Calorimeter model & Milky Way

Kim McAlpine

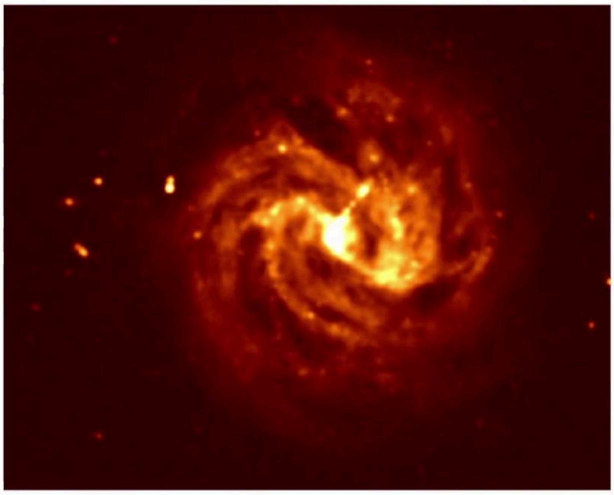
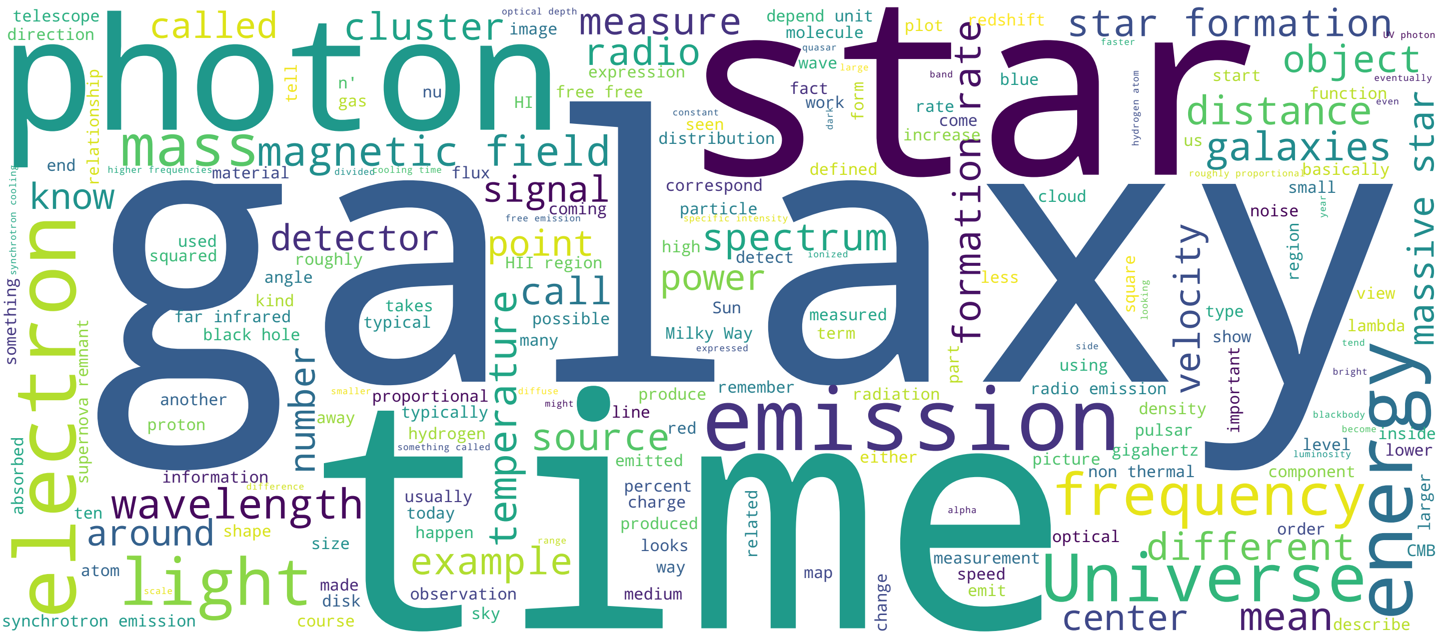


Image courtesy of SARAO



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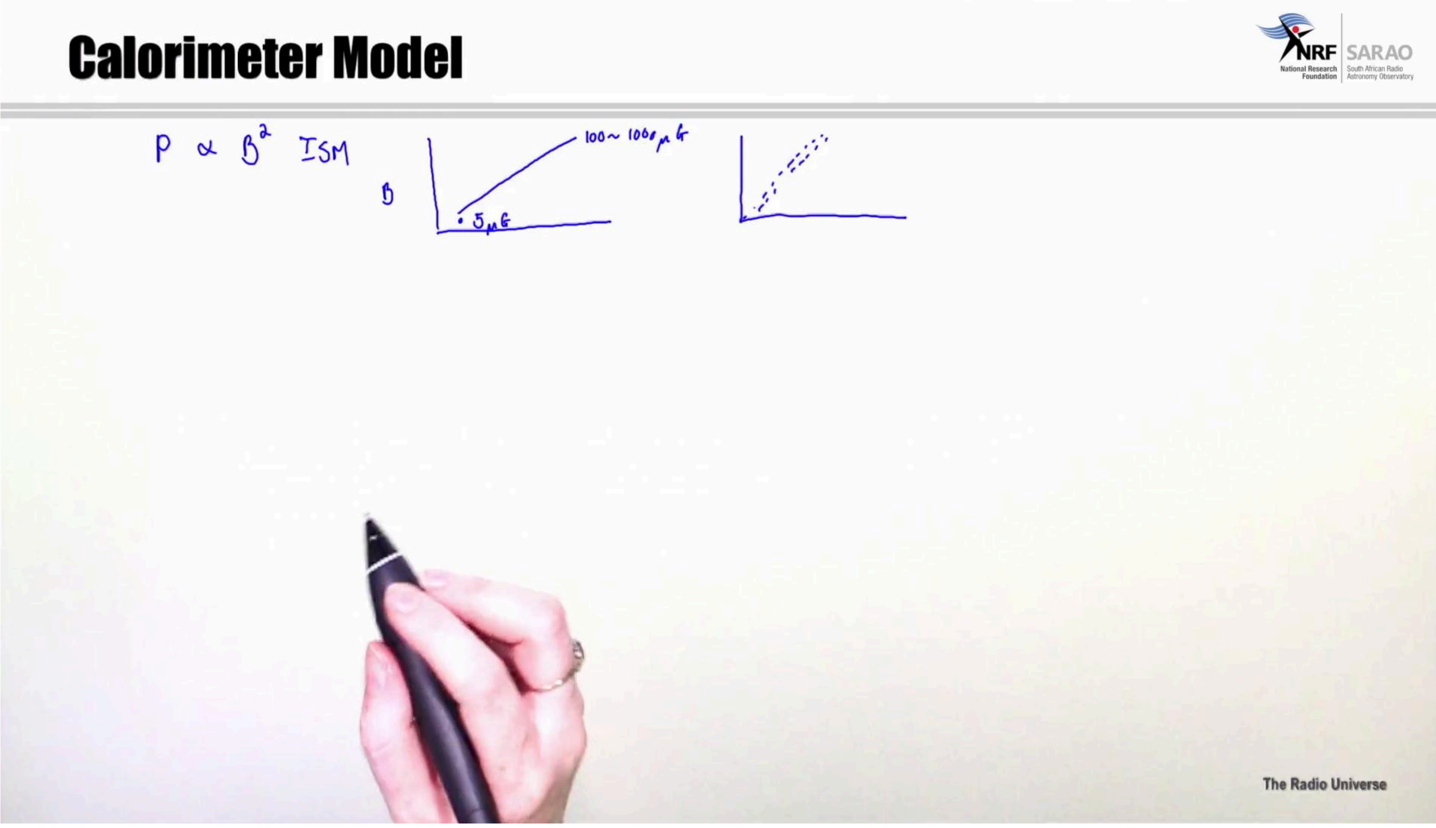
Video

At the end of our last lecture, we learned that the far infrared emission from dust which is heated by young stars is very tightly correlated with the synchrotron emission at radio wavelengths. In this lecture, we'll explore in more detail why that might be and why this relationship gives us confidence that we can use the radio continuum as a way to measure the star formation rate of a galaxy and then we'll end by considering what the radio emission looks like from our own galaxy, the Milky Way.

Notes

Summary

0m 05s

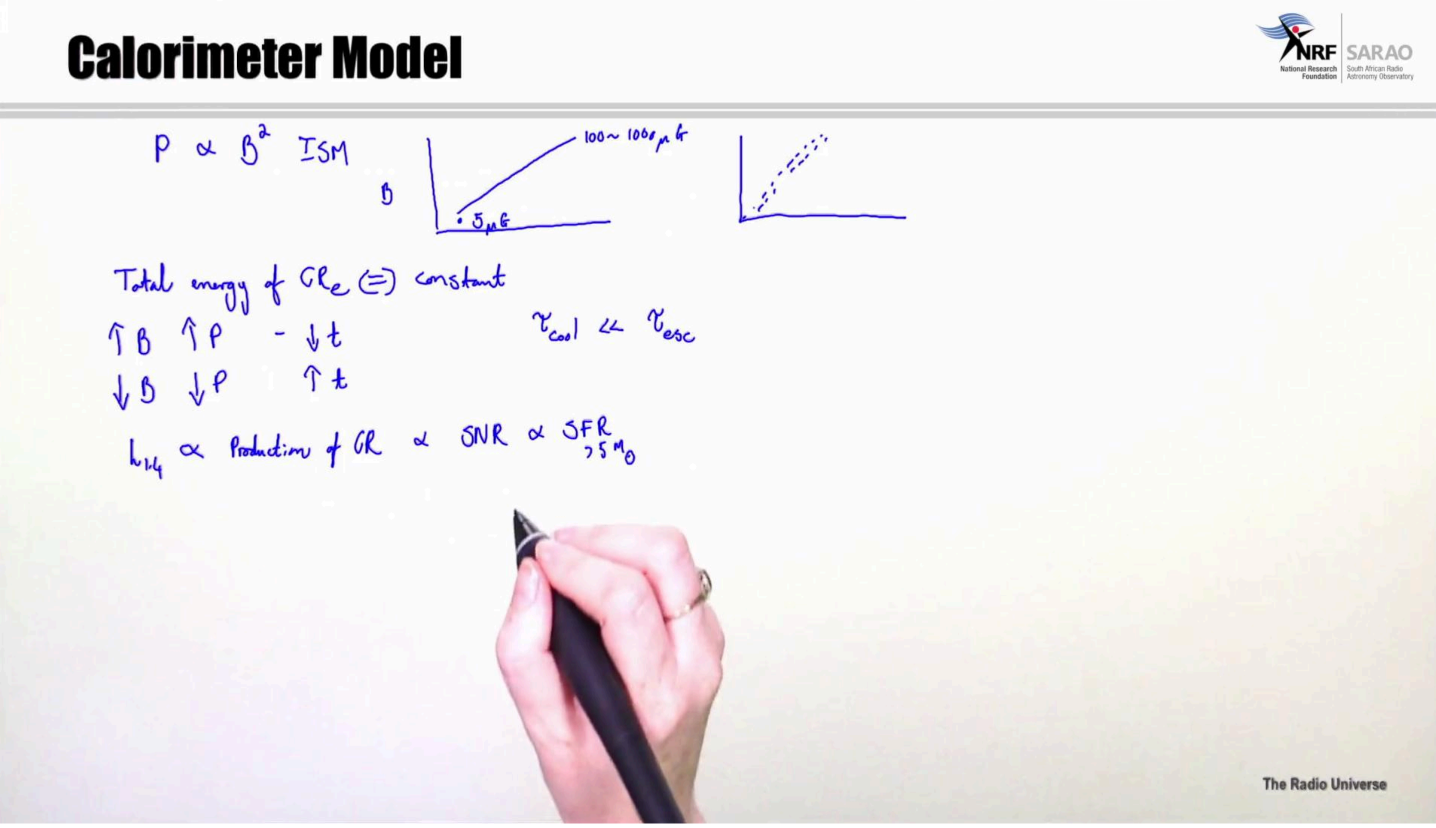


So as I mentioned before, it's quite surprising that the synchrotron emission would be so closely correlated with the far infrared emission from a star forming galaxy and that's because you know that the power of a synchrotron emitter is proportional to the magnetic field of the galaxy and the magnetic field in the interstellar medium can vary greatly depending on the density and star formation rate of the galaxy. So, for example, for a normal galaxy like the Milky Way, you could have a magnetic field of around five microGauss but for a very powerful and compact star bursting galaxy, you could have a magnetic field that's more like a hundred to a thousand microGauss. And over this wide range in magnetic fields, the magnetic field strength, the far infrared radio correlation stays effectively linear and in place. So in order to explain this far infrared radio correlation, we have something called the calorimeter model.

Notes

Summary

0m 33s

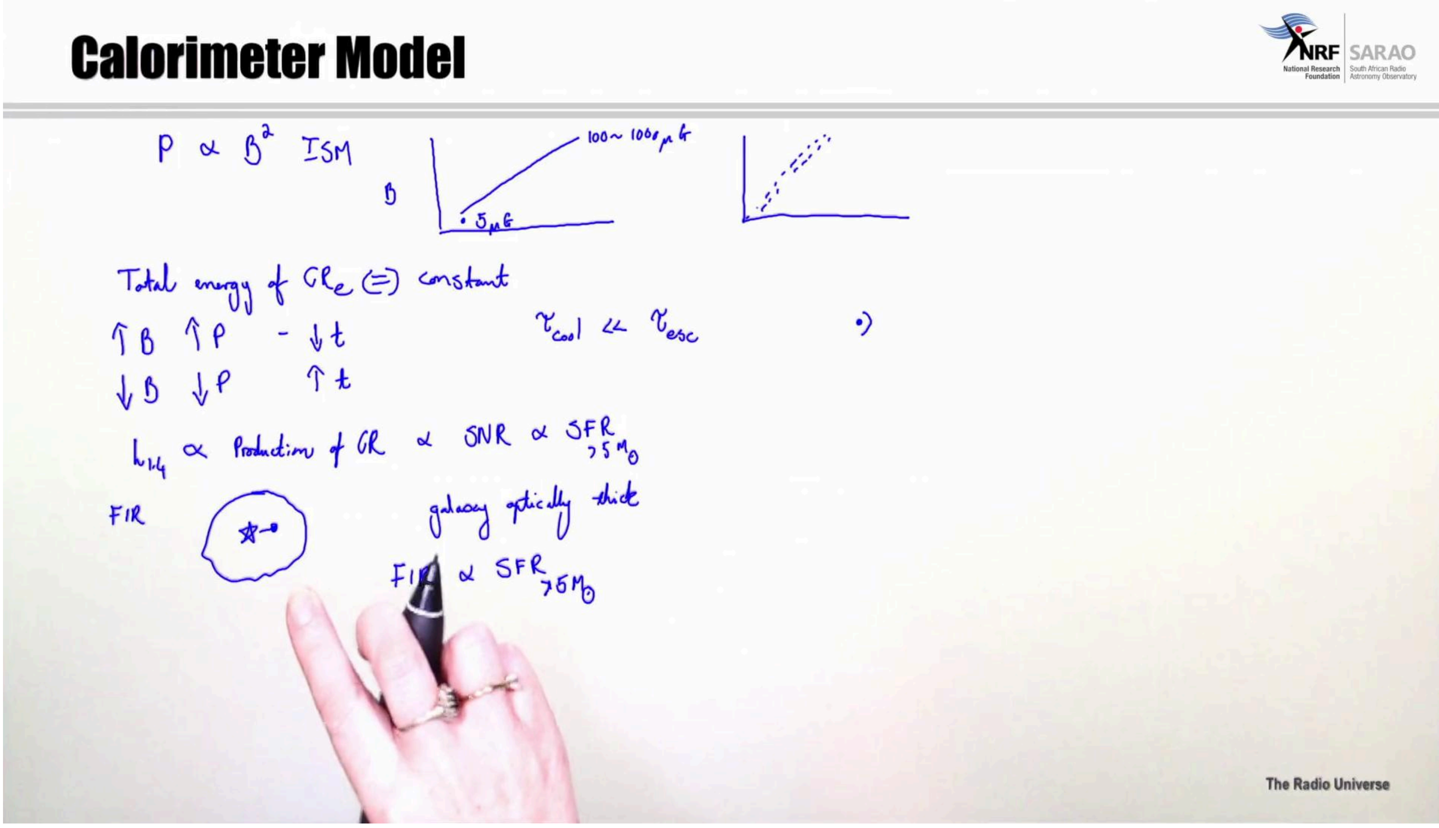


So the calorimeter model says that the total energy emitted by an electron is effectively roughly constant and we reach this conclusion by saying that if you have a very high magnetic field then you will emit a very high power but only for a very short time so that you have a very short synchrotron cooling time whereas if you have a lower magnetic field then you'll have a lower power but you'll be able to radiate for a much longer time and this time it takes for the electron to lose all of its energy via radiation is called the synchrotron cooling time and we make the additional requirement that we say that this synchrotron cooling time must be very much shorter than a time it takes for this electron to escape the galaxy. So eventually that cosmic ray electron will leave the galaxy. But we say that before that it will emit all its emission as a radio emitter. So in this case what we're saying is that the 1.4 gigahertz luminosity of the synchrotron emission is roughly proportional to the production rate of cosmic ray electrons in a supernova remnant which then is roughly proportional to the rate of supernova explosions which then is roughly proportional also to the star formation rate of massive stars because these massive stars have short lifetimes and so the faster they're produced, the faster the supernova rate will be.

Notes

Summary

1m 37s

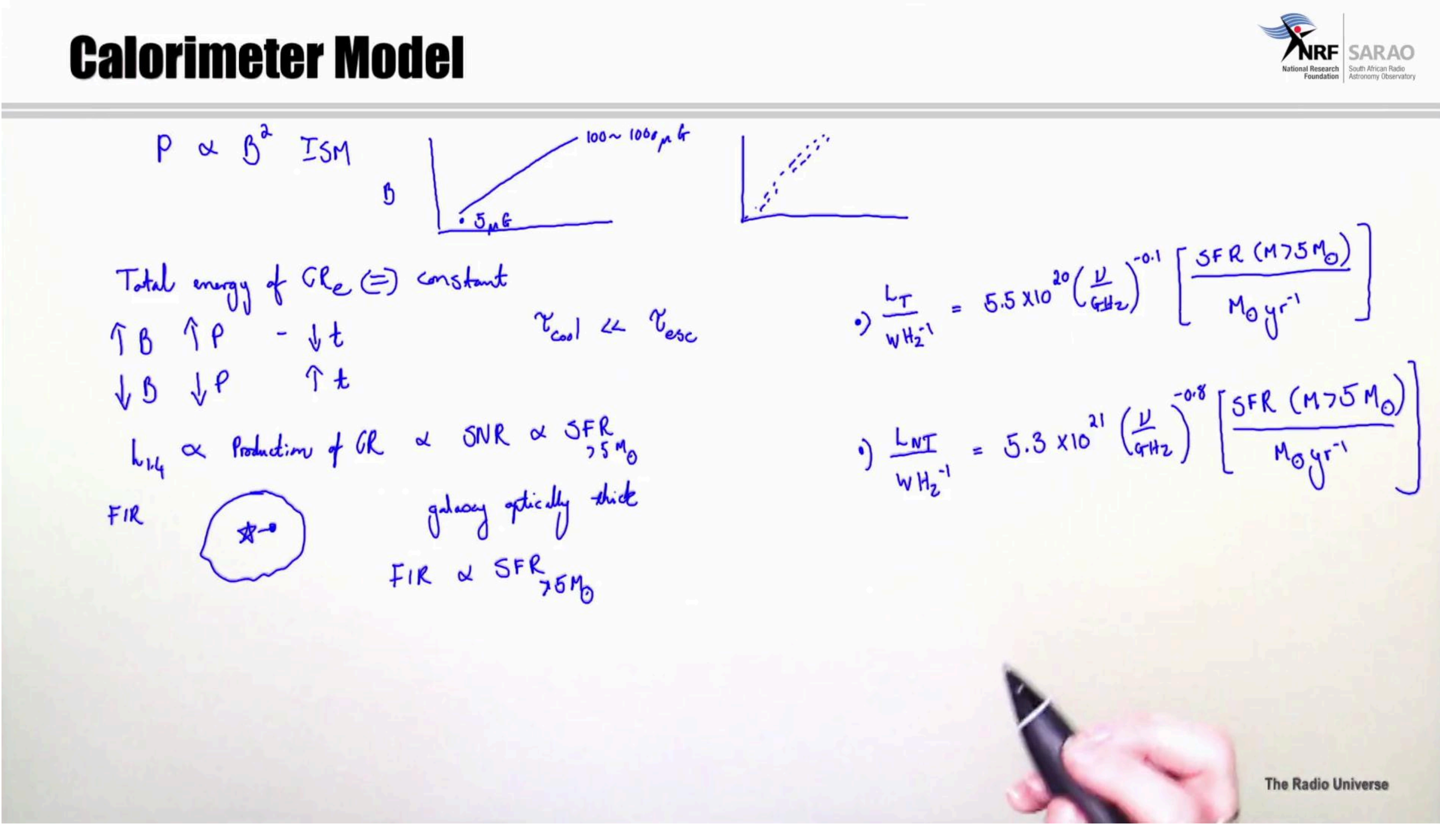


And so we can say that the 1.4 gigahertz is a measure of the total energy of all of the star formation rate in the galaxy for massive stars. Similarly, for the far infrared luminosity what we claim happens is that all of the UV photons from a massive star are absorbed by an intervening dust cloud. So for every star, all of its UV photons are absorbed by the dust in the galaxy. And so the galaxy is effectively optically thick to UV radiation. Which then means that for every photon that's produced by a massive star there will be a corresponding photon that is produced in the far infrared and so we can say that this far infrared luminosity is then proportional also to the star formation rate of the galaxy but only for some very massive stars because it's the massive stars that are born in these very very dusty molecular clouds. The more massive stars are born in the more massive clouds then the more massive clouds have the most dust. So from this, we're able to then come up with a relationship that describes how the radio luminosity is related to the star formation rate of a galaxy and one of the really great things about radio luminosity is that it's completely unaffected by this dust extinction.

Notes

Summary

3m 15s

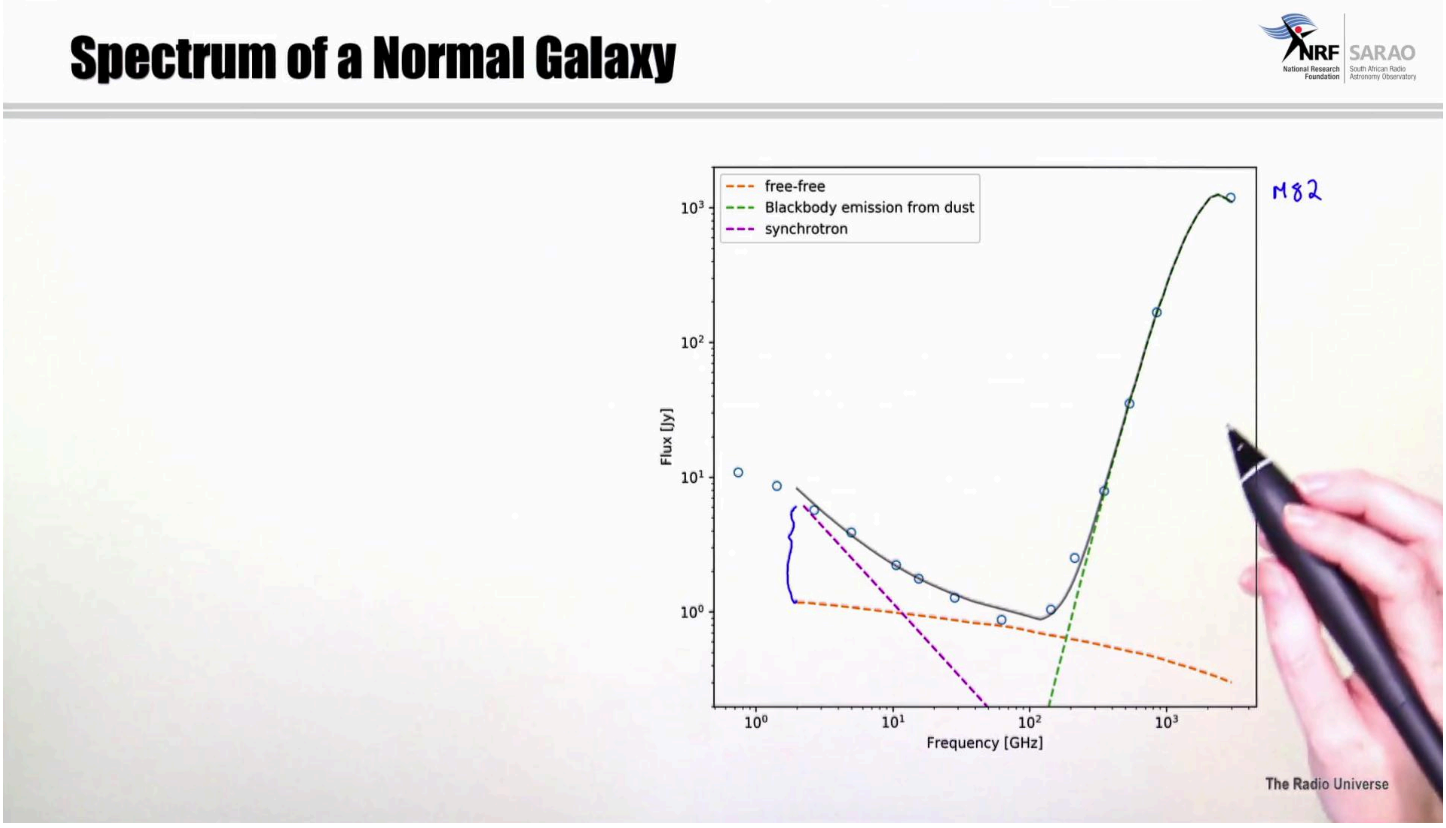


So you're able to measure the star formation rate from up from the radio emission even if it's completely obscured in the optical. So there are two relationships. One that describes the relationship between the thermal radio emission and the star formation rate and one that describes the relationship between the non-thermal or synchrotron emission and the star formation rate where they're given by these equations. So here we'll say that the thermal radio luminosity is related to the star formation rate by this equation where the luminosity is given in watts per hertz and the star formation rate is given in solar masses per year and here we have a correction which says that we can work it out for any frequency by taking into account its spectral index and the same for the non-thermal component and you can clearly see that the non-thermal component here is very much larger than the thermal component.

Notes

Summary

4m 48s



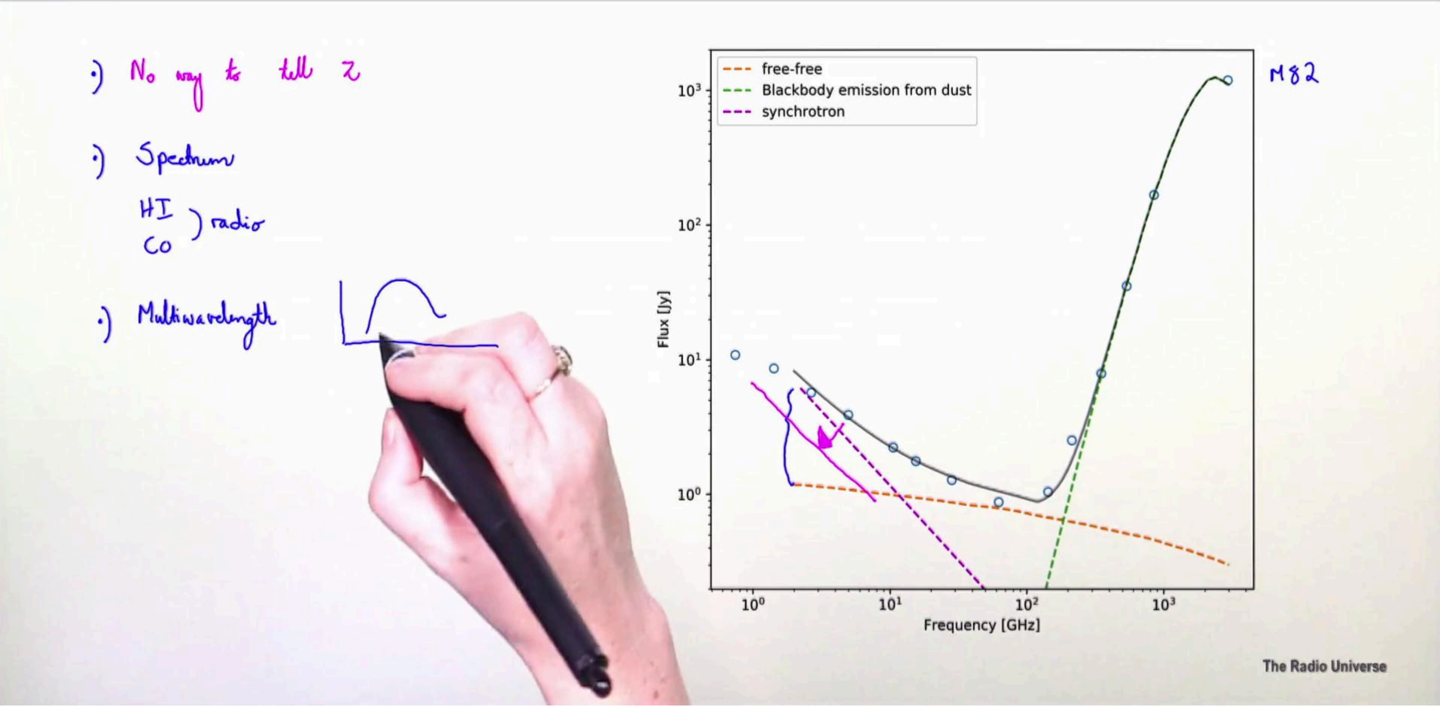
All of this information about the emitters that we see in the radio can be combined together to form the spectrum of a normal galaxy. Here we have an example spectrum for a galaxy. This is very similar to the spectrum of M82 and here the dark line represents the integrated spectrum from all the different contributors to the overall spectrum and at low frequencies we can see here in purple the synchrotron contribution where we have the typical steep spectrum of a synchrotron emitter. We can also see the contribution from free-free emission in HII regions which has this much flatter spectrum and then as we proceed to higher frequencies, we can see the gray or blackbody emission from the heated dust in the galaxy which is heated by the UV photons from the stars. So here what you can tell is that if you go down to relatively low frequencies here at around 1.4 gigahertz then the most of the emission comes from the synchrotron. Right. It's roughly ten times their power as in synchrotron emission compared to free-free. But as we proceed to higher frequencies, say, at roughly 40 to a 100 gigahertz then much more of their emission that you'll see comes from free-free emission and as you go to even higher frequencies, almost everything that you're seeing is effectively dust.

Notes

Summary

5m 50s

Spectrum of a Normal Galaxy



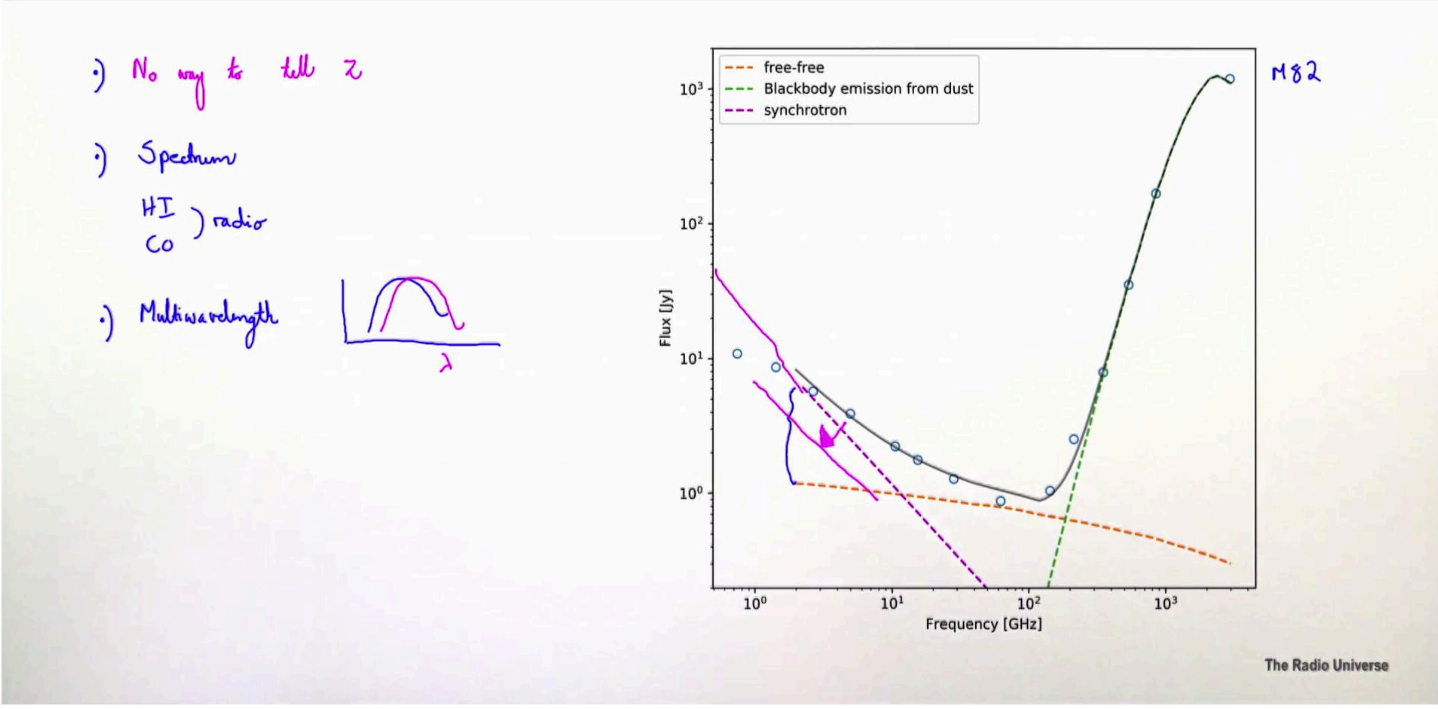
Another important thing to note about this is that if you have radio measurements in this regime that the spectrum of this this power law spectrum is basically invariant under redshift. So if I was to have a Doppler shift of the spectrum then it would have basically the same shape just at a slightly different frequency so you would measure the same shape but the power would be lower and so from this there's no way to tell if the power is lower because of distance or because you have an intrinsically fainter object. So there's no way to get the distance from a continuum spectrum and so that means that in order to get the distance for your radio emitter, you need to get information from some other wavelength. So either you can take a spectrum and you can look for either HI or you could look for CO in the radio or if you want to, you could go and look at another wavelength and you can use other lines in the optical just to look for a spectrum to get a distance or it's also possible to combine radio with a multi-wavelength data over a range of wavelengths which then sometimes allows you to get a measure of distance because especially in the optical you tend to have a characteristic shape which then will shift with redshift.

Notes

Summary

7m 18s

Spectrum of a Normal Galaxy

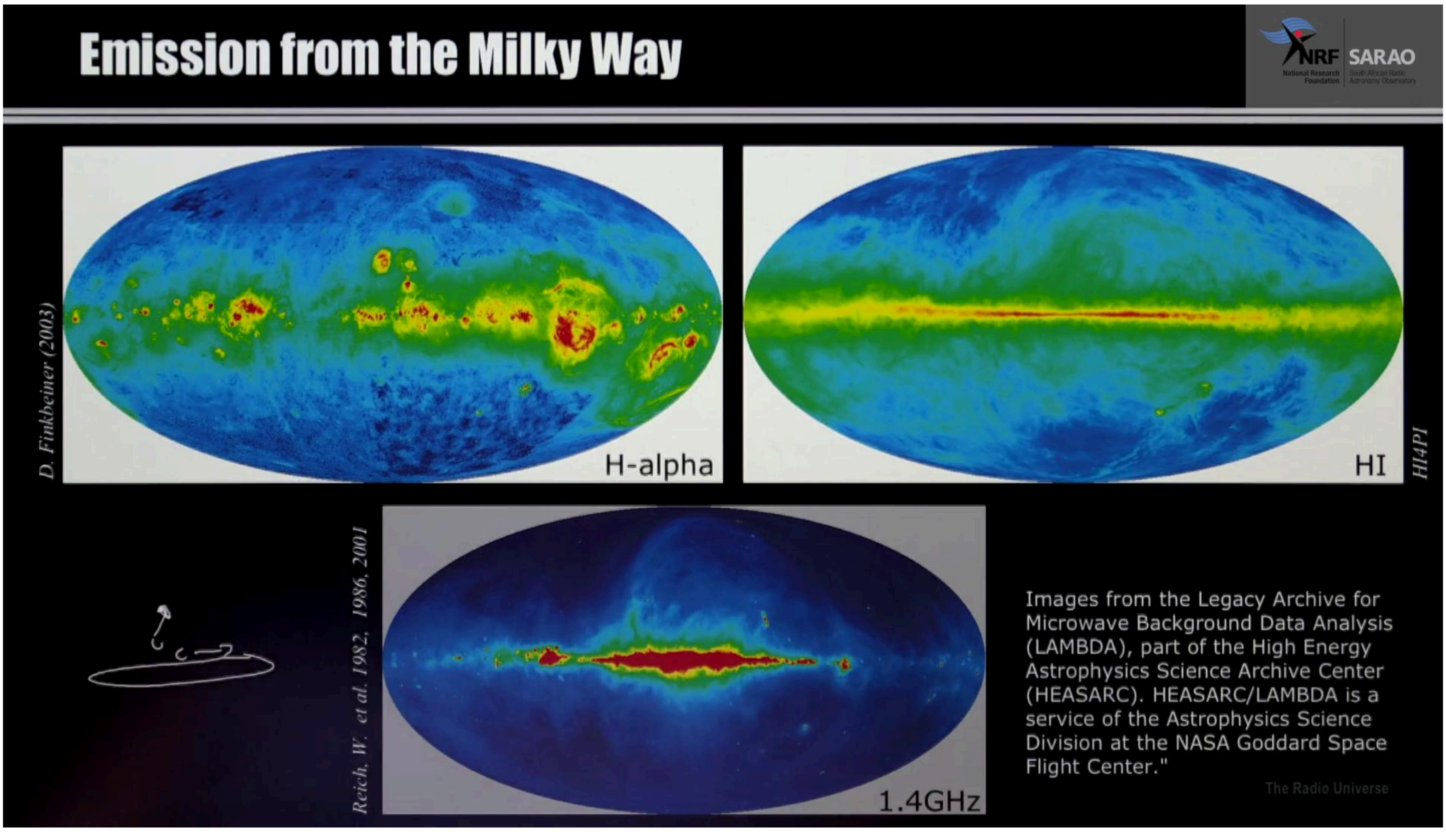


If this is wavelength which then allows you to get a measure of the distance. But from a continuum picture of a galaxy alone, you can't tell how far away it is and it's also not possible with only a single frequency snapshot to say what the contribution is from free-free versus synchrotron. You need multi-frequency information to do that. Another thing to notice about this plot is that if these little dots are the data points for M82 then it's starting to turn over here without getting a synchrotron spectrum that just continues on increasing forever and that's because of synchrotron self-absorption at this point.

Notes

Summary

8m 50s

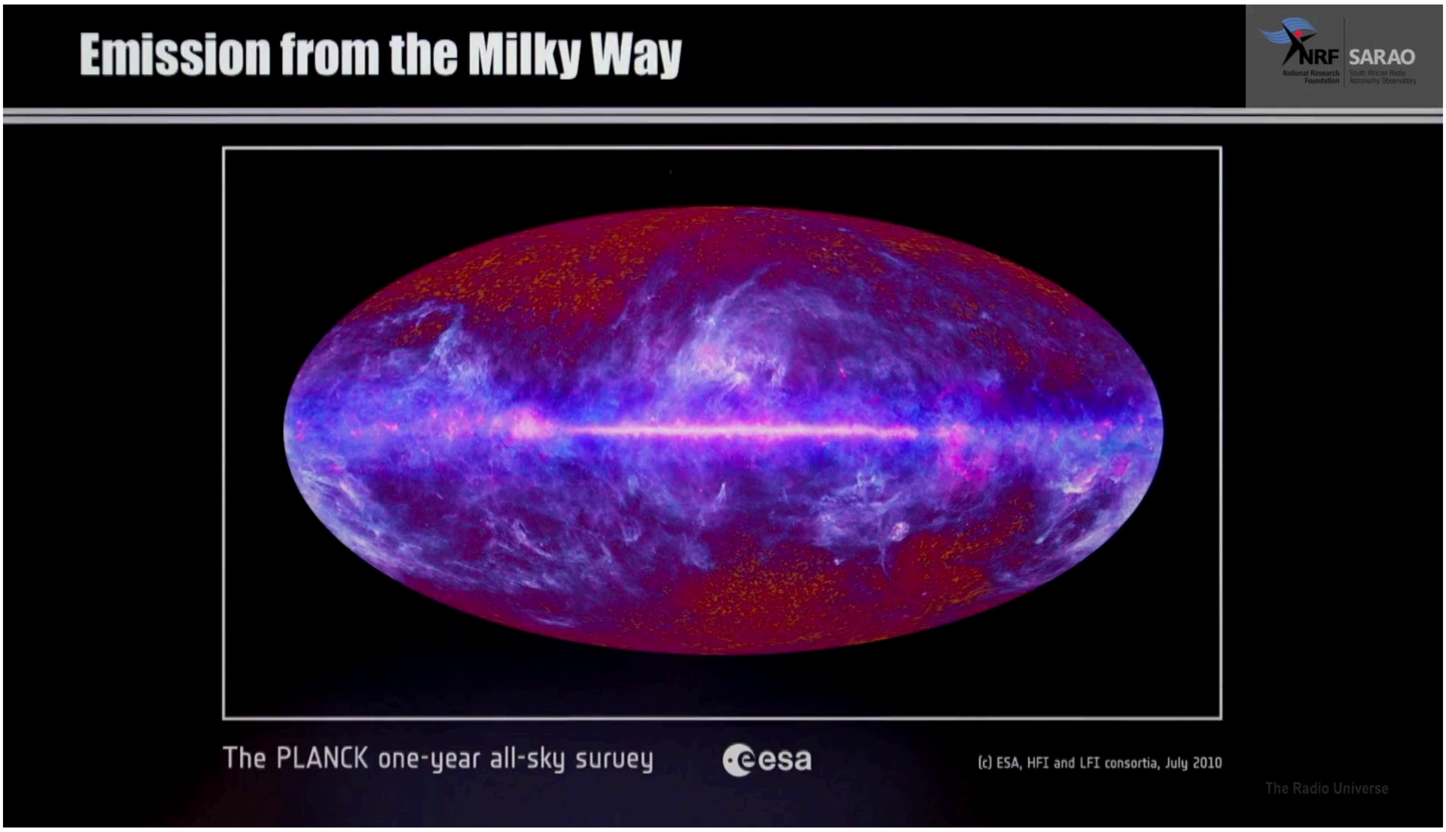


Our galaxy is a disk galaxy. It's a spiral galaxy. And so if we point our telescopes along the disk then we'll see emission from our galaxy here and if we point our telescopes above the disk then we'll see emission from outside the galaxy. And so here we have a plot of what the emission from the disk looks like at various wavelengths. This is a plot of the emission from the Milky Way. This is the disk of the galaxy in H-alpha and this is from above and below the galaxies, the galactic plane. This is what it looks like in HI and there'll be a separate lecture on HI in a later video. And this is what it looks like at 1.4 gigahertz so this is what it looks like in radio continuum. And you can see that in the HI the disk extends much further and is much brighter than at 1.4 gigahertz.

Notes

Summary

9m 29s



This is a multi-wavelength composite of what the galaxy looks like from the Planck emission.

Notes

Summary

10m 24s

If we were to zoom in to the center of our galaxy which is around 25,000 light years away from our Sun, if we point our telescope there then what it would look like in radio waves would be this very spectacular image. You cannot see the center of the galaxy at optical wavelengths. It's completely obscured by interstellar dust so this whole region would just be dark if you were to see with an optical telescope. But in radio, we can see that actually this is a very interesting and busy place. So over here what you have is something called the Sagittarius A-star which is believed to be a supermassive black hole and all this lit up material here is ionized gas around the supermassive black hole. There are all these very interesting features that you can see here including these arcs of emission and these filaments of emission which are believed to be related to the magnetic field of the black hole but their origin is not very well understood. Over here we have Sagittarius B-stars which are ionized HII regions and over here we have two supernova remnants and another HII region. So the center of our galaxy is a very interesting place indeed.

Notes

Summary

10m 29s