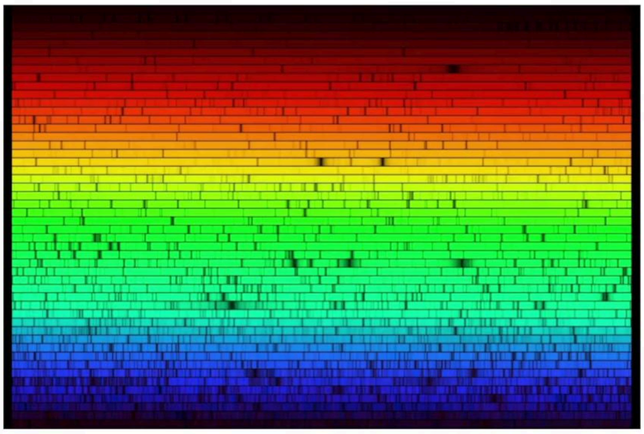
Blackbody emission and radiation transport (Part 5)

Kim McAlpine



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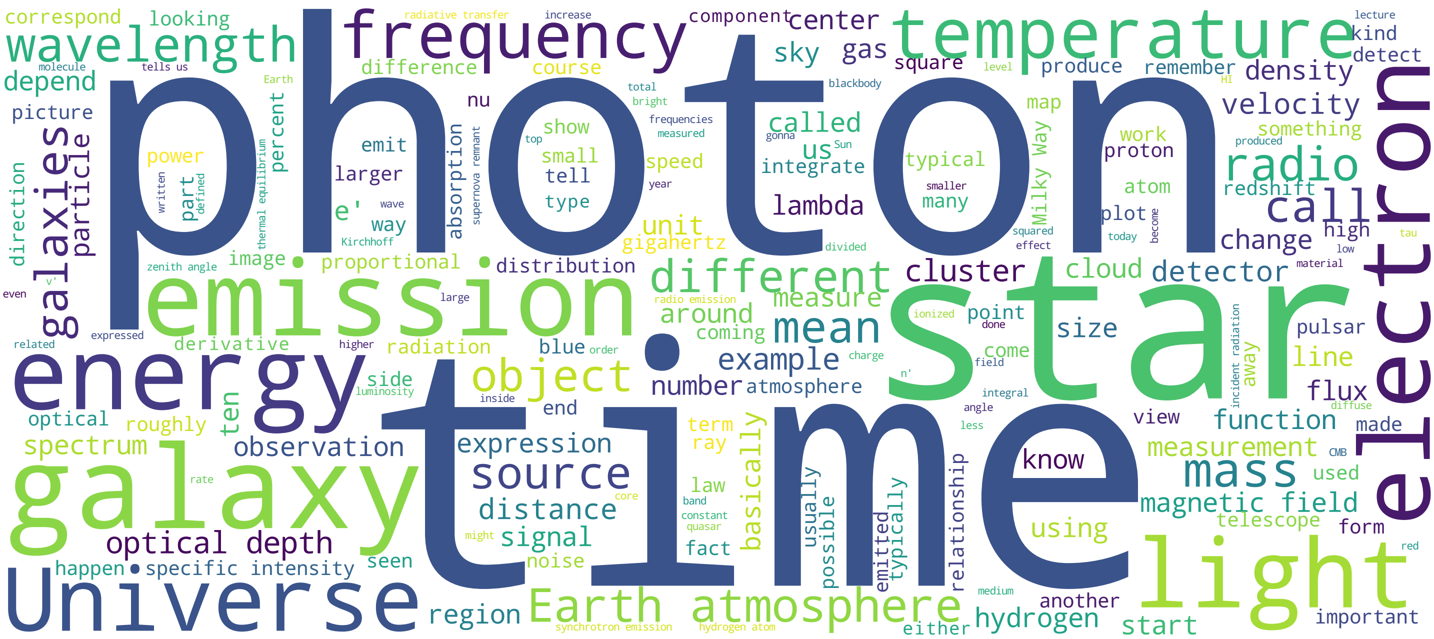

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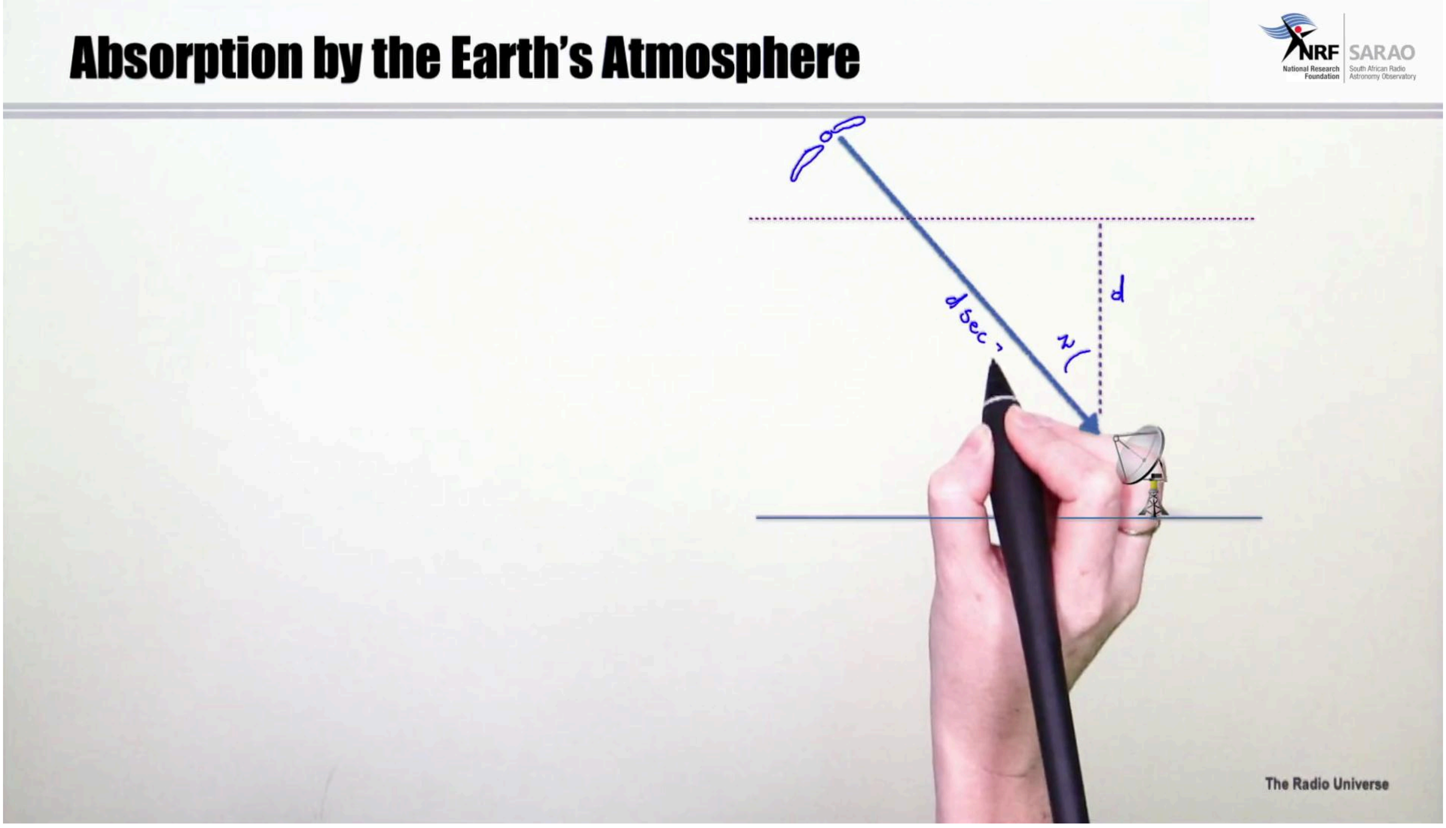
Video

Radio antennas are located on the surface of the Earth which is very convenient from an engineering perspective but it has the inconvenient side effect that we have no choice but to contend with the effect of the Earth's atmosphere on our photons. In this lecture, we'll be using the radiative transfer equation and Kirchhoff’s law to understand how the atmosphere absorbs and emits radiation and how to correct for this effect in our measurements of the flux of distant objects.

Notes

Summary

0m 05s

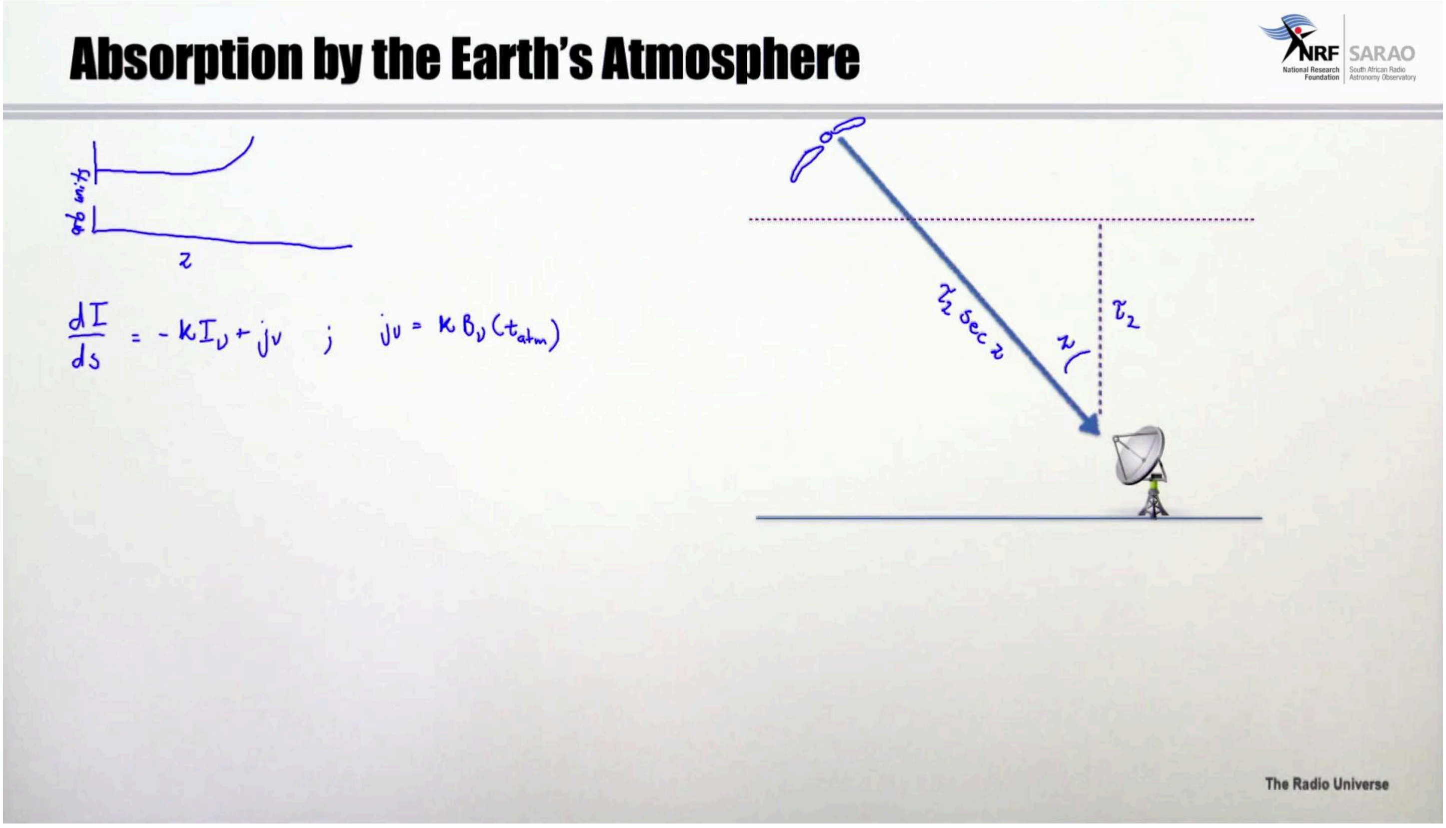


As astronomers what we frequently want to do is measure the flux from some distant object. However, the photons from this object have to travel to Earth via the Earth's atmosphere and this atmosphere can absorb some of those photons or emit in its own photons which can distort our measurement of the flux of the source we're interested in. In this slide what we'll do is we'll show how to use Kirchhoff's law in combination with the radiative transfer equation to derive a relationship between the observed intensity of the emission of the Earth's atmosphere with its optical depth and from that you'll be able to then work out the absorption of the Earth's atmosphere at any given time. So what you can see from this plot here is that if the telescope is pointing directly upwards, it's looking through a smaller amount of atmosphere compared to if it was looking at some angle away from the directly up angle. We call this the zenith angle so the angle from zenith where zenith is when the telescope points directly upwards and it's easy to see from this that if the distance here is 'd' then the distance through the Earth's atmosphere here is 'd' times the sec of the angle 'z'.

Notes

Summary

0m 34s

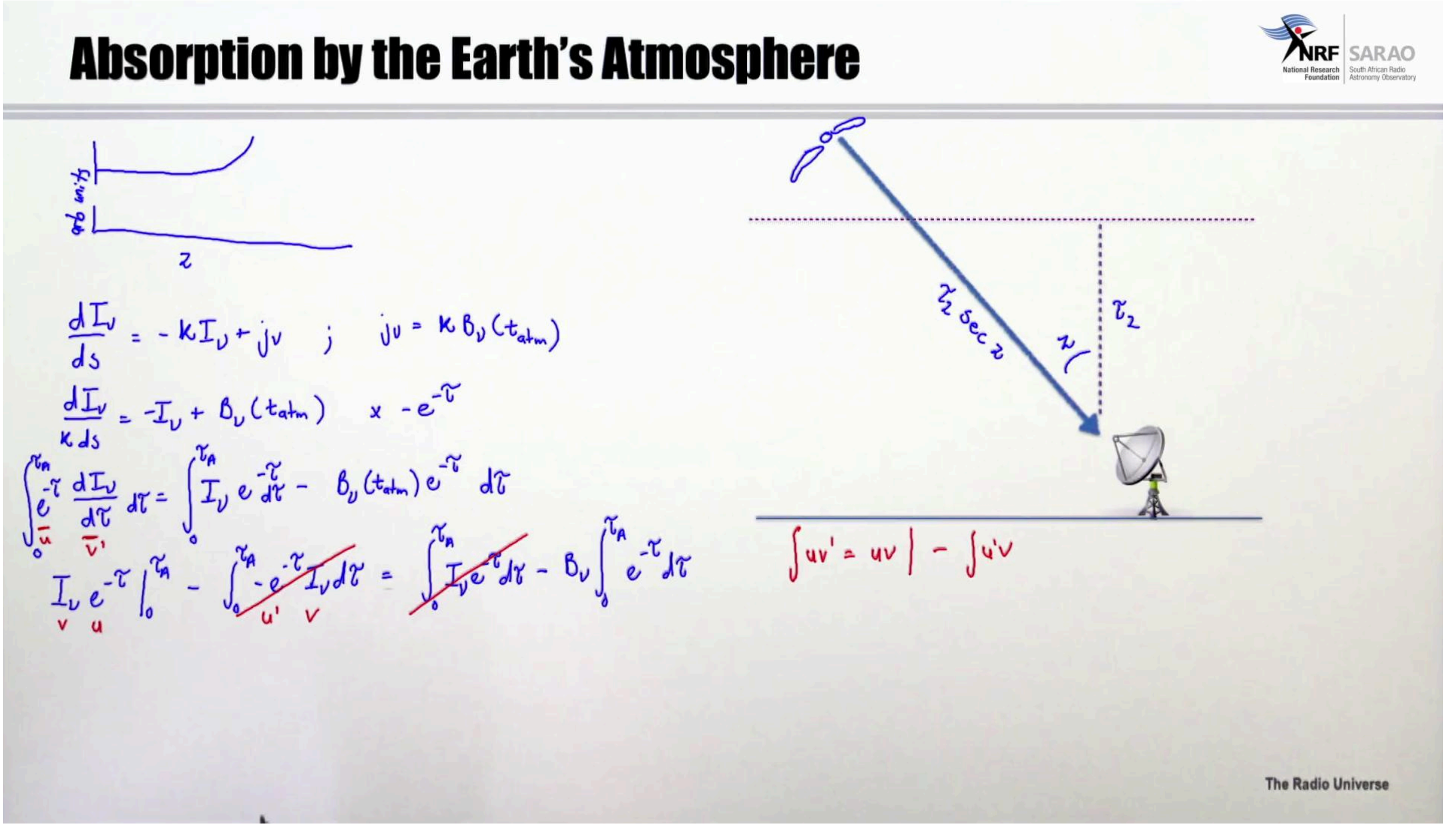


So if you have a optical depth here of, say, tau 'z' then the optical depth of the Earth's atmosphere here will be tau 'z' times the sec of 'z'. And what this means is that if you were to plot a plot of the specific intensity of the emission of the Earth's atmosphere as a function of the zenith angle 'z', you would see that as you move towards the horizon it starts to increase quite a bit. One of the features of radio dishes is that it's not often easy to have an exact scale on these maps but it's very easy to measure differences between measurements. So you might only have arbitrary units here but you can measure the difference between the measurements at one zenith angle compared to another. So to do this we start with our radiative transfer equation and because the Earth's atmosphere is approximately in local thermal equilibrium it's acceptable for us to use Kirchhoff’s law which tells us that the emission coefficient is related to the absorption coefficient using this equation where you say the emission coefficient is related to the absorption coefficient times the Planck function at the temperature of the atmosphere.

Notes

Summary

1m 58s

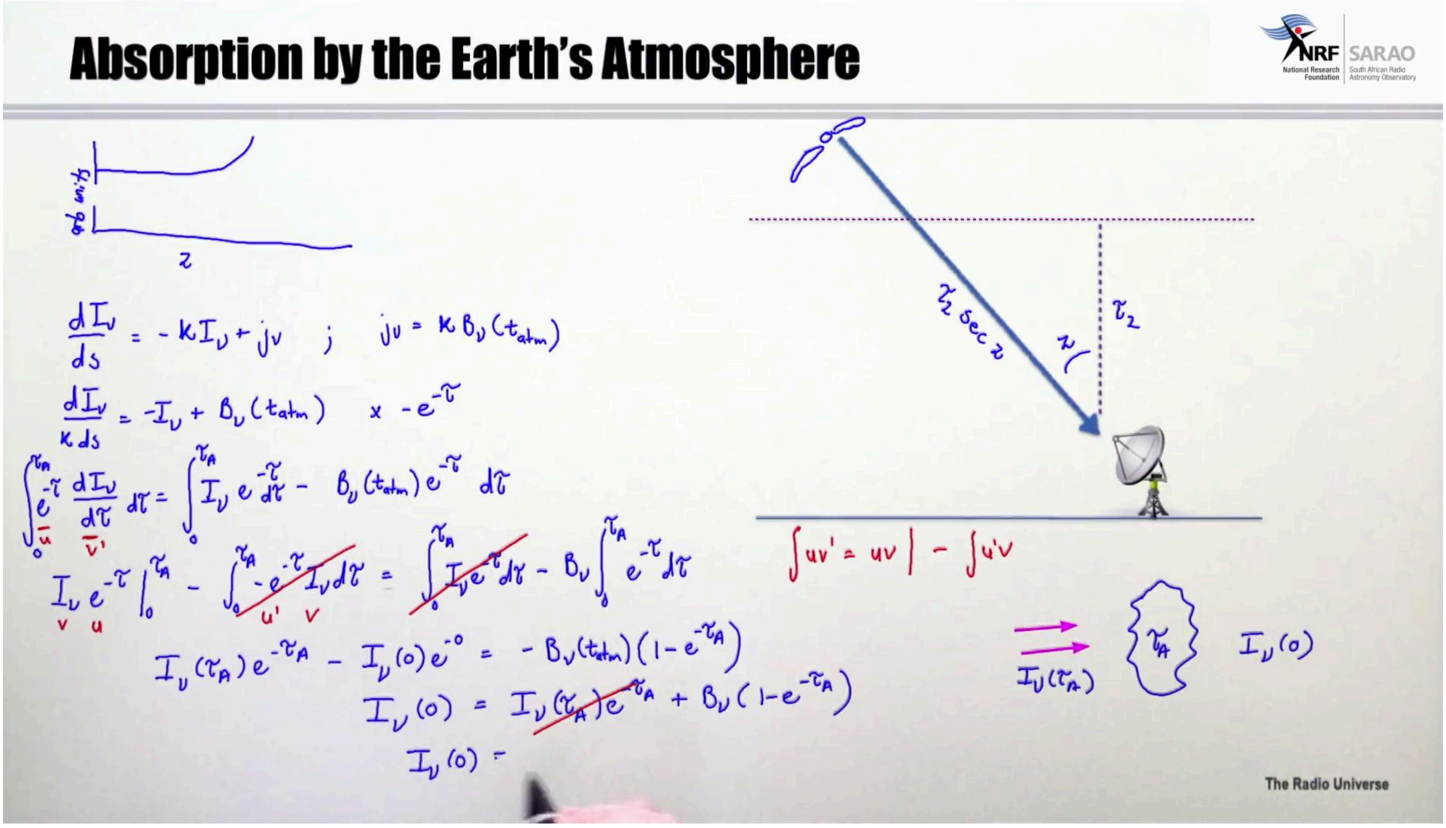


If we substitute this into this equation and divide both sides by the 'k' term or the kappa term, what we end up with is and what this effectively is is going to be 'DI' divided by the negative of 'd' tau. If we then multiply both sides of this equation by minus 'e' to the minus tau, what we end up with is and now we can integrate both sides of this equation over optical depth where we integrate from the point of the telescope where optical depth is then zero up to the top of the Earth's atmosphere. We will say that the optical depth is 'TA'. We can integrate this expression using our expression for the integrate by parts formula which if you recall go something like this where you say the integral of 'u' times the derivative of 'v' is equal to the integral of 'u' times 'v' minus the integral of the derivative of 'u' times 'v'. So in this equation we'll say that 'e' to the minus tau is 'u' and this is equal to the derivative of 'v'. So in that case. In this case we have then if you multiply 'uv' then you have 'e' to the minus 't' times 'I' and here we take the derivative of 'e' to the minus tau here to get 'u' dash and 'Iv' is still 'v' and then you'll see that these two terms essentially cancel out and so what we're left with is then.

Notes

Summary

3m 26s

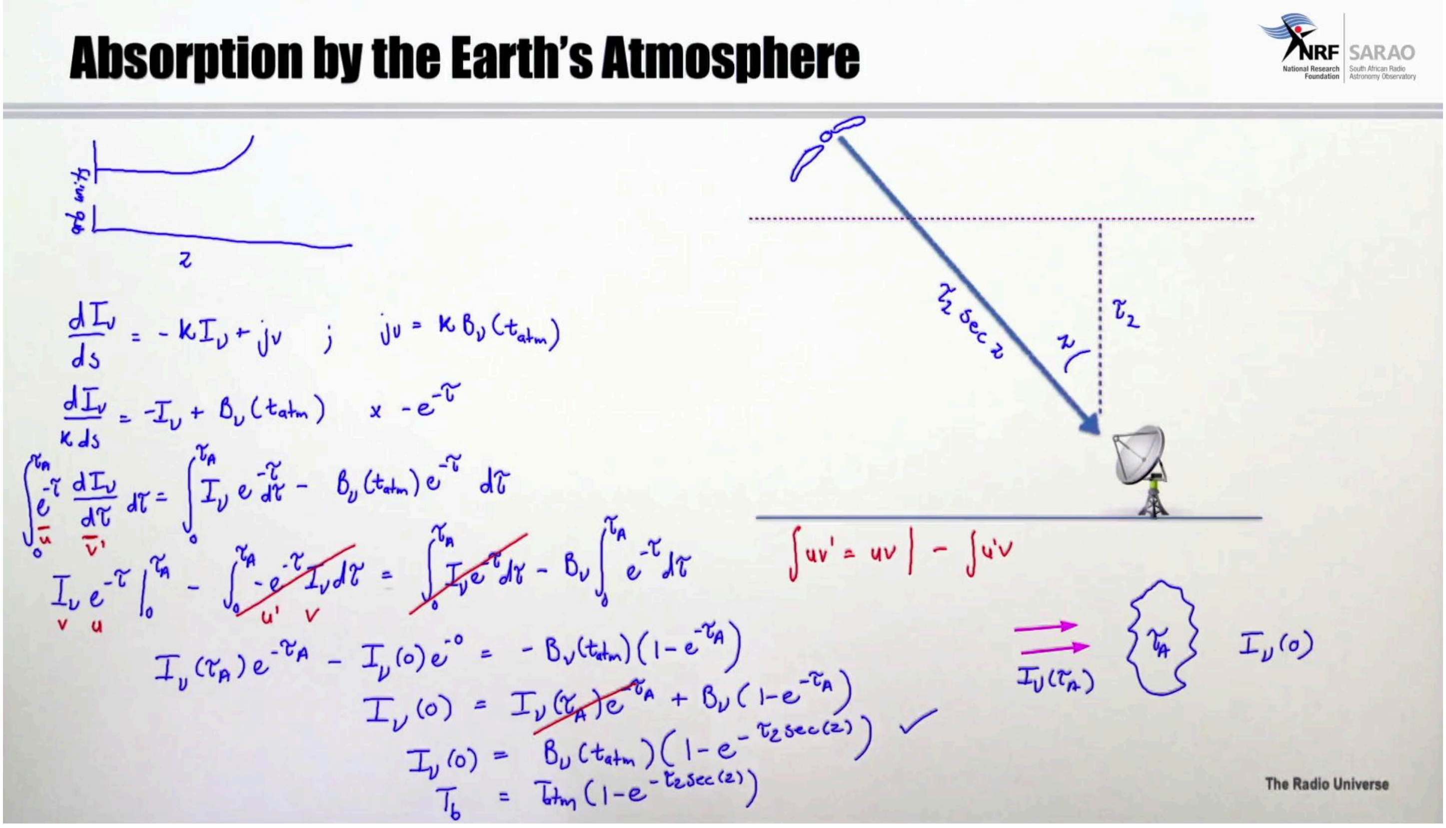


If we rearrange this equation we get this equation which is an important equation because it tells us that if you have some incident radiation and then you have some intervening cloud with a optical depth of tau 'A', for example, then this tells you the relationship between the incident radiation and the measured radiation which you get over here. So long as this cloud is in local thermal equilibrium so this is a general expression which can be used in this scenario. For the case of absorption from the Earth's atmosphere, emission from the Earth's atmosphere, we can usually assume that the emission from the top of the atmosphere is negligible so we can discard this incident term, incident radiation term and what you're left with is the relationship between the measured specific intensity, the Planck function at the temperature of the Earth's atmosphere and the optical depth of the atmosphere and the optical depth of the atmosphere here can be written as a function of the zenith angle. So we can say that.

Notes

Summary

6m 13s



It's possible to write this expression in terms of specific intensity as it's done here but remember that we often express specific intensity in terms of units of brightness temperature in which case you can rewrite this as being the brightness temperature of the Earth's atmosphere here is equal to the temperature of the Earth's atmosphere times one minus 'e' to the minus 'tz' sec 'z'. And so from here we have an expression to get the absorption from the Earth's atmosphere from its emission.

Notes

Summary

7m 33s