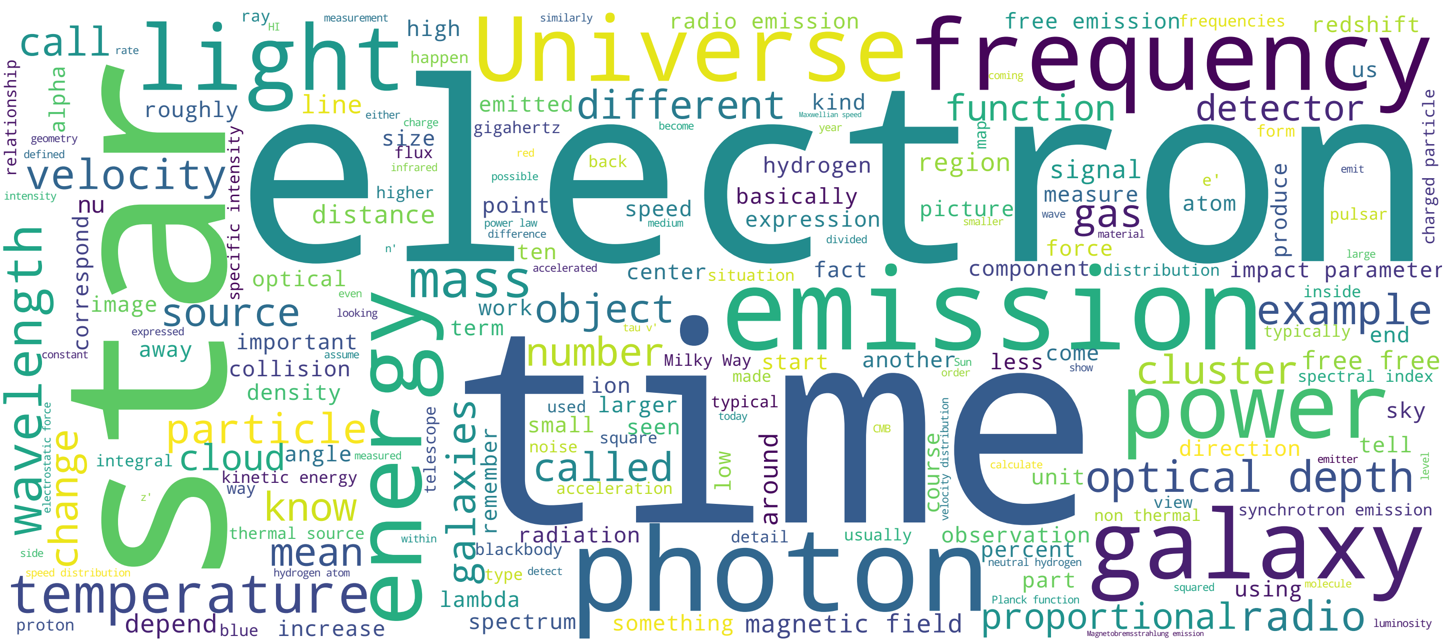
Continuum Emission (part 2)

Kim McAlpine



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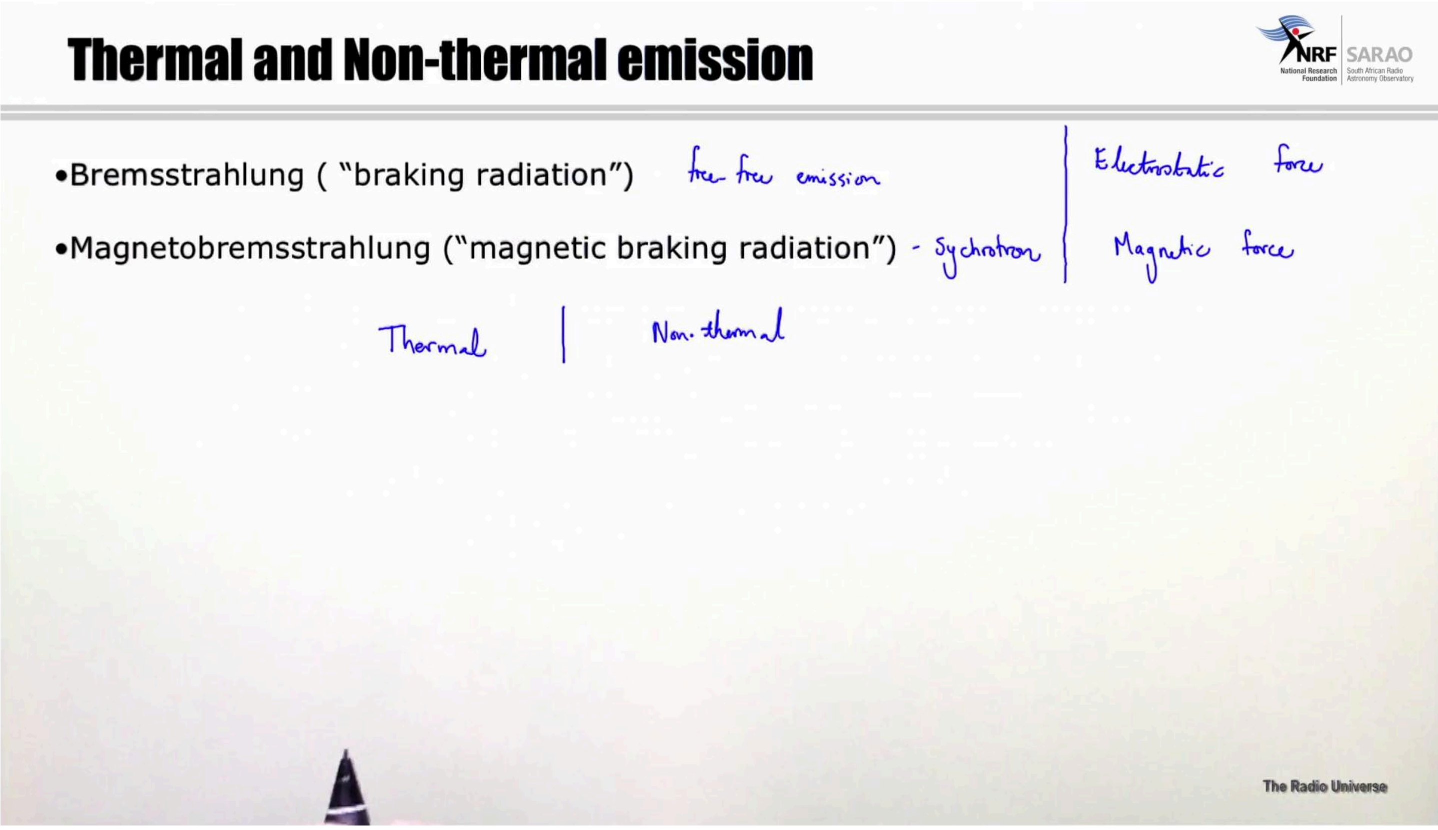
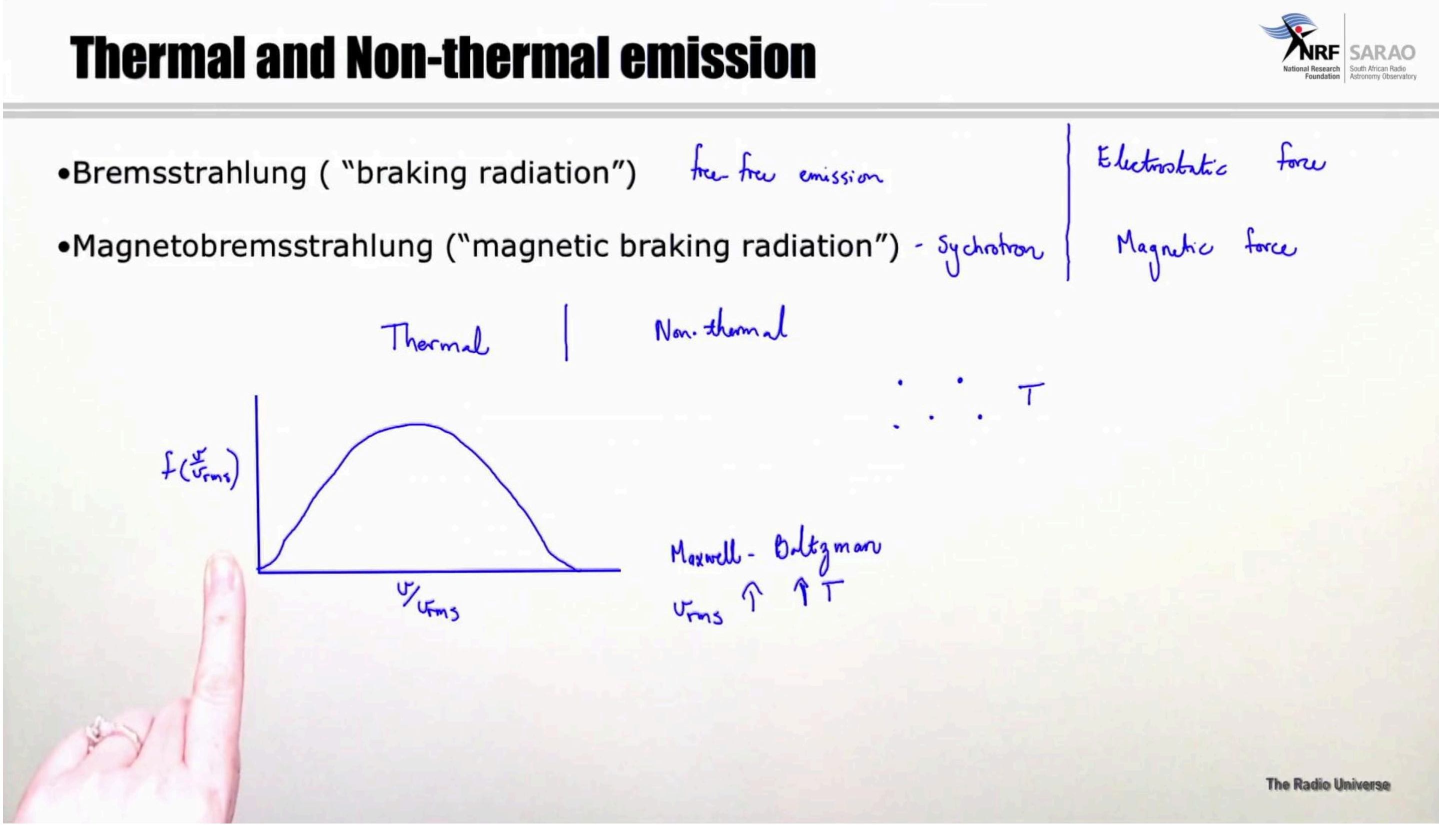


In the previous lecture, we studied Larmor's formula which told us that an accelerating charge particle produces dipole radiation where the power of that radiation depends on the acceleration of the particle. In this next lecture, we'll be learning about Bremsstrahlung emission which is the emission that occurs when free electrons and free ions interact electrostatically and, therefore, become accelerated and produce emission. A charged particle can be accelerated either by an electrostatic force. So, for instance, charged particles that are attracting and repelling each other or by a magnetic field, where a magnetic field attracts or repels a charged particle. In the case of the particle being accelerated by electrostatic force, then the emission is called Bremsstrahlung emission and if it's accelerated by a magnetic force, it's called Magnetobremsstrahlung emission. Sometime this Bremsstrahlung emission is also called free-free emission, and Magnetobremsstrahlung emission is also sometimes called synchrotron emission. Astronomers like to categorize emission as either being thermal or non-thermal in nature. And the important thing to realize is that the division between a source being thermal or non-thermal depends on its velocity distribution.

Notes

Summary

0m 05s

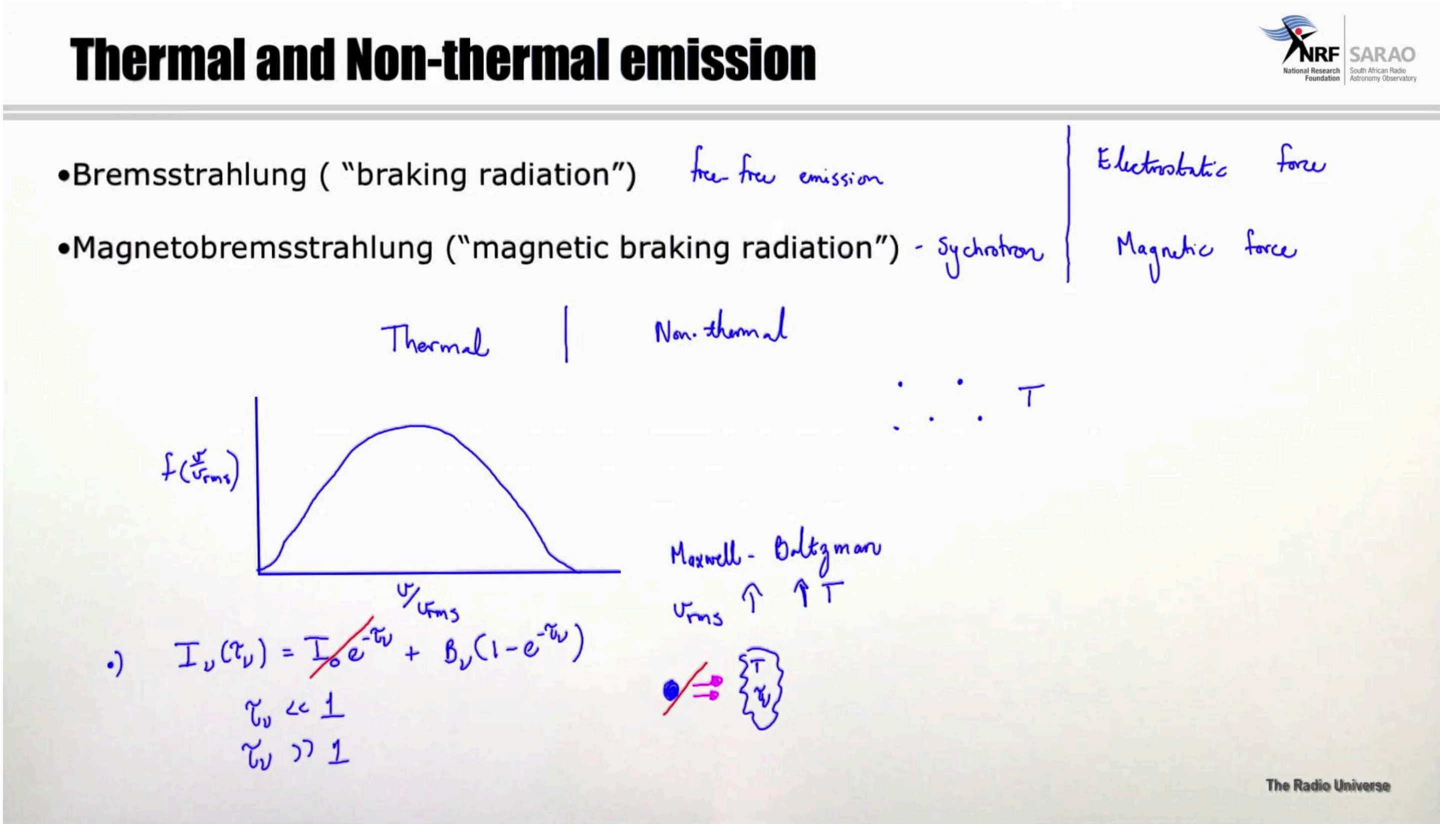


So in a scenario we have particles which are moving freely and they are not interacting with each other very often and their speed is mostly determined by their temperature so there's not something acting on them to accelerate them. Then these particles have a velocity distribution that has a very characteristic shape and this velocity distribution is called the Maxwell-Boltzmann distribution or sometimes it's called the Maxwellian speed distribution. We weren't going to too many details about this but something or what it tells you is that the velocity of the particles will have a specific distribution which will cluster around the RMS speed of the of the of the particles. So if we plot velocity over the RMS, I mean speed over the RMS speed, then you have this characteristic profile which tells you the distribution and that the RMS speed here will increase with increase in temperature. If your particles have this Maxwellian distribution, then it can emit either Bremsstrahlung or Magnetobremsstrahlung emission and in that case it will be thermal. So even mechanism can produce thermal or non-thermal emission. It only depends whether or not the particles have this particular speed distribution.

Notes

Summary

1m 42s

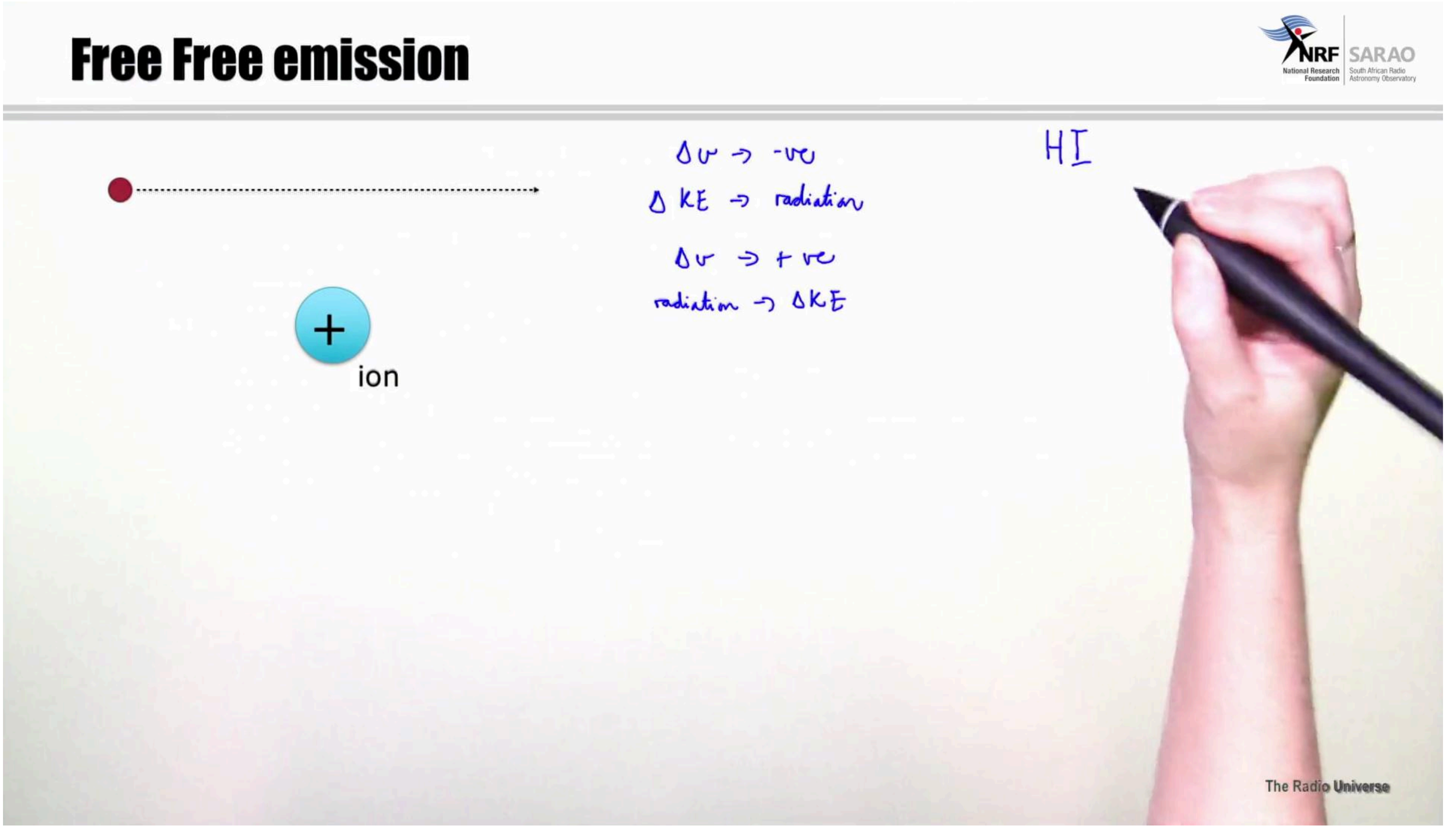


So a thermal source does not necessarily have to have, for instance, a blackbody emission profile. So if we go back to our original equation that relates the emission that we see from a cloud to the incident emission and the emission from a cloud. So we have a background source. We have some cloud which has a temperature and an optical depth, and we have some incident radiation from this background source then we have this equation that is this. Now we're interested only in the emission from a cloud so there's no background emission so we cancel this. So what we can say is that the emission that we see from the cloud is related to the blackbody profile by this relationship and that if you have a very lower opacity or a very small optical depth then, in general, the emission won't be equal to a blackbody and only as you go to higher and higher opacities, will this term start to fall away and you'll start to see a blackbody emitter.

Notes

Summary

3m 19s

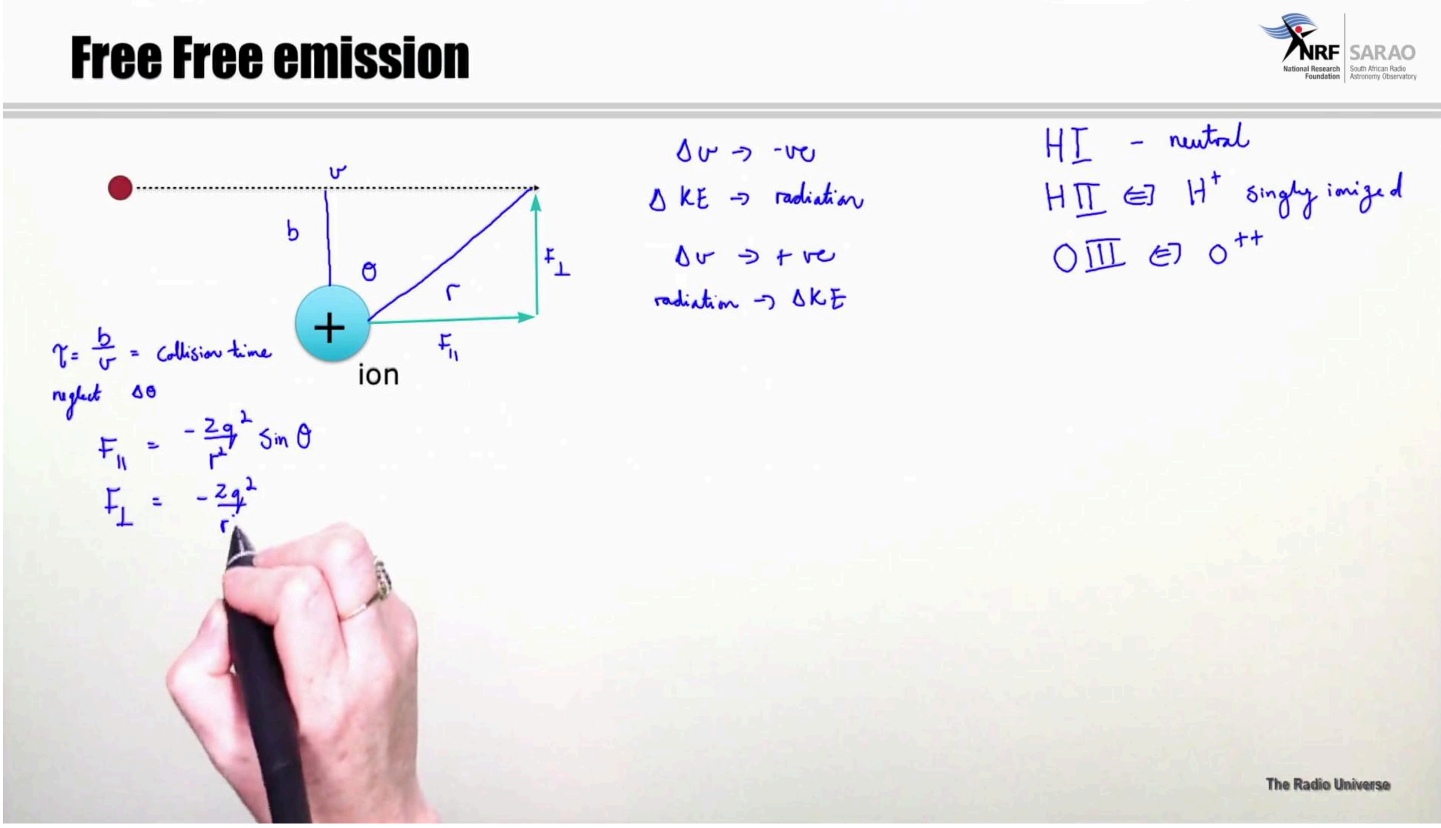


In Astrophysical situations, it's common to have regions of hot diffuse ionized plasma so that means the temperature is hot enough that the electrons have been stripped from their ions and the electrons and the ions move freely in a gas. In this situation, an electron might pass by a positively charged ion and when it does, it will experience a force of attraction between them due to the electrostatic interaction and this will act to accelerate the electron. If this interaction acts to reduce the speed of the electron so its speed decreases, then the kinetic energy the change in the kinetic energy of the electron will be emitted as radiation. If the inverse process happens where the interaction acts to increase the speed of the electron then there will be absorption and radiation will be converted to kinetic energy. This electrostatic interaction and the production of emission is called Bremsstrahlung radiation, literally breaking radiation because the electron is slowing down. It's also called free-free emission because the electron is free before the interaction and also free afterwards. It's a curiosity of astronomical literature, that we often refer to the neutral medium with the Roman numeral 'I'.

Notes

Summary

4m 35s

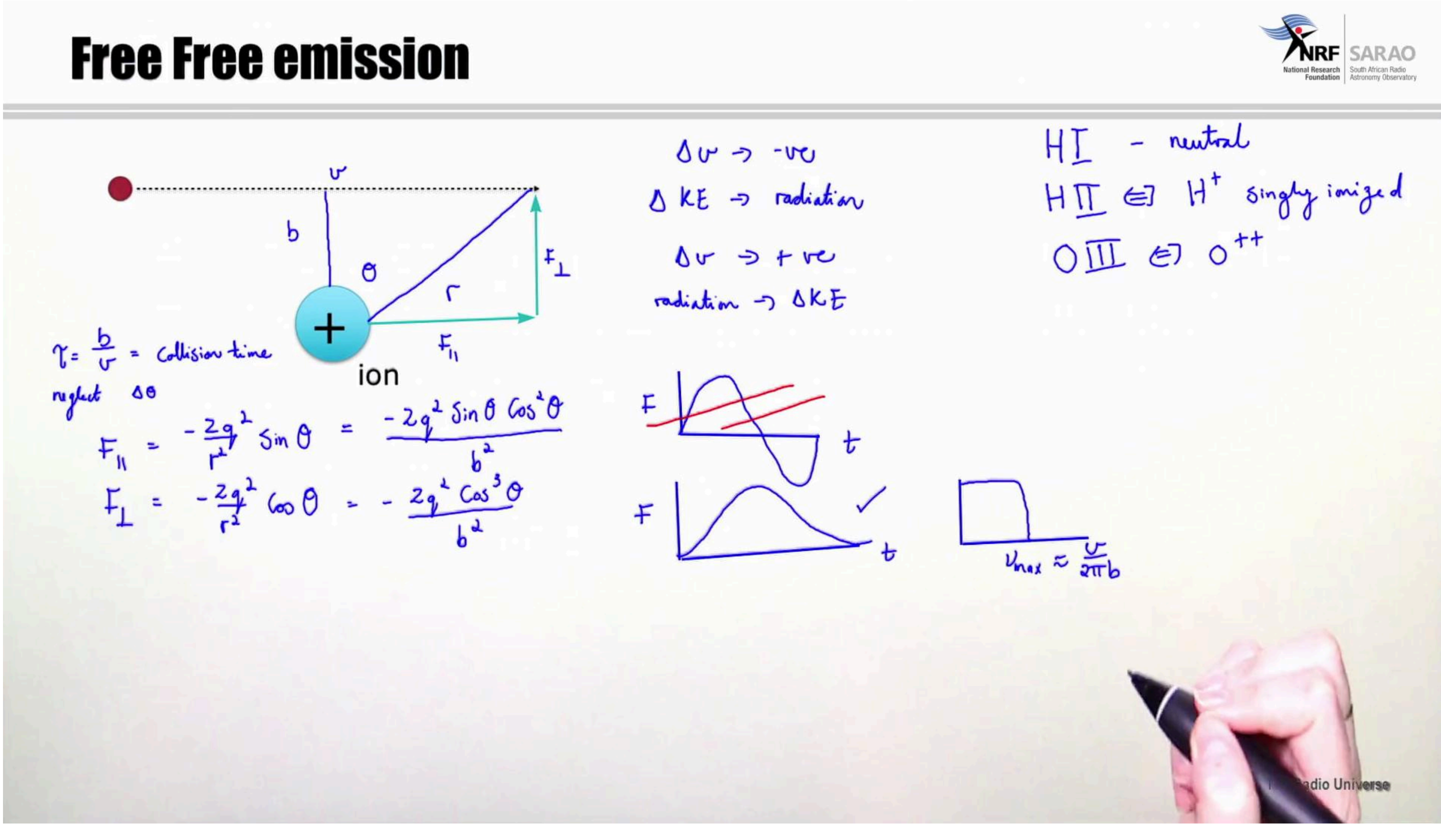


So, for example, 'H I' means neutral hydrogen gas. Where a singly ionized hydrogen gas will be called 'H II' so 'H II' is really synonymous. with 'H plus'. And similarly for heavier elements, for example, 'O III', is then doubly ionized Oxygen or 'O plus plus'. As this electron passes by the ion, we can define its closest approach as 'b' which is also called the impact parameter. It will have some velocity 'v' and the distance between the ion and the electron 'r' will depend on this angle theta. We also define something called the collision time which depends on the impact parameter divided by the velocity of the electron. We assume that the ion is very much more massive than the electron and that there's a very small change in the angle of the electron's path so we can neglect any change in theta during this interaction. From this we can see that there will be a component of this electrostatic force which is parallel to the direction of the electron's motion and also one that is perpendicular. From the geometry of the situation, we can write these forces as being equal to the following terms.

Notes

Summary

6m 11s

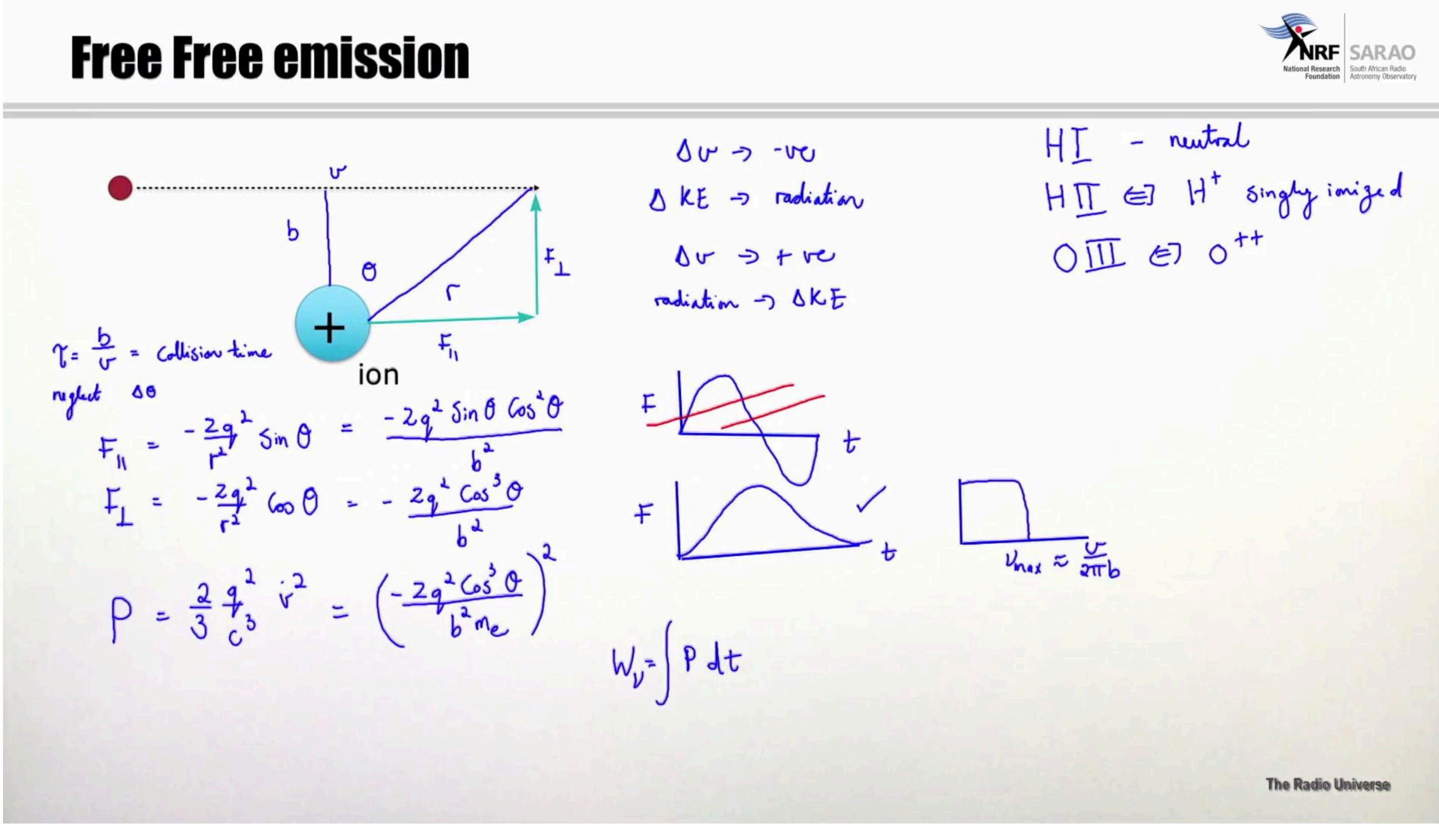


Where ‘z’ here is equal to the number of positive charges on this ion so if you had, for example, ‘O III’ here then 'z' would be equal to two and ‘q’ is the charge of one electron. We can rewrite this equation in terms of the impact parameter and then what you end up with is this. What that tells you is that as the electron moves past the ion, it experiences a force in that parallel direction which changes as a function of angle or time like this. Where in the perpendicular direction the pulse profile looks something like this. We can calculate what the frequency of the emission will be from its time signature using a Fourier transform. And we won't go into too much detail about that here except to say that when you do a Fourier transform on these two pulse profiles, what you discover is that there's very little radio emission from this from the parallel component of the force and that there's some radio emission from the from the perpendicular component and so what that looks like is that it emits radiation at all frequencies below some critical frequency which depends on the speed and impact parameter of the collision.

Notes

Summary

7m 51s

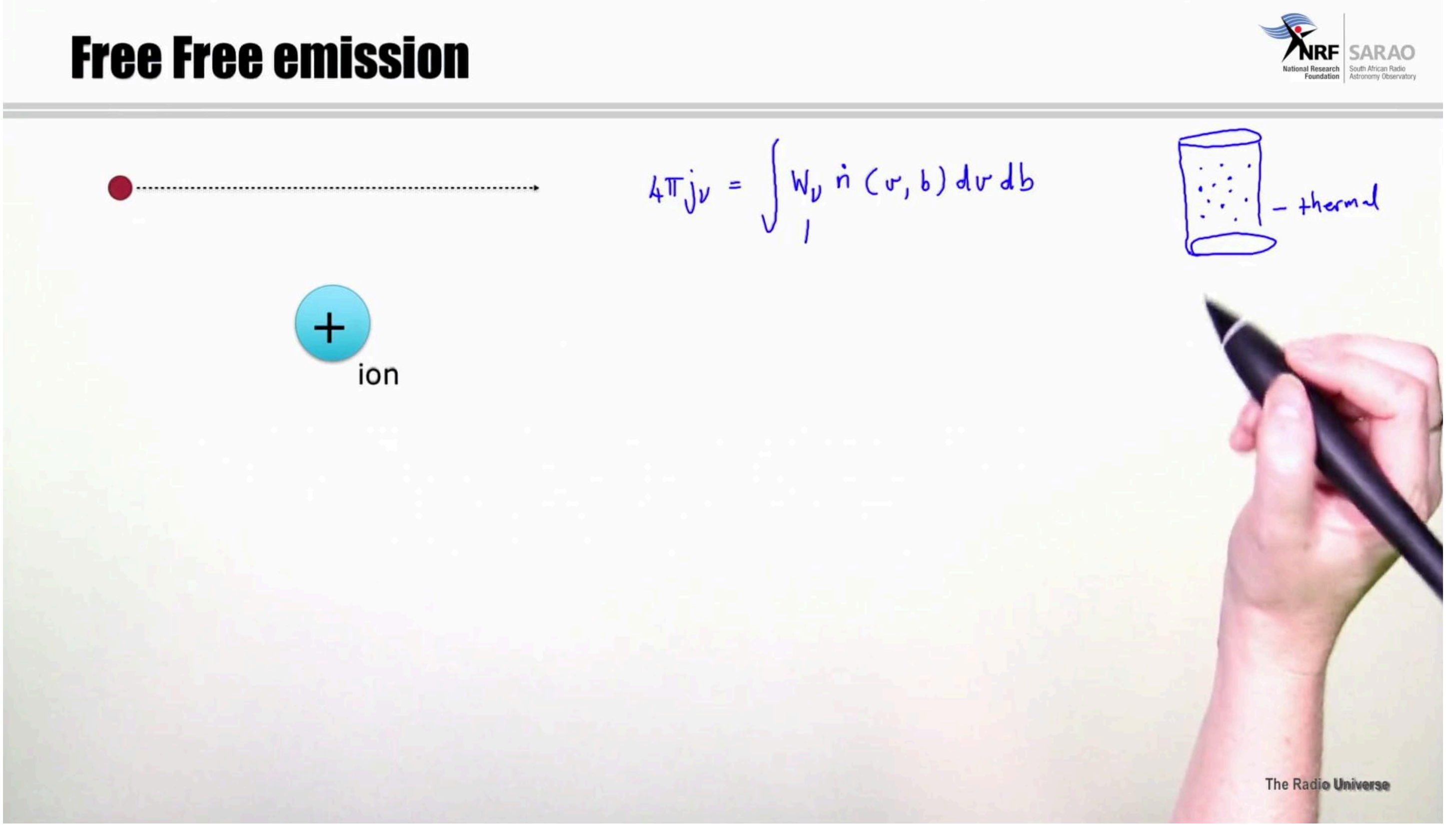


So knowing that we can use Larmor’s formula again to work out what the power would be per collision using the equation from our earlier slides which is that we have the acceleration, we can just give it this perpendicular force divided by the mass. This gives us the power per collision as a function of time or theta and so if you'd like to know what the power is for the entire collision, we have to integrate over all times so that we can know the power per collision for the entire time that the collision has taken place.

Notes

Summary

9m 36s

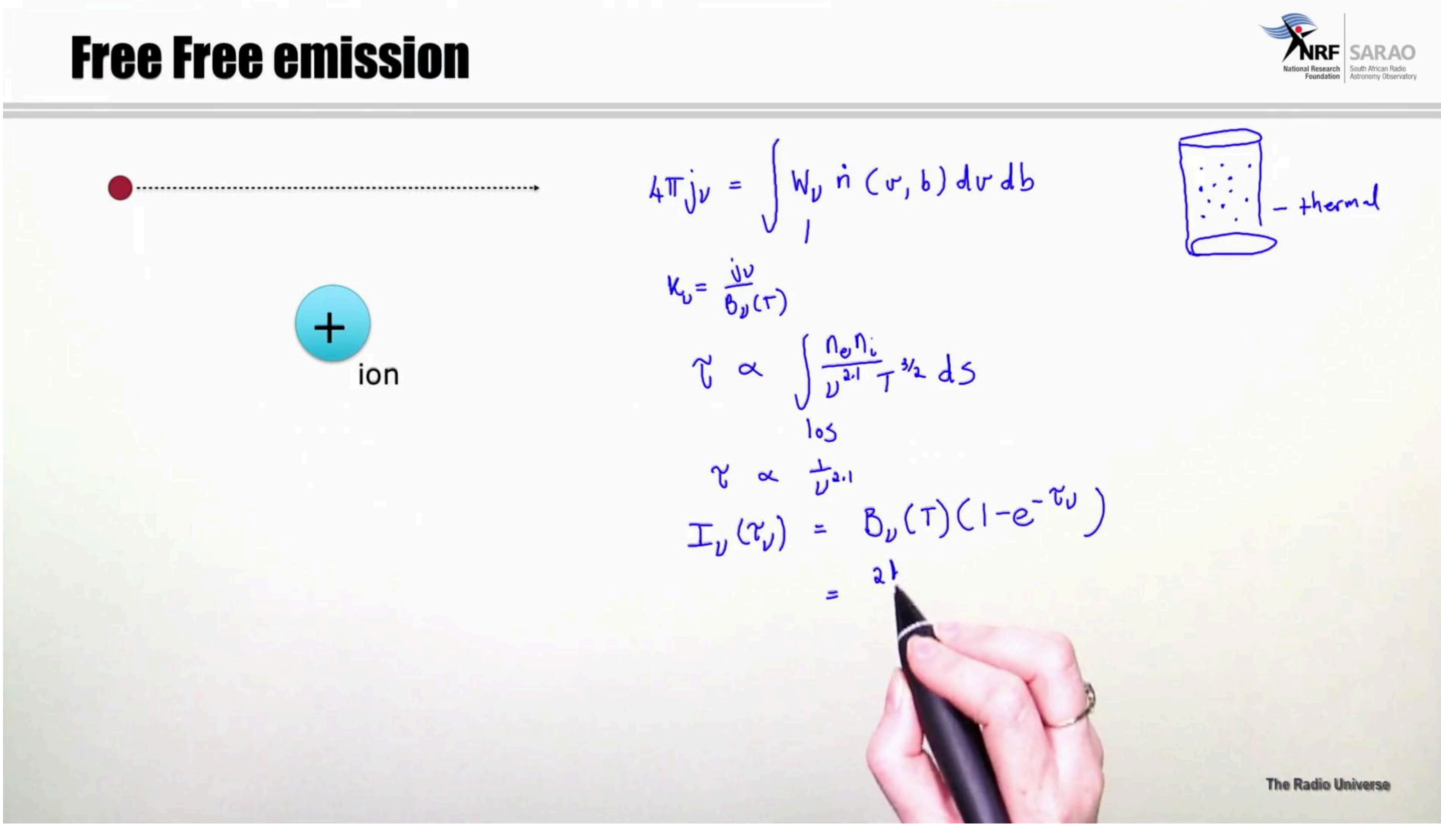


So now we've calculated what the power would be for a single collision but, of course, what we have is a region of ionized plasma with many many particles where there'll be many many collisions. So inside this region of interest, there'll be many ions and many electrons that are interacting with each other. And so we can estimate what the spectral power will be for all of these emitters if we integrate the power per collision over all of the collisions happening per unit time as a function of velocity and impact parameter. And this integral is by definition equal to four Pi times the emissivity coefficient from our radiative transfer equation. So this is the part in an interval per unit frequency where the expression depends on velocity and impact parameter and this is the number of collisions per unit time with the given velocity and impact parameter. So we won't go into the details of doing this whole integral. It becomes very complicated but simply say that you can know roughly what the velocity distribution is because we assume that the source is a thermal source and so because it's a thermal source and we know that the velocity profile will be the Maxwellian speed distribution and you can make some assumptions about the relevant impact parameters within this within this space using physical intuition.

Notes

Summary

10m 16s

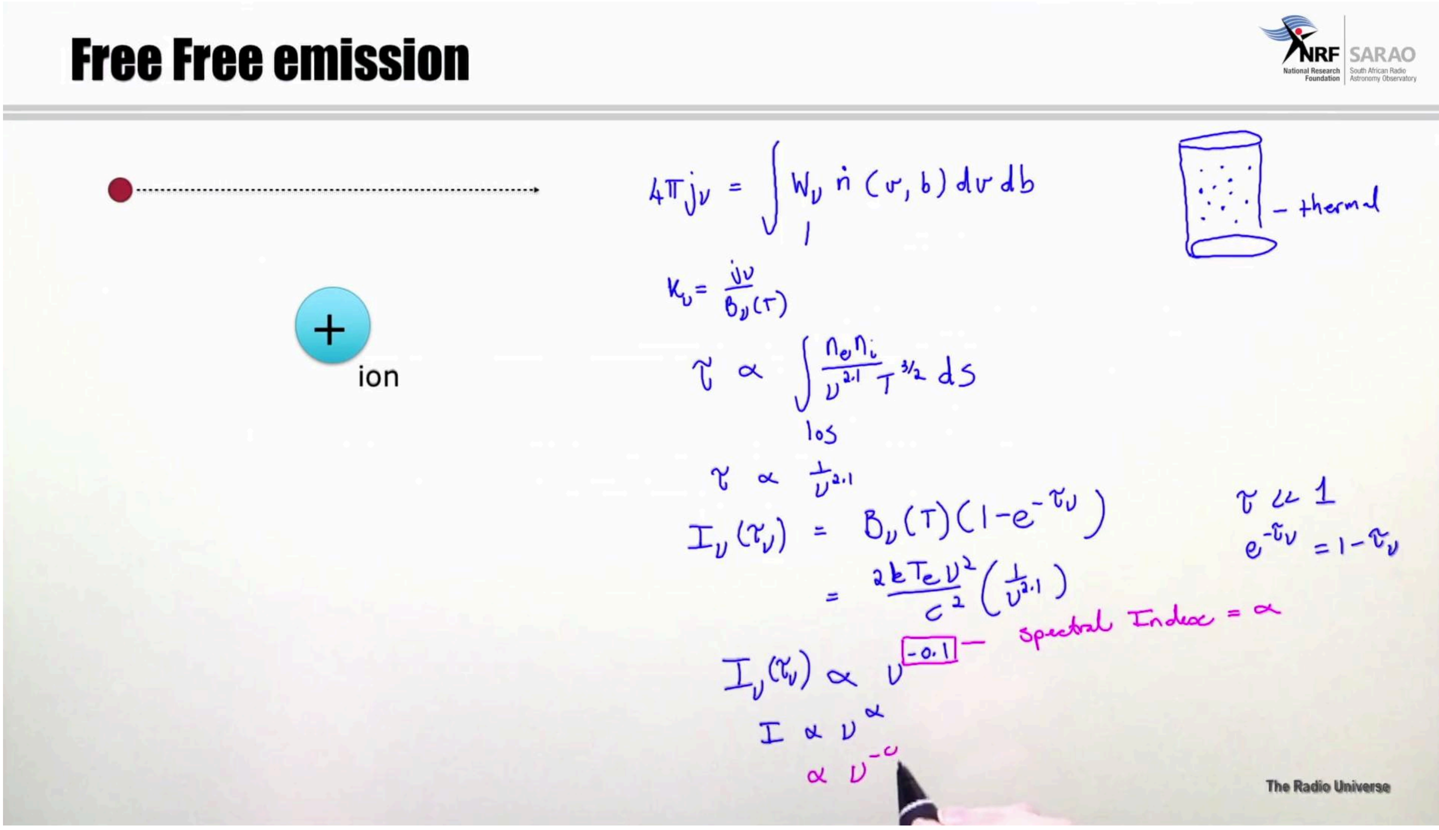


Once you've got your this integral, we can use our usual Kirchhoff's relationship to say that the emission coefficient will be equal to the absorption coefficient over the Planck function. And so we can say from this we can calculate from this integral will be able to calculate the optical depth. So we say here without getting into the details or too many proofs that the optical depth of a free-free emitter is roughly proportional to the integral of the number of electrons times the number of ions over the frequency to the power of 2.1 to the temperature power of three over two 'ds' over the line of sight between over the line of sight of the absorber. So what we can say here then is that the optical depth is roughly proportional to one over nu to the power of 2.1. If we go back to our equation that we've been using all along which tells us that the specific intensity will be for an absorbing cloud then what we end up with is the usual equation that 'I' nu 't' nu is equal to the Planck function times one minus 'e' to the minus tau 'v' because we don't consider any background radiation in this situation. So because we're in the radio regime, we can approximate the Planck function with the Rayleigh jeans law.

Notes

Summary

11m 59s

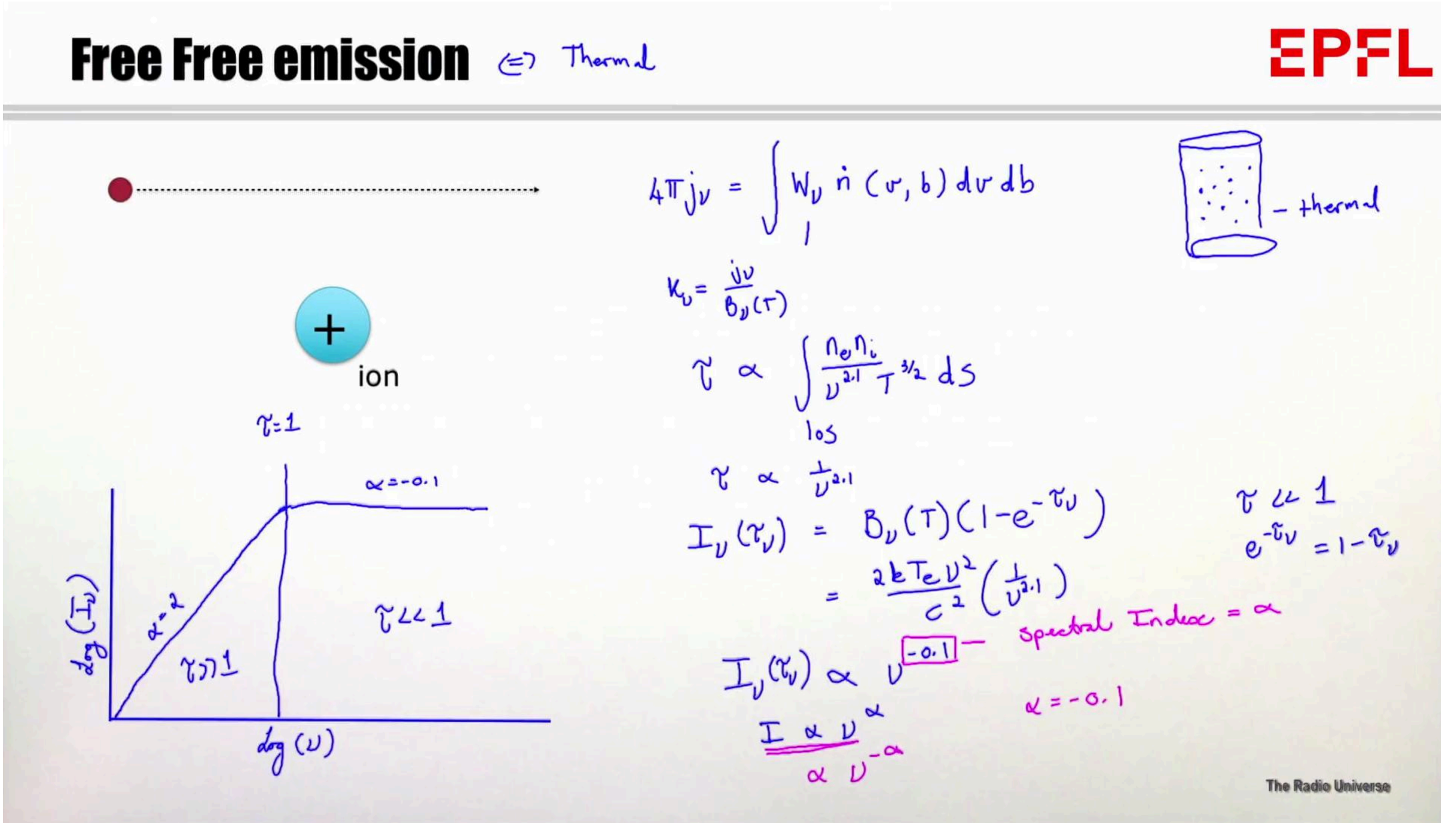


And if the optical depth is very much less than one, if it's very low then we can replace 'e' to the minus tau 'v' with the expression that is equal to one minus the optical depth and so we can replace this with the optical depth because one minus one minus tau 'v' will be tau 'v' and we said that this is proportional to one over nu to the power of 2.1 and so the end result of this is that the spectral intensity here will be proportional to nu to the power of minus 0.1. This kind of relationship where we say one quantity is equal to another quantity raised to a power is a power law and it turns out that much radio emission can be described as being a power law function of the frequency and so because of that this index has a special name, which we call the spectral index. And so we often characterize radio sources as being something that the intensity is proportional to the frequency times this to the power of the spectral index where alpha is the spectral index. There are two actual conventions that are widely used and one is that 'I' is proportional to the frequency to alpha and the other is that it's proportional to the nu to the power of minus alpha.

Notes

Summary

13m 49s

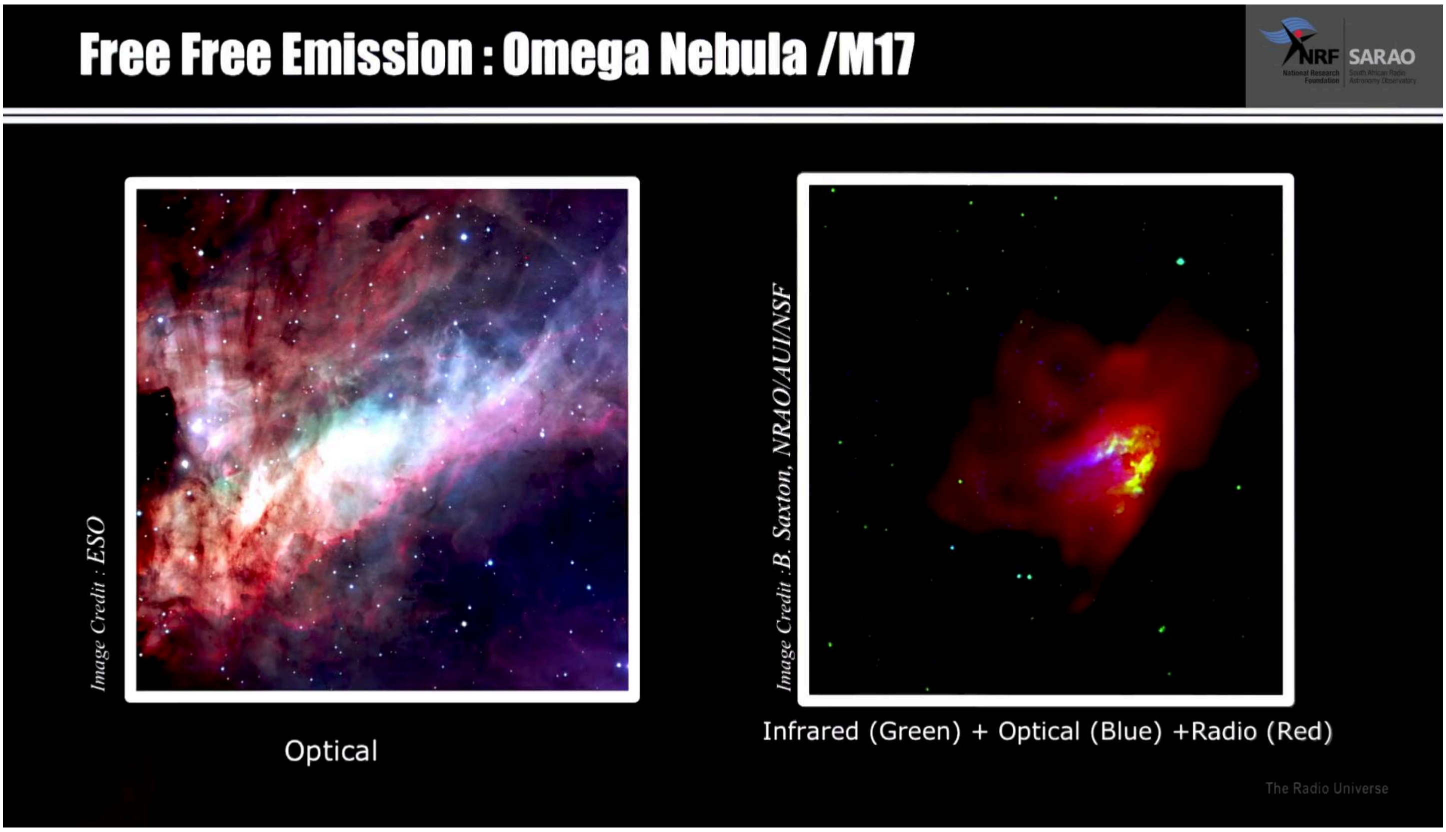


So it's important when reading a paper to always check which convention is used. So for this series of lectures, we'll always use this convention and so in this case alpha is equal to minus 0.1. With this in mind, we can consider what the specific intensity of a free-free emitter will look like as a function of frequency. So what we've just learned is that when the optical depth is very much less than one so at high frequencies when the optical depth is very much less than one, we'll have a relatively flat spectrum. So alpha here will be minus 0.1 and the optical depth will be very much less than one. As we proceed to lower frequencies, the optical depth will change and as optical depth increases here so tau is very much greater than one then this term becomes smaller and smaller and the emission looks more and more like a blackbody Rayleigh jeans expression and so then the spectral index here will be roughly equal to two and here is roughly where the optical depth equals one. Because free-free emission is so often associated with thermal sources, it's very often used interchangeably with the word thermal. But remember that it's only truly a thermal source because we have this Maxwellian speed distribution.

Notes

Summary

15m 35s

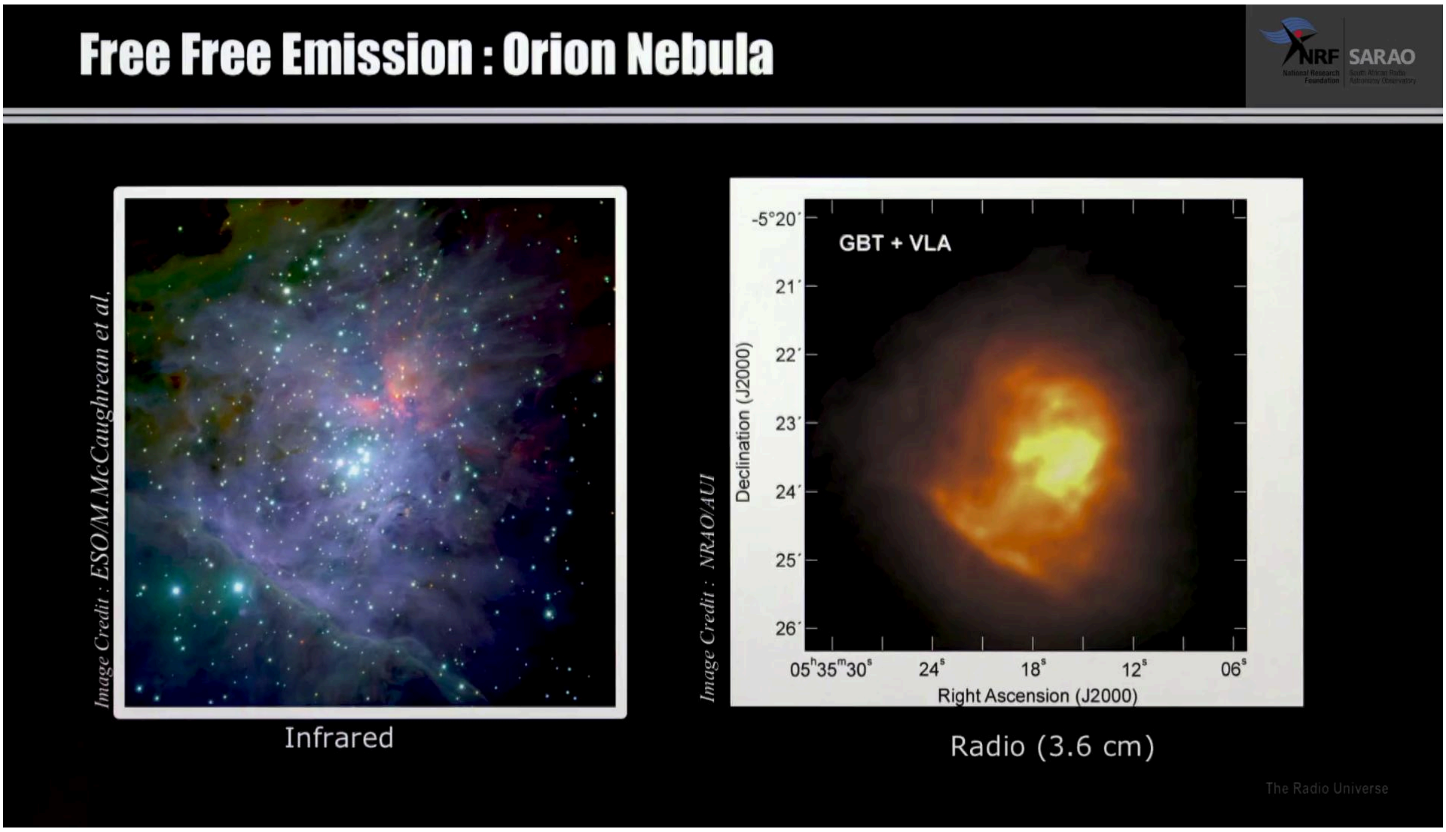


Here we have some examples of free-free emission from the Omega nebula.

Notes

Summary

17m 18s



This is what it looks like in optical and here in the radio is all the free-free emission from free electrons and similarly this is the Orion nebula where we see it in the infrared and we can also see free-free emission in the radio.

Notes

Summary

17m 28s