Radio Astronomy

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Lec-30

Week 10 Lecture 1

So, we remember this particular slide where we have a model image. So, we have a model image in this segment. This was the UV coverage and this was the antenna layout. So, it went from 2 to 256 and it finally have an image cover of that. So, we did more than that as there were more things were covered. So, this thing.

Yeah. So, basically, what happens is that you have, we have talked about that you have the visibility. So, visibility. So, yeah.

So, basically, let me just go ahead with this slide. So, visibility is just something where the color comes from the sky. So, supposedly, there was, we have done, uploaded a small tutorial, a small demo where we have shown how the analysis is done, actually, in some software called CASA. CASA, Common Astronomy Applications. OK, so CASA or CASA has done all the analysis and also made into a small demo, which is already uploaded.

I'm not sure exactly what the status, but it will be done. So, the most important part is that the visibility is of clear transform of the eye. Now, supposedly, you have, you have, now supposedly, you have discrete coverage in the U and V space because you have a finite number of baselines. And so, U, K and P, K are finite numbers. And so, that's causes the nature problem.

So. Sorry, I'm having to keep the job there. So, visibility as a function of U and V, just simply clear transform of eye, which is over here, eye. Now, because of finite number of baselines, y finite number of baselines, we have, supposedly, we have an array of in a y shape. And we do have very fixed pairs of x, i and j. So, that only causes some U, K and P, K to be covered in the U and V space.

So, we can write this in terms of the sampling function, which you already mentioned last time, which is nothing but a bunch of delta functions, this time in Kronecker delta, where you have the sampling equal to one, when there is a response and it is zero, then it's not. So, we have already said that this multiplication of the v, the visibility with the sampling function is Fourier transformed to this eye, which is eye 30, or the corrupted beam, basically. That will be what we've done. So, that part was also involved in the image. Now, imagine one thing, this is the Fourier transform.

$$S(u,v) = \sum_{k=1}^{M} \delta(u - u_k, v - v_k)$$

$$V(u,v)S(u,v) \xrightarrow{\mathcal{F}} T^D(l,m)$$

$$T(l,m) * s(l,m) = T^D(l,m)$$

Now, we already know that there is something called a fast Fourier transform. And this, in order to make it happen, because this simple Fp is a discrete Fourier transform, it takes a long time to offer. To save time to make it faster, more economical in computation, we use fast Fourier transform, but this requires the data to be graded. It has to be a regular graded data, not just arbitrary. So, we have to first read the, the visibilities, which is a function of u and v, that has to be graded.

And then it Fourier transforms into the grid of the image. Okay, in this case, that also turns out to be another image. This we did a little bit when we were discussing one of the problems, which came out because if this has nx times ny number of pixels, then this also will be having nx times ny number of pixels. Okay, typically nx and ny are equal. So, you have the regular grid, square grid, instead of a regular grid.

So, typically you have nx for all major purposes is equal to ny. And it also has some kind of value of 2 to the power n, to make the Fourier transform work for them. So that's what was said. Yeah. So, what happens is then, ignore that.

$$V^G(u,v) = V(u,v)S(u,v) * G(u,v)$$
$$\xrightarrow{F} T^D(l,m)g(l,m)$$

But. Yeah, so. Yeah, so now we have the visibility and the sampling function. And now because of you have to create the data, you also have a greedy function. Now, don't worry about all this thing we are just discussing, just to complete the picture. None of this has any relevance to the exam, n exam.

Don't worry about it. Just try to enjoy what you're learning. So, effectively. Am I audible still? Yes, sir. So, we already said that the visibility and the sampling function are the multiplicators.

And now, because of gridding, because of the data, this is something like a greedy convolution function. So, we use this function as a greedy convolution function. And that finally gives rise to power n, which is the 30 image. That's one of the things. And we will come to the fact that how we finally get rid of that starting component.

But before we go there, one more interesting thing to do is that we discussed this earlier, that the visibility which we observe is not ideal. So, we would like to be discussing so far, assuming that this is ideal. Okay, there is no production, but we know we are observing this with a sky, which has two antennas. Each antennas have a lot of electronic components, an LNA, a mixer, etc, etc. So, all of them has some kind of a gene attached to it, because remember, we have these problems, we did multiple types.

$$\widetilde{V}_{ij}(t) = g_i(t)g_j^*(t)G_{ij}(t)V_{ij}(t) + \varepsilon_{ij}(t) + \epsilon_{ij}(t)$$

What happens if you have a cascading amplifier, there's three stages, each stage has its own gain and own noise temperature. So, there will be some gains coming from the electronics part. So, all those we have somehow compressed and coincides them into this particular expression, which all defines a non-identity of each telescope or pair of telescope. How do we go about that? First of all, I is the I-th antenna and J is the J-th antenna. So, any pair of antennas.

GI and GI is the individual antenna gain at the function of time and frequency will also be there. GJ is for the next antenna in the pair. GJ star comprises of the complex conjugate. So, the star here is the complex conjugate. How do we define complex conjugate? Suppose you have a complex number, Z is X plus IY.

So, Z plus IY, Z conjugate is X minus IY. You can also represent it in terms of e to the power i theta, e to the power minus i theta. So, let us come back to this. So, GI and GJ are the two independent antenna dependent gates. Each gain is dependent on just that particular antenna.

Then there is something which depends on the baseline or the pair of antenna, cannot be factored individually to this antenna or that antenna. It depends on the baseline. There are numerous other things. Let us not worry about it currently. And there are two other things.

There is an additive offset and simply thermal noise. So, remember, this is the ideal visibility which we have been using so far in the previous slide. Now, this is the real observed one. And you have to actually get rid of all of this to get to the ideal visibility. Because that is what we are actually interested in.

We are not interested in a non-ideal situation. We will take care of that by the process called calibration. When we are using this term in the demo, please refer to this particular slide. This is called calibration which takes our non-ideal visibility of VI being tilde IJ observed, goes as close as possible to the VIJ often says ideal or model. And this process is called calibration.

Okay, that is all. Another thing to know is that there is something called the thermal noise, which comes again the similar thing. Like you have a system temperature and you have that causes the basic perturbation in the signal detection. But as you take more and more number of samples, if this term is following zero mean motion, then it reduces to zero. The ideal after we can sample. Okay, so let's move on to the next part.

I skipped this part. Another important thing which comes into this discussion is that something called, there is a redundancy in the entire observation. Like you have three pairs of epsilon, I, J and K. So, I, J and K are three antennas. And so if you write down the expression of the non-ideal observations, clearly you can see if you have three pairs of antennas, three antennas, and if you write down all the phases correctly, so you have a GI, GJ star, then GJ, GK star, and then GK, GI star. So if you write down all of them, then this phase is essentially gets cancelled out and this is called the closure phase.

If there is no systematic argument, they will proceed in cancel out. Just don't worry about it right now. Just remember this is a very interesting property by which a lot of other effects which doesn't, cannot be taken care of by simple calibration can also be ensured by this. One property is the closure phase where you have at least three antenna in the loop. And for amplitudes, you need to have four by the same logic.

And you have I, J, K and L in that case. These are just simply something which may not be used. None of this will come in the exam. So don't worry too much about this.

It's just for the fun to know. Now, another thing which you have seen is if you have uncalibrated data, you typically will see the amplitude distribution of function of UV distance as like this. It is more or less scattered. You are showing three points from three different observations. One of them is a kind of flux calibrated. Another one is called phase calibrated and the main target source.

So this is before calibration. After calibration, it simply looks like a fan. And why that is so, we will come to know very, very soon. So you remember that we did Fourier transform, right? So suppose that there was a Fourier transform of a source which is just centrally picked. Okay, the Fourier transform of that went to being a constant. So a delta function Fourier transform into a constant.

We go back to the slides of Fourier transform. You will remember in the very first few weeks. So what happens is this is that the relationship which we will be using. So typically, calibrators are very, very compact sources.

They are not resolved. So typically the response in the Fourier space will be kind of a single line. In this case, because of their multiple frequencies, we don't really expect that line, but we expect like something like a fan, which it does, perfectly does for this particular case. Okay, same thing for a point source or a compact source, the response should be like. For extended source, it should be like, ah, gosh, right? So it's also something like similar. It is falling as like more or less like exponential.

It's a similar thing also exists. We have done the two dimensional Fourier transform part where you can see that. So why, the question was that, why do we observe these two particular things? If you go back, if you see that the visibility which is coming out of interferometer is proportional to the Fourier transform. Now when you do a Fourier transform, the entire units, everything goes for a constant. So what we do here, we observe just the correlation, which doesn't have any physical unit. Because it is some correlation of the electric field state or the voltage from the ith and the jth and the jth star.

So it doesn't have a physical unit. So what we do, we observe a known source, in this case something called a 3C286. It's one of the sources in the third Cambridge survey, one of the very first surveys done. Okay, remember we showed you the Cambridge interferometer. It's one of the first few surveys done by that. It's a very well known source, very compact and very light.

It has to be. And we know what the values are. So we kind of bootstrap. We observe this and we know the flux, what it should be. And we know the correlation, what we have given. So if y Jansky is linked to some x correlation, then we can find the correlation of the target source and fix our Jansky scale to it. And by doing this flux calibration, we actually input the flux value to the data of the target field.

Phase have something similar. It basically takes care of the atmospheric effect and reduces the error in the analysis, which may be positive for atmospheric effects. Okay, so that's also good. Next. Yes, this is something like what the uncalibrated point source looks like.

When you calibrate it, it looks like a dot at the center. And for a target source, the uncalibrated looks like this. But when you calibrate it, it looks like a kind of a super. This is taken from another workshop. It's shown very well. I'm sure that the demo which we have created that shows the analysis from a GMR together and I hope we will go through it and enjoy it as well.

Now, one thing which has to be shown is this is the PSF or the point spread function, which is because of one of the interferometer. This is the UV coverage we've already mentioned this. Now, by doing the imaging, we have a dirty image. So it has the imprint of this missing coverage of the UV in the plane because we don't have all possible responses. So there are different bolts or caps which causes this point spread function.

Now, then the journey from the point spread function and product image, which is called the dirty image into the actual image. Is what is called deconvolution because the linear part that will be on the actual source in the sky with the point spread function, you get this dirty image. Okay, so because this front route is convolution, the back part is called deconvolution.

And that's not a linear process. So there is a lot of tricks. So if you want to go this way, it's called convolution. We have already done this, but if you want to go from this dirty image back to the clean image, this is called deconvolution. And this is not a linear process. And it has to be done in an iterative way. But this process is known as, again, by this particular thing, it's called clean.

The most famous algorithm is designed to do this operation of deconvolution. It's called clean. There are many variations of the clean algorithm available. And it lies as the interferometer gets more complicated, sophisticated, you need to develop variants of this algorithm to stay in a concurrency. Okay, some other different kind of things, like I think we have found the self calibration.

So the original calibration, the uncalibrated parallel intergalaxy looks like this. If you do self calibration and a few other steps, which you also, we have shown in the particular analysis tutorial, you will see a very clean picture of this. Okay, so I think we will stop here for the time being.

And it's almost close to two hours. So yeah, thanks for joining us. And really, this has been a very interesting. Thank you.