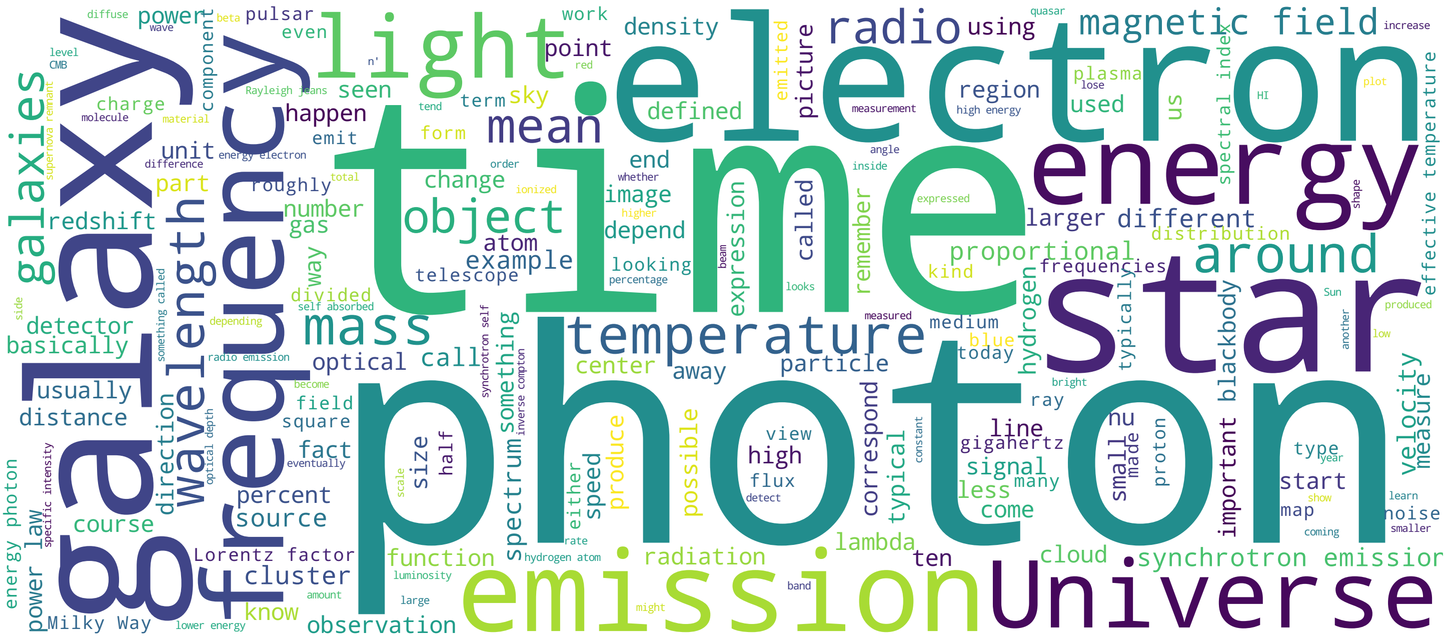
Continuum Emission (part 4)

Kim McAlpine



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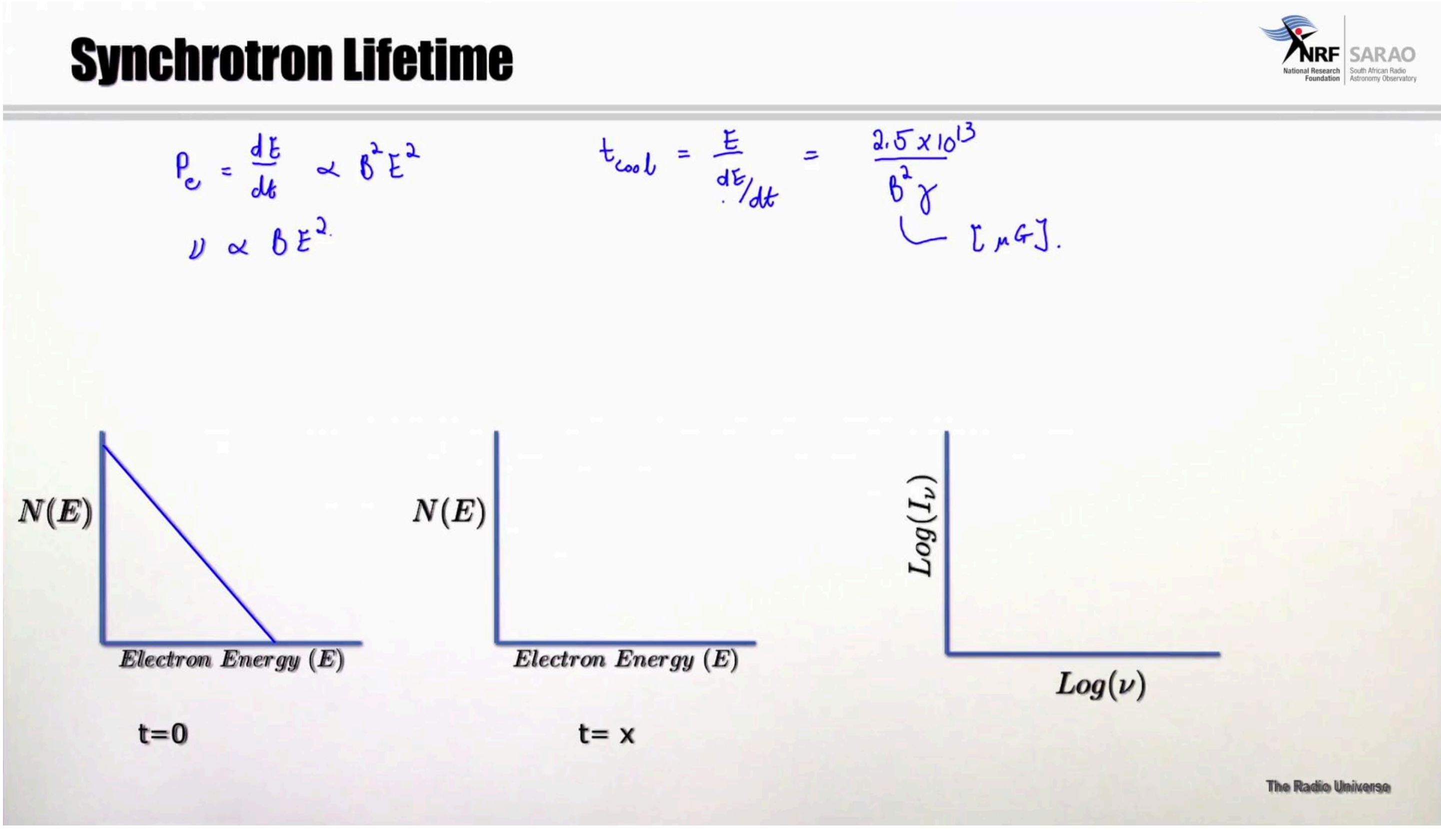
Video

In our final lecture on continuum emission processes, we'll be continuing our exploration of synchrotron emission where we'll be particularly learning about processes that modify the spectrum of synchrotron emission from being just a straight power law and we'll learn how the plasma ages and loses energy and also how it can at very high densities self-absorb emission to change the shape of the spectrum.

Notes

Summary

0m 05s



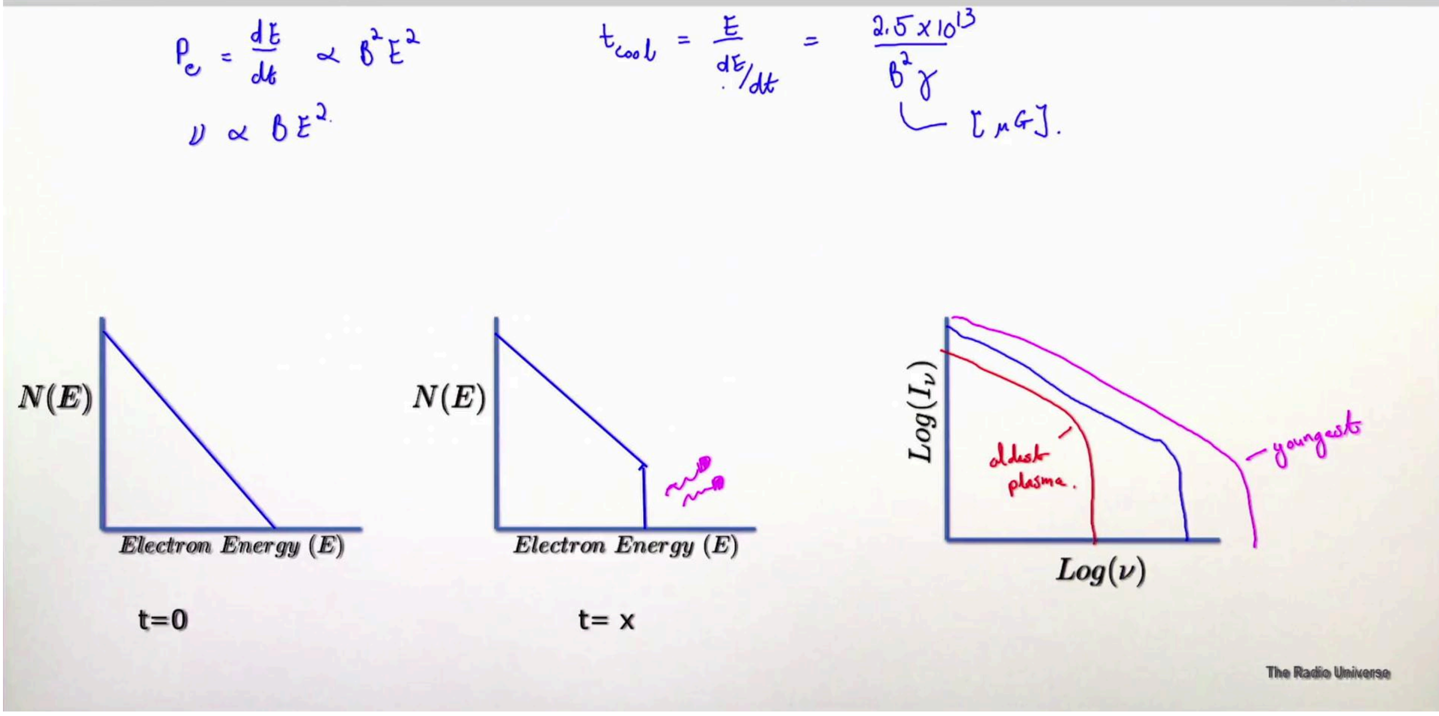
So in the previous lecture we learned that the power for a given electron which is equal to the change in energy per unit time, is proportional to 'B' squared times 'E' squared. And what that tells us is that for higher energy electrons they radiate their power away their energy away more quickly and so they'll lose their energy on a shortest timescale and it's possible to define something called the synchrotron cooling time which is the time it takes for an electron to lose its energy by synchrotron radiation and that is given by the energy of the electron divided by the power, and if you calculate this then eventually what you end up with is that it depends on the magnetic field and the Lorentz factor and it's related by this equation, where this magnetic field is given in units of microgauss. So remember also that we have that the frequency of the emission we see for synchrotron is proportional to 'B' times 'E' squared. So what does these two equations tell us is that if you had some blob of synchrotron emitting plasma where your electrons have the usual power law distribution then when they're first accelerated they have this power law distribution.

Notes

Summary

0m 30s

Synchrotron Lifetime

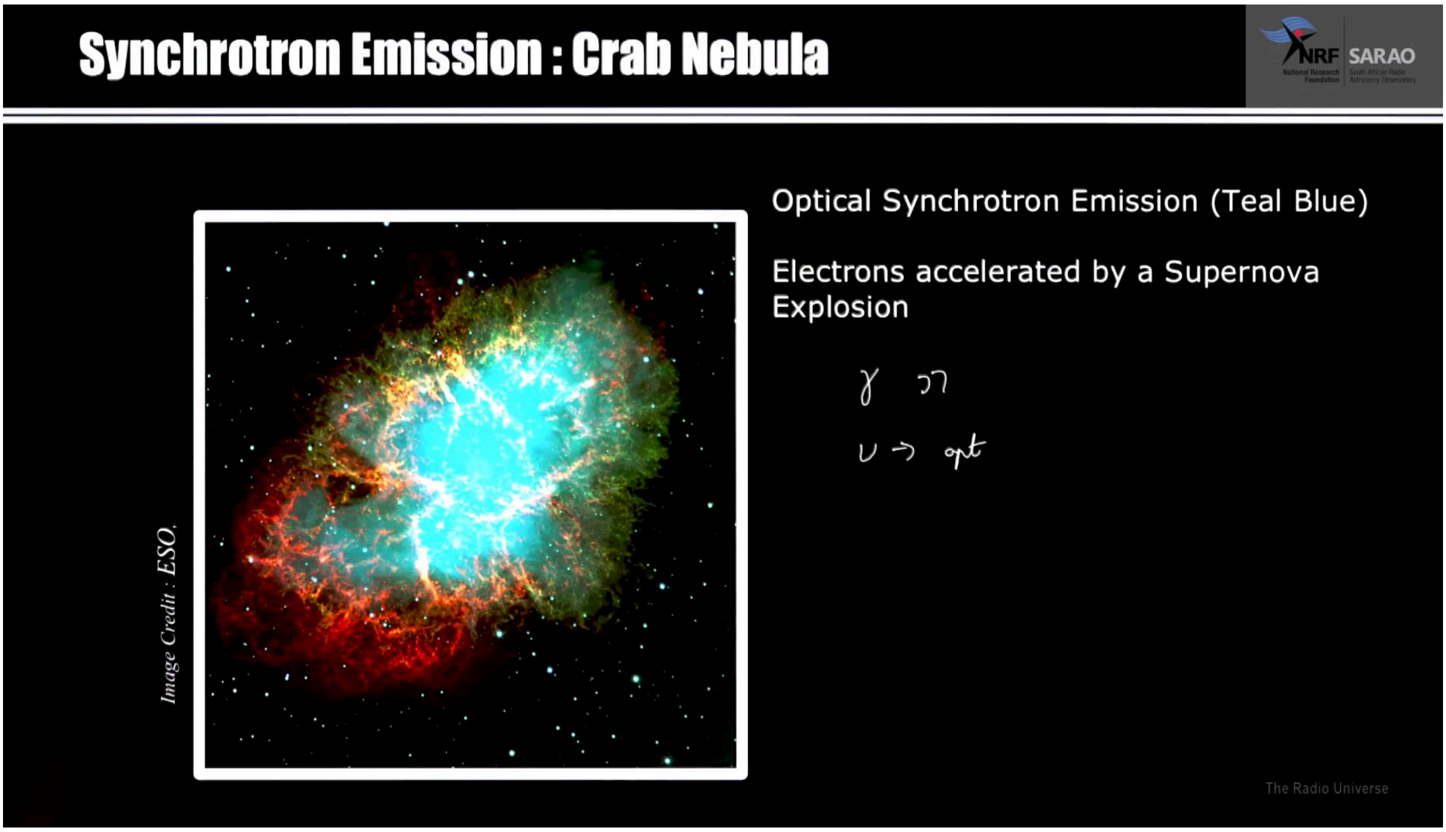


But if you were to look at the same blob of plasma sometime later then all of these high-energy electrons would have lost their energy by radiating it away and so what you would see is that there would be a sharp cutoff at some energy where all of this energy has been radiated away. And what that translates into is that you'll also have a sharp cutoff in the frequency distribution of your synchrotron emission. So when you look at the spectrum of your synchrotron emission then you'll see that there's some cutoff here where the older the plasma is, the lower frequency this cutoff will happen at. So if you have say, three sets of plasma which look like this and like this then this is the yongest plasma and this is the oldest plasma.

Notes

Summary

1m 58s



Here we have some examples of synchrotron emission. This is synchrotron emission from the Crab Nebula where the blue cyan emission is optical emission and this is the case where the Lorentz factor was very very high and so the frequency of the emission was boosted into the optical frequency regime.

Notes

Summary

3m 12s

Synchrotron Emission : Hercules A

NRF SARAO

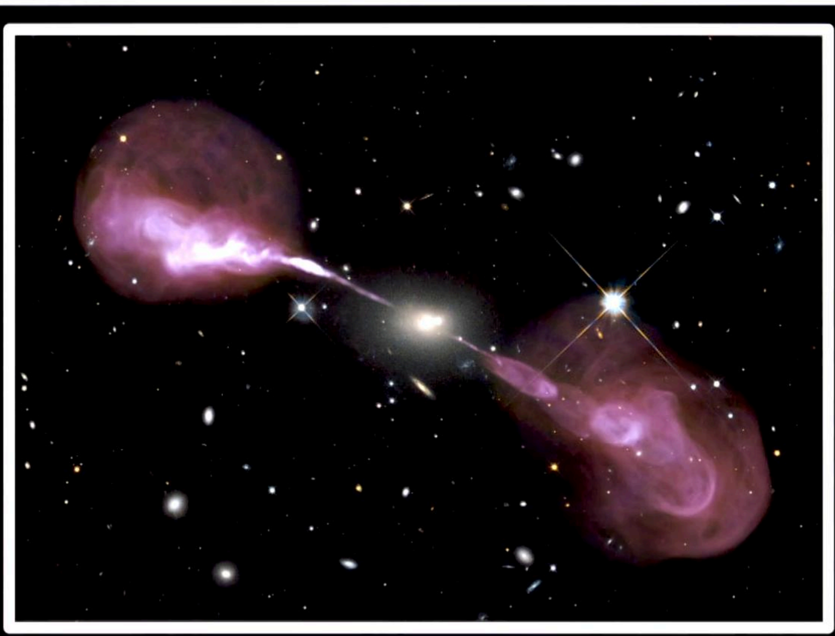


Image Credit :, NASA, ESA, S. Baum and C. O'Dea (RIT), R. Perley and W. Cotton (NRAO/AUI/NSF), and the Hubble Heritage Team (STScI/AURA)

The Radio Universe

Another example of synchrotron emission in extra galactic source is the emission from these very diffuse radio lobes that are shooting out of a galaxy. This is also a synchrotron emission.

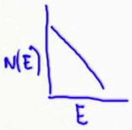
Notes

Summary

3m 37s

Synchrotron Polarisation

% polarisation $= (\beta+1)/(\beta+7/3)$



$\beta = 5/2$

% $= 72\%$

•) Ordered magnetic

•) few percent

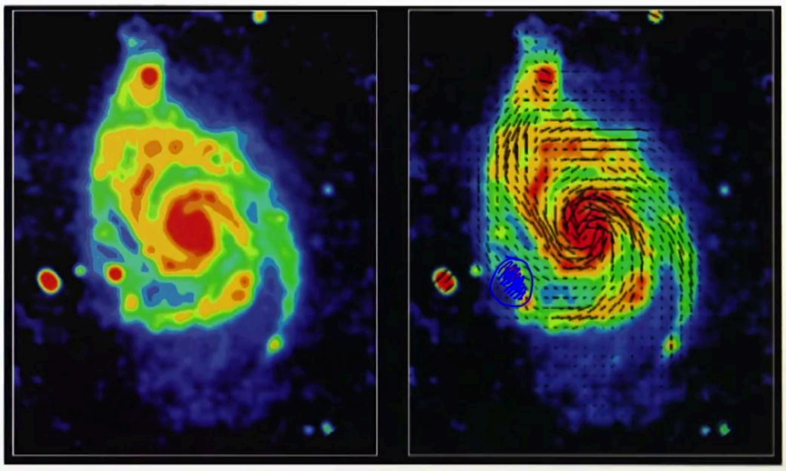


Image courtesy of NRAO/AUI
Investigators: Rainer Beck (MPIfR Bonn, Germany),
Cathy Horellou (Onsala Space Observatory)

The Radio Universe

The theory of synchrotron emission predicts that it will be very highly polarized, where the percentage of polarization depends on the index of the power law of the electron energy profile. So the percentage polarization is equal to beta plus one divided by beta over three where remember beta is the spectral index of the energy profile of your synchrotron electrons. So for a typical value where we say that beta is around five over two, there this predicts a percentage polarization of around 72% which is very very high. But this prediction is based on having ordered magnetic fields in the galaxy. And so if you don't have an ordered magnetic field then the percentage of polarization goes down the less ordered the field is and for a completely unordered field the percentage of polarization is zero. In galaxies we typically measure polarization of around a few percent and some of this is because we don't have a completely ordered magnetic field and some of this is because of the various depolarization effects between you and the source which include things like the size of the beam which might be integrating over some large region here which then sums together regions with different polarization angle which depolarizes the source.

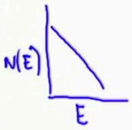
Notes

Summary

3m 50s

Synchrotron Polarisation

% polarisation = $(\beta+1)/(\beta+7/3)$



$\beta = 5/2$

% = 72%

·) Ordered magnetic

·) few percent

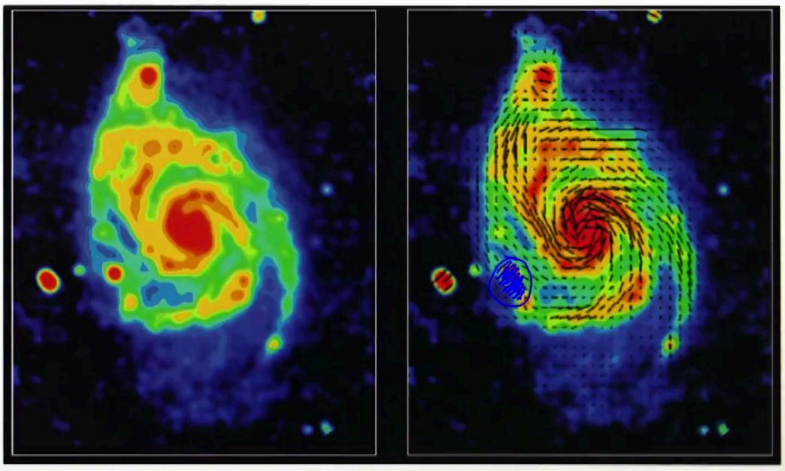


Image courtesy of NRAO/AUI
Investigators: Rainer Beck (MPIfR Bonn, Germany), Cathy Horellou (Onsala Space Observatory)

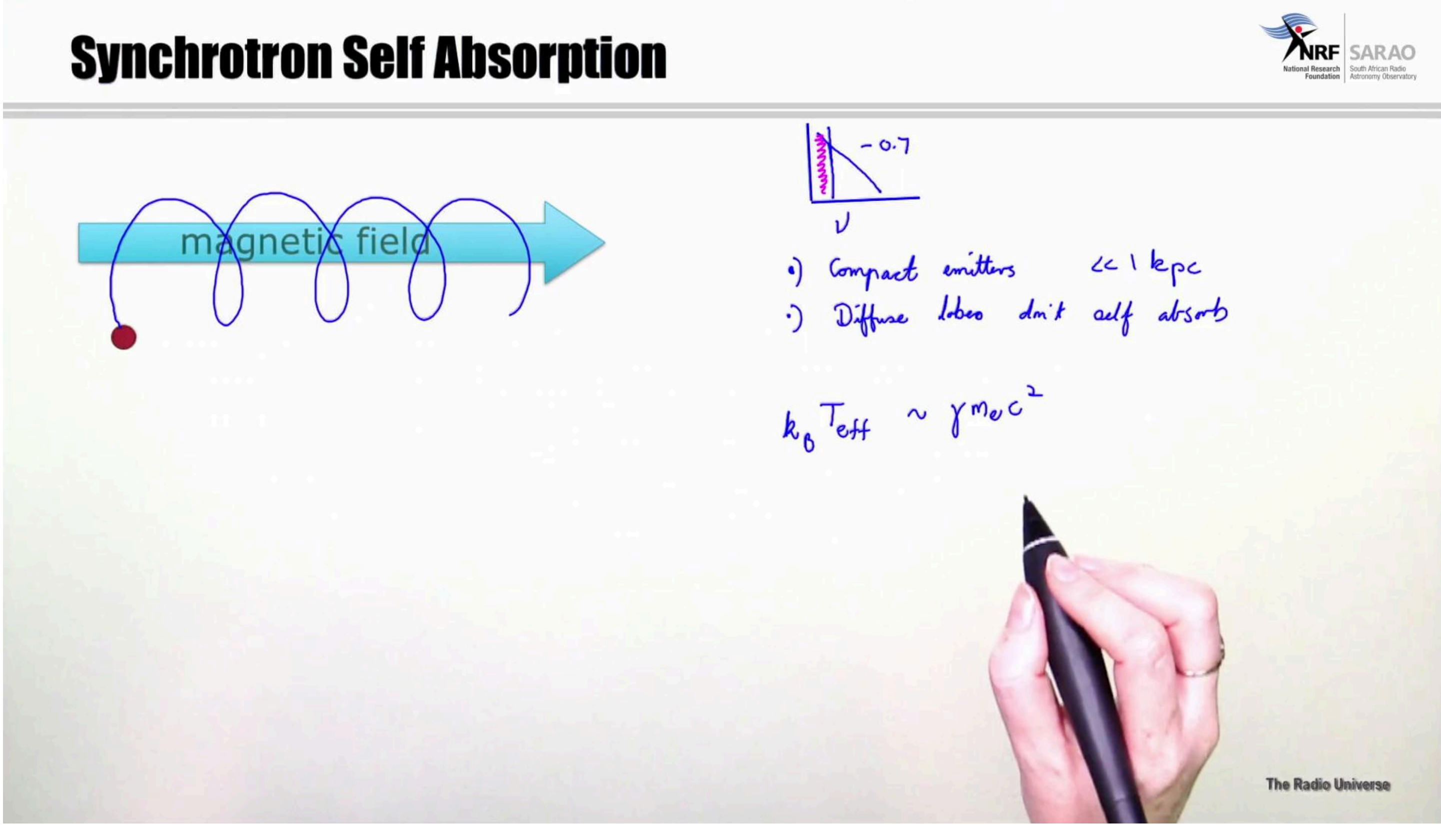
The Radio Universe

Here we have an example of what the polarization angle and intensity looks like for a typical galaxy where the longer the vector here, the more and more highly polarized the source is.

Notes

Summary

5m 26s

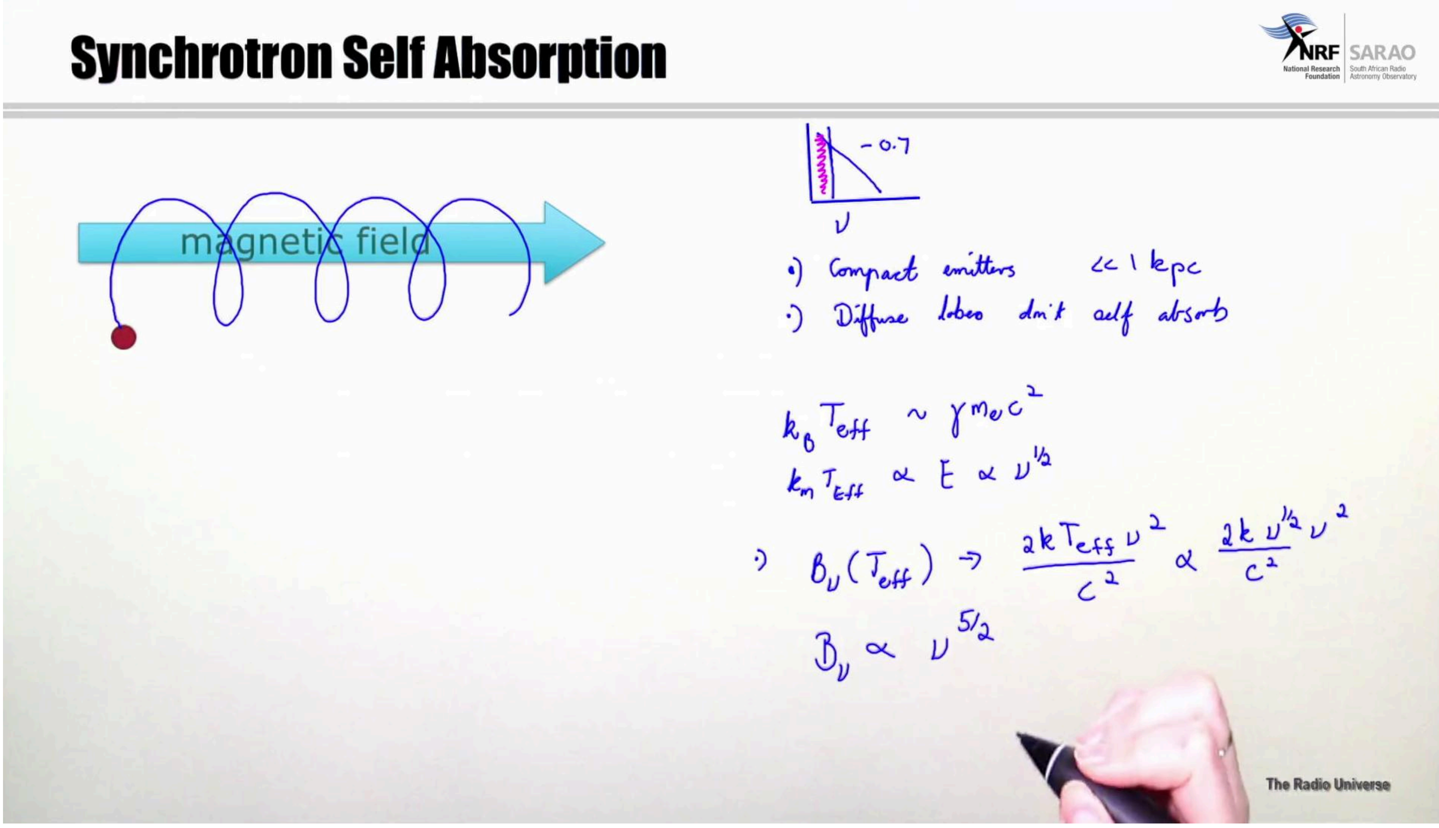


It might seem when we're looking at our spectrum of synchrotron emission with the spectral index of minus 0.7 that as we go to lower frequencies that the amount of radiation will increase indefinitely. But this isn't the case for any emission any mechanism that can produce emission, it can also absorb emission and so it's possible for a spiraling electron to absorb a photon as well. And what happens is as the density of photons increases then these very low energy photons here which have reached some very high density will become absorbed by synchrotron absorption. So this synchrotron absorption is usually not noticeable in very diffuse sources. It's only *[inaudible]* compact sources and by that we mean images with the size of less than around one kiloparsec. For very diffuse emitters like radio lobes from very large AGN, we don't usually see a synchrotron absorption. We can roughly work out what the spectral shape of a synchrotron self-absorbing system will be by considering that we can define something called an effective temperature for a relativistic gas where we say that the effective temperature is defined to be proportional to the relativistic kinetic energy by this equation.

Notes

Summary

5m 41s



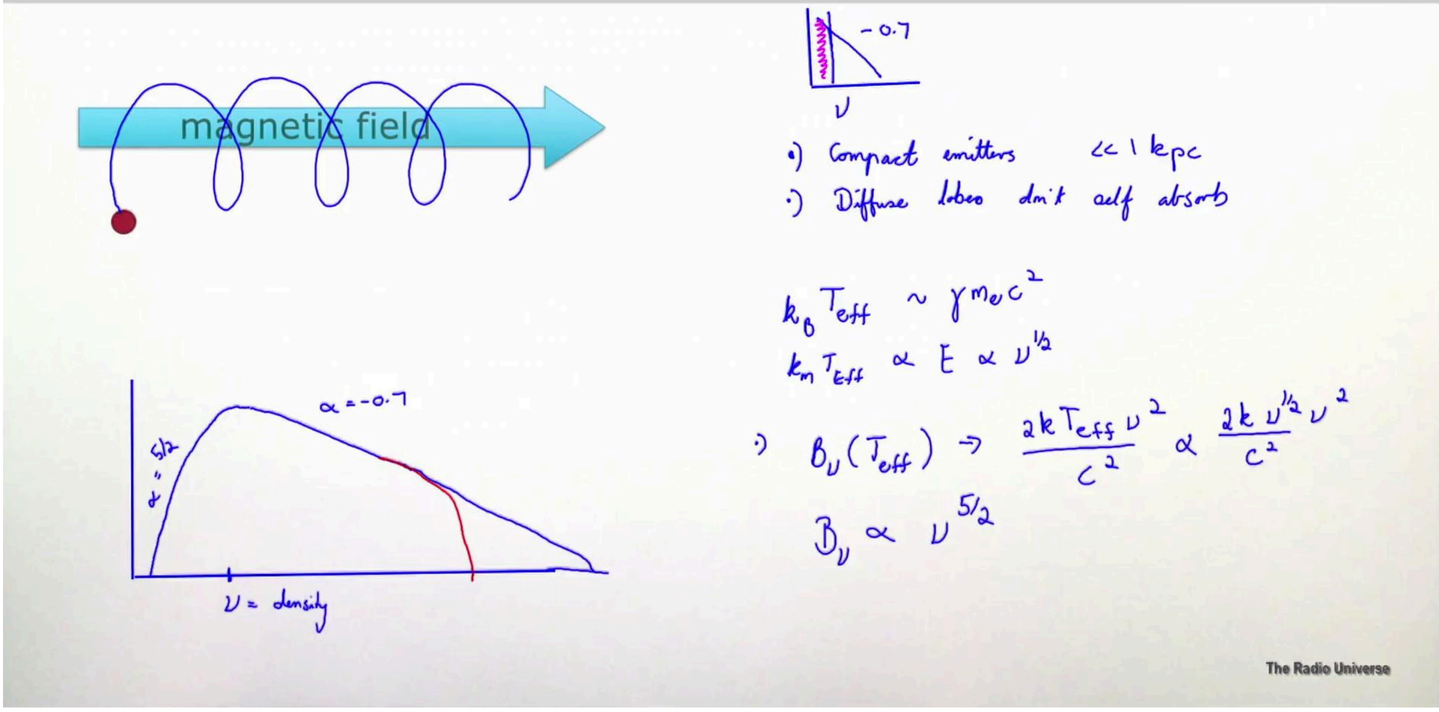
So from this, we can say that we know that the effective temperature then is proportional to the energy because it's proportional to the to this Lorentz factor which means that it's also proportional to the frequency that that it's emitting at to the power of a half. We can also use the fact that a blackbody is a perfect emitter so, therefore, it's not possible for an object at a given temperature to emits more radiation than a blackbody would at a given temperature. So we can say that the emission from a synchrotron self-absorbed system has a blackbody profile with the temperature given by this effective temperature that we've defined. And because we are in the Rayleigh jeans radio regime or in the radio regime we can use the Rayleigh jeans approximation so from that we can say that the spectral intensity is equal to the Rayleigh jeans approximation. But now we can say that this effective temperature is approximately proportional to the frequency to a power of a half. Which then means that the spectral intensity of a self-absorbed system is proportional to the frequency to the power of five over two.

Notes

Summary

7m 42s

Synchrotron Self Absorption

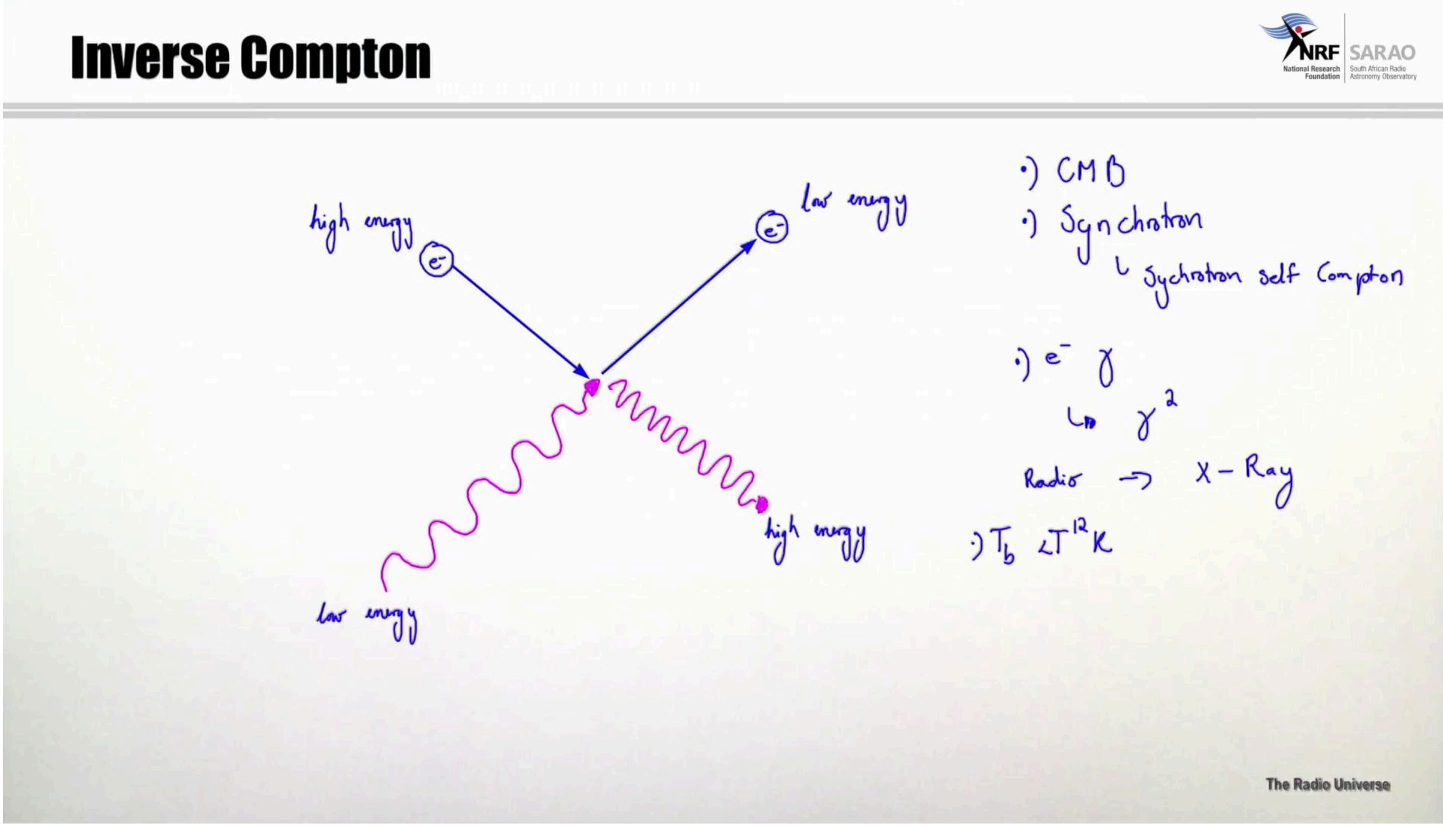


So when we look at our overall spectral profile for a synchrotron emitter, at intermediate frequencies we'll have our power law spectrum and then if it's a compact which will have a typical spectral index of around minus 0.7 then if it's a compact source there'll be some frequency at which the self-absorption starts to be important and this depends on the density of the photons and the medium and so at this point it'll be start to become self-absorbed and here we'll have a spectral index of around five over two and then depending on whether or not the spectrum has very old plasma, you'll either have a power law out to higher frequencies or you'll start to see that there's a high frequency cutoff here.

Notes

Summary

9m 21s



Inverse Compton scattering isn't a way to create new photons but it is a way of changing the frequencies of the photons that you already have. So inverse compton scattering happens when you have a high energy electron which has some velocity which collides with a lower energy photon. When these two collide with one another, there's an energy exchange and what you end up with is a lower energy electron and a very high energy photon. The lower energy photons can come from the background cosmic microwave background radiation which we'll learn about in a later lecture or it can come from the synchrotron source itself in which case it's called synchrotron self-compton emission. If the electron is ultra-relativistic and it has a and it has a very large Lorentz factor then the new photon can have its energy increased by a factor of gamma squared, and so that means that a radio photon can be up scattered to even an x-ray photon. This inverse compton process provides another way of cooling synchrotron sources so it's a way for synchrotron emitters to reduce their energy and this tends to limit the brightness temperature of a synchrotron source to less than around 10 to the 12 Kelvin.

Notes

Summary

10m 20s