an infrared light bulb.

Then we have a star at 3,000 Kelvin colored red, the Sun at about 5800 Kelvin colored yellow, and finally a hot start at 15,000 Kelvin colored blue. Just for reference, the visible light spectrum is on there.

You'll notice a couple of things as we crank up the temperature from humans through cool stars to hot stars. Number one, the curve gets higher. The hotter it is the higher the curve. There's more area under the curve. The second thing you notice is the maximum of the curves shifts over to shorter wavelengths, to bluer wavelengths. The hotter it is the more the curve shifts toward the blue.

So the first rule in simple terms is: the hotter you are, the brighter you are. Hotter objects emit more light from a given area than cooler objects emit from an area of the same size. That goes along with our observation that the higher the temperature, the higher the curve. The relationship of the temperature to how much light comes out is given by

$$\text{Power} = \sigma\ \text{Temperature}^4 \cdot \text{Area}$$

So if you want to make something emit more power, become brighter, there are two ways to do it. You can keep the temperature the same but make the lightbulb bigger. Or you can keep the lightbulb the same size but increase the temperature. The second option is very effective! The power emitted goes up by the fourth power of the temperature. So you change the temperature a little bit, you raise that to the fourth power, you get a whole lot more light coming out of it. This describes the curves going up as your crank up the temperature.

The second rule in simple terms is: hotter objects look bluer. Cooler objects look redder. This is completely opposite from your psychological color map where blue is cool (ice cold blue) and red is hot (iron is red hot). The physical color map is completely opposite. It's hotter objects that look bluer, and cooler objects look redder. Don't ask me how come we got such a disconnect between the physical and psychological color maps. I'm just noting it.

That shift of the peak curve toward the blue, toward higher energies, as you crank up the temperature, is quantified by

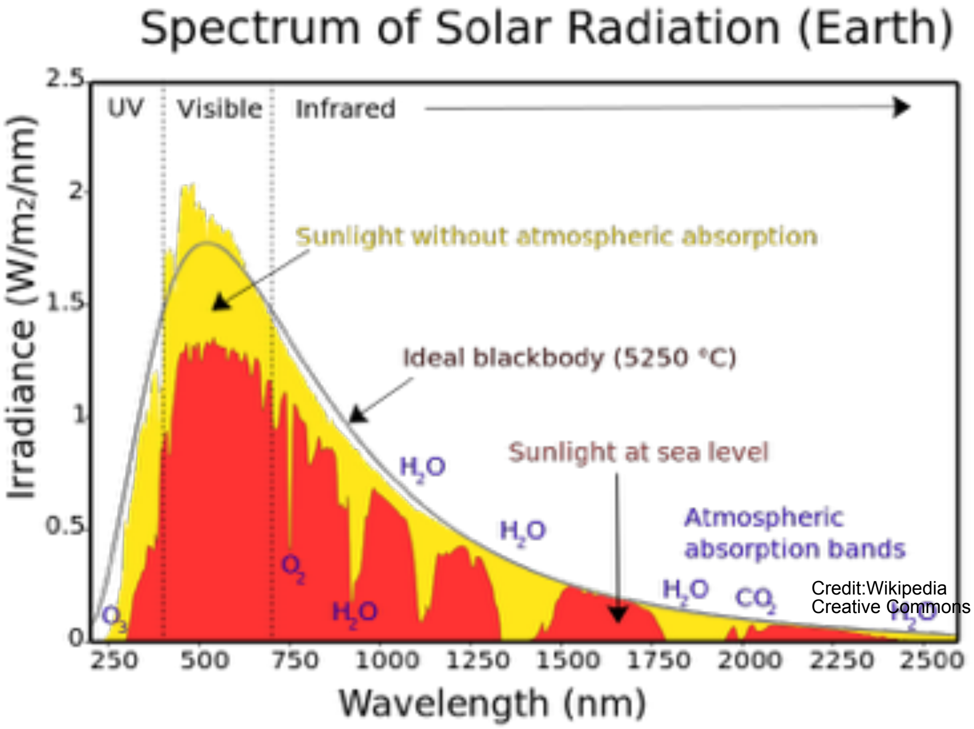
$$\text{Wavelength}_{\text{peak}} = \frac{2.9 \times 10^6}{\text{Temperature}}\ \text{nm}$$


Credit:Wikipedia Public Commons

This says the location (the color, the wavelength, where the peak occurs) is a constant divided by the temperature. We don't have to worry about where the constant comes from. Simple. The peak wavelength is inversely proportional to the temperature.

You already intuitively know this. If you take an object like a fork or maybe a poker like the image shown above — maybe with a marshmallow and a piece of chocolate on to make a s’more — initially your poker appears black because its radiating the infrared as its heating up. As it begins to get hotter it begins to glow red and then yellow - getting bluer and bluer - until finally, we'll see something that we call white hot, in which case your s'more is probably burned and you'll have to make another one. But this is the transition from going from cool to hot, going from redder wavelengths to bluer wavelengths.

So how do we interpret an actual spectrum? The spectrum of a real object is usually not so clean as to just be a thermal continuous spectrum, or an emission line spectrum, or an absorption line spectrum. It's usually a combination of all them. But by carefully studying the spectral features, we can learn a great deal about the objects that produce them — their temperature, their density, their composition, and how fast they're rotating, how fast they're moving, and more. Wholesale amounts of information just from the analysis of the light.



Credit:Wikipedia
Creative Commons

As an example the image above shows the spectrum of the Sun at Earth's surface. The y-axis is a measure of brightness and the x-axis is our familiar wavelength or color. Note the solid dark curve - that is the underlying continuous thermal spectrum we've been talking about. From this thermal spectrum we start punching holes in it - rainbows with holes - due to absorption at specific wavelengths (specific colors) from water vapor, carbon dioxide and other gasses in our atmosphere.

Thanks! Bye Bye.