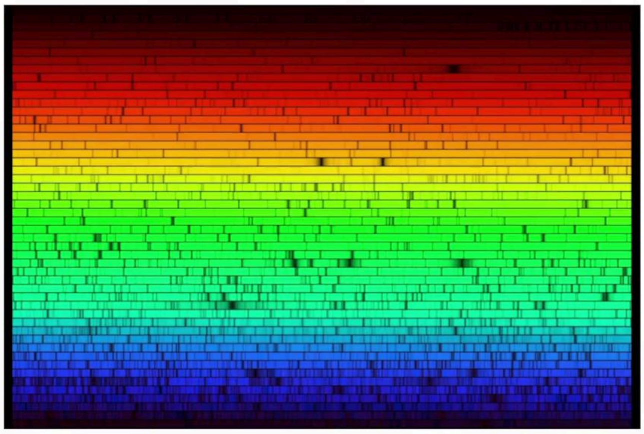
Blackbody emission and radiation transport (Part 2)

Kim McAlpine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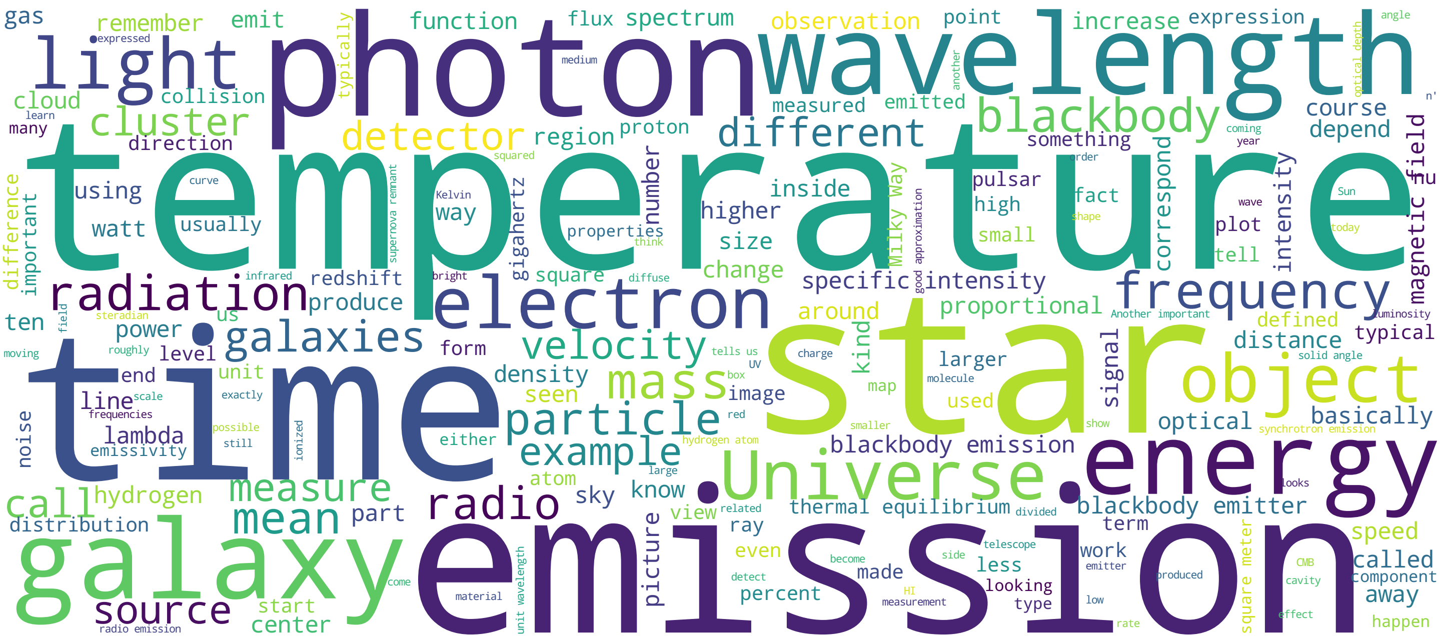

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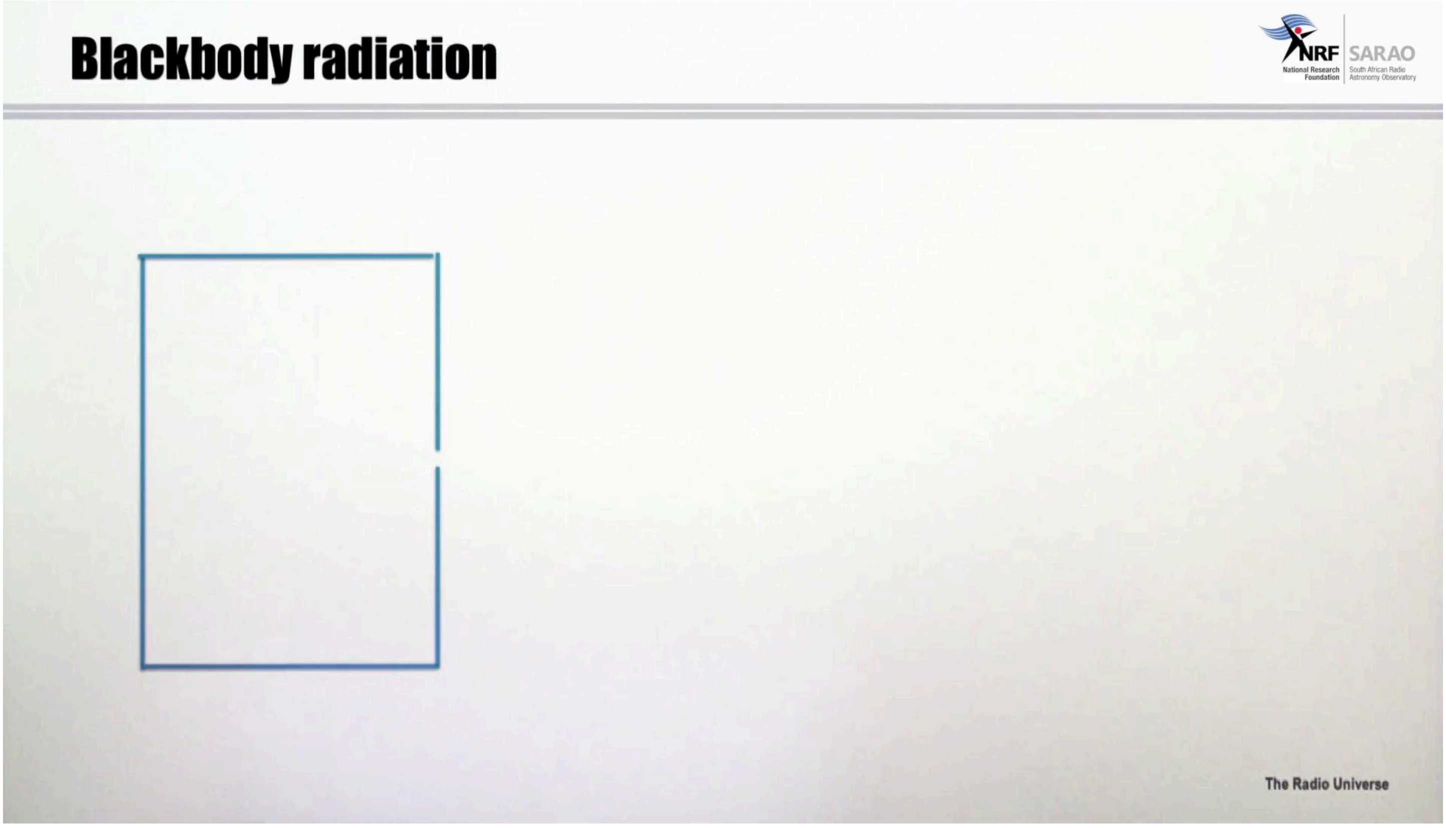
Video

In today's lecture, we'll be learning about the properties of blackbody emitters and particularly learning how their emission can tell us something about the temperature of a blackbody radiator.

Notes

Summary

0m 05s

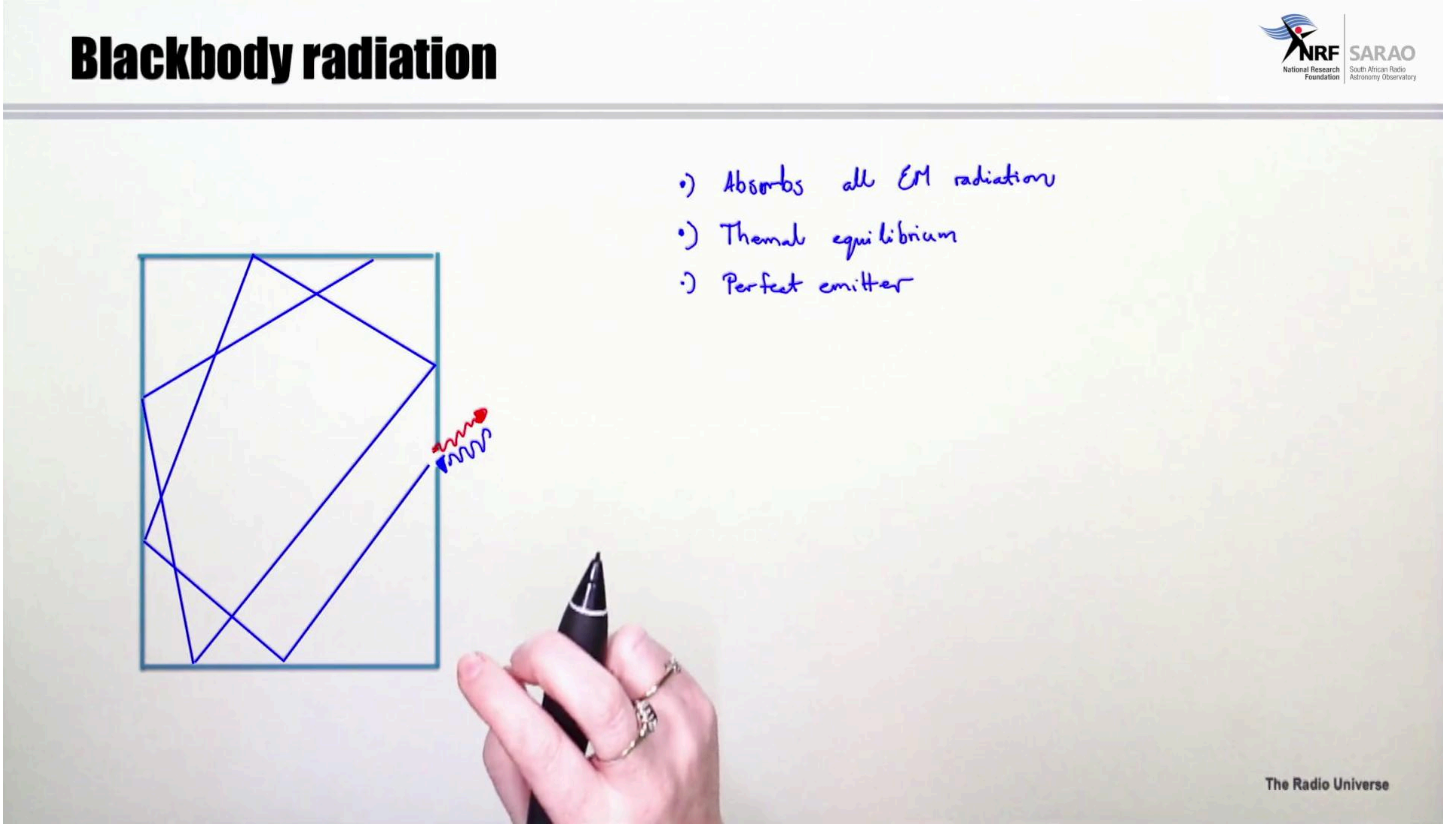


Today we're going to learn about a very famous type of continuum emission and all of its properties. We're going to learn about blackbody emission. So a blackbody emitter is effectively an idealized body which absorbs all electromagnetic radiation that falls on it which is why it's called the blackbody and this property is important because what it tells us is that any emission you see from a blackbody comes directly from the blackbody itself. It's generated by the blackbody and it's not reflected from other nearby objects. Blackbodies are also in thermal equilibrium so what that means is that they have a constant temperature and that the temperature of the body is constant everywhere on it so the temperature of the blackbody isn't changing and there are no hot spots and cool spots on it. It's just the same temperature everywhere on its surface. Another important property of blackbody emitters is that they all have the highest amount of radiation at a given temperature that can be emitted. So if you have a blackbody, if you have a blackbody and you have some other kind of emitter and they're both of the same temperature, the blackbody will always emit a greater amount of radiation.

Notes

Summary

0m 15s

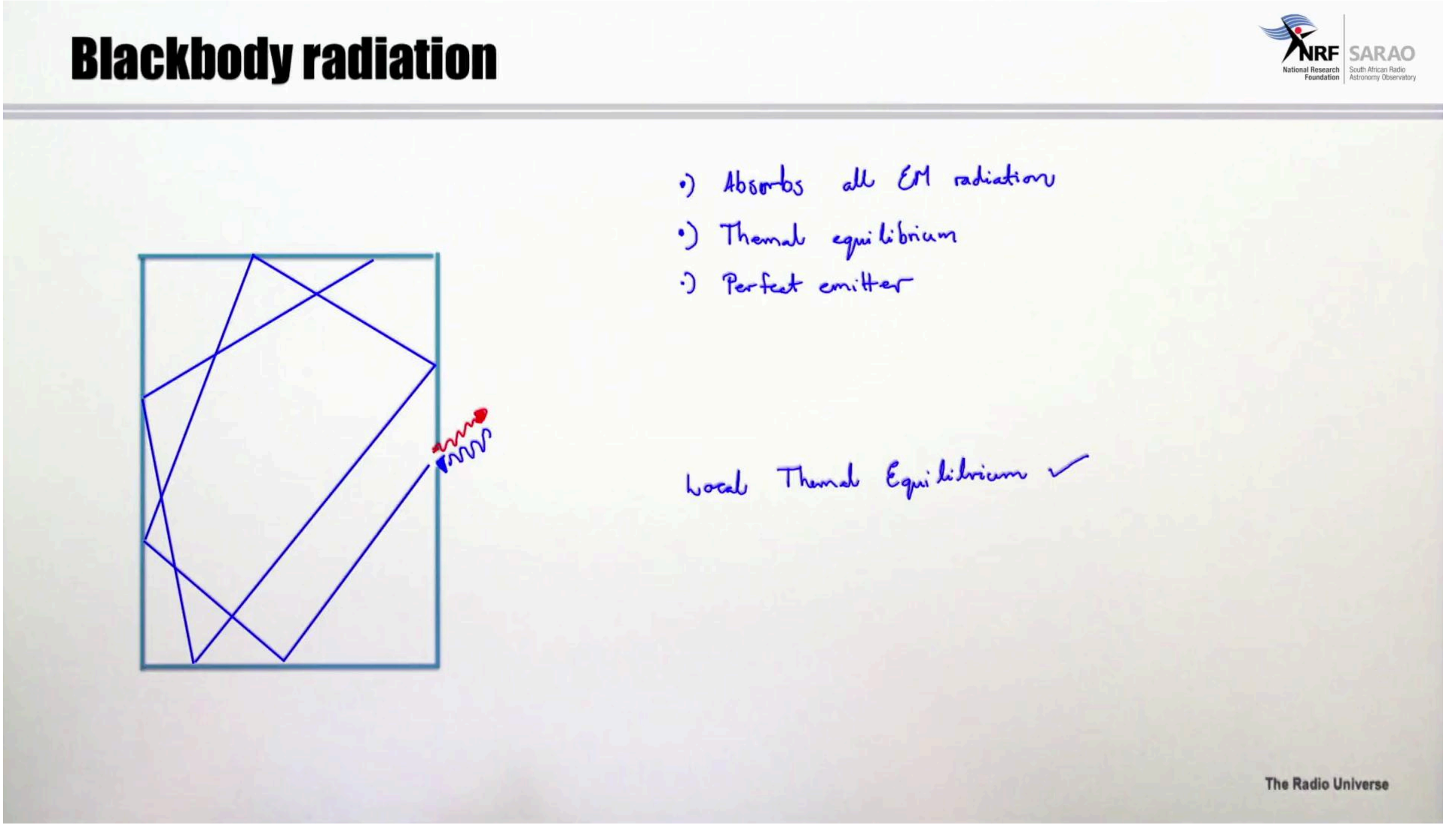


An example that approximates this idealized behavior of a blackbody is a cavity with a small hole in it. So a cavity with a small hole in it is considered to be a good approximation for a blackbody because if you have some kind of incident radiation so if there is a photon that arrives at this blackbody and gets in through the small hole then that radiation will just be reflected inside the box more or less forever and is very unlikely to ever escape from inside this box and so all the photons that hit this little hole will be absorbed and that some very small amount of radiation might escape out of this cavity which is the radiation that we'll be studying. But this amount of radiation that's escaping out of this small cavity is very small and so its effect on the thermal equilibrium of the photons that are inside the box is going to be really essentially negligible. These blackbody emitters or this hole has been shown to have a very specific shape to its emission which basically arises because there's only a fixed number of wavelengths and vibrations that are allowed with inside this cavity of a finite volume.

Notes

Summary

1m 36s

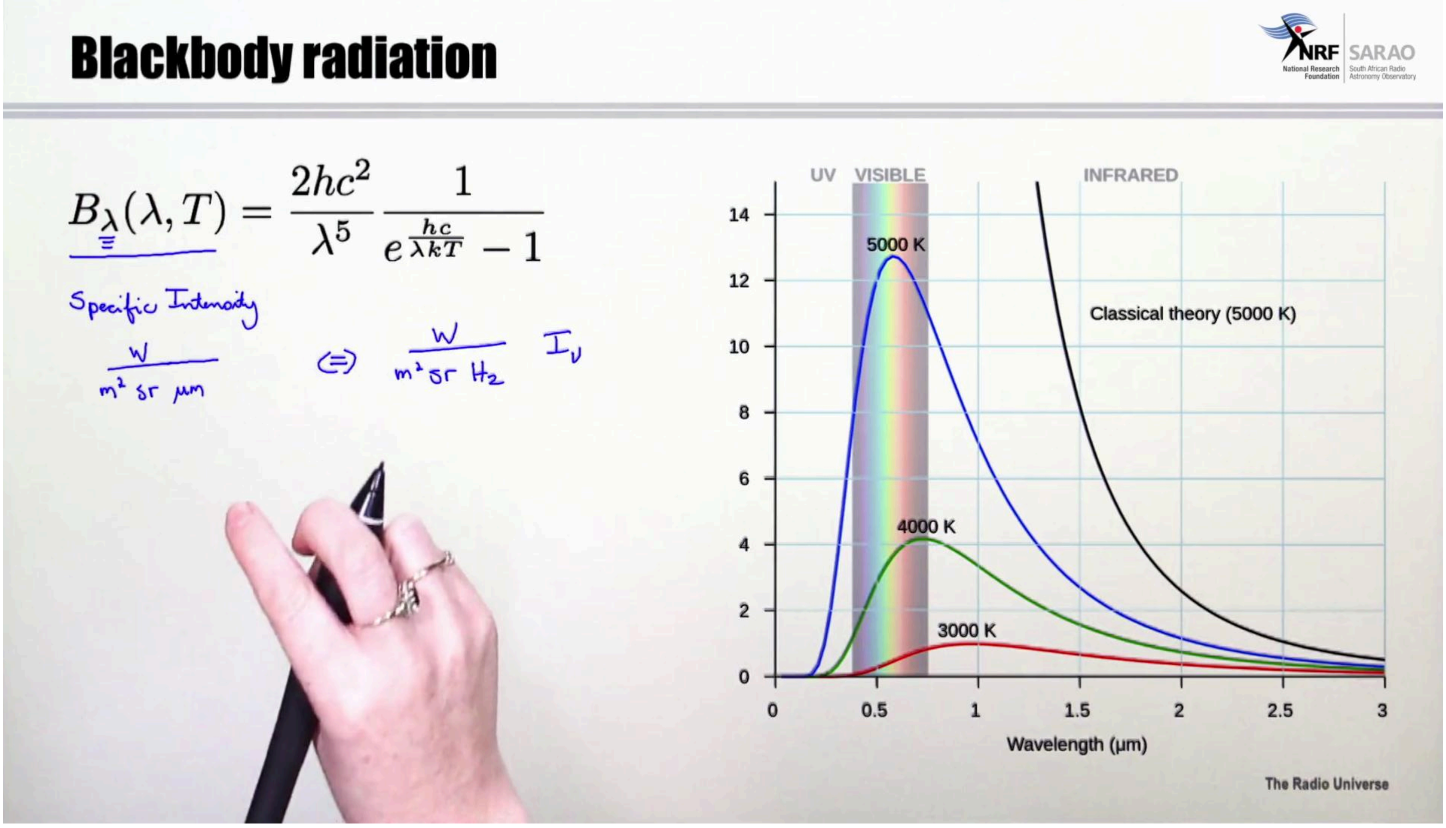


So knowing what this emission is, is very useful for astronomers because we're able to approximate many astronomical objects as being blackbody radiators. People usually use it as a good description of the Sun's radiation or perhaps the planet's radiation and you can still use blackbody radiation as a good approximation of a body's emission even if it's not in perfect thermal equilibrium. You can use it even if it's in something called Local Thermal Equilibrium which effectively means that it just has a well-defined temperature. So even if it is exchanging energy with another medium but if temperature remains roughly constant, you can still call it an Local Thermal Equilibrium and in that instance blackbody radiation is still often a very good approximation for the radiation from an object.

Notes

Summary

3m 06s

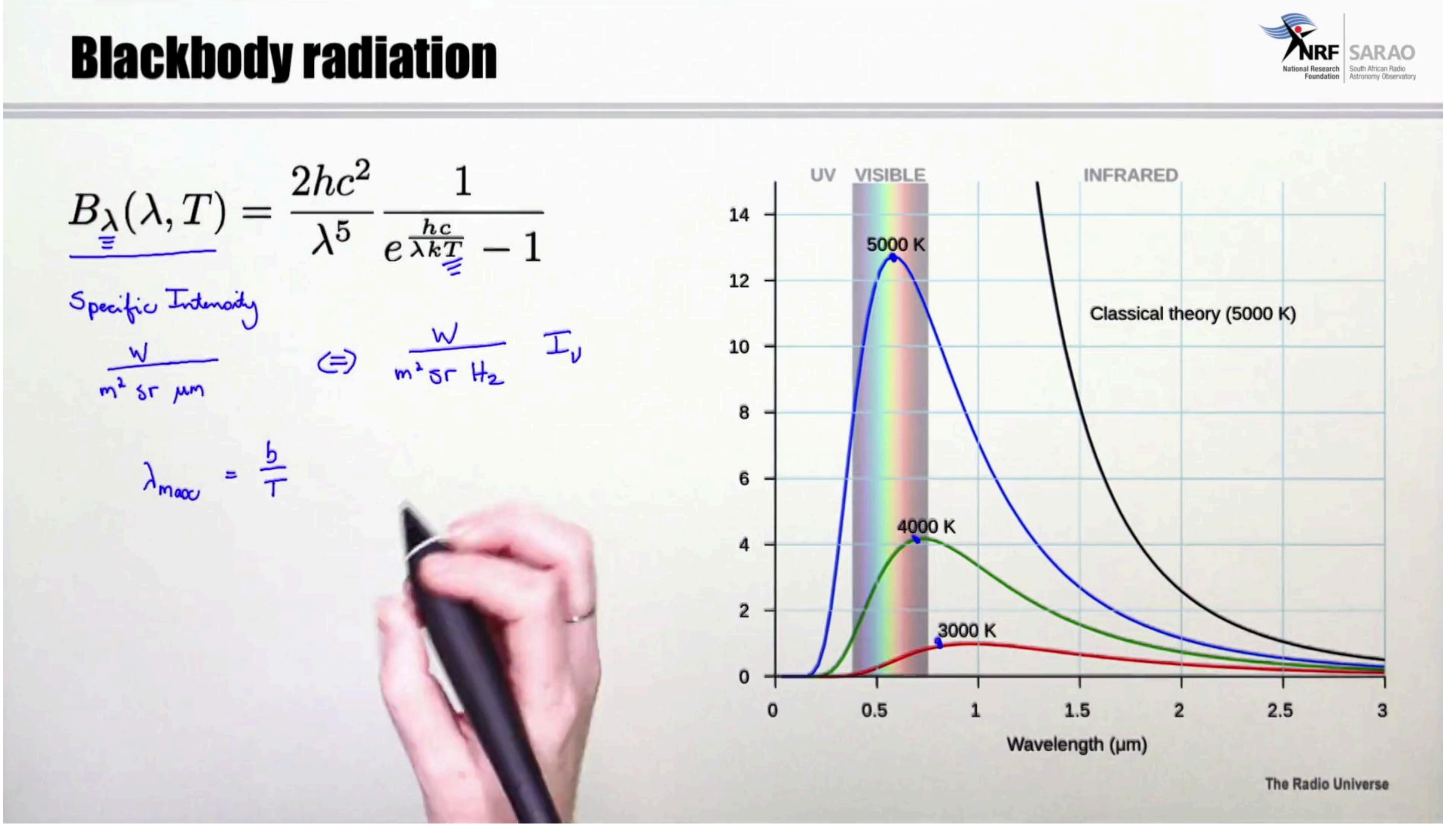


The emission from a blackbody is described with this equation which is also sometimes called the Planck function after Max Planck who was the first scientist to successfully describe this emission with an equation. Here we've plotted what this looks like as a function of wavelength for several different temperatures so you can see this is what the blackbody looks like, blackbody emission looks like for a low temperature object and for increasing temperatures. This equation is describing what the specific intensity of the blackbody is. Now remember from your previous lectures that specific intensity is a measure of the watts per meter squared per steradian per micrometer or some other measure of wavelength. So it's a measure of the power per solid angle per unit area per unit wavelength and the subscript at the bottom here tells you that you're measuring specific intensity here per unit wavelength. However, specific intensity can also be measured per unit Hertz so watts per square meter per steradian per Hertz so you can measure it per unit frequency as well as per unit wavelength. Remember that specific intensity is a is a property of the emitter.

Notes

Summary

4m 10s

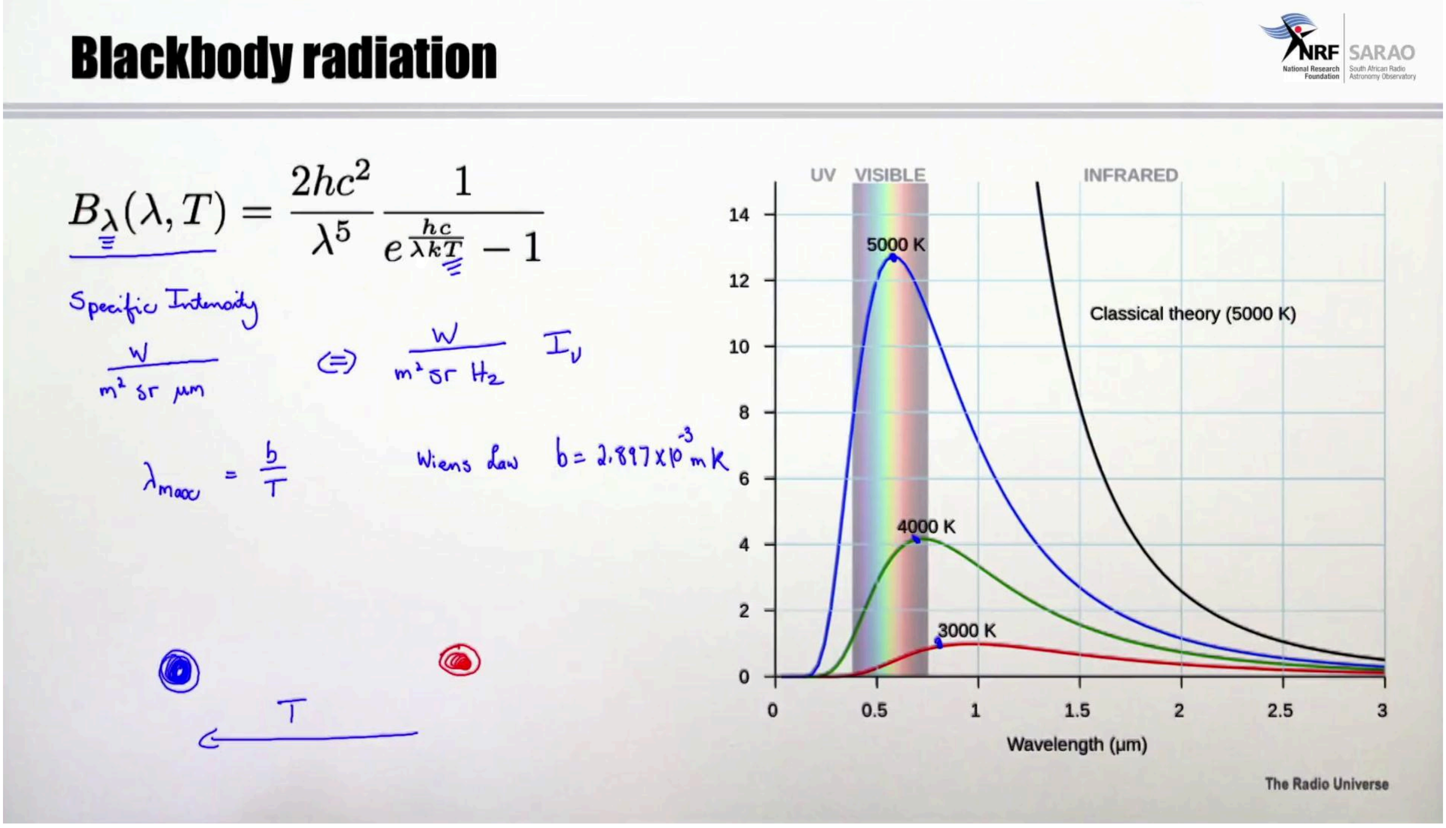


It doesn't change with the distance at which you're detecting the object and that's because it's defined per unit solid angle. So what that tells you is that if you move your detector further away from the object that you're looking at, the watts per square meter will go down but the solid angle will also go down and so that allows that to compensate for the decrease in watts per square meter. So it doesn't matter how far away you are from an object, specific intensity will always be the same. Another important thing to notice about this blackbody emission profile is that it only depends on temperature so if you know the temperature of a blackbody then you uniquely know what its emission will look like and vice versa. If you have it's emission you can uniquely measure its temperature. An interesting thing to note from this plot of blackbody emission is that the higher the temperature, the shorter the peak wavelength of the emission appears to be. And this tendency has a special name. It's called what has been characterized using a special law which says that the max wavelength of blackbody emission is related to the temperature of the object you are studying by this equation.

Notes

Summary

5m 45s



This is called Wien's Law and what that tells us is that the color of an object is significantly affected by its temperature so cooler objects will emit more of their radiation at longer wavelengths and so will appear redder and hotter objects will emit more of their radiation at shorter wavelengths and so will appear bluer. So you have hot blue objects and you have cool red objects.

Notes

Summary

7m 09s

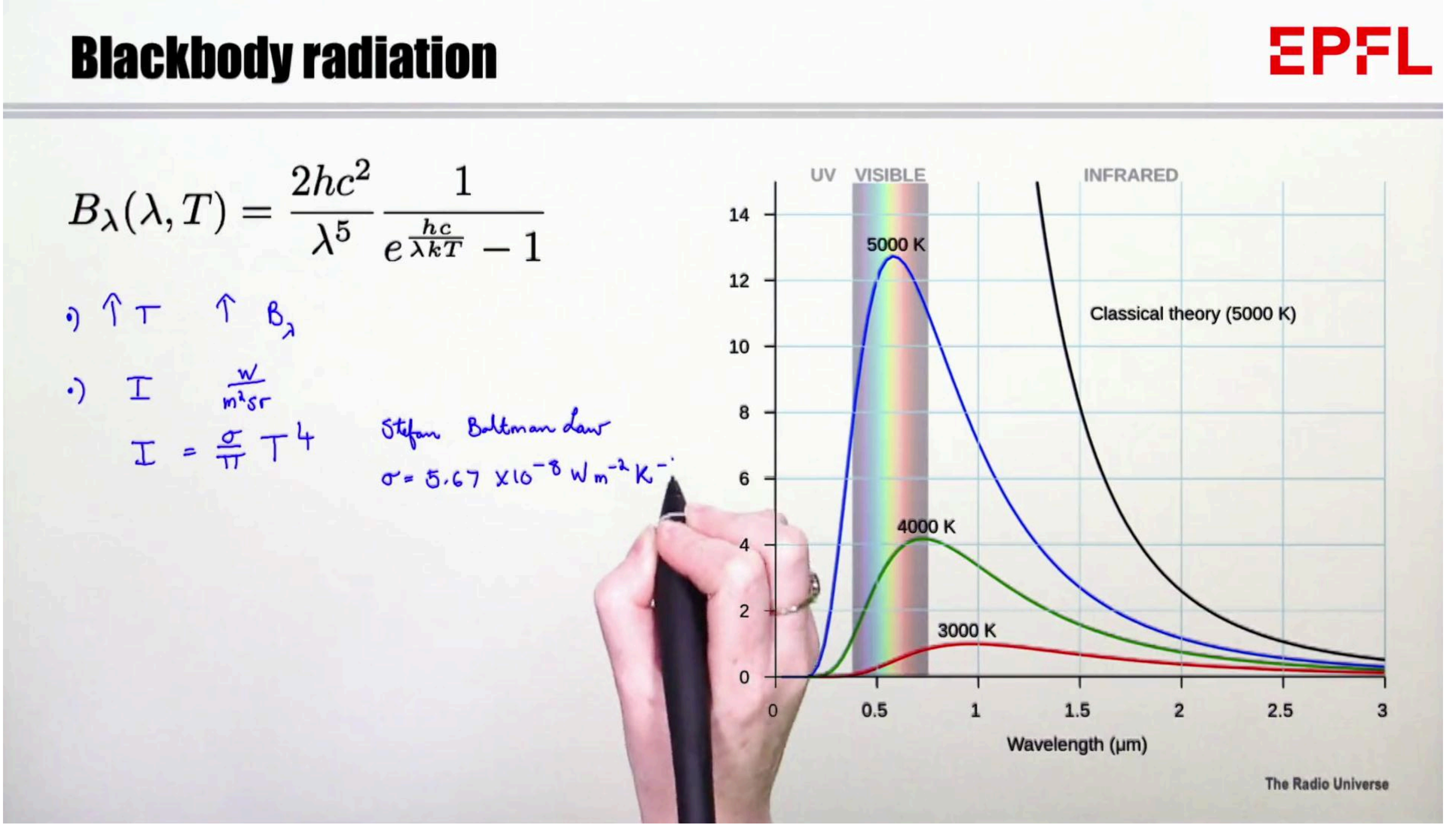
Temperature and Color

A concrete and very famous example of this color dependence of stars can be seen in the constellation of Orion. So stars have their emission approximately like a blackbody and this star in the top here as you can see looks very red in the picture while this star in the bottom looks a sort of blue white color. This top star is Betelgeuse. It has a temperature of around 3,300 Kelvin and it emits about 85% of its emission in the infrared which is why it appears so much redder. This star is Rigel. It has a temperature of around 12,000 Kelvin and it emits 60% of its emission in the UV which is why it appears to be this blue white color.

Notes

Summary

7m 49s

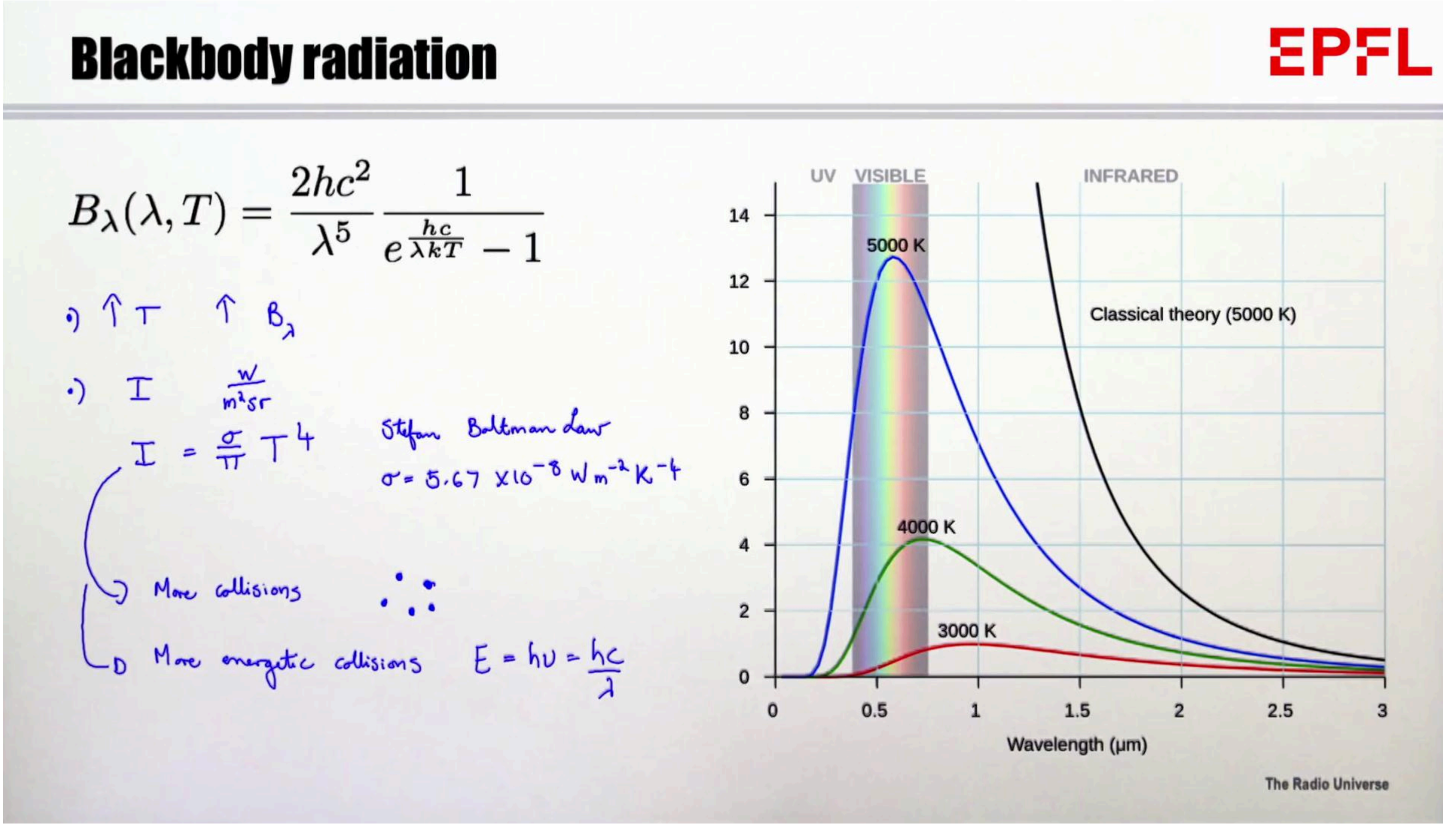


Another important property of specific intensity and temperature in this plot is that you'll see that for every temperature the higher the temperature, the higher the specific intensity at any given wavelength. So if you have a higher temperature then you will also have a higher specific intensity at any wavelength. But what you can also see is that the total amount of emission so if you were to integrate all of the intensity underneath the here underneath the curve here for 5,000 Kelvin, you would see that it's a lot more than the total amount of emission that you get at lower temperatures here. So if we were to integrate this whole thing across all wavelengths then what we can measure is the intensity and this intensity is in units of watts per square meter per steradian but now we've taken away the dependence on wavelengths because we're integrating over all wavelengths and that this intensity is then proportional or proportional to the temperature to the power of four. So as temperature increases, the total intensity of light increases really rapidly and this form of this proportional relationship is called the Stefan–Boltzmann law where sigma is...

Notes

Summary

8m 49s



You can think of these two very interesting characteristics of blackbody emission, the increasing amount of radiation with increasing temperature and the decreasing maximum wavelength as temperature as being explained by the number of collisions inside a blackbody emitter. So if you imagine that you have a body with some temperature which has a number of particles which are all moving with some velocity, as you increase the temperature, the velocity of these particles will increase and so the total number of collisions between these particles will increase and so there'll be more particles that are collisionally excited and more emission coming from this. So this part of the Stefan-Boltzmann law happens because you have more collisions or you can think of it as being that way. But also because the particles are moving faster and faster, you'll also have many more energetic collisions and remember that energy is related to wavelength by this relationship. So the more energetic the collisions are, the shorter the wavelength of the emission that you produce and so that is why you have this two interesting characteristics of blackbody emission.

Notes

Summary

10m 22s

Blackbody radiation

EPFL

$$B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k T}} - 1}$$

- $\uparrow T \quad \uparrow B_\lambda$
- $I \quad \frac{W}{m^2 sr}$

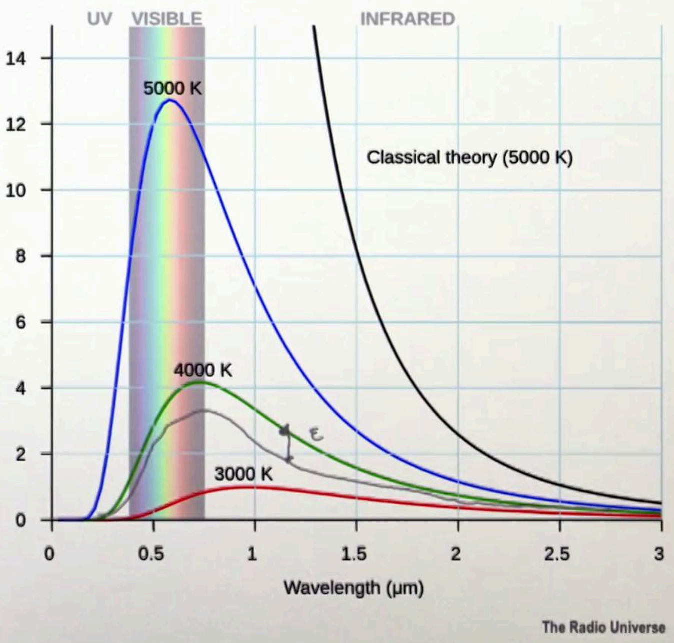
$I = \frac{\sigma}{\pi} T^4$ Stefan Boltzman law

$\sigma = 5.67 \times 10^{-8}\ W m^{-2} K^{-4}$

→ More collisions

→ More energetic collisions $E = h\nu = \frac{hc}{\lambda}$

Gray body $\varepsilon <$ $I = \varepsilon \frac{\sigma}{\pi} T^4$



So remember that I said that blackbody emitters have the highest amount of emission for a given temperature of any object so any other object that you measure at say, 4,000 Kelvin would have some emission that is below this level, this green line on the plot and the difference between the blackbody emitter and this other thing that you might be measuring is characterized by a proportionality constant called the emissivity and there is a special kind of body called a grey body emitter which has an emissivity which is completely constant. So what that means is that the shape of its emission is exactly the same as a blackbody emitter over wavelength. It's just that it's decreased by some factor which is the emissivity. So in that case you will also have that if you have a grey body emitter then you have an emissivity that's less than one and you can say that the intensity for this grey body emitter would just be the emissivity times the intensity for a blackbody emitter.

Notes

Summary

11m 40s