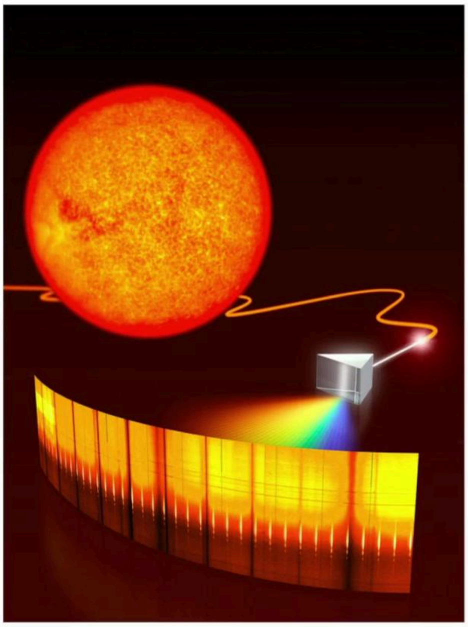
Spectral Lines (part 3)

Kim McAlpine



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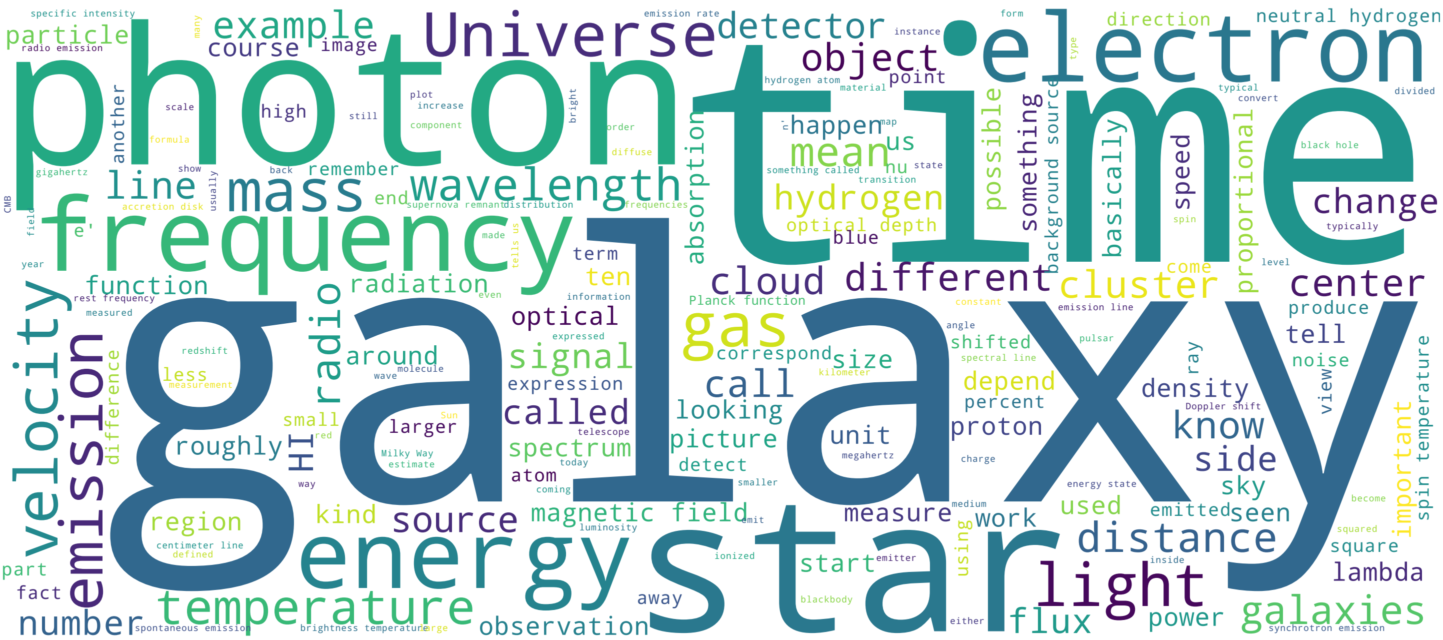


Search MOOC

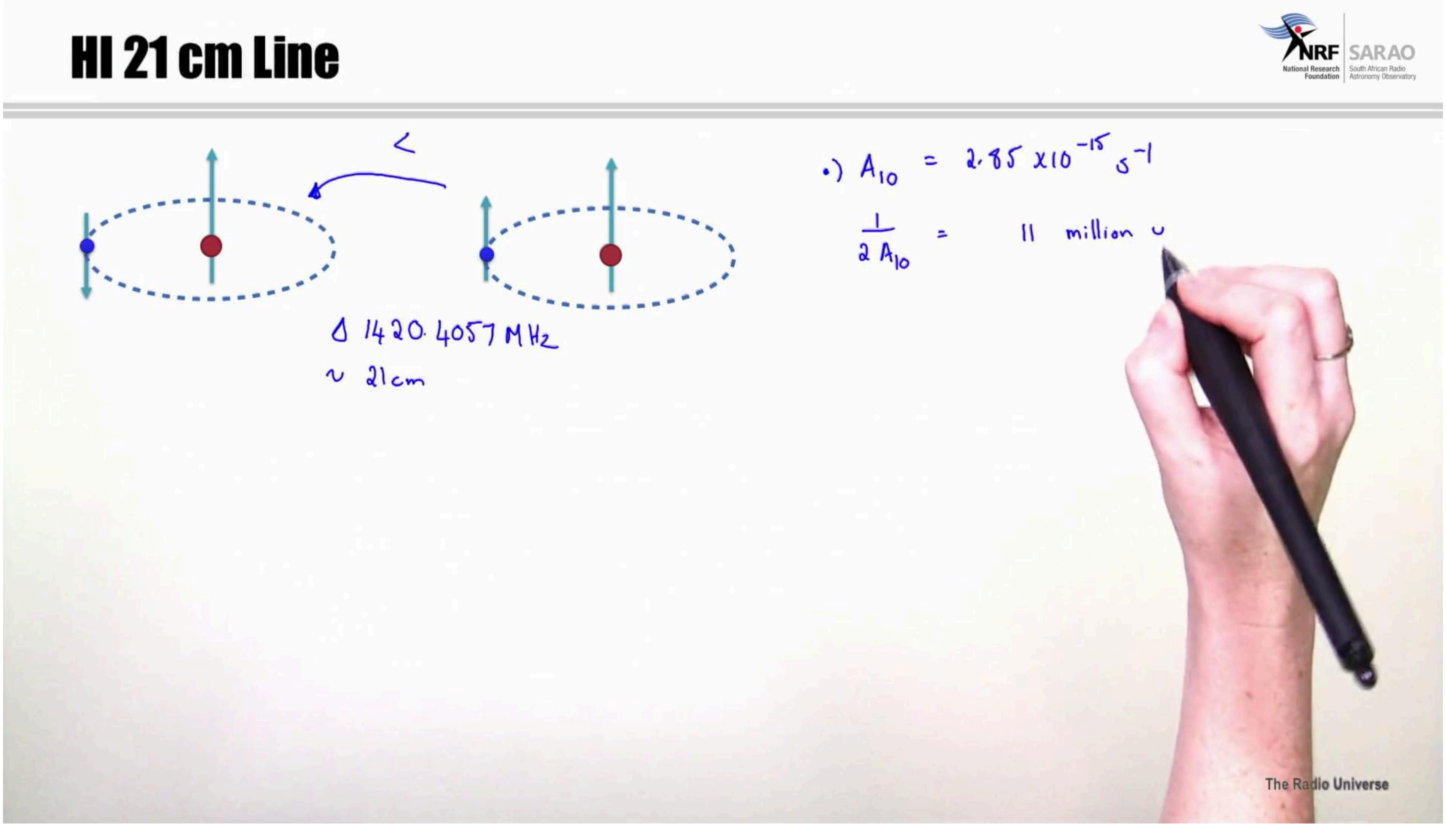
Video

Neutral hydrogen is the most abundant element in the Universe and it forms the fuel for making stars. It's out of neutral hydrogen that we condense molecular hydrogen and eventually form stars. So how do we trace this very important gas? How do we understand how it's distributed within a galaxy and how it's exchanged within galaxies that are interacted? The main way that we do this is through the HI 21-centimeter line which we will learn about more in this lecture.

Notes

Summary

0m 05s

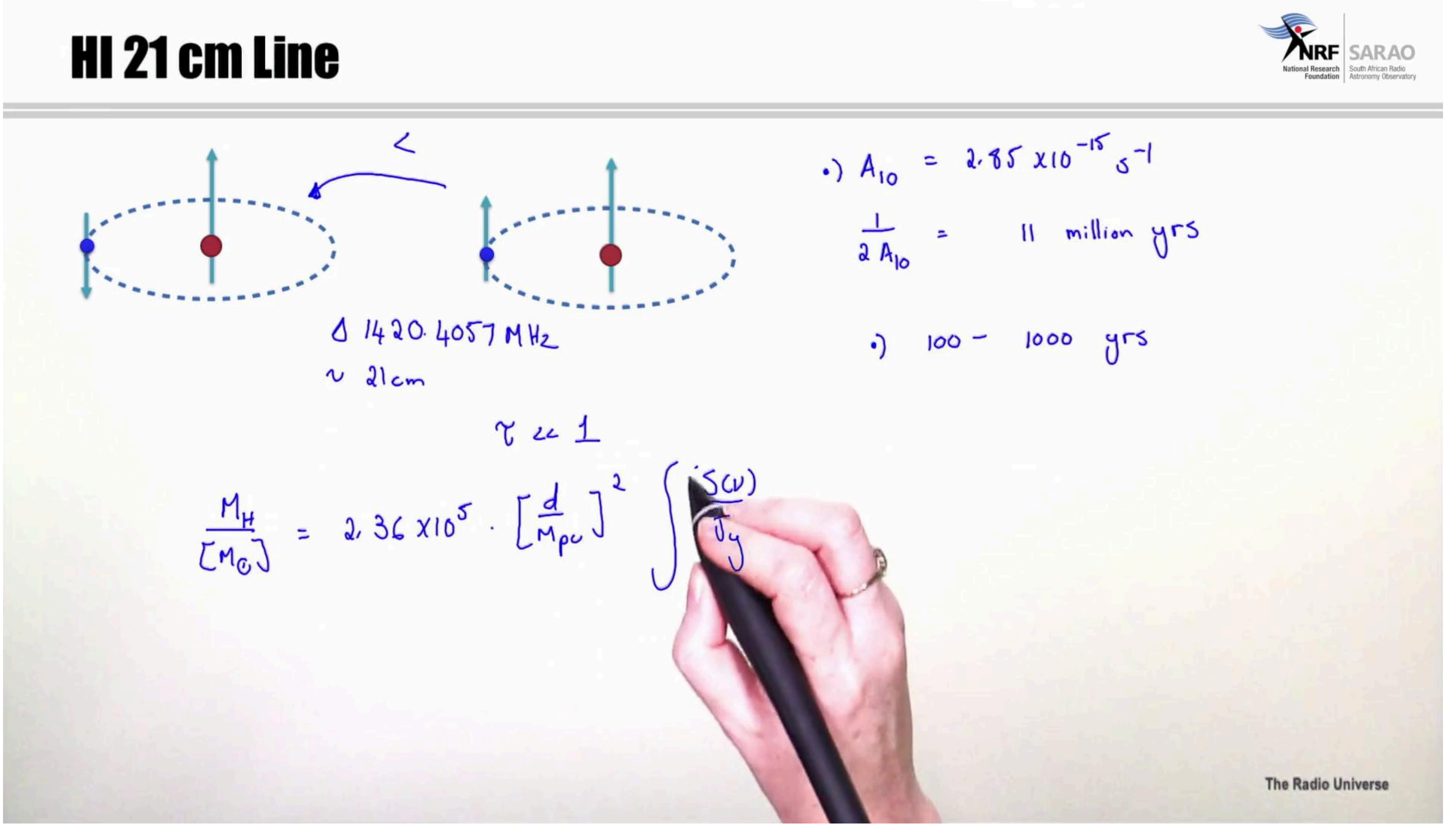


The most important spectral line in radio astronomy is without doubt the HI 21-centimeter line. So the HI 21-centimeter line happens when you have a hydrogen atom in its ground state and if it's in its ground state, if the spin of the electron is aligned with the spin of the proton then that is in a slightly higher energy state than if your electron is anti-aligned with the spin of the proton. And so if you transfer from this state to this state then a photon is emitted with a frequency of 1420 megahertz or roughly close enough 21 centimeters. This is a highly forbidden transition so what that means is that it has a very low spontaneous emission rate and doesn't really occur very often. The spontaneous emission rate for this transition is around 2.85 times ten to the minus fifteen per second which if you follow our formula from before where we say that the the time it will take for the transition to occur is then one over two times 'A' over the spontaneous emission rate works out to be roughly once every 11 million years.

Notes

Summary

0m 36s

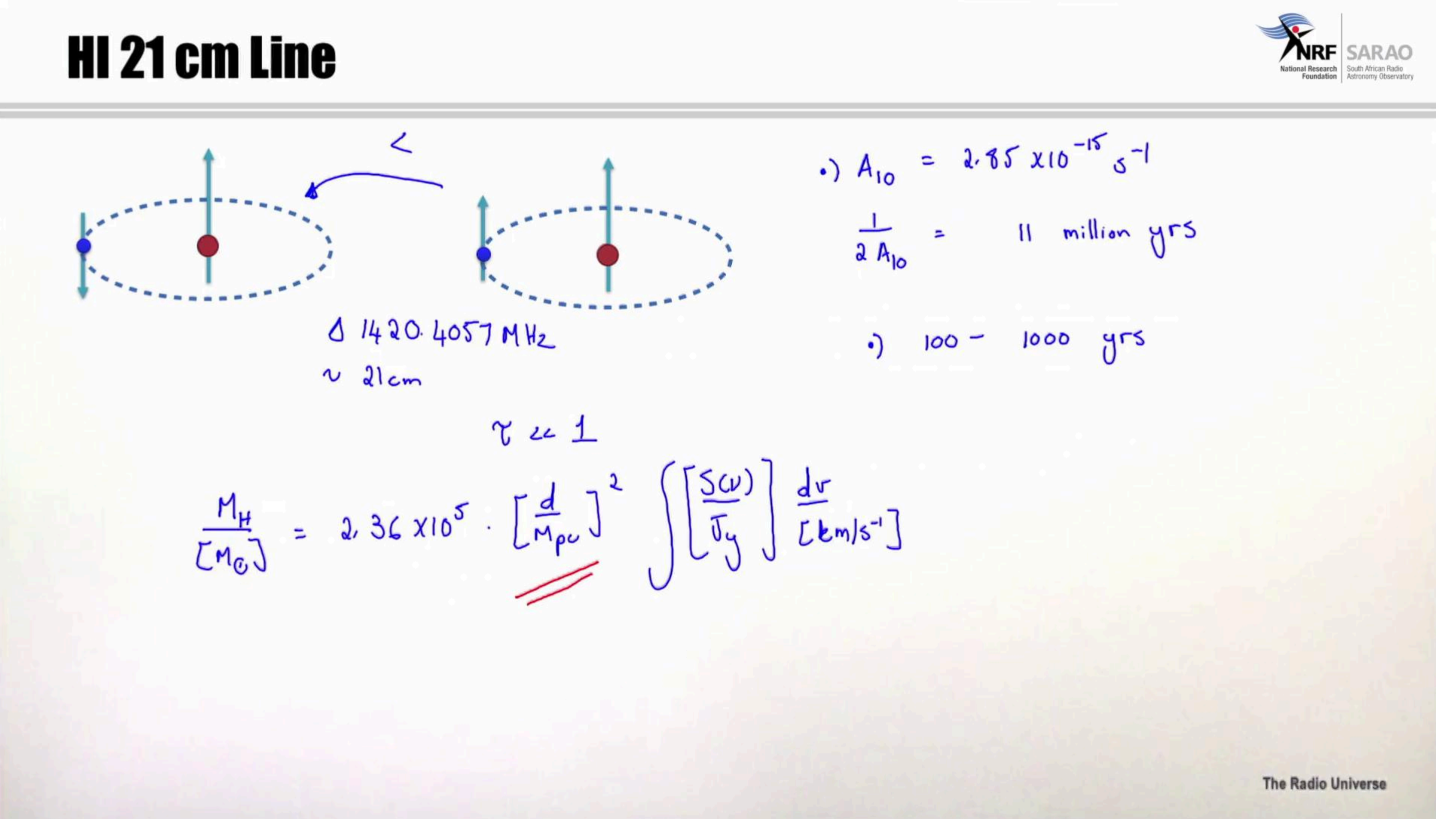


So for most of the time HI is actually collisionally excited in the interstellar medium in the galaxy so when you have collisions that causes the spin flip transition to happen and those can happen in roughly once every few hundred to, say, a few thousand years in a typical ISM conditions depending on the temperature of the gas. So HI is usually collisionally excited and even though this is a relatively rare transition for once every hundred to every thousand years because hydrogen is so abundant, we still see the 21-centimeter line from gas in very strong emission in nearby galaxies so we're able to detect it even though it's a relatively rare transition because of its abundance. One of the really great things about this line is that if it's optically thin so if tau is less than one then the flux of the line gives you a direct estimate of the mass of the hydrogen in the galaxy. So from that we have this very handy equation which tells us that the mass of hydrogen in units of solar mass are equal to some constant of proportionality times the distance in megaparsecs times the flux of the line in janskys kilometers per second.

Notes

Summary

2m 01s

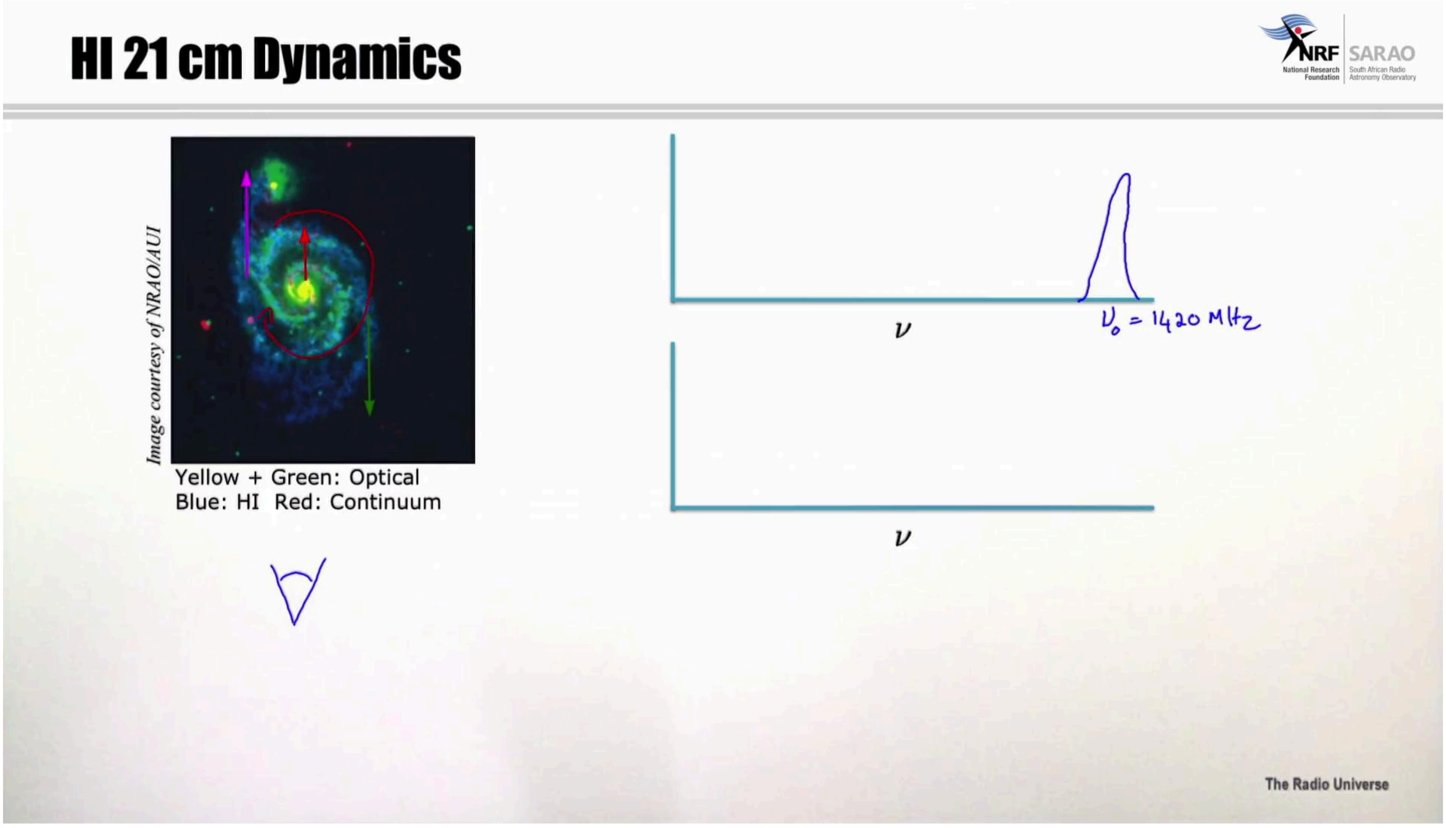


So if you add up all the flux of your line underneath the line then multiply it by this factor and take its distance into account then you can know exactly how much HI is in your galaxy. And the other really great thing which we'll discuss in the next slide is that we can also calculate the distance to the HI objects because we have information about its velocity from the Doppler shift.

Notes

Summary

3m 35s



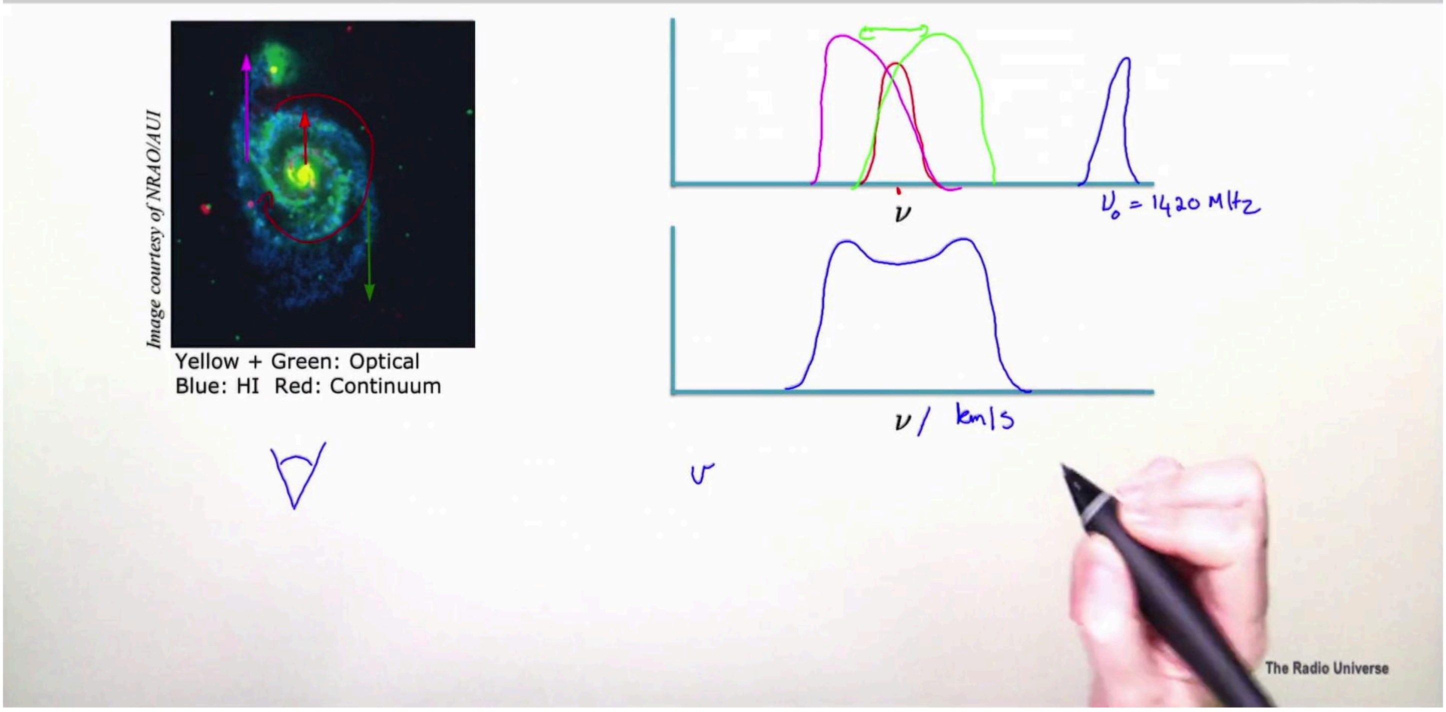
One of the really great things about spectral lines is that because you have a well-defined expected rest frequency, you can easily tell if your emission has moved away from this expected rest frequency, for instance, of 1420 megahertz for HI line and see if there's any indication of radial motion. Remember the Doppler shift only probes motion in the direction of the line of sight so towards or away from the observer. But, for instance, if you had a galaxy like this one where in this plot the HI is shown in blue contours, if you're looking at a galaxy and this galaxy happens to be moving away from you with some velocity then you would easily see that in a shift in the HI frequency. As this is probably a rotating system, you can imagine that much of the gas is actually rotating around inside this galaxy and so what that means is that on one side of the galaxy the gas in the galaxy will be rotating away from us and so this gas will be shifted to even lower frequencies compared to the center of the galaxy whereas on the other side of the galaxy the gas will be rotating towards us and so this will be shifted to higher frequencies relative to the center of the galaxy.

Notes

Summary

4m 01s

HI 21 cm Dynamics

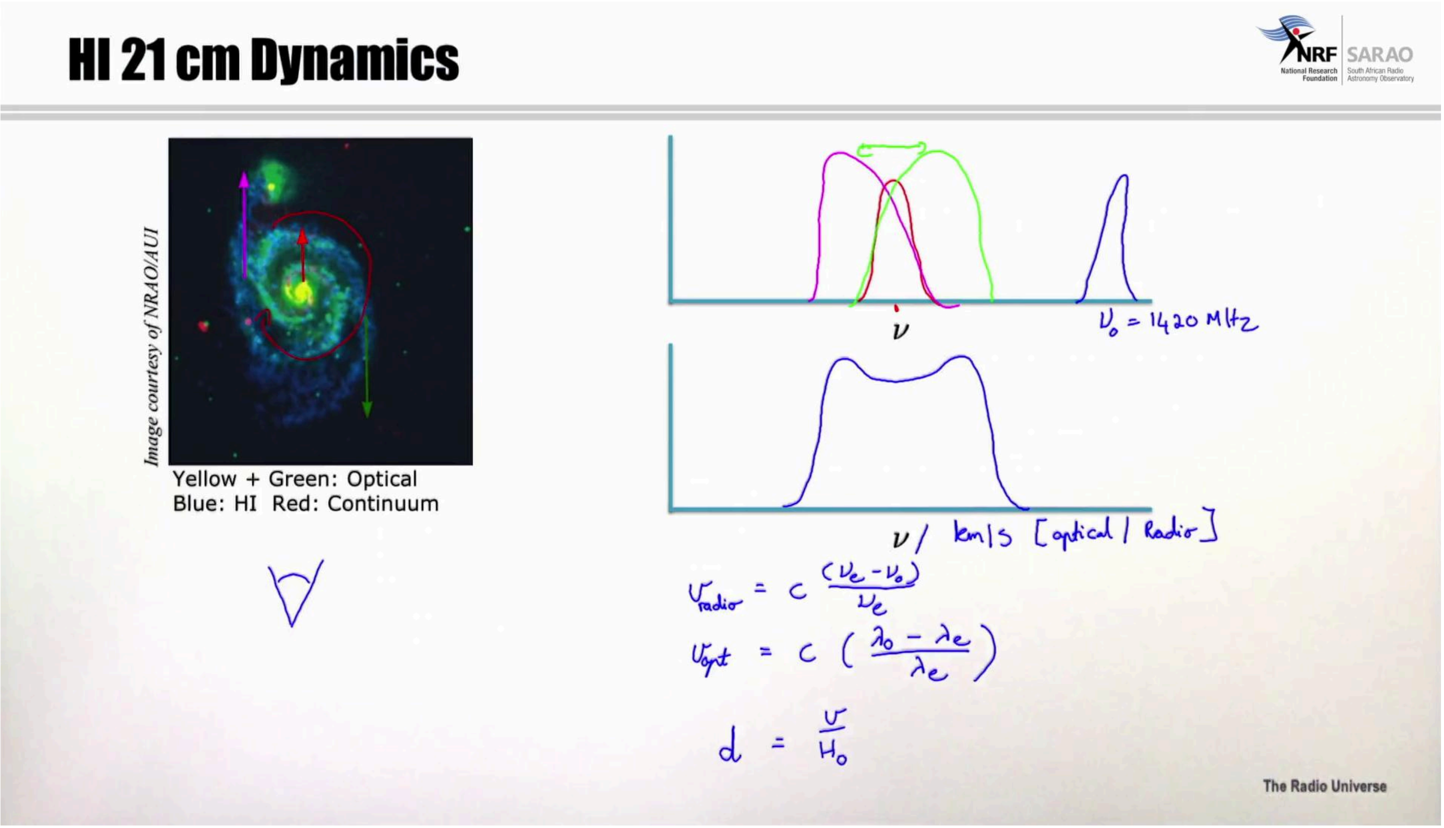


If we were to combine all of that what we see is that the center of the galaxy is shifted to some frequency which tells us about the velocity of the whole galaxy. And the one side of the galaxy the gas is shifted to even lower frequencies and on the other side of the galaxy the gas is shifted to slightly higher frequencies. Where the difference in the peaks here will tell you about the rotational velocity of the system and the difference of the mean position from the ‘v-not’ tells you about the velocity of the galaxy relative to us. And so what you'll end up with is something like this. You'll have a double peaked profile and if you were to integrate all of the flux underneath this profile then from that you can estimate the HI mass. But remember I also said that you would need to be able to estimate the distance and so from that you need to be able to estimate the speed, the recession speed or recession velocity which then you can convert to distance using Hubble's law. But an important thing to know is that there is a bit of an ambiguity in the way radio astronomers and optical astronomers define velocity. So it's common to label this bottom axis not with frequency but with velocity in kilometers per second.

Notes

Summary

5m 26s

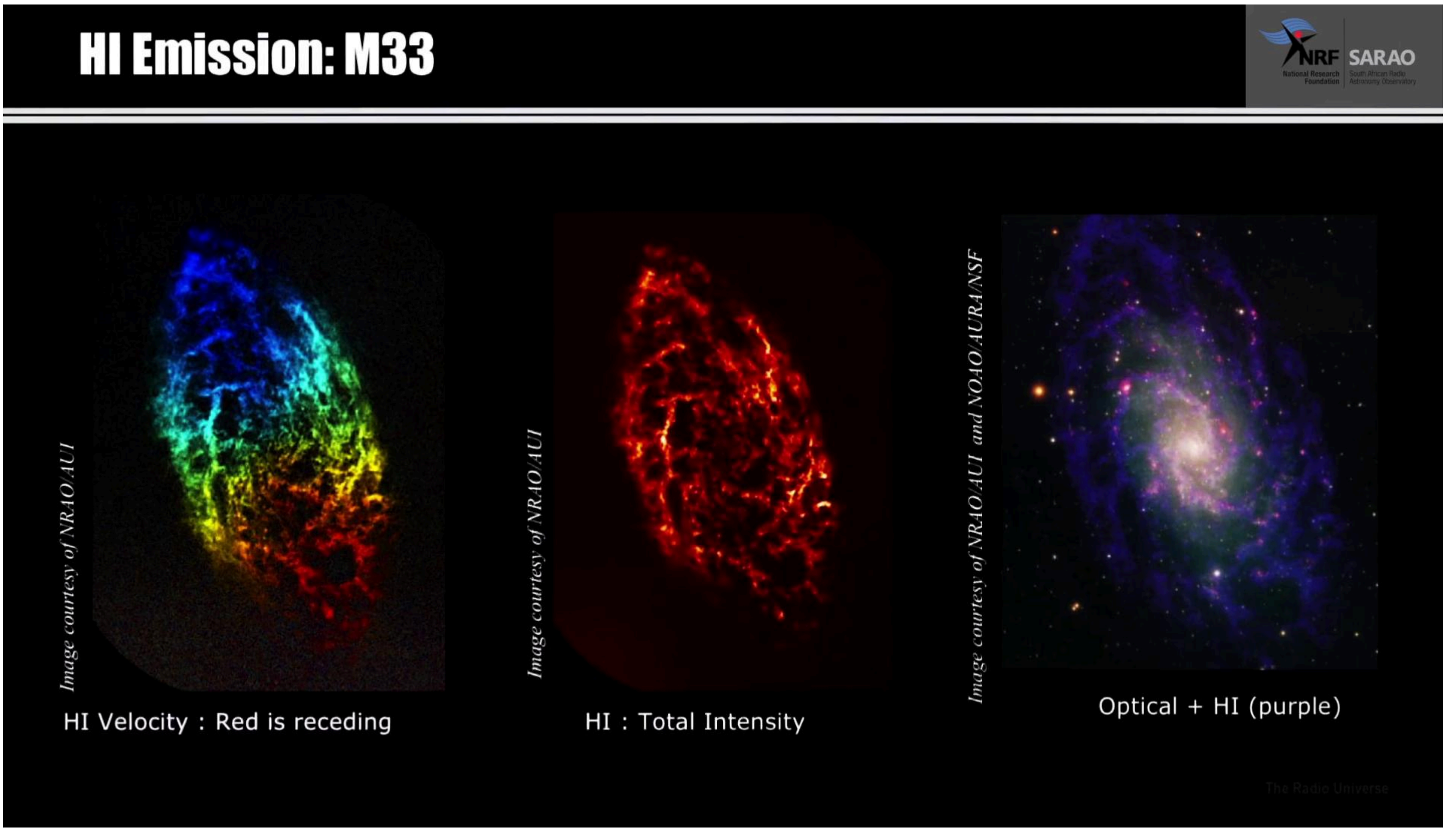


But if you do this then you have to indicate whether you're using an optical or radio convention. So in the radio, we radio astronomers are used to working with frequencies and so we define the velocity here as being equal to 'C' times the emitted frequency minus the rest frequency over the emitted frequency where optical astronomers define 'v' as being 'C' times the rest wavelength minus the emitted wavelength over the rest wavelength. So when you have your velocity, when you've calculated it hopefully using the correct convention then what you know is that you can work out the distance by using Hubble's law where you say that distance is equal to the velocity divided by the Hubble constant. So once you have velocity, you can work out distance and you can easily calculate the flux here and so from that you can work out the HI mass. So if you but remember that it's important to know which of these two conventions are used because if you assume the velocity is in one convention then when you try to convert it back to frequency or wavelength you'll get the wrong answer if you haven't used the right convention.

Notes

Summary

6m 53s

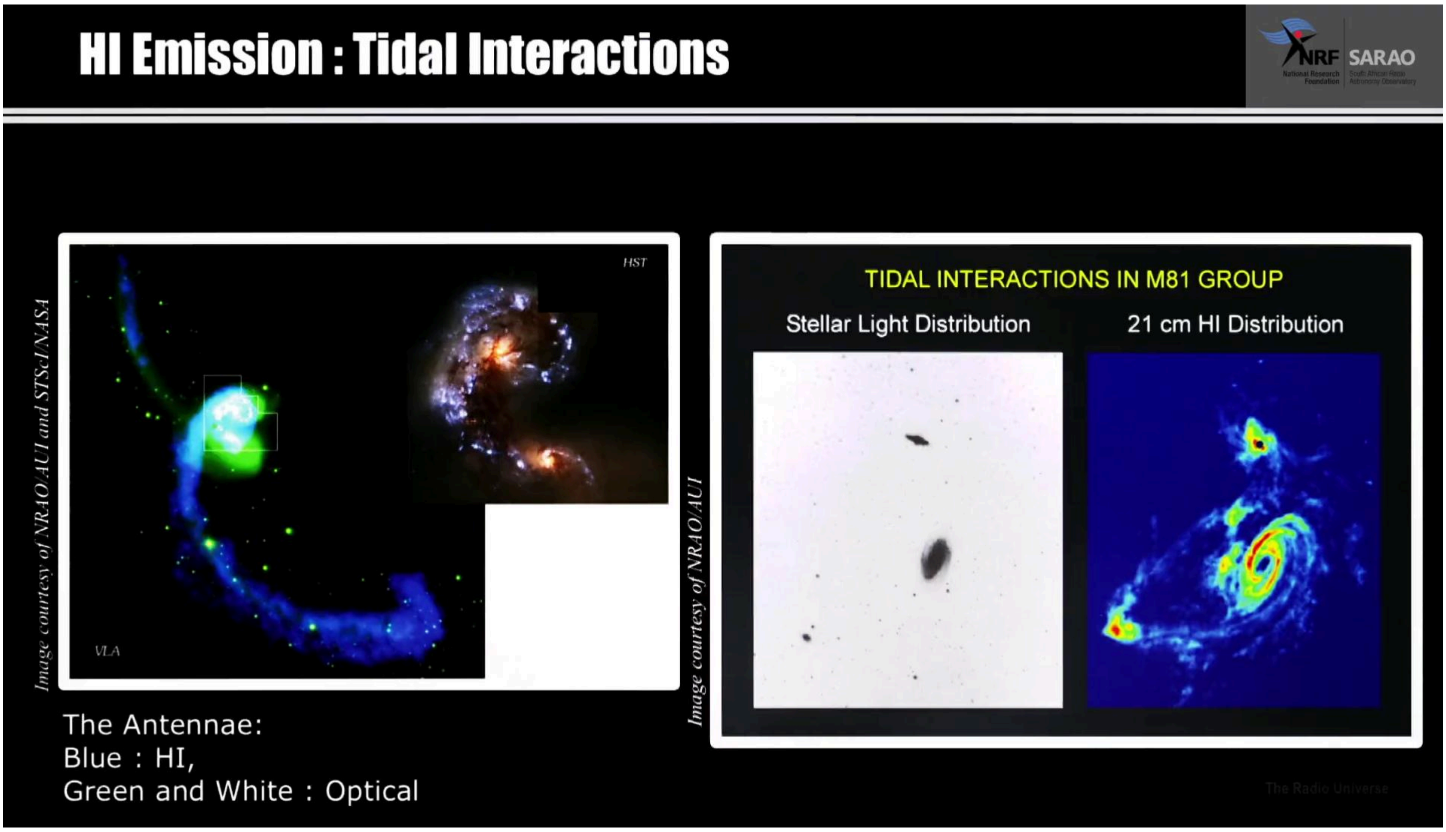


Here we have some examples of what HI emission looks like. So here we have the total intensity of the neutral hydrogen in a galaxy. Here we have the neutral hydrogen plot in purple overlaid on top of the starlight which is in the background here and you can see that the HI extends much further than the starlight and that's because we're able to probe to very low gas densities using HI emission. Over here, this is the same galaxy but here we've colored the gas in the galaxy by its velocity relative to the center of the galaxy. So here the gas in this part of the galaxy is receding relative to us and here the blue, the galaxy is coming towards us relative to the center of the galaxy.

Notes

Summary

8m 16s



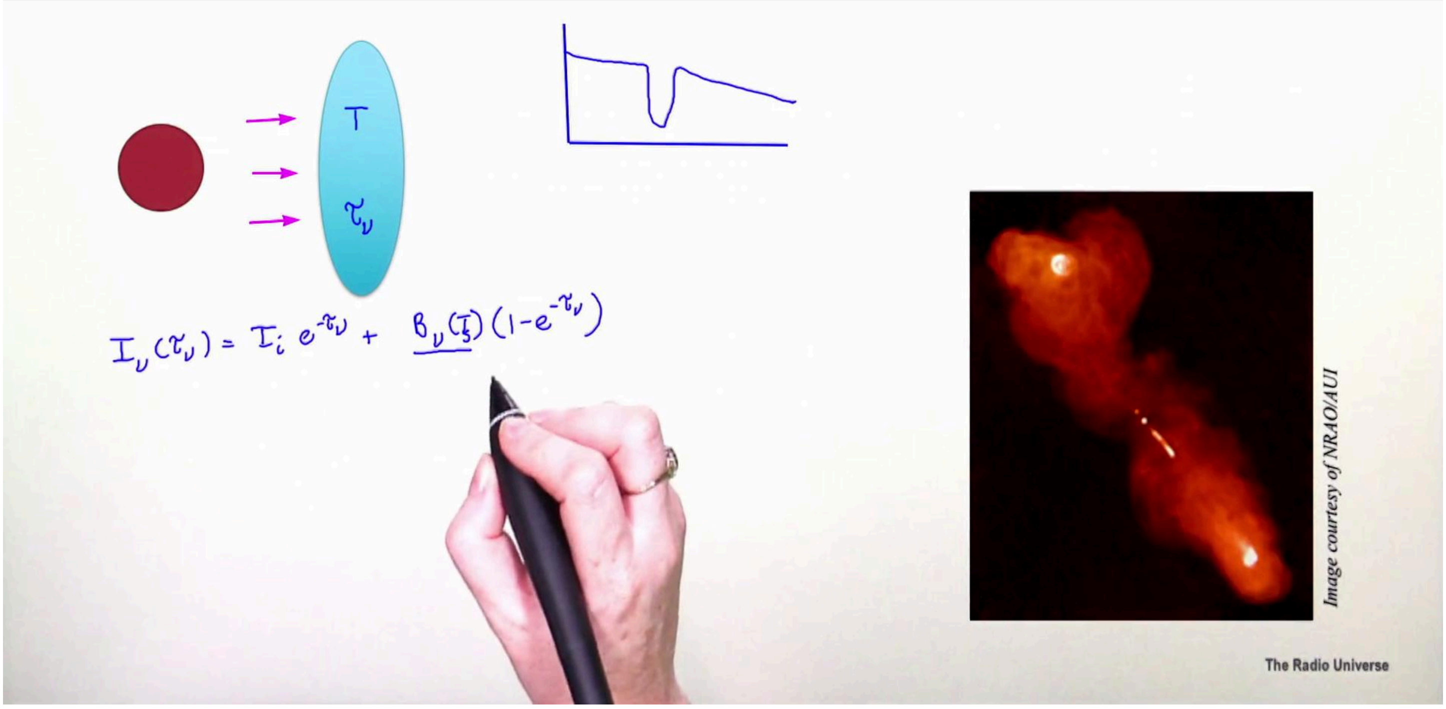
Another very nice feature of HI. Because it's able to probe low gas densities, you're able to see faint features that you aren't really able to see in stellar light. And so, for example, in this picture of the Antennae galaxy, you can see all of this gas that has been stripped out of the galaxies as they've interacted with each other which are not so clearly visible in stellar light. It's the same here when you look at this interacting system here, we have three galaxies which when you look in the optical look completely separate. But here when you look at the HI, you can see they're clearly connected by these tidal features which show that they're interacting with each other.

Notes

Summary

9m 07s

HI Absorption

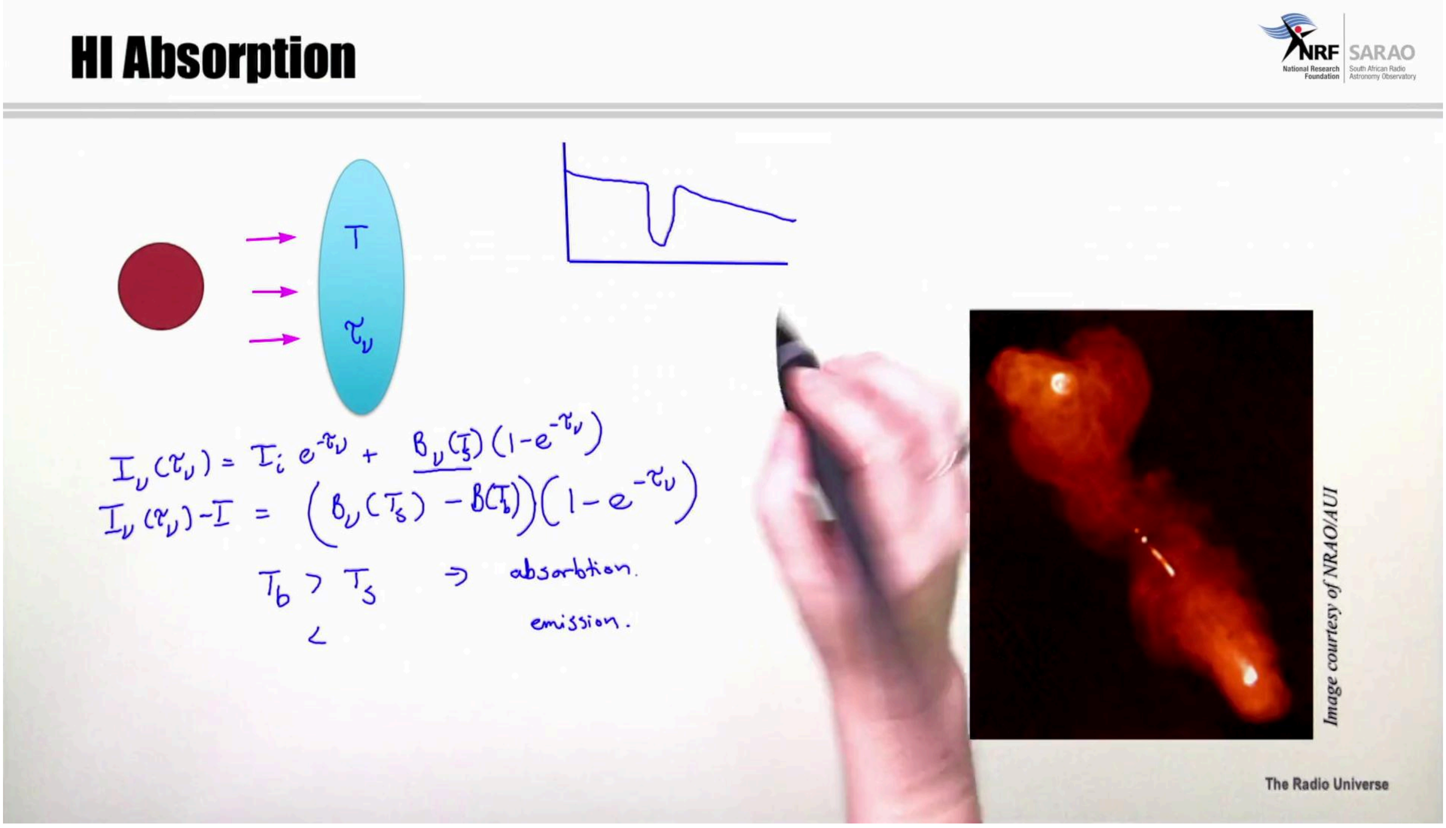


HI emission, HI is not only seen in emission but it's also seen in absorption. So in that case what you see is a dip in your radiation against some strong continuum background source. So if you kind of cast your minds back to when we did radiative transfer, you might remember that we discussed the case of if you have some incident photons that fall on a cloud and if that cloud has some temperature, if that cloud has some temperature and an optical depth then it's possible to calculate what the emission will look like on the other side of this cloud and that is given by the following formula. So what this formula says is that if this is the incident radiation times by 'e' to the minus of the optical depth plus the Planck function of the temperature of the cloud times one minus 'e' to the minus optical depth. So it's possible to extend this formula to work in the case of looking for absorption against a background continuum source and we'll say then without proof really that it's possible to use this equation when using spectral lines by replacing this expression with a Planck function of something called the spin temperature so instead of this being the kinetic temperature of the gas, we characterize the emission of this cloud by something called the spin temperature which just tells you something about how excited the gas is and what its state is.

Notes

Summary

9m 48s

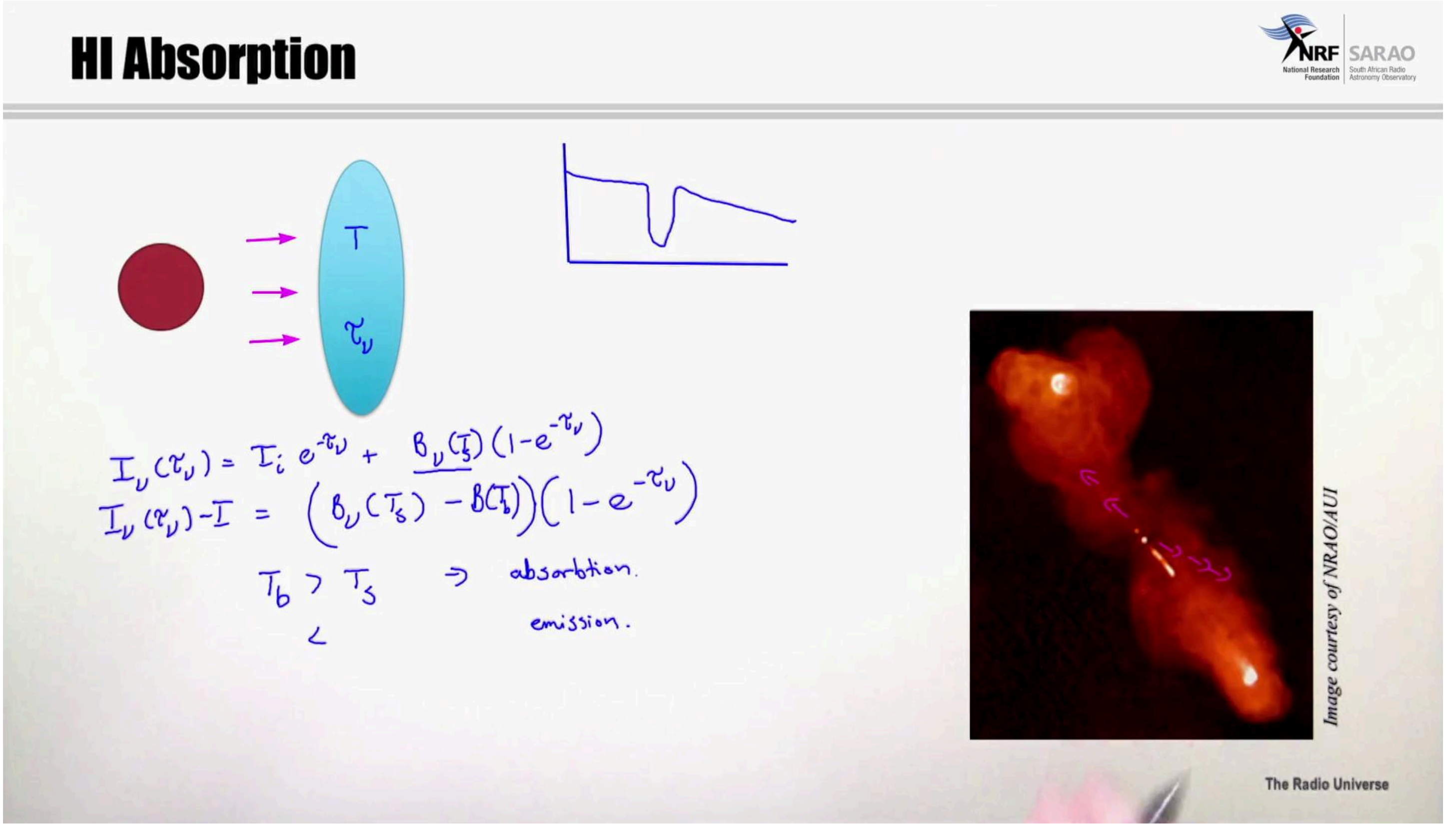


So in this case, it's possible then to say what is the change in your radiation level here against the background so to do that we just minus 'I' on both sides of this equation and what that gives you then is that you'll say the Planck function minus the spin temperature minus the incident radiation will then be multiplied by one minus 'e' to the minus tau 'v'. So again if we replace this here by the Planck function times the brightness temperature of this background source, remember that we said we could say that any emitter has a brightness temperature which is just the Rayleigh-Jeans function of its specific intensity so in that case what we can say is that if the brightness temperature of the background source is greater than the spin temperature then what you'll have is absorption. So if the spin temperature here is lower than the brightness temperature of the continuum source, you get absorption and otherwise you get emission. Absorption is really great because what you're looking for is a small dip against a very strong background source. So this means you're able to detect this small change at very very large distances or high redshifts compared to if you're looking at an emission line where the flux would start to drop off very quickly.

Notes

Summary

11m 35s



But, of course, you have to get very lucky because you need this strong background continuum light to absorb against. People usually use this kind of absorption to look for either accretion disks around supermassive black holes in big AGN systems or they look for evidence of very fast outflows because you can also look for Doppler shifts on the absorption lines as well as emission lines. So they look for very fast outflows which they believe might influence how the galaxy evolves with time.

Notes

Summary

13m 20s