Radio Astronomy

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Week 11 Lecture 01

So I think we all we have gone through this and just one last time. So I welcome all of you to this live session of radio astronomy. We are on week 11 and almost coming towards the end and we hope you are enjoying this course. We have tried to go slow in the second half of this particular course and and try to revisit all the important concepts. I think they're trying to also give you relevant amount of practice problems that you can kind of reflect on what has been taught in the in to the first eight, nine weeks and also how we are proceeding slowly after that. So I think that should be sufficient to prepare for your final examination and we will also give you if you look at the 11th and the 12th with assignments, you will see that there are a lot of things have been revisited and to discuss.

So I think it will keep practicing those and the all the assignments that should be sufficient for you to and take a look at the lecture slides, the videos which have been shared. It should be sufficient. There's a few more videos coming up this week and the next week and both of them. It should be easy.

The paper is not not lengthy, nor it is quite descriptive. It's based on MCQs and numerical type questions. So I think what we will will do mostly in the last few videos of this this week and next week are mostly for a completeness purpose. Don't worry too much and concentrate more if you're giving a final exam, concentrate more on the on the on the assignments which have been shared and that should be sufficient. Okay and we will give one we shared a lot of materials and we will share more and make sure that they are available before by early next week.

Okay so when we come here next week we will have a final let's take a stock of the situation what else is there and we will just process. Okay so but don't worry there will be few lectures with this shared this week and next week. They're mostly for your understanding and completeness of the of this particular field called the Rheostomics. If you're worried too much about the exams I think if you follow the the nature of the questions, types of the questions and kind of things which are being shared in the assignments and asking the assignments that are over more or less. Okay if you have any questions we will answer it at the end of this particular session.

Let us get started and finish a couple of things which would be uh we wanted to be completely clear about. So as we have seen we've started with a single uh a dish and that has a particular

diameter. We tried to replace that with a bunch of small smaller diameter antennas and try to coordinate the signal. We used the earth's rotation to for the earth's location synthesis. This thing is more or less common like what we have done in the Young's double-sleeve experiment if you have done it all.

So it's more or less similar to that we have seen there is a pinch between the two uh if you have the two signals coming from the two antennas there is a the observer's of a fringe pattern like this which is kind of similar to the Young's double-sleeve experiment. We didn't refer to this before we did not know given the variety of students in this particular course whether this will be quite uh another common experiment or will it be another unknown experiment for this particular particular batch. So we didn't refer to this uh at all but it's something like a Young's double-sleeve experiment where you have two slits over here and they have a finite dimensions uh slit width and they're separated by a distance of B over here. Okay and so this B is the distance in the two slits and the B is also corresponding to the distance between the two antennas which we have uh discussed uh so far. And for any two antenna we can separate by a distance of B which is called the baseline will give rise to this fringe and as the baseline with the length becomes larger and larger the fringe frequency will become larger and so that's one of the important aspects.

So for one particular baseline you have one particular fringe pattern for different baseline pairs antenna pairs uh with a distance against the different patterns. It's more or less exactly similar to what we have for this Young's double-sleeve experiment where you have a light wave coming in there are two slits separated by a distance of B and each of them have say a slit width of capital D say and this D is comparable to the diameter of the dishes and B is comparable to the separation. What happens is if there's only one single slit it only suffers diffraction and if there are two slits there's also interference pattern. So that's what kind of this has been too not going further into that because I'm not exactly sure the diverse group that we have for this particular course as that can be another three different discussion for another particular course. So anyway so we have also seen that in different pairs of antennas give rise to different kinds of fringes if you add all of them up then you finally get the UB distribution which we have seen and then we put a transform that you get a dirty image which is kind of thing which convulses with this particular PSF for the point spread function and then if you do the finally the calibration and and the deconvolution also known as clean we finally get a clean image or the finally what we expect to see in the sky.

Okay that's a pretty pretty simple to look at it's pretty it's a bit more complicated in actual practice we have gone through this particular video where we have shown that for a single point source we have a response which is kinds of growth and becomes better and better as the number of antennas increases in this bottom left panel and the UV coverage also becomes more and more regular and more filling. So one thing is very clear to get a better image of the sky you need more number of antennas and this is a particular aspect please please note that so if you have more number of antennas if more number of baselines you have a better UV coverage a better UV coverage gives you a better image please remember that so that's one thing is very true so if you want to depending on what kind of science you want to do with this particular interferometer you will have different distribution of these tissues at different distances. Okay we'll come to that in a

bit this we have already done we have we have shown that the visibility yeah so the visibility is a 2D Fourier transform in a particular assumption that the it is only covering a very small part of the sky so i which is the image in the sky is a Fourier transform of the visibility which is in UMP coordinate system and this in physical optics is also known as band signal zernic wave theorem. We have also discussed that the baseline which is the distance between any two antennas and its components in x y and z directions is just nothing but is can be trusted into uvw values but this is a function of two parameters the h naught the hour angle for the center of the field and delta naught as our angle changes with local time so then this due to our position the same set of the same baseline vector will give rise to number of coordinates just because of the relation of the Earth. Now so this basically jumps to the fact that this is a spectrum so we observe the sky at a large range of spectrum frequency ranges this is a particular spectrum given for the bla or the very large array and you can see the spectrum supposed to be very smooth because any sky signal is is should have been much smoother but in this particular case it is not a bit smooth but you can see a lot of this strong features over here and then over here we have so what happens is that as you observe at different frequencies there are man-made transmissions which occurs at different frequencies and these becomes like noise to us this is also called radio frequency interference sorry radio frequency interference which is kind of what happens because of the man-made interferences due to the desired transmission like cellular phones aircrafts satellite communications etcetera and there are different things that here in this particular case you can see that for the bla between 1050 megahertz and 1150 megahertz you can see that of these aeronautical signals coming up and the glonus signal is the GPS navigation satellite at 12 t near about there are different others like air traffic controller, weather balloons, satellite and other GPS glonus transmission near about 1550 megahertz to 1650 megahertz etc all this you can find the cell phone tower at 1950 megahertz above is all a kind of clouds for entire spectrum so these are noise and actually because of the radio signal is very weak what is getting observed by the radio telescopes all these signals has to be actually flagged so you must have seen when we have given this small demo about how the data analysis is done that there are ways to remove these things and they're called flagging okay so flagging means you essentially flag or remove the unwanted signal from the data the data which is not the signal the data which is not coming from the celestial source but actually be created somewhere nearby or manually okay so one thing is that imaging of the data so we have done the imaging we said that we have we have removed the fsp sorry the pss the point spread function now the same expression which we wrote in terms of the 2d Fourier transform if you remember there is this ai uh a and i are both functions of l and n and you have e to the power 2 pi i u l plus d m d d l d m and that gives you rights to the visibility u v okay now that is a integral equation and it's a Fourier transform now you can write the same thing in terms of in terms of matrix format using something called the jones matrix formalism um it's a bit sophisticated so we're not going into details about it but effectively you can write in terms of the matrix equation and you can write the a times r m is equal to v observe and the matrix the formalism of the matrix kind of fixed here of the all the different terms so anyway this is how the things are implemented actually in one of the softwares in the use for the data analysis for imaging and you have different steps like your data column the model column and the pilot residual so this deconvolution part has to be done iteratively and it's a non-linear process so you basically go through a process of uh the king deconvolution as you improve the image of quality of the image effectively what you do is you have a psf the one and that is convolved with the

actual image of the sky which is your dirty image and that is because of the uv coverage the psf is created so here's easy coverage uh is a Fourier transform of the psf so that's how you do so the get go from the actual sky to the dirty images of convolution so going back from a dirty image to the actual image of the sky is called deconvolution which goes down so the different uh and several areas in the world which are operating right now uh we are talking about spoken about gmrc we have we haven't quite spoken about the ska so ska or the square kilometer array as you understand um so we spoke about that uh each dish is the area of each dish is given by something like proportional to pi d squared divided by four divided by four right where d is the dimension the diameter of the dish so if you have n number of antennas in the in the in this particular array then you simply multiply this by n a with n a number of antennas this gives you the total area of the total uh packing area for the particular area okay and i put in a proportional stand because there's some some efficiency parameters involved in this particular calculation so the the whole concept of the square kilometer arrays this quantity over here is almost like one square kilometer okay that much of collecting area will be uh covered by this large gigantic telescope so the first phase of this particular uh telescope has started to be to be constructed uh the one which is the lowest uh low band part going from 50 megahertz to 350 megahertz that particular one telescope will be built in somewhere in western australia and the part which is the mid telescope uh 350 megahertz something around 40 gigahertz these things numbers are quite a little bit um not fixed so they they may vary as the telescope as the telescopes comes to the final design this this numbers may vary so the more or less design parameter is that there will be the maximum baseline um it will be around 65 kilometers for this particular telescope in the low and 150 kilometer for the mid so you can clearly understand so given so now you're you're becoming an expert in this particular thing so if you're going to ask okay what is the resolution for sk1 low you can of course you can find out for the lowest frequency 50 megahertz ish you can calculate what's which image that corresponds to which uh which lambda uh which the film you can you can put in the value of the lambda and then you can find what the d max is 65 kilometers right so lambda is corresponding to how much is about uh it's corresponding what is the lambda corresponding to 50 megahertz you could calculate that and then uh the b max is given by around 65 kilometers so that's what your your number is so lambda over b max will be your effectively your resolution so given all these numbers now you are able to figure out what will be the different resolution aspect for this particular system or any telescope given these values similarly you can figure out what is 650 megahertz corresponding to 300 megahertz is roughly uh one one meter so we can talk about 600 meters so let us we can try to answer this so roughly around let's take a simpler example so say around 75 meters lambda is equal to four meters okay and the b max is 65 kilometers so you can easily calculate what will be the lambda by b max similarly for here lambda is about one meter for 300 so about 600 it is roughly around 0.

5 meters and the max will be around 150 kilometers so you can again calculate the um the lambda over b max so you can calculate the resolution for this at 600 measurements okay this is for new 12 to 600 megahertz and it's going to be 75 minutes okay so that's kind of where we can we can move the another amazing part of this particular telescope is that the amount of data you can collect um through the um uh over time so the expected data rate is kind of 157 terabytes of data per second because there's so many elements so many electronics involved the rhetoric is pretty hard and in this particular case is two terabytes per silk it's really down to so this is the this

is the the state of the art uh the ferret radio astronomy which is a telescope going to be built and this is kind of uh do all the greatest um science possible um in this particular frequency bands and we can touch base on them as well after students for the lectures we will have this in one of the lectures covered in a lecture video of last week so um but the striking part is that even somebody likes to do data science with this kind of telescope is the perfect uh place to do that and that's because see the amount of data collected in here 157 terabytes per second two terabytes per second so this will amount to a huge amount of data rate and you could apply all different kinds of data science techniques uh in order to get um uh reliable science out of it and and make sense of what it is this is an artist's conception this is uh still um stuff under designing and redesigning this is something how the sk mid sk1 mid will look once it is going built which is of uh um the designs are all uh individual antennas if you can see and they have the dish and the feed if you have seeds which like the offset criterion feed it's not in the center in the focus just in the you know a little bit offset but it makes sure that all the rays which is coming over here kind of mix in the particular focus um which is near there okay uh the one with the low is a different kind of design and these are individual dipoles each of them and all the individual dipoles kind of make a collection of them and this becomes one tile it is called a tile okay so individual dipoles are all of these individual dipoles kind of faces up and becomes a single tile and this is how the one low will look like when it comes more or less in this so uh as you might be aware of there are several different mega science projects in India and SKA is one of the mega science projects right over here where we are looking into and this is what we are excited about this is one of the mega science project which India is part of the others being the very famous one is right here the light to India the digestion waves observatory then pretty much for optical observations and also the large electronic collider the H-phoson external you see quite a more uh he cares about dust particle physics oh now here is something which we really are doing science as you know as you've seen that for actually when you do synchrotron radiation or just along radiation uh we are we are studying uh stuff which is happening in all over the sky uh we also can use this kind of large telescopes to stare into the a very early uh part of the universe looking at much much fainter signals okay so here what we are looking is if this is the big bang over here then this is the first uh uh last surface of last scattering or what we can see if we look back in time we will see only up to here and we cannot go beyond because of the optical depth so this is from where we see the cosmic microbe background variation of CMDR what happens after that was the universe expanded and became neutral and it stays neutral as because there's no nothing no particular source to to produce photons to ionize the midline again so um so we waited for a long time and then finally after quite uh half a billion years uh since the big bang then first stars first galaxies first black holes etc started forming and then they started evolving to our current generation our currently known galaxies stars and black holes etc so this this epoch where the first stars galaxies and black holes were formed the universe also became from the completely neutral to ionized and this area is called epoch of re-ionization and so this is the ages where uh extended period which is not very well studied because of the absence of the suitable probe to do that now with that sense of you know better telescopes bigger telescopes looking at precision uh this things become precision uh this things become possible and the particular you know a probe which is mostly important is the hydrogen atom has a in this ground state it has an electron and a proton and the electron has it went into the spin chip uh then it kind of emits a photon of at the reference of 21 centimeter so the the the lambda of that particular transition is lambda is 21

centimeter or the frequency is given as 1.421 gigahertz okay so that's the the frequency and that is the particular transition which we use to probe this particular age so that's uh the science part of it and why wasn't it done before uh do people try to do that this is more precise so this is the hyperfine transition of the hydrogen from um one is half to zero s half don't worry about all of these things if you don't understand uh this transmission and this particular transition happens as with the rest of the end of the meter it's a very very powerful line this particular line is used to study nearby galaxies the because our our own galaxy has been matched completely in each one and please look into the videos just for completeness there's more discussion on this uh videos you can leave circulated for this week and next week uh please look into that but then just for your own um complete information um don't worry too much about this particular material for your final example and so uh yeah that is the there's a particular transition which is a very important for from nearby galaxies nearby interstellar medium um it's very important probe and the same probe is now used to study the early individuals okay and it was just very nascent from al-khalifa so a few numbers just to give you a hint of cosmology so in cosmology what happens is we just to be define the distance in terms of chemical nature okay which is uh the c so um a wavelength which is um the normal transition the 21 centimeter for a particular z that uh transition will be um at a larger um uh wavelength okay or at a smaller frequency so what we said we said the original frequency was uh 14 20 14 20.404 kind of megahertz uh was five meters sorry so if that particular line is coming from a red shift of um say um six or seven then this particular frequency 1420 will be divided by z plus one okay and the lambda will be multiplied by z plus one to get the right lambda okay so that is the red shifted thing and also there is a look back uh each calculation which is given over here i don't worry too much if you are really not missing that so let's skip all this and we'll go to uh area the next one yeah right so uh that's a particular transmission uh a transition line right so we use spectroscopy to to kind of uh look at the lines and understand particular um you know get an idea about the environment from where it is coming on okay to understand it is a very hot or cold area or it's density of the particular medium and also we mentioned by that the spectral line stuff okay now there are another kind of science you can do with the continuum sign which is discussed we have discussed at length is something called synchrotron radiation right so for synchrotron radiation what happens is that there's a very um it's spectrally very smooth that this is has almost no shape in terms of the spectral it's not like the one with the lines so here in this case in spectral line like in a very small area you can have like a multiple spectrum like this over like q four megahertz or six megahertz so like that but for a synchrotron radiation like over a large amount of things of hundreds of megahertz it will have a very smooth kind of a slope okay so the difference between the continuum emission and spectral line emissions have very fast varying variation in the flux density as a function of frequency whereas continuum does with very smooth very very slowly over the frequency range so synchrotron radiation uh this is what we are observing our own galaxy this particular pattern is for our own galaxy and we are seeing it in terms of synchrotron radiation at a frequency of 408 megahertz okay a lot of science has been done has been done and can be done using simplest the synchrotron variation at different frequencies for example if you have a particular source and you have its spectrum covered at different frequencies then you can particularly suppose you have a spectrum over here and a plug sensitive over here then you can actually connect them and derive what is called a spectral index the new spectra index you can talk about the electron distribution following that particular anything okay we can make the same

map at different frequency this is like a very very study from 10 megahertz range up to five terahertz that's quite a huge range where you're looking at studying at the galaxy so if you're looking at looking at again a wide field of view you also have the chance to detect various kind of things like you can encounter like this kind of radio galaxies the different kinds of radio galaxies a particular image taken at around 300 to 500 megahertz with with gmrt with a new gmrt so the upgraded gmrt and we're looking at a particular part of the time which corresponds to something called lism1 or not one field and so we detected make this image in this particular frequency band and then you can identify individual sources there are very very point-like sources like this one there are very extended sources like this one or even this one okay and if you zoom into few of them you can understand the nature of those particular things let's look at another image for example if you're looking at something like this this is the another part of the sky this particular part of the sky is called loftman hole okay and this particular image is made around at 327 megahertz with the gmrt and now if you look at this part of the sky you see if you zoom them up you look at this is called the giant radio galaxy okay you can see the the hot spots over here and similarly there is also another time to do galaxy this is coming from somewhere yeah it's a 16 by 16 uh field of view uh huge image this is something which is not coming from a single point but you have observed multiple pointings across the sky and what you call it stitch them together which is called a mosaic so you do something called a mosaic and it sticks all of them together and again larger field of view okay so that's a part of the thing so now another thing is that we have of course we have we do have our our cost in my favorite background is there we have after that there is our different layers of dark ages we talk of the realization then finally we have the extra galactic foregrounds the the galaxies the all the stars in our own galaxy itself however all of this signal essentially comes in so they do come in through our own ionosphere the earth's ionosphere okay and that gets corrupted when it passes through that particular medium the ionosphere is nothing but a plasma screen okay so it has electrons and that makes um you know different affects the incoming electromagnetic signals in different ways we can have so outside most of it can be also broken up in the atmosphere uh thermosphere and ionosphere has different layers the f layer the e layer and the d layer different layers uh contribute differently so if you can see this there is a diffraction so it acts like a lens there can be absorption and emissions from the d layer so mostly the the reflection happens in f and e layers and d layer is mostly responsible for absorption the density of the so anyway this is this is a plasma uh screen it has a lot of effect on the incoming or trans-ionosphere signals so any signal which is coming from the cosmic sources has to pass through the atmosphere and as the frequency of the observations or actual emission of this particular sources uh coming close to something called the plasma frequency okay then this particular effect of the atmosphere becomes more and more stronger so yeah you should know how to calculate the plasma frequency okay plasma frequency is nothing but a essentially a cut off so any any layers which has a frequency less than the plasma frequency will basically simply cannot enter the earth it will get reflected back from the from the top similarly any any kind of signals coming originating from the earth will never leave the ionosphere it will get reflected back completely to the earth okay that's the effect of the frequency okay and it is it is kind of check one of the lectures last week uh week number 12 which will be coming and we have the formulation of that but anyway this is kind of a function of electron density of the particular medium and it corresponds to that so the frequency is not also constant across the entire globe depending on the geomagnetic location the further

frequency can change it can also change with the solar activities so just to see how why this ionostatic thing is a big problem so this is a local observation of one particular field which is not important for this particular discussion what is important is that in the in the left hand side what you are seeing over here is that you're seeing something which is uh quite a kind of slow so what you see is not so waves passing through but it is not disturbing the major sources they are more or less steady right so let me just get away so if you see that if you look at particularly concentrated on this source and this source you will see they are not leaving this particular area not that much okay but so they're not reflected much they're interesting what's happening is as we move through the frame the 30 seconds interval between each frame okay so as you move through you're probably moving to like few minutes or tens of minutes and these two sources are not essentially crossing the neighbors now look switch back to your knowledge your attention to the right hand part of the image and you can see that if i make a hole it's almost touching the boundaries each and every time but if i make a close hole like this you can see it when it comes out of that uh it tries to come out of the area and also succeeds that very often so similar um kind of things this is a much more disturbed ionosphere and this is a very quiet now what happens is when we make an image we essentially what we what we do we do remember we integrate over the visibility with time okay so we keep on adding the snapshots one after the back then bang and we make a con image so this point source which was looking like this if i make an image it will look like wherever it has gone right it will look like an extended source which is supposedly a point source now will no longer look like a point source but it looks like an extended so that's distortion ionosphere typically feels okay and that's why we are we are very worried and we are we want to take care of the atmospheric effects as as things as we make try to make uh better and better images and better and better uh reductions with very different so yeah thanks for listening