Zeeshan Ahmed: Okay. Hi, everyone. My name is Sean I met. I'm a scientist at slack and today my lecture.

Zeeshan Ahmed: Is about the CMT or the cosmic microwave background.

Zeeshan Ahmed: And in the team if this summer institute

Zeeshan Ahmed: I am going to teach you a bit about how we try to get at these almost invisibles using the CMT so on my very title slide I put a rough outline. So we'll do a brief intro, you've seen a bit of

Zeeshan Ahmed: Cosmology theory and and various effects of the early universe and the evolution of late universe and hopefully this morning, you heard a bit more about neutrinos in the context of cosmology. So this first little bit will be short.

Zeeshan Ahmed: I'll just briefly highlight that the science targets that will speak to like relics neutrinos primordial gravitational waves.

Zeeshan Ahmed: A bulk of this lecture will be on how one designs a CME experiment.

Zeeshan Ahmed: With a with a big focus and sensitivity and a little bit of overview of systematics and we'll talk about how calibration maps and analysis is done for difficulty and the experiments and I'll conclude in the last few minutes

Zeeshan Ahmed: Telling you a bit about see me stage for which is a very large ground based Next Generation Z and we experiment that many of us are trying to put together over this coming decade.
Zeeshan Ahmed: And hopefully the information in this lecture will enable you to actually go back and do some calculations for yourself and see

Zeeshan Ahmed: Whether the CMT's for science case makes sense and whether the experiment is being SPECT properly so that's sort of my goal for today for you to walk away with a sense of how one

Zeeshan Ahmed: Designed to see me experiment. One quick word about the background image. So what you're seeing over here in the center is the bicep to camera.

Zeeshan Ahmed: So this is the bicep to inflation search camera that operated at the South Pole from 2009 to 2012 and this taken this picture is taken a very special time of year.

Zeeshan Ahmed: It is sunset. Which of the South Pole happens only once a year, and then you have a very long night and that's when you observe and are up here in the top right is

Zeeshan Ahmed: A scale image of what polarization signals by step two is observe this this particular instrument is now been replaced by by step three, which I'll refer to quite a bit in the talk, as we do our

Zeeshan Ahmed: Calculations okay

Zeeshan Ahmed: Alright so let me get that out of the way. Good.

Zeeshan Ahmed: Okay, that didn't quite work.

Okay, let's leave that on good

Zeeshan Ahmed: Okay, so let's get started.
Zeeshan Ahmed: Let's go to see me intro. Okay. So, as I said earlier, you've seen a cosmology quite a bit already in in SS1. This week, but this is my quick story of the Universe cartoon. So what you're seeing over here is

Zeeshan Ahmed: The rough scale of the universe is a function of time.

Zeeshan Ahmed: On a logarithmic scale much heavy emphasis on the very earliest times the first few minutes and then and then the first few hundred thousand years, of course, we are here today 13.8 billion years after whatever the start of the universe was and the universe appears to be expanding

Zeeshan Ahmed: So maybe it was a bit smaller in the past.

Zeeshan Ahmed: And in fact we know from the Light Element abundances we observed today that the conditions of the universe were very hot.

Zeeshan Ahmed: In its in its early stages. Now, the earliest light that we end up seeing in our universe comes from this point to be here.

Zeeshan Ahmed: This is the cosmic microwave background. So this is the time when the hot plasma of the universe is cool down enough and goes neutral.

Zeeshan Ahmed: And light is able to first freely propagate. Okay. And so it is the black body relic light of this phase this hot primordial plasma phase of the universe. Okay. And so that's that's what we see today as a cosmic microwave background.

Zeeshan Ahmed: If you take it all sky picture of the CM be with something like the plonk satellite, which was the last big see me space mission, you get something like this. So I gotta explain this image for a second. So if you were to take the picture as is
Zeeshan Ahmed: It's dominated by single, single color, if you will, or a single temperature and that is a black body temperature of 2.73 Kelvin. So that's the monopole signal or the DC term.

Zeeshan Ahmed: Of the CSV picture. So we take that out. And we also take out this as a term a dipole term. So that is just a gradient across this this picture that's about 3.3 mil Calvin. Okay. And that is caused by our motion.

Zeeshan Ahmed: Relative to the CME rest frame. Okay, so you've taken out those components and then you observed that you left with these bumps and wiggles or anisotropy or fluctuation. So we'll use those words interchangeably, and they're on a much smaller scale, right. So you're seeing that the range of you here is a few hundred micro Calvin.

Zeeshan Ahmed: On top of the main signal that is 2.73 Calvin. Okay, so that's that's these fluctuations are tiny. And you would think, okay, is this noise. But no, we measure actually all of this with extremely high signal to noise.

Zeeshan Ahmed: Okay. Um, one thing that you can do for the sake of studying this and to make the math easier is to write this whole picture of anisotropy fluctuations down

Zeeshan Ahmed: As a sum of spherical harmonics. Okay, so these are your standard spherical harmonics, because we're dealing with a

Zeeshan Ahmed: With you can imagine that we're on the inside of a sphere. And this is the projected image of that of that sphere. So we want to do math on that surface of the sphere. So we expanded a spherical harmonics.

Zeeshan Ahmed: And notice that in this some we're going over multiple L and all these directions and which, for every else fans from minus lol. OK. So if you count that up. That is to l plus one AMS okay but notice
that the sum is going from to infinity, because we've taken out the model in the dipole

39
Zeeshan Ahmed: Okay, so we have that. And so we can write this whole picture down as it's almost vertical harmonics and you have these aliens.

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Zeeshan Ahmed: What do we do next. Okay, so it is useful to talk about this in terms of

41
Zeeshan Ahmed: Multiple space or frequency space. If you're more familiar with.

42
Zeeshan Ahmed: For a transforms and for your space. Okay. So we write down something called the angular power spectrum. And so that's just saying that you've taken those aliens that we talked about.

43
Zeeshan Ahmed: On the last slide and you're taking the average power in them. So remember the aliens can go book plus and minus because the image has both hotspots and cold spots.

44
Zeeshan Ahmed: But we're taking the power in them and you see that 12 plus one over here showing up when you average them because there's no preferred direction.

45
Zeeshan Ahmed: The universe and the CMDR is a tropic so that means that there's no a priori reason for the ends to look different. So this, the son of ends from minus lol or the different types of

46
Zeeshan Ahmed: L anisotropy shapes you can take you some over those. And so you end up with this term, which we call cl or the angular power spectrum.

47
Zeeshan Ahmed: Which is which is giving you that average power. Now I can plot that out as a function of multiple okay and you see now very clearly that, of course, there was structure in that image I showed you earlier it was not just noise and you will see that power.
Zeeshan Ahmed: The power shows this characteristic feature of peaks, and it turns out that what this what the image is actually telling us. And what this angular power spectrum tells us is that their characteristic features and characteristics scales and that we're observing what the

Zeeshan Ahmed: Photon very on Florida, the plasma at that time as it was oscillating. There were sound waves in this thing.

Zeeshan Ahmed: And it's telling you what that would that look like at that time. Okay. I just know that for plotting convenience, we we write this, this term called DL.

Zeeshan Ahmed: Which is just looking at the power contribution per logarithmic L. Okay, so this has some advantages and plotting and other reasons. So this, if you look at a CSV Angular power spectrum instead of plotting this term CL you'll typically see DL. Okay.

Zeeshan Ahmed: And I should also note, of course, that the most prominent peek over here at this at this multiple of 200 plus corresponds to a degree in size and as a rough approximation la something like 180 over over theta and thousand degrees right so this is one degree mean something like 180

Zeeshan Ahmed: So, so you can look over here and look at the degree or size on the on the sky and the bottom puzzle, the multiple so the great thing, of course, about this is that

Zeeshan Ahmed: Our lambda CDN model, which has six parameters as you've probably heard of in in previous lectures.

Zeeshan Ahmed: Describes the entire Universe in a very, very nice and standard way and we haven't yet observed any significant deviations.
Zeeshan Ahmed: From this and and the cool thing for this this CME Angular power spectrum is that the line that is generated by just six parameters fits all these data points.

Zeeshan Ahmed: Right, so this is is truly remarkably fantastic in the success of the the land Acedia model and how see MB has played a huge role in our understanding of of the standard cosmology. Okay. So keep this in mind this is how we do and get a power spectrum.

Zeeshan Ahmed: Now, the other thing that we've we've observed and I've started making progress on is looking at the polarization of the light, so C NB light turns out

Zeeshan Ahmed: Also ends up being linearly polarized this polarization. Second one was first detected about maybe 20 years ago.

Zeeshan Ahmed: And today, this is, this is the frontier of our progress. We're trying to measure polarization better because it tells us a lot of things. This is again a plonk all sky image.

Zeeshan Ahmed: The color of it here is actually just temperature the rods are the lines are the interesting bit have been here. The, the, the

Zeeshan Ahmed: Orientation of the line is, of course, is telling you the orientation of the polarization and the length of the line is telling you the polarized intensity. So, notably here, of course, that

Zeeshan Ahmed: This image is smooth so only the five degree data over here is most prominent

Zeeshan Ahmed: And the span and temperature, you know, as we talked about is hundreds of micro Kelvin. But look at how small the polarization signal is it's point four one micro Kelvin is the size of this this slide. So it's a much smaller.
Zeeshan Ahmed: Signal. So just like for temperature, we can take an angular power spectrum of this guy, too. And let me show you just with a cartoon right now, not with real data what all of that means. Okay, so this is the same angular power spectrum and you'll recognize this line as the line for temperature.

Zeeshan Ahmed: And the polarization power is quite a bit suppressed because only a small fraction of that see me light ends up being linearly polarized. I'm in.

Zeeshan Ahmed: So, okay. So let me talk about this this for a second. So the polarization when you convert to a power spectrum can be broken into this basis of a modes and be modes and what it is is if you look at that polarization spectrum of a here or you look at the polarization image and you see all these you know patterns over here do is basically we're seeing the patterns can be broken down into things that are Carl free or you know or have primarily divergence and divergence for your things that primarily have curl. Okay, that's what we're going after. And the reason we break it down this way is because cosmology.

Zeeshan Ahmed: And in fact, astrophysics also ends up preferring one or the other. For various kinds of processes going on in the history of our universe.

Zeeshan Ahmed: Okay, so this is how they get broken up. Now let's walk through this. So in standard Lammas EDM cosmology. You only get temperature.

Zeeshan Ahmed: And you get emails. Okay, so these are the two things that are present and last scattering or this is the point at which the CME is emitted.
Zeeshan Ahmed: So at that redshift at red shirt of 1100 you end up getting these two components. And what ends up happening is as the photons travel to us through the our entire cosmic history, they get lens.

Zeeshan Ahmed: Right. And this is, you've heard about this to hopefully in the lectures. The past couple days so

Zeeshan Ahmed: So lending is intervening and changing the direction of those photons. And in the process, converting some of these emails are these clean curl free patterns and the patterns that have curl and you end up getting this kind of power spectrum. And that's lens.

Zeeshan Ahmed: This is a lens in the mode which is created from the lending of emails. Okay, the some of the power from here just becomes be more power.

Zeeshan Ahmed: This is actually an incredibly powerful tool because it enables a reconstruction of all of the matter that sits between the CMT and us. Okay. And it also measures neutrino properties which will come back to

Zeeshan Ahmed: Then there is this elusive inflationary gravitational waves of primordial gravitational waves that can also cause

Zeeshan Ahmed: A purely a p signal that looks like this. And this is shown over here as a dashed line because we haven't observed the signal and you know it's amplitude can vary.

Zeeshan Ahmed: So there was also the chance of course that if this is low enough dismiss it entirely below the lens in vivo signal.

Zeeshan Ahmed: Okay, so, but keep that in mind, or we'll talk about this in a little bit. And note, note that it's Angular scale is about multiple of 100 and this. The lensing Wiimote peaks peaks at higher multiple right closer to 1000
Zeeshan Ahmed: Okay, let's talk a bit more about lensing because this is actually something that we're now starting to

Zeeshan Ahmed: To measure with our instruments and and as a fantastic program, many, many things. So I just said that the ECB photons are getting lens as they're traveling and their as their traversing all the structure

Zeeshan Ahmed: So these deflections happen and they're on average about two to three minutes because our managers, A is a scale, scale on this on the sky. Right. So it's 60 degree.

Zeeshan Ahmed: And an arc second, by the way, is the 16th of that. So the lending efficiency or the most of the lending occurs around redshift have to. Okay, so the when the universe was about

Zeeshan Ahmed: Three times smaller than it is right now. And the cool thing about this is that the deflections don't end up sort of canceling each other, they end up being coherent.

Zeeshan Ahmed: And they end up being coherent on degree skills, which is about 400 megabytes a second, the size. If you're thinking about it in terms of size, so let's illustrate that for a second. With an image.

Zeeshan Ahmed: This is a, this is a simulation and the very top panelists temperature in the middle panel of his, his emails. And so this is the stuff that I said is standard at

Zeeshan Ahmed: At the point that the CME is released and there's no be modes. But if you lens. It then the deflections occur can see this

Zeeshan Ahmed: So hopefully the video is keeping up and you saw a little change in deflection
Zeeshan Ahmed: Or a little change in the image. And so the image get both t and he get distorted and you suddenly end up with this be signal. Okay.

Zeeshan Ahmed: So basically over here and these got distorted. Let me go back and show you that again. So this is undistorted.

Zeeshan Ahmed: Switch on lensing. And you saw that t and he got distorted and you ended up with a be signal. So this is now an incredibly powerful tool to probe all that structure because you have this fresh new signal of lending be mode, as well as the distortions that were caused over here, right.

Zeeshan Ahmed: So, so, so we'll talk about this too, as we were talking about our, our instrumentation. Okay, so this is.

Zeeshan Ahmed: The data we have so far right, and with with with all the Aero bars. So we saw this again foggy, this is d.

Zeeshan Ahmed: As a function of multiple. This is all from the plunk 2018 data release so they of course plot plot as well as several other experiments over here.

Zeeshan Ahmed: The tea is fairly well measure. You can see this, the error bars and T are pretty small. You can barely even see them.

Zeeshan Ahmed: I the emails are he power is also pretty well measure, not as well as temperature and you see that as you get to higher multiple.

Zeeshan Ahmed: Maybe there's more work to do here and the be you see is just starting to get measured right. Look at the size of these error bars. It's hardly any points over here. So this is the frontier, especially if we want to understand.

Zeeshan Ahmed: This structure formation of the universe and also get to some interesting things like neutrino properties.
Zeeshan Ahmed: Use occasionally see this kind of plot to buy tea. This is a cross correlation of the temperature and emails. Okay, this also provides a handle.

Zeeshan Ahmed: On on cosmology, because you can put this into your likelihood as well. And I want to highlight this last plot over here five phi, this is the power.

Zeeshan Ahmed: In the lensing potential. The lensing potential is the field that is causing the gradients that causes deflections. Okay, so when we, when we saw this a second ago, going from here to here, there is a lensing potential.

Zeeshan Ahmed: That is that basically an effective scale or feel that is telling you how much those photons are reflected over the course of cosmic history.

Zeeshan Ahmed: And and this this lensing potential ends up being a very powerful tool and perhaps Scott talked about this this morning as well.

Zeeshan Ahmed: This is another thing that we want to measure it really well and this you measure by looking at the correlations between t and e and be impair so you take T AMP or t AMP or t and B.

Zeeshan Ahmed: And that's how you reconstruct this and so by improving our measurements on all of these we we do we

Zeeshan Ahmed: We we construct this and, and, again, get a better handle and many, many things. Okay, so I'll spend a couple of slides quickly going through. Therefore, the things that we haven't measured as well. And what they'll get us right so this is a science potential of Next Generation see me.
Zeeshan Ahmed: So this is the plot you want to look at to remind yourself of what kind of information comes from which part of these power spectrum.

Zeeshan Ahmed: The temperature primarily has told us that space is flat and we know now very well how much ordinary matter AND dark matter. There is that call comes from here.

Zeeshan Ahmed: But in combination of temperature, a combination of temperature and he modes actually tell us if there are any other

Zeeshan Ahmed: relativistic particles in the early history of the universe that we might have missed. Right. I mean, there's a premium not produced

Zeeshan Ahmed: Or they're not abundant today they're hard to produce and accelerators or cross sections are small, but if they existed. Early in the universe, their gravitational effect would let us know.

Zeeshan Ahmed: There's a bunch of ionization that I don't cover in this in this lecture we won't talk about this much. But this is another piece of information that you end up getting

Zeeshan Ahmed: And then

Zeeshan Ahmed: This is, this is the Wiimote polarization and this primarily is telling us the massive neutrino.

Zeeshan Ahmed: Because of that lensing potential I talked about. And then, of course, is this point about inflation that we talked about. So these. So the some of these things are the are the science goals.

Zeeshan Ahmed: That really motivate motivate us all of these. In fact, but the this lecture is primarily trying to address like relics massive the neutrino and and inflation. So let's just briefly.
Zeeshan Ahmed: fly through those because I realized I'm a little bit behind. So hopefully Scott talked about this, the number of relativistic species is

Zeeshan Ahmed: Is the contribution, apart from photons.

Zeeshan Ahmed: To the, the, the energy density and radiation in the early universe so its gravitational measuring the effect of anything that was relativistic early

Zeeshan Ahmed: The standard is to get three ish and the three corresponds to our standard three neutrinos.

Zeeshan Ahmed: But we can measure this really well with small error bars and you're not necessarily expecting this to go to four or five or something.

Zeeshan Ahmed: Because fractional contributions can also be made by the various kinds of particles. So by measuring this really well and going into this, these

Zeeshan Ahmed: These fractional values and ineffective. We can actually discern some stuff about particles we may have missed in the early universe. The current value, is this okay you can read that offline.

Zeeshan Ahmed: The effect we're looking for. By the way, if you're changing and effective is a changing

Zeeshan Ahmed: The phasing and some of the power of these peaks. This is showing

Lisa Kaufman: Me. Sorry to interrupt you graduate.
Zeeshan Ahmed: Yeah.

Lisa Kaufman: Sometimes you're speaking is positive. Maybe if we stop your video will be able to

Zeeshan Ahmed: Keep okay we can try that. Yep.

Zeeshan Ahmed: Video

Zeeshan Ahmed: Okay.

Zeeshan Ahmed: Let's see, and just feel free to interrupt. Again, if you're if we have issues, although I'm not sure what we'll do. Um, okay. So this is just to give you a flavor of how the the peaks might change if you're going after this kind of signal.

Zeeshan Ahmed: Scott probably talked about neutrino mass as well. The idea here is that the matter power gets suppressed at

Zeeshan Ahmed: At small scales and the observable of matter power and the CME is again and that lensing potential that I was talking about.

Zeeshan Ahmed: So this is a simulation of lensing potentials and how they would change with different contribution of neutrino masses. So this is how you can try to phone if you measure this really well. You can try to get to nutrient a mess. Okay.

Zeeshan Ahmed: Then finally primordial gravitational waves, hopefully you got a bit of this yesterday from Julian savas lecture at inflation your seating fluctuations.

Zeeshan Ahmed: Or rather, inflation is magnifying quantum fluctuations.
Zeeshan Ahmed: To

Zeeshan Ahmed: Microscopic scales. And so you end up with scale or perturbations intensive organizations that tend to perturbations are called gravity waves.

Zeeshan Ahmed: Or gravitational waves. And they're very weak now to be directly observed, but what they could have done is in the past history of the universe. They could have imprinted a signal in the cosmic microwave background in polarization. Okay. And the measurable NCLB by looking at the beam or polarization is the ratio of the tensor modes to the scale or modes and that tells us the energy scale of inflation. So this is not a direct probe of primordial gravitational waves. But it is a very solid indirect probe. Okay, so even if inflation occurred. Many, many, many inflation models predict gravitational waves. And those were able to imprint. The CMT polarization and that's what we're after.

Zeeshan Ahmed: These are the current constraints over here.

Zeeshan Ahmed: So this is our lensing be mode line and these are two models of cancer modes of our point oh five and RF point oh one.

Zeeshan Ahmed: And you see that we're only beginning to scratch the surface of it here.

Zeeshan Ahmed: These are points from bicep kak you'll see this typically in this talk as BK BK 15 his bicep tech data through 2015.

Zeeshan Ahmed: And and these two first two points are only upper bounds. Right. And so this will talk about foreground in a bit. But there's
there's a lot more work to do over here, right. So we want the sensitivity to be able to take deeper here.

00:25:07.800 --> 00:25:14.490
Zeeshan Ahmed: Okay, let's jump into how a CME experiment is designed and the first bit of this is about statistical sensitivity.

00:25:15.720 --> 00:25:18.780
Zeeshan Ahmed: So using that very same plot that I showed you earlier.

00:25:19.860 --> 00:25:31.200
Zeeshan Ahmed: We're roughly here and sensitivity and our sensitivity. So this, this is of course I'm still showing cl or our power vs multiple but I'm

00:25:31.800 --> 00:25:41.700
Zeeshan Ahmed: I'm going to introduce other unit to be here, which is map depth. We'll talk about map depth in a bit, but you just, just remember for now that we're roughly at 15 nano Calvin degree.

00:25:42.600 --> 00:25:57.360
Zeeshan Ahmed: Okay, so this is nano Calvin's temperature and degrees is like the the scale in the sky and we're a degree scale. So this is what we're after. So this is a convenient unit and by step three is roughly at the sensitivity and we want to do in power about 50 times better.

00:25:58.680 --> 00:26:06.390
Zeeshan Ahmed: Or in this this mapped up to unit about the square root of that. So roughly seven times better. And we want to get to this number of seven NENA Calvin.

00:26:07.830 --> 00:26:15.690
Zeeshan Ahmed: Degree. Okay, so how do we measure that. Now we've already talked about this, we're looking at a black body radiation.

00:26:16.830 --> 00:26:24.900
Zeeshan Ahmed: And at every point in the sky as we would we call fluctuations in temperature, basically, that that black body power being a little bit different.

00:26:25.260 --> 00:26:33.990
Zeeshan Ahmed: Right, so we're, we're, what we're measuring is actually power and we're saying that X amount of power corresponds to this temperature. So that's what we're after.
Zeeshan Ahmed: Let's write down power. So power ends up being this integral of the planet spectral brightness. So this is stuff you can just, you know,

Zeeshan Ahmed: Find a standard textbooks or Wikipedia, if you want. It's, you know, you grab this formula and you integrate this over the frequency range that you observing

Zeeshan Ahmed: Multiplied by how responsive your detector is and how much light it's collecting or throughput. Okay.

Zeeshan Ahmed: We make this assumption that it is diffraction limited. We'll talk about this. Hopefully if we have time, but basically

Zeeshan Ahmed: You can put all these things into this integral and calculate how much power you should get from the CME right

Zeeshan Ahmed: I've also shown over here, this low frequency limit approximations. If you're trying to do this by hand. Sometime, then you can simplify your arrow right because it goes directly St. But anyway, so you have this formula, and you can plug it in.

Zeeshan Ahmed: You can plug in these numbers. And so what we say is if you look at this plot of the here on plotting again that plonk spectral medians and

Zeeshan Ahmed: So this is basically the, the, the black body radiation for different temperatures as a function of frequency in which you might be observing it

Zeeshan Ahmed: You look at the line of it here for see me and I'm seeing. I'm trying to figure out how much power I accumulate over here. If I have a detector that is looking at the frequencies. Right.
Zeeshan Ahmed: So I have chosen 95 gigahertz for convenience later. And I'm saying that the amount of light it's able to the frequency ranges able to let it as about 30 megahertz.

Zeeshan Ahmed: And the efficiencies as a sector is 40% and you do this computation. And you get this number point one six people. Once that's how much you would observe if you're only looking at the CMT and and nothing else. You can ask the question, now, how well can I measure this, how quickly, etc.

Zeeshan Ahmed: So let's talk about that. And for that we need to talk about noise. So, we define this thing called noise equivalent power. Okay, it's just a measure of sensitivity of the system.

Zeeshan Ahmed: You can read the definition yourself and you can read. Read this up offline using other sources but

Zeeshan Ahmed: If you first assume that your detector isn't voiceless, then the first noise on that power you need to consider actually is a fundamental noise of the the light itself or the CME photons.

Zeeshan Ahmed: Okay and this is called photon noise and that photon noise is a combination of shot noise and a bunch of noise.

Zeeshan Ahmed: Okay and this is called photon noise and that photon noise is a combination of shot noise and a bunch of noise.

Zeeshan Ahmed: Okay and these things add an auditor and

Zeeshan Ahmed: The units are these funny units where we've squared, this term. So, to walk square for hurt, but the any P or noisy pulling power ends up being these units of watts per router. So that's a funny unit, but it's it's typically how noises described

Zeeshan Ahmed: Basically deal with the square of it. Um, so, anyway. There's a formula for this to this p is just the same long spectral
Zeeshan Ahmed: Radiant that we put in and for our example, then you end up with this number. Okay, so it's a very small number of the full time noises.

Zeeshan Ahmed: 4.8 out of watts per foot hurts. Okay. Otherwise it's 10am I going to be a team. So I'm so good noise is pretty small, if this was your only noise.

Zeeshan Ahmed: But it's also telling you that if you integrate long you're able to beat down this noise. Right. So as you integrate as you collect more photons your sensitivity gets better by this factor of routine.

Zeeshan Ahmed: Okay, but unfortunately this is not, not the only noise and we'll, we'll talk about this. We'll talk about that soon.

Zeeshan Ahmed: Right, we're talking about NoSQL and power. We need to talk now about noise a coolant temperature.

Zeeshan Ahmed: So any P is kind of not what we're after. We're after temperature, temperature fluctuations. So you can convert all of this back into a basis of temperature.

Zeeshan Ahmed: And that it turns out it's fairly easy. You take the NEP that'd be computed previously and you divided by the derivative of that plunk.

Zeeshan Ahmed: spectral power. Okay, or the spectral radiant.

Zeeshan Ahmed: And you end up with this deep, deep EDT can be calculated. There is this route to funny term to convert from unit bandwidth. So we went units per hurts you convert it to units of seconds. And here I'm not writing it a square. So you get this funny unit of
Zeeshan Ahmed: Calvin. Second, but we'll, we'll be talking quite a bit about any tease now. So this so you ended up with the photons intrinsic noise being something like 27 micro favorite second

190
00:31:16.380 --> 00:31:21.750
Zeeshan Ahmed: Now this is the crazy part right to get to the sensitivity, we're talking about if you had a single

191
00:31:22.080 --> 00:31:38.310
Zeeshan Ahmed: Noise less detector observing in space. No other sources of noise. There's some other implicit assumptions. We'll get to it will take 3500 years right so this is this is craziness and we haven't even accounted for all the all the noise terms that come into this

192
00:31:39.510 --> 00:31:47.610
Zeeshan Ahmed: Later, of course, you will see that the solution over here as they of course you don't observe with one one sensor you observed many, many, many sensors and so that reduces the amount of time you take

193
00:31:48.120 --> 00:31:54.690
Zeeshan Ahmed: But anyway, so we need to do an accounting of all the power that's coming into the system and all the noise equivalent temperature. Okay.

194
00:31:56.040 --> 00:31:58.560
Zeeshan Ahmed: So next we'll talk about kilometers and I know that

195
00:31:59.760 --> 00:32:04.350
Zeeshan Ahmed: Can't talk about this and you heard this earlier today to a little bit

196
00:32:05.850 --> 00:32:12.600
Zeeshan Ahmed: from Linda. Please talk so we can speed through this. The general idea is a kilometer is measuring power.

197
00:32:14.130 --> 00:32:21.600
Zeeshan Ahmed: Power comes in gets absorbed. It's led out through this week from a link and you're using a thermometer on the absorber.

198
00:32:22.890 --> 00:32:27.900
Zeeshan Ahmed: To keep track of how much the temperature is changing on this absorber. And that gives you a sense of

199
00:32:29.040 --> 00:32:35.280
Zeeshan Ahmed: What the optical power. Power is you can you can kind of see the units and stuff of these terms offline if you'd like.

Zeeshan Ahmed: So modern day super sensitive kilometers us Transition. Transition at sensors.

Zeeshan Ahmed: There are other kinds of thermostat or, you know, temperature sensitive resistors, you can use for this application, but

Zeeshan Ahmed: In the end we do use Transition. Transition at sensors. These are thin metal films. And the idea is you operate them in this very narrow region where small changes in temperature can lead to large changes and resistance. That's right. So, this this hopefully

Zeeshan Ahmed: Makes sense. That's how you get all of your sensitivity.

Zeeshan Ahmed: And and note that, because all the superconducting and you're writing the superconducting edge, you're typically a fairly cold temperature. So, this whole thing is is cryogenic

Zeeshan Ahmed: There's a bit of math to be here, but let me just show you the, the high level picture.

Zeeshan Ahmed: I'm just trying to show me here that this is how the bias circuit for a transition at sensor is set up for this for these kilometers you voltage bias the T. S.

Zeeshan Ahmed: And that gives you an electrical power which is v squared over the resistance of the tea. Yes. And the sum of this electrical power and the optical power is what flows out of the kilometer into the bath and you can do a driven and convince yourself pretty quickly that this whole

Zeeshan Ahmed: Enterprise, it ends up being stable because the optical power and the electrical power remaining balance, meaning if the optical power goes up the electrical power comes down.
Zeeshan Ahmed: Right. So instead, instead of being able to heat it up and kick it out of the the transition, you're able to remain in transition.

Zeeshan Ahmed: There there's another term that if you're trying to do some calculations offline is the strength of that feedback that is causing this to remain in transition. That's called the loop gain.

Zeeshan Ahmed: So that's a bit here, but we don't need to go into the details.

Zeeshan Ahmed: Um, so now we can talk about bolometer noise terms.

Zeeshan Ahmed: So each of the resistance is in the circuit has its

Zeeshan Ahmed: Johnson noise and you can write that down. And the reason I passively mentioned the loop gain is because it does show up over here if you calculate it properly. But anyway, these are numbers you can plug in

Zeeshan Ahmed: The most prominent thing, it ends up being in kilometers is an athlete and C and B is the thermal carrier noise. So that's just the thermal fluctuations across this joint. So this, this ends up being actually almost comparable.

Zeeshan Ahmed: To the photon noise and I should issue a warning over here that the circuit is actually read out by putting a squid over here. Another thing that hopefully can talk about yesterday.

Zeeshan Ahmed: And you have to consider its noise contributions to for simplicity we we leave it out of the year. Okay. And it has been negligible for bicep, which is the basis for all the calculations that I'm showing you. Okay, so this is what a TS actually looks like.
Zeeshan Ahmed: So it's a suspended in film as I was talking about. Look at the scale over here. This is a third of a millimeter. So very, very tiny devices.

219
00:35:38.370 --> 00:35:48.750
Zeeshan Ahmed: Power comes in over here and gets deposited. This is the actual TV yes part. This is where the biasing circuit comes in and this black stuff you're seeing over here is

220
00:35:50.250 --> 00:36:06.510
Zeeshan Ahmed: It's just you know 10 air or I should say thin vacuum because you know there's a you holding this whole thing cold and in a vacuum. But there's there's nothing over there. This is just a tiny film suspended on on legs and the legs is what gives you the conductance.

221
00:36:08.640 --> 00:36:21.510
Zeeshan Ahmed: Okay, you need to cut a couple in the power you do that optically. There are all kinds of schemes to get the optical power in you can receive that CME light coming in, into horns direct the horns into

222
00:36:22.320 --> 00:36:35.190
Zeeshan Ahmed: These orthogonal transducers. And you'll see the shape, by the way, is important because to do your Q and you measurements, you're using a kilometer each right so you have one polarization sensitive kilometer another one.

223
00:36:35.820 --> 00:36:51.480
Zeeshan Ahmed: You difference them and you get your cue Stokes parameter and you take a different orientation 45 degrees off and you get to use Stokes parameter. So these are what give you your first cut of polarization and then you convert to end.

224
00:36:52.650 --> 00:36:57.690
Zeeshan Ahmed: Anyway, that the thing that I've shown in circles of A. Here's a tea. Yeah, so that the image that I showed you before, corresponds to this.

225
00:36:59.460 --> 00:37:13.320
Zeeshan Ahmed: You another scheme is where use antennas and put little tiny lenses on top of each one of them here again the tea. Yes, or in the circles and advice that we've used these antenna arrays that some of the signal.

226
00:37:15.030 --> 00:37:19.740
Zeeshan Ahmed: And direct them to these tiny TS bloggers over here. Okay.
Zeeshan Ahmed: This is a focal plane of 500 CMT kilometers using that last technique that I showed you, so their antennas. Each of these squares is taking in light. And you'll notice that if you keep zooming in and go into

Zeeshan Ahmed: The network of pictures, you'll see these orthogonal slots and this is where you get the polarization sensitivity. So you're a and b detectors and their differences, what gives you the polarization and this is again that image of the transition at sensor longer

Zeeshan Ahmed: Okay, we need to add atmosphere because we're observing from Earth.

Zeeshan Ahmed: So this is just showing a picture of the all my site, but basically you want to go too high and dry deserts to minimize absorption of the signal.

Zeeshan Ahmed: And if you look at a world map of how how good you can get basically you're looking for the bluest blue regions where the water vapor content in the sky is the lowest. So typically we go to places either the South Pole.

Zeeshan Ahmed: Which is a 10,000 feet. Okay. It's a dry desert in the planet and you can look at 2010 to 20% of the sky or you go to the church planter in Chile, which is actually

Zeeshan Ahmed: slightly uphill of where all my so this is at 17,000 feet, very, very low water vapor in the sky over here are two and 50 to 70% of

Zeeshan Ahmed: The sky can be mapped so you can write down a contribution of what the the the brightness is from the atmosphere.

Zeeshan Ahmed: Okay, and you have these windows. The you shapes you see over here where it is sufficiently low that if you place your kilometers in here.
Zeeshan Ahmed: Then the amount of power, you're adding to your system corresponds to 10 to 20 Calvin and remember that's 10 to 20 Calvin on top of the 2.73 Calvin.

Zeeshan Ahmed: So we're adding up noise terms as well as power terms. And so we need to incorporate these into our power estimates and EP and entities. Okay.

Zeeshan Ahmed: Very briefly, let's talk about telescope and optics is the same kind of story. If you were able to set up a system where you're collecting the light which we do for

Zeeshan Ahmed: Telescopes, these are really reflecting systems. This is a refracting system.

Zeeshan Ahmed: You can achieve diffraction limited performance, which means that basically your image is not doesn't have aberrations. So if you design your system. Well, you can get a good image.

Zeeshan Ahmed: And what you're trying to do is design us in a way so that your diffraction limited field of view is maximized. And what that means is basically that you can pack a lot of kilometers over here, instead of just one below it. Okay, so that's what we're. That's what we're aspiring to do

Zeeshan Ahmed: And each of these elements, by the way, is also adding a few Kelvin of noise. So we got to keep that in mind.

Zeeshan Ahmed: This is a focal plane that we built a few years ago. And this has 2500 kilometers. So by maximizing that the fractions will feel the view.
Zeeshan Ahmed: Were able to put in 2500 kilometers into this Cameron look this is half a meter across and you can do even better. Now, even just a few years since this this was put together.

Zeeshan Ahmed: Um, I'm going to skip this bit about beams, but this is basically telling you your instruments resolution. You can read this offline. And we have an extensive campaign of how to

Zeeshan Ahmed: Map, the resolution of the instrument and this is important for the following reason. So if you look at this image of a plan satellite that has only five are committed resolution.

Zeeshan Ahmed: By having a bigger collecting dish and improving a resolution.

Zeeshan Ahmed: You can go to something like this. Right. I mean, the resolution. This resolution is close to one argument. And so you can see a lot better and you're able to reconstruct higher L modes. Because of this,

Zeeshan Ahmed: Okay, then the one final piece of instrument building. I want to point out is that if you put together a focal plane like this.

Zeeshan Ahmed: And you projected onto the sky, you're actually at a given time sampling only a small part of it.

Zeeshan Ahmed: So what this means is to be able to construct an image like this with the CMT. This is a bicep to map, you have to scan the focal plane across the sky and you have to

Zeeshan Ahmed: You have to sort of turn it in different orientations to build up the information in this map. Okay, so that's this point of view here. We're scanning to get coverage.
Zeeshan Ahmed: But that part needs to an inefficiency over here if characterize this as one minus alpha and this will come up in a second that alpha becomes important when you do your calculations for map noise.

Zeeshan Ahmed: Okay, so we talked about C NB we talked about tea. Yes. NOISE. We talked about sky. We talked a little bit about optics and so now you can do all these calculations for the amount of power, you're getting

Zeeshan Ahmed: The NEP and the resulting any tea and then the time it would take to get to bicep three sensitivity or to futuristic CBS for sensitivity of that number seven nano Kelvin degrees. Okay.

Zeeshan Ahmed: Um, so, without going into details. Perhaps I should just point out that, once you're done adding all these contributions, the point one six becomes 2.8

Zeeshan Ahmed: And the amount of power, you're receiving and the noise is gone up quite a bit to your, your at any T of 27 micro Kelvin would second or 287

Zeeshan Ahmed: And basically, to get to the kind of sensitivity, we want for our futuristic science cases we're talking about 400,000 years if you integrate with only one millimeter. And so this is good because this is this is good exercise and you can try this offline.

Zeeshan Ahmed: And there are actually some resources in the in my very last slide for where you can use an online calculator for this kind of thing.

Zeeshan Ahmed: You see that you need to go to something like 100,000 kilometers to be able to measure this signal in a reasonable amount of time.

Zeeshan Ahmed: You hear. I'm saying it's four years right in four years. If you have 100,000 kilometers, then for this 95 gigahertz signal you get to the sensitivity in that time.
Zeeshan Ahmed: Okay, so you need lots and lots of bloggers.

Zeeshan Ahmed: Um, let me say a couple of words about systematics.

Zeeshan Ahmed: We care about polarized for grounds. This is really important because as you're observing the sky here we're sharing a plot of how much polarization signal you get from various sources.

Zeeshan Ahmed: As a function of the bands are observing in. So for the plan satellite they observe and 30 gigahertz 44 gigahertz 70 hundred and all these bands uses the great bands.

Zeeshan Ahmed: But the signal you're observing is not purely CME which has shown the sign over here. You also have contributions from synchrotron and from dust from the galaxy.

Zeeshan Ahmed: So to be able to estimate the CME signal properly, you need to be able to subtract the synchrotron and thermal does really well.

Zeeshan Ahmed: And that means measuring them and reconstructing the shape really well.

Zeeshan Ahmed: Okay, so that means that even the hundred thousand kilometers that I talked about 495 gigahertz, which incidentally of you here is not enough. You need some sensitivity and all these other bands to be able to construct this and subtract it off.

Zeeshan Ahmed: And we do this, of course, but you know bolometer is have different different colors, this is just showing you a picture of how bicep does. These are our kilometer arrays for these three different frequencies in these three atmospheric windows.
Zeeshan Ahmed: Then the other big thing and systematics one needs to worry about is the instruments' stability. This is we've made the assumption that we're averaging down noise.

273
00:45:01.350 --> 00:45:13.470
Zeeshan Ahmed: And that noise can be averaged down if it's random. And if it's zero mean. So any deviations from this ends up systematically biasing our measurements. And so there's a whole

274
00:45:14.760 --> 00:45:22.950
Zeeshan Ahmed: slew of measures that need to be taken to prevent that most prominently we filter out the parts that don't obey

275
00:45:23.790 --> 00:45:31.950
Zeeshan Ahmed: The, the things that can be averaged down right it's the statistics is not such that it can be average down, we have to take it out and that leads to a loss and sensitivity.

276
00:45:32.910 --> 00:45:42.060
Zeeshan Ahmed: Then I've given a few examples. Over here of other kinds of fluctuations that can occur temperature drifts electronics and so forth, you need to control this very tightly

277
00:45:42.690 --> 00:45:57.900
Zeeshan Ahmed: fluctuations of the atmosphere, you can't control, but we're we fortunately been lucky in that the atmosphere is on polarized. So in polarization. You don't see a lot of this at a good, a good side like the sample.

278
00:45:59.280 --> 00:46:17.490
Zeeshan Ahmed: There are other systematics from from the beam or the spot that you're seeing in the sky. If you're not, if, if you're detectors and be detectives are not aligned pointed the same way that shape mismatches, then you can have issues and you can end up with effects that contaminate and

279
00:46:18.720 --> 00:46:29.370
Zeeshan Ahmed: Cause leakage into polarization or particularly into be modes, there's, there's many other things over here, you can think about filtering operations.

280
00:46:30.150 --> 00:46:40.440
Zeeshan Ahmed: Band passes. If you're a detector and up detector aren't looking at exactly the same bands, you can have some some problems there. Right. Because remember, all of this is being built by
Zeeshan Ahmed: Different sing and be contributions.

Zeeshan Ahmed: Okay, so, um,

Zeeshan Ahmed: These are some of the telescopes that are in the field right now, taking into account all the stuff we've talked about power noise systematics. These are some of the higher resolution instruments.

Zeeshan Ahmed: This is a polar bear Atacama cosmology telescope south pole telescope various dish sizes. These are some of the detectors that they have. And they're serving 10 to 15% of the sky. Okay.

Zeeshan Ahmed: And and because they had these big dishes, they have better resolution, they're able to see down to hire multiple

Zeeshan Ahmed: These are some of the lower resolution experiments specifically designed to go after the inflation signal, they tend to have, they tend to have smaller apertures and low resolution.

Zeeshan Ahmed: And so the cost is that you can see the higher L signal, but this is ok for inflation. It turns out that these more compact designs end up being


Zeeshan Ahmed: Um, so those are kind of the experiments that are in place right now. And these have, you know, on the order of a few thousand kilometers.

Zeeshan Ahmed: And remember for the future generation, we're already talking 100,000 kilometers plus. So that's where we want to get to
Zeeshan Ahmed: Before we get back into CM PS4. Then I'll let me talk you through a typical analysis and how things go. So you calibrate first and you calibrate fairly frequently we talked about this earlier. Like you can you can use

00:48:15.450 --> 00:48:29.640
Zeeshan Ahmed: Distance sources over here and there's a mirror directing light from from an artificial calibration source into the camera and you can understand the beam properties and any problems you have with the beams. This is an example. For instance,

00:48:31.440 --> 00:48:36.780
Zeeshan Ahmed: By by doing this calibration. You can do polarization calibration. You need to understand the angles. Very well.

00:48:38.430 --> 00:48:46.560
Zeeshan Ahmed: I won't go into the details of this except to say that you have to understand because the systematics all of these things really well and that's where calibration is important.

00:48:47.670 --> 00:48:59.550
Zeeshan Ahmed: And then I'm going to skip these two slides and just take you to the punch line over here, which is how a map is constructed. Okay, so I have my

00:49:00.150 --> 00:49:14.310
Zeeshan Ahmed: focal plane. And what we do is we scan across the sky, back and forth, back and forth, back and forth. And so this is showing for one pair of detectors, or one and be giving you a cue stochastic signal.

00:49:16.470 --> 00:49:25.410
Zeeshan Ahmed: You create a line as a map, then you move up a bit and do that all over again. And you keep doing that till you build these patches. Okay.

00:49:25.890 --> 00:49:30.240
Zeeshan Ahmed: Then you rotate the side of the camera. So that's our detectors are looking at a different part of the sky.

00:49:30.960 --> 00:49:41.850
Zeeshan Ahmed: And we do this, at least in bicep. We do this with four different angles. And so you get this. And as you integrate over the, over the course of the year and seasons are changing and the sky is moving you built up this
Zeeshan Ahmed: And this is from one pair of detectors and now if you do this for all your detectors. Now, you end up with your maps. Okay.

Lisa Kaufman: You should have five minutes left.

Zeeshan Ahmed: Of five

Lisa Kaufman: Five minutes.

Zeeshan Ahmed: Okay, I

Zeeshan Ahmed: Guess we're running oh yeah okay I

Zeeshan Ahmed: For somebody that was kind of clocking 45 minutes in, but okay so so this now you get your maps, this is, this is the temperature signal. This is the cube signal the signal.

Zeeshan Ahmed: You'll see the characteristic pluses and crosses. If you take out all the signal, you're able to see the noise. Okay. And this noise. So there's a preliminary mark over here, we'll, we'll skip over that.

Zeeshan Ahmed: Over here I just quickly highlight that these are the formulas that help you connect the next that we talked about in terms of the kilometers and the map depth.

Zeeshan Ahmed: So this is how you can do that calculation and for bicep and with 2500 kilometers and observing for three years, we have reached this roughly 15 nano Calvin degree sort of map Noise Okay um
Zeeshan Ahmed: We're gonna have to skip through a bunch of this. Let me just jump actually to

Zeeshan Ahmed: How we're making progress going to see me as for in the interest of time. Okay, so let's go to hear

Zeeshan Ahmed: Um, so this is showing a progression over time of

Zeeshan Ahmed: How our bolometer accounts have increased and how we've managed to gain sensitivity right so 10 years ago we were making cameras with 500 kilometers. Today we're making cameras with 30,000 kilometers.

Zeeshan Ahmed: And the goal is to for the next generation build CMT s for which will have 500,000 kilometers. Okay.

Zeeshan Ahmed: This is a very ambitious program utilizing both the South Pole and chalet sides and lots and lots of cameras and kilometers to get to those sensitivity targets that I talked about getting to that sort of seven nano Kelvin degree.

Zeeshan Ahmed: Range so that you can construct your tea and be very well. So, so this program is going to pursue inflation.

Zeeshan Ahmed: Light relics neutrinos dark energy large scale structure. You'll also participate in a multi messenger astronomy, hopefully, lots of new discoveries

Zeeshan Ahmed: As I said, serving a large part of the sky and I'm a lot of huge increase, increase in sensitivity, we aim to build this experiment in this coming decade and we want to start taking data at the end of the decade.
Zeeshan Ahmed: A this is our collaboration. When we last met were about 236 members from 14 countries we're always looking for more people to participate in our exciting science.

00:52:39.240 --> 00:52:44.160
Zeeshan Ahmed: This is our meeting from this week. And now we're in remote meetings. So this was all a resume.

00:52:47.160 --> 00:52:48.810
Zeeshan Ahmed: And

00:52:50.130 --> 00:53:02.190
Zeeshan Ahmed: The place. We want to get to is best summarized by looking at this, this angular power spectrum again. So most of the most of the stuff you see over here is data points and those error bars.

00:53:02.850 --> 00:53:13.620
Zeeshan Ahmed: So that's the colored lines and the end the pluses that you see over here. And if you notice very closely and you can perhaps look at this on your PDF offline that

00:53:14.130 --> 00:53:20.790
Zeeshan Ahmed: We want to reduce with CBS for the Aero bars and all of these things to these gray line techno sort of errors.

00:53:21.780 --> 00:53:36.540
Zeeshan Ahmed: Over here, and the lens and you can see towards the higher multiples of those Aero bars are visible again. But for temperature. It's in virtually invisible for emails, we want to finish measuring it really well too high. Multiple and lensing be modes. We want to completely characterize

00:53:38.250 --> 00:53:42.990
Zeeshan Ahmed: And to get this sort of thing. This is the kind of instrument we need to build

00:53:44.070 --> 00:53:56.880
Zeeshan Ahmed: We want to have a wider your survey located in Chile observing for seven years using to six meter diameter telescopes and 270,000 kilometers. Okay, over six.

00:53:58.530 --> 00:54:09.150
Zeeshan Ahmed: frequency bands and for the inflation search, there's a separate survey that happens primarily from the South Pole. It uses the equivalent of 18 bicep threes.
Zeeshan Ahmed: With much higher kilometer density. So that, remember we calculated about 100,000 kilometers for that one band. When you throw in all the bands, you get to about 155,000 bloggers, excuse me, and its own dedicated

Zeeshan Ahmed: Higher resolution telescope to measure the lensing signal and subtract that and to be able to get to search for the primordial gravitational wave signal.

Zeeshan Ahmed: So that's the survey another seven years in parallel with this survey from South Pole. So, so this is the ambitious program that we're trying to build

Zeeshan Ahmed: In the next 10 years, much more information on this is available online at our website. You can look at the science book technology book.

Zeeshan Ahmed: And a project book. If you're interested, but most of the fun stuff is in the science book in the technology book. Um, so, so I think that's sort of wrapping this up there. There are many sections of the talk that I had to end up

Zeeshan Ahmed: Skipping but I i I'm hoping that it still serves as a reference for you if you read through the slides and there's also another final bit that I that I put into the here which is

Zeeshan Ahmed: How I got the source materials and information for for most of this talk, there's a pretty good set of lectures in a CME dedicated school like, was it a lot more detail. You can do this lectures over here.

Zeeshan Ahmed: There's Python scripts and modules that you can play with with fake CSV data that's available over here.
Zeeshan Ahmed: All the noise calculations that I've done, and showed you. Very, very quickly, you can go back and do those carefully with this online calculator and then they're these papers that that are good introduction to belong mentors CB telescopes and so forth.

Zeeshan Ahmed: Okay, so let me put up this slide as the last one. This is the catheter. Hey, again, of the at South pulled research station that operated on through 2019 and has recently been upgraded.

Lisa Kaufman: Thank you so much. Sure, that really nice talking.

Lisa Kaufman: And we'll have 15 minutes for questions. Sit on will be moderating the question for you.

don gu: Okay, thanks. Nice, nice lecture. And so it looks like we probably need to wind back to some basics of based on some of the early part of the questions. So, so maybe let's start with page for side for.

don gu: There, there are actually two people ask the same question.

don gu: Is why you need to take out the model and dipole before you can see we have the high order on assault.

Zeeshan Ahmed: Okay. Now, that's it. That's a great question. I'm primarily all we're doing is we're

Zeeshan Ahmed: Saying that these fluctuations are pretty tiny. Right, we're talking about 300 Michael Calvin fluctuations. So, that is, whatever it is, right 0.003 or 0.0003
Zeeshan Ahmed: Is it your offset terms so that if you were to put that in and that your images dominated by that. Right. So we're just saying that we're subtracting this offset.

Zeeshan Ahmed: we're subtracting the offset to be able to see this tiny fluctuations.

Zeeshan Ahmed: Okay, so I can if I were to make this image in the fall, dynamic range meaning showing the zero to 2.73 then you would see only one color, right, it would be the color that corresponds to 2.73

Zeeshan Ahmed: So we subtract off the part

Zeeshan Ahmed: That is constant across the image.

Zeeshan Ahmed: And then you're left with these these these tinier fluctuations.

dong su: Okay, thanks. So the next question is, why is a CMT linear or

Zeeshan Ahmed: Ah,


Zeeshan Ahmed: I, I have some slides specifically for
Zeeshan Ahmed: Think. Let's see if I can find this

Zeeshan Ahmed: Yeah, so this is interesting. So what

Zeeshan Ahmed: ends up happening is

Zeeshan Ahmed: So, this is this. This is a good cartoon for this. Okay, so at the time the CMT is in its

Zeeshan Ahmed: Color pre CMS data to whether this is the primordial plasma as you're heading into the stage where the electrons start getting kicked off.

Zeeshan Ahmed: By protons and neutrons plasma starts becoming neutral what's happening around and still is that

Zeeshan Ahmed: You have something called Thompson scattered. You can read about this. There's, there's

Zeeshan Ahmed: plenty, plenty of literature on this if you google Thompson scattering right what's happening is your, your, your

Zeeshan Ahmed: Your photons.

Zeeshan Ahmed: Your see me photons come in and Thompson scatter

Zeeshan Ahmed: And if you

Zeeshan Ahmed: If you read a bit more about Thompson scattering. You'll, you'll
Zeeshan Ahmed: You'll learn the following things. One, you'll see that if you have any kind of light coming in, even if it's on polarized, right. So we're showing this with a hot and cold spots and by convention, the colors. The colors are blue, higher frequency. Therefore, it is hot. Right. So this is more the physics convention, then, then the thermometer covering convention. So we're seeing that if you have light coming in and scattering off and electron, it turns out that you need this quarter folder structure where you have maybe hot, hot, cold, cold.
Zeeshan Ahmed: The scattering occurs.

Zeeshan Ahmed: And to generate neck polarization needs needs to occur, such that the radiation that comes out is perpendicular to go to all the incoming light. Okay.

Zeeshan Ahmed: And the polarization direction that comes out needs to be parallel. So

Zeeshan Ahmed: Disturbing here needs to be parallel to that this will be here needs to be parallel to that. OK, so now if you have this temperature differential like this, you end up with more polarized intensity

Zeeshan Ahmed: Here and then here.

dong su: And therefore you're literally polarized that way.

dong su: Okay.

Zeeshan Ahmed: And this is a bit of a thought experiment that I'll admit, even when I was a student. It took me a while to think this through and understand where you can convince yourself that you need these arrangements or quadruple runs off trapeze.

Zeeshan Ahmed: To end up with a net new polarization and because this Thompson scattering is occurring. And that really plasma the radiation that you get up get out ends up having this organization.

dong su: Okay.
Zeeshan Ahmed: I hope that helps.

don su: Okay, thanks. So the next question is on page five

Zeeshan Ahmed: Yeah, good. So this is an excellent question. So why is that what you know what is the business of this peak. Um, so you have a

Zeeshan Ahmed: First approximation of photon.

don su: Bearing on through it.

Zeeshan Ahmed: Just think of it as protons, electrons, protons through just the standard standard particles that are better at this time President at redshift of 1100

Zeeshan Ahmed: And the things that we care about your most are the photons and their interactions with all the regular regular baryonic map. So this is a fluid and it's oscillating

Zeeshan Ahmed: Okay, and it's oscillating coherence. So you got it. You got to think about this, too, because if it weren't coherent and can end up a structure like this. So,

Zeeshan Ahmed: There's all kinds of stuff going on. But what is this telling you is the most prominent scale of oscillation is this size of about one degree and today sky. Okay. And this is telling you basically how the sound waves are propagating in that oscillating plasma and what their characteristic
Zeeshan Ahmed: Sizes. And so when that decoupling occurs when the photons are all finally free. Then they have walked away.

01:02:57.300 --> 01:03:01.350
Zeeshan Ahmed: Having sort of preserved this picture of what that plasma look like at that time.

01:03:02.490 --> 01:03:05.730
Zeeshan Ahmed: And what what the scales of its most prominent features work.

01:03:10.050 --> 01:03:10.290
dong su: I hope

01:03:10.680 --> 01:03:13.770
Zeeshan Ahmed: And if and if not, we can find some offline material to

01:03:15.330 --> 01:03:17.220
Zeeshan Ahmed: To link and go

01:03:17.610 --> 01:03:26.310
dong su: Or you can add a note in the in the text answer. Eventually, or something like that. Okay, let's move on to the next question. On page 11

01:03:27.330 --> 01:03:27.900
And

01:03:29.370 --> 01:03:37.590
dong su: Another basic issues. What is driving the growth of the the error bars. When you go to the harvest

01:03:38.670 --> 01:03:48.810
Zeeshan Ahmed: I'm excellent question. Okay. So the question is, why, why is it harder to do this. Why are the error bars larger okay so to do that I need.

01:03:48.810 --> 01:04:11.250
Zeeshan Ahmed: To point out that know the difference between the loop points which are long and everything else. Typically you'll notice that everything else that is not plonk has a larger bunkers and. And the reason is twofold. So first let me, let me say plunk being at a space mission.

01:04:11.250 --> 01:04:12.200

Zeeshan Ahmed: Is does not have to contend with the atmosphere.

Zeeshan Ahmed: Right. So there's a huge chunk of noise that is taken out.

Zeeshan Ahmed: Because I remember in when we were doing our accounting and I was trying to show you very quickly on top of to Calvin, we were adding something like 1020 Calvin and if you don't have that. So your noises a lot, lot, lot reduced

Zeeshan Ahmed: Which ends up, meaning that you can use a lot pure blood meters, but also the other important thing is that

Zeeshan Ahmed: As long as the satellite is able to do an all Sky Survey. And many of these other experiments are not able to do an old Sky Survey the survey only 10 to 20% of the sky when you serve all sky.

Zeeshan Ahmed: For every L you're picking 12 plus one moves. Okay. But if you're doing a cut sky or small branch in the sky. You don't have access to all those directions and all those nodes. So you're not able to average down those

Zeeshan Ahmed: Seals okay so if you're measuring a CL, you're doing it with incomplete information.

Zeeshan Ahmed: Your sample variances, meaning that in your small patch of sky. You've sampled only a fraction of the total 12 plus one modes available to you. So a satellite can always do better in that sense that you can get access to all your 12 plus one modes and you can for a ground based experiment.

Zeeshan Ahmed: A related point of view here you'll notice is that plonk cuts off over here and doesn't go down much farther

Zeeshan Ahmed: That has to do with
Zeeshan Ahmed: And you'll see the planks all an error bars. The blue points in their barn start increasing over here. And that has to do with the systematics of the polarization sensor and I believe this is true. Maybe I should take this offline and that it not having enough resolution.

Zeeshan Ahmed: To to map, map this stuff out further. So that's and part of this is because as you get to higher L. You need to have a bigger dish right and bigger dishes in space are very expensive and the machines are doing the math. And so you can do that a lot better over here.

Zeeshan Ahmed: So you want expect. So there are there are no planned space missions or several proposals.

Zeeshan Ahmed: In at the moment.

Zeeshan Ahmed: There are some that are actually been been successful in getting through early R amp D stages. But for the moment we're assuming that in you. We don't have

Zeeshan Ahmed: Satellite successor to plan to be able to map these things out much better or with improvement and resolution and so forth and so

Zeeshan Ahmed: The other points that you're seeing here are all these ground based experiments and they'll, they'll get better over time they will have the resolution to be able to map this out, they'll be limited primarily by the number of modes. They can measure and how many kilometers. You're putting

dong su: Okay, thanks. So I'm actually well here. There's another question.

don su: So given the lending potential to I think that probably the first part is taking the law hundred 50, then how come the lending remote signal is peaking at larger L.
Zeeshan Ahmed: Ah, that, that, that's interesting. Okay, so, so that the lead. Okay, so the lensing potential is actually reconstructed from all of these three

Zeeshan Ahmed: And the lensing potential is primarily giving you the scale of again the most prominent features in all of that lensing.

Zeeshan Ahmed: Okay, so that's why it ends up taking a slightly different multiple compared to the other things. So, so let's let's actually what might be helpful is if I if I go back over here.

Zeeshan Ahmed: Or maybe this this point of view here. We're saying that the signal the lending signal as the photons have passed through all of your cosmic history, they get lens. The most by

Zeeshan Ahmed: structuring your membership to and

Zeeshan Ahmed: Would you end up seeing over here, remember, is

Zeeshan Ahmed: You're not getting you're getting an integrated

Zeeshan Ahmed: Path of

Zeeshan Ahmed: Light does come through right not seeing the fluctuations is a function of time. You're seeing

Zeeshan Ahmed: What the results in any fluctuation is and how rather how much
Zeeshan Ahmed: Deviation, there is 100 Amish deflection. There is of the lights, you're basically trying to see

Zeeshan Ahmed: Going from this image to that image. You see that so so the the potential that causes that movement ends up taking in a different place, but that perhaps not not so difficult to see.

Right.

Zeeshan Ahmed: It doesn't have to exactly correspond to what you see in the beauty and EMP

Lisa Kaufman: Thank you.

Lisa Kaufman: I think that's the end of our time working

Lisa Kaufman: Well, this is actually the end of our time. So if this can be the last question.

Lisa Kaufman: Okay, yeah, maybe the rest of

Lisa Kaufman: It.
dong su: Yeah.

Zeeshan Ahmed: Okay, thank you.

Lisa Kaufman: Thank you.

Thanks to all the speakers.

dong su: Are you gonna ask this one.

dong su: Yeah.

dong su: Yeah.

God

Zeeshan Ahmed: Do I can cure saddam now.

Lisa Kaufman: Yeah, looks like he's muted.

Zeeshan Ahmed: I think I caught it offline. Maybe

Okay.

donh su: That's the whole point.
Okay.

Lisa Kaufman: Okay, I'm going to stop the recording now.