WEBVTT

1
00:00:03.389 --> 00:00:10.650
Zeeshan Ahmed: Okay. Hi, everyone. My name is Sean I met. I'm a scientist at slack and today my lecture.

2
00:00:11.670 --> 00:00:14.190
Zeeshan Ahmed: Is about the CMT or the cosmic microwave background.

3
00:00:15.269 --> 00:00:18.210
Zeeshan Ahmed: And in the team if this summer institute

4
00:00:19.380 --> 00:00:34.470
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

5
00:00:36.120 --> 00:00:50.400
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.

6
00:00:51.480 --> 00:01:00.030
Zeeshan Ahmed: I'll just briefly highlight that the science targets that will speak to like relics neutrinos primordial gravitational waves.

7
00:01:01.230 --> 00:01:04.950
Zeeshan Ahmed: A bulk of this lecture will be on how one designs a CME experiment.

8
00:01:05.940 --> 00:01:18.630
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

9
00:01:19.740 --> 00:01:31.680
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.

10
00:01:32.640 --> 00:01:41.280

Zeeshan Ahmed: And hopefully the information in this lecture will will enable you to actually go back and do some calculations for yourself and see

11
00:01:42.030 --> 00:01:52.830
Zeeshan Ahmed: Whether the CMT s for science case makes sense and whether the experiment is being SPECT properly so that's that's sort of my goal for today for you to walk away with a sense of how how one

12
00:01:53.910 --> 00:02:04.320
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 is the bicep to camera.

13
00:02:04.950 --> 00:02:15.630
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.

14
00:02:16.140 --> 00:02:27.270
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

15
00:02:28.350 --> 00:02:41.880
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

16
00:02:43.020 --> 00:02:45.150
Zeeshan Ahmed: Calculations okay

17
00:02:46.260 --> 00:02:49.080
Zeeshan Ahmed: Alright so let me get that out of the way. Good.

18
00:02:50.790 --> 00:02:51.900
Zeeshan Ahmed: Okay, that didn't quite work.

19
00:02:54.390 --> 00:02:56.220
Okay, let's leave that on good

20
00:02:57.300 --> 00:02:58.440
Zeeshan Ahmed: Okay, so let's get started.

21
00:02:59.520 --> 00:03:18.000
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 in SSI. This week, but this is my quick story of the Universe cartoon. So what you're seeing over here is

22
00:03:19.410 --> 00:03:22.320
Zeeshan Ahmed: The rough scale of the universe is a function of time.

23
00:03:24.030 --> 00:03:44.100
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

24
00:03:46.080 --> 00:03:48.390
Zeeshan Ahmed: So maybe it was a bit smaller in the past.

25
00:03:49.410 --> 00:03:56.520
Zeeshan Ahmed: And in fact we know from the Light Element abundances we observed today that the conditions of the universe were very hot.

26
00:03:59.130 --> 00:04:07.740
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.

27
00:04:09.120 --> 00:04:17.280
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.

28
00:04:17.640 --> 00:04:32.760
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.

29
00:04:34.590 --> 00:04:49.440
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

30

00:04:50.790 --> 00:05:05.730
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.

31
00:05:06.120 --> 00:05:21.480
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.

32
00:05:22.860 --> 00:05:28.410
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

33
00:05:29.520 --> 00:05:44.070
Zeeshan Ahmed: 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.

34
00:05:44.580 --> 00:05:56.790
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.

35
00:05:57.330 --> 00:06:07.890
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

36
00:06:08.310 --> 00:06:15.060
Zeeshan Ahmed: As a sum of spherical harmonics. Okay, so these are your standard spherical harmonics, because we're dealing with a

37
00:06:15.660 --> 00:06:25.590
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.

38
00:06:26.790 --> 00:06:47.400
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
00:06:49.560 --> 00:06:55.920
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.

40
00:06:57.000 --> 00:07:03.870
Zeeshan Ahmed: What do we do next. Okay, so it is useful to talk about this in terms of

41
00:07:05.160 --> 00:07:08.370
Zeeshan Ahmed: Multiple space or frequency space. If you're more familiar with.

42
00:07:09.420 --> 00:07:19.530
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
00:07:20.820 --> 00:07:31.140
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
00:07:31.800 --> 00:07:41.040
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
00:07:41.880 --> 00:07:53.310
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
00:07:54.030 --> 00:08:02.310
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
00:08:03.090 --> 00:08:18.420
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.

48
00:08:19.740 --> 00:08:36.060
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

49
00:08:37.110 --> 00:08:43.830
Zeeshan Ahmed: Photon very on Florida, the plasma at that time as it was oscillating. There were sound waves in this thing.

50
00:08:45.150 --> 00:08:55.620
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 we write this, this term called DL.

51
00:08:56.340 --> 00:09:11.160
Zeeshan Ahmed: Which is just looking at the power contribution per logarithmic L. Okay, so this has some advantages and plotting and other 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.

52
00:09:12.450 --> 00:09:31.020
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

53
00:09:33.120 --> 00:09:42.510
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

54
00:09:45.360 --> 00:09:51.330
Zeeshan Ahmed: Our lambda CDN model, which has six parameters as you've probably heard of in in previous lectures.

55
00:09:54.150 --> 00:09:56.460
Zeeshan Ahmed: Describes the entire

56
00:09:58.560 --> 00:10:04.470
Zeeshan Ahmed: Universe in a very, very nice and standard way and we haven't yet observed any significant deviations.

57
00:10:04.890 --> 00:10:14.940
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.

58
00:10:15.450 --> 00:10:32.760
Zeeshan Ahmed: Right, so this is this 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.

59
00:10:34.950 --> 00:10:44.670
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

60
00:10:45.150 --> 00:10:50.730
Zeeshan Ahmed: Also ends up being linearly polarized this polarization. Second one was first detected about maybe 20 years ago.

61
00:10:51.300 --> 00:10:59.850
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.

62
00:11:00.840 --> 00:11:07.890
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

63
00:11:08.340 --> 00:11:18.390
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

64
00:11:20.310 --> 00:11:25.230
Zeeshan Ahmed: This image is smooth so only the five degree data over here is most prominent

65
00:11:25.740 --> 00:11:37.290
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.

66

00:11:38.550 --> 00:11:45.360
Zeeshan Ahmed: Signal. So just like for temperature, we can take an angular power spectrum of this guy, too. And let me

67
00:11:46.080 --> 00:11:56.760
Zeeshan Ahmed: 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 as the as the line for temperature

68
00:11:57.810 --> 00:12:06.930
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

69
00:12:08.130 --> 00:12:21.930
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

70
00:12:23.940 --> 00:12:32.190
Zeeshan Ahmed: 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

71
00:12:32.520 --> 00:12:47.460
Zeeshan Ahmed: 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.

72
00:12:49.230 --> 00:12:56.820
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.

73
00:12:57.360 --> 00:13:05.460
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

74
00:13:05.940 --> 00:13:12.270
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.

75
00:13:13.020 --> 00:13:28.200
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.

76
00:13:28.740 --> 00:13:34.140
Zeeshan Ahmed: Right. And this is, you've heard about this to hopefully in the lectures. The past couple days so

77
00:13:35.250 --> 00:13:50.190
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.

78
00:13:51.690 --> 00:13:59.190
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.

79
00:14:00.240 --> 00:14:12.450
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

80
00:14:13.140 --> 00:14:19.470
Zeeshan Ahmed: Then there is this elusive inflationary gravitational waves of primordial gravitational waves that can also cause

81
00:14:19.890 --> 00:14:28.320
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.

82
00:14:28.890 --> 00:14:34.320
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.

83
00:14:35.100 --> 00:14:48.840
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

84
00:14:50.370 --> 00:14:56.670
Zeeshan Ahmed: Okay, let's talk a bit more about lensing because this is actually something that that we're now starting to

85
00:14:57.570 --> 00:15:10.560
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

86
00:15:11.700 --> 00:15:23.040
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.

87
00:15:25.290 --> 00:15:34.500
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

88
00:15:35.160 --> 00:15:43.620
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.

89
00:15:44.040 --> 00:15:54.930
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.

90
00:15:58.080 --> 00:16:06.240
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

91
00:16:07.800 --> 00:16:14.520
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

92
00:16:16.410 --> 00:16:19.410
Zeeshan Ahmed: So hopefully the video is keeping up and you saw a little change in deflection

93

00:16:20.370 --> 00:16:28.110
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.

94
00:16:28.590 --> 00:16:34.650
Zeeshan Ahmed: So basically over here and these got distorted. Let me go back and show you that again. So this is undistorted

95
00:16:35.190 --> 00:16:52.530
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.

96
00:16:55.770 --> 00:17:01.560
Zeeshan Ahmed: So, so, so we'll talk about this too, as we were talking about our, our instrumentation. Okay, so this is

97
00:17:02.070 --> 00:17:07.590
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

98
00:17:08.100 --> 00:17:17.790
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.

99
00:17:18.180 --> 00:17:23.670
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.

100
00:17:24.450 --> 00:17:33.660
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

101
00:17:34.620 --> 00:17:46.680
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

102
00:17:49.620 --> 00:17:54.840
Zeeshan Ahmed: This structure formation of the universe and also get to some interesting things like neutrino properties.

103
00:17:56.130 --> 00:18:05.340
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.

104
00:18:06.030 --> 00:18:17.160
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

105
00:18:17.670 --> 00:18:31.110
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

106
00:18:31.950 --> 00:18:40.230
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.

107
00:18:40.650 --> 00:18:48.510
Zeeshan Ahmed: And and and this this lensing potential ends up being a very powerful tool and perhaps Scott talked about this this morning as well.

108
00:18:49.470 --> 00:19:00.180
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 t or t AMP t or t and B.

109
00:19:01.140 --> 00:19:08.550
Zeeshan Ahmed: And that's how you reconstruct this and so by improving our measurements on all of these we we do we

110
00:19:10.470 --> 00:19:24.960
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.

111
00:19:26.640 --> 00:19:33.810

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.

112
00:19:34.380 --> 00:19:42.750
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.

113
00:19:43.500 --> 00:19:51.270
Zeeshan Ahmed: But in combination of temperature, a combination of temperature and he modes actually tell us if there are any other

114
00:19:52.200 --> 00:19:57.450
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

115
00:19:57.870 --> 00:20:07.380
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.

116
00:20:08.700 --> 00:20:15.900
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

117
00:20:17.430 --> 00:20:18.120
Zeeshan Ahmed: And then

118
00:20:19.710 --> 00:20:25.230
Zeeshan Ahmed: This is, this is the Wiimote polarization and this primarily is telling us the massive neutrino.

119
00:20:25.740 --> 00:20:34.560
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.

120
00:20:35.220 --> 00:20:49.320
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.

121
00:20:50.490 --> 00:20:58.320
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

122
00:20:59.640 --> 00:21:03.360
Zeeshan Ahmed: Is the contribution, apart from photons.

123
00:21:05.160 --> 00:21:12.780
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

124
00:21:14.130 --> 00:21:19.320
Zeeshan Ahmed: The standard is to get three ish and the three corresponds to our standard three neutrinos.

125
00:21:20.550 --> 00:21:26.820
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.

126
00:21:27.960 --> 00:21:34.800
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

127
00:21:36.300 --> 00:21:48.510
Zeeshan Ahmed: These fractional values and ineffective. We can 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.

128
00:21:49.890 --> 00:21:54.990
Zeeshan Ahmed: The effect we're looking for. By the way, if you're changing and effective is a changing

129
00:21:58.620 --> 00:22:02.370
Zeeshan Ahmed: The phasing and some of the power of these peaks. This is showing

130
00:22:02.880 --> 00:22:04.440
Lisa Kaufman: Me. Sorry to interrupt you graduate.

131
00:22:05.490 --> 00:22:05.790
Zeeshan Ahmed: Yeah.

132
00:22:07.500 --> 00:22:13.470
Lisa Kaufman: Sometimes you're speaking is positive. Maybe if we stop your video will be able to

133
00:22:15.330 --> 00:22:17.250
Zeeshan Ahmed: Keep okay we can try that. Yep.

134
00:22:21.120 --> 00:22:21.750
Zeeshan Ahmed: Video

135
00:22:23.280 --> 00:22:23.580
Zeeshan Ahmed: Okay.

136
00:22:23.700 --> 00:22:36.960
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.

137
00:22:39.330 --> 00:22:45.720
Zeeshan Ahmed: Scott probably talked about neutrino mass as well. The idea here is that the matter power gets suppressed at

138
00:22:46.500 --> 00:22:53.130
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.

139
00:22:53.460 --> 00:23:05.970
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.

140
00:23:07.530 --> 00:23:20.070
Zeeshan Ahmed: Then finally primordial gravitational waves, hopefully you got a bit of this yesterday from Julian savas lecture at inflation your seating fluctuations.

141
00:23:21.150 --> 00:23:25.620
Zeeshan Ahmed: Or rather, inflation is magnifying quantum fluctuations.

142
00:23:26.910 --> 00:23:27.630
Zeeshan Ahmed: To

143
00:23:28.680 --> 00:23:36.480
Zeeshan Ahmed: Microscopic scales. And so you end up with scale or perturbations intensive organizations that tend to perturbations are called gravity waves.

144
00:23:37.290 --> 00:23:46.050
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

145
00:23:46.710 --> 00:24:08.070
Zeeshan Ahmed: 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

146
00:24:09.180 --> 00:24:23.700
Zeeshan Ahmed: 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.

147
00:24:26.100 --> 00:24:28.200
Zeeshan Ahmed: These are the current constraints over here.

148
00:24:29.220 --> 00:24:38.940
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.

149
00:24:40.020 --> 00:24:42.840
Zeeshan Ahmed: And you see that we're only beginning to scratch the surface of it here.

150
00:24:44.190 --> 00:24:51.870
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

151
00:24:52.410 --> 00:25:06.180
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.

152
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.

153
00:25:15.720 --> 00:25:18.780
Zeeshan Ahmed: So using that very same plot that I showed you earlier.

154
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

155
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.

156
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.

157
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.

158
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.

159
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.

160
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.

161
00:26:35.010 --> 00:26:43.620
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,

162
00:26:44.700 --> 00:26:54.840
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

163
00:26:56.550 --> 00:27:02.580
Zeeshan Ahmed: Multiplied by how responsive your detector is and how much light it's collecting or throughput. Okay.

164
00:27:04.080 --> 00:27:10.080
Zeeshan Ahmed: We make this assumption that it is diffraction limited. We'll talk about this. Hopefully if we have time, but basically

165
00:27:10.440 --> 00:27:16.890
Zeeshan Ahmed: You can put all these things into this integral and calculate how much power you should get from the CME right

166
00:27:17.850 --> 00:27:32.070
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.

167
00:27:33.300 --> 00:27:41.010
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

168
00:27:41.550 --> 00:27:47.640
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

169
00:27:48.510 --> 00:27:58.080
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.

170
00:27:58.680 --> 00:28:09.390

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.

171
00:28:10.590 --> 00:28:28.020
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.

172
00:28:29.460 --> 00:28:39.540
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.

173
00:28:41.880 --> 00:28:47.400
Zeeshan Ahmed: You can read the definition yourself and you can read. Read this up offline using other sources but

174
00:28:48.450 --> 00:28:59.100
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.

175
00:28:59.520 --> 00:29:07.290
Zeeshan Ahmed: Okay and this is called photon noise and that photon noise is a combination of shot noise and a bunch of noise.

176
00:29:08.400 --> 00:29:11.850
Zeeshan Ahmed: Okay. And these things add an auditor and

177
00:29:12.900 --> 00:29:26.790
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

178
00:29:27.870 --> 00:29:28.440
Zeeshan Ahmed: Because you will

179
00:29:29.460 --> 00:29:36.840
Zeeshan Ahmed: Usually deal with the square of it. Um, so, anyway. There's a formula for this to this p is just the same long spectral

180
00:29:37.530 --> 00:29:44.280
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

181
00:29:44.820 --> 00:29:53.340
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.

182
00:29:53.940 --> 00:30:05.940
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.

183
00:30:07.020 --> 00:30:12.570
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.

184
00:30:17.460 --> 00:30:22.320
Zeeshan Ahmed: Right, we're talking about NoSQL and power. We need to talk now about noise a coolant temperature

185
00:30:22.650 --> 00:30:31.530
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.

186
00:30:31.950 --> 00:30:42.720
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

187
00:30:44.220 --> 00:30:46.560
Zeeshan Ahmed: spectral power. Okay, or the spectral radiant

188
00:30:47.910 --> 00:31:03.870
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

189
00:31:04.980 --> 00:31:15.300

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.

200
00:32:36.630 --> 00:32:43.710
Zeeshan Ahmed: So modern day super sensitive kilometers us Transition. Transition at sensors.

201
00:32:44.610 --> 00:32:49.170
Zeeshan Ahmed: There are other kinds of thermostat or, you know, temperature sensitive resistors, you can use for this application, but

202
00:32:49.800 --> 00:33:05.700
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

203
00:33:06.900 --> 00:33:08.970
Zeeshan Ahmed: Makes sense. That's how you get all of your sensitivity.

204
00:33:11.010 --> 00:33:20.160
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

205
00:33:22.020 --> 00:33:25.830
Zeeshan Ahmed: There's a bit of math to be here, but let me just show you the, the high level picture.

206
00:33:26.340 --> 00:33:36.780
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.

207
00:33:37.560 --> 00:33:54.270
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

208
00:33:55.380 --> 00:34:05.190
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.

209
00:34:05.730 --> 00:34:11.790
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.

210
00:34:14.220 --> 00:34:24.450
Zeeshan Ahmed: There there's 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

211
00:34:25.590 --> 00:34:28.080
Zeeshan Ahmed: So that's a bit here, but we don't need to go into the details.

212
00:34:29.640 --> 00:34:32.670
Zeeshan Ahmed: Um, so now we can talk about bolometer noise terms.

213
00:34:33.720 --> 00:34:37.020
Zeeshan Ahmed: So each of the resistance is in the circuit has its

214
00:34:38.040 --> 00:34:48.270
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

215
00:34:49.050 --> 00:35:02.820
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.

216
00:35:04.650 --> 00:35:13.620
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.

217
00:35:14.820 --> 00:35:29.130
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.

218
00:35:30.690 --> 00:35:37.920

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.

227
00:37:21.210 --> 00:37:35.130
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

228
00:37:35.580 --> 00:37:50.070
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

229
00:37:51.840 --> 00:37:54.450
Zeeshan Ahmed: Okay, we need to add atmosphere because we're observing from Earth.

230
00:37:56.250 --> 00:38:04.860
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.

231
00:38:06.060 --> 00:38:20.310
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.

232
00:38:23.160 --> 00:38:33.690
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

233
00:38:34.380 --> 00:38:42.450
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

234
00:38:43.020 --> 00:38:54.150
Zeeshan Ahmed: The sky can be mapped so you can write down a contribution of what the the the brightness is from the atmosphere.

235
00:38:54.720 --> 00:39:00.810
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.

236
00:39:01.350 --> 00:39:11.250
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.

237
00:39:11.820 --> 00:39:23.130
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.

238
00:39:24.360 --> 00:39:31.860
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

239
00:39:32.910 --> 00:39:38.310
Zeeshan Ahmed: Telescopes, these are really reflecting systems. This is a refracting system.

240
00:39:39.900 --> 00:39:48.960
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.

241
00:39:50.370 --> 00:40:06.120
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

242
00:40:09.450 --> 00:40:09.990
Zeeshan Ahmed: And

243
00:40:11.130 --> 00:40:16.560
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.

244
00:40:18.450 --> 00:40:27.330
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.

245
00:40:27.660 --> 00:40:35.700

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.

246
00:40:36.750 --> 00:40:46.290
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

247
00:40:47.100 --> 00:41:00.870
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.

248
00:41:02.280 --> 00:41:08.850
Zeeshan Ahmed: By having a bigger collecting dish and improving a resolution.

249
00:41:10.200 --> 00:41:21.420
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 see a lot better and you're able to reconstruct higher L modes. Because of this,

250
00:41:22.020 --> 00:41:28.470
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.

251
00:41:29.190 --> 00:41:35.010
Zeeshan Ahmed: And you projected onto the sky, you're actually at a given time sampling only a small part of it.

252
00:41:35.670 --> 00:41:43.920
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

253
00:41:44.280 --> 00:41:54.240
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.

254
00:41:55.410 --> 00:42:06.720

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.

255
00:42:08.610 --> 00:42:20.010
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

256
00:42:21.300 --> 00:42:34.020
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.

257
00:42:34.680 --> 00:42:42.750
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

258
00:42:43.800 --> 00:42:51.480
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

259
00:42:52.080 --> 00:43:06.600
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.

260
00:43:07.800 --> 00:43:14.520
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.

261
00:43:14.850 --> 00:43:23.010
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.

262
00:43:23.430 --> 00:43:33.030
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.

263
00:43:34.260 --> 00:43:35.970
Zeeshan Ahmed: Okay, so you need lots and lots of bloggers.

264
00:43:37.380 --> 00:43:41.100
Zeeshan Ahmed: Um, let me say a couple of words about systematics

265
00:43:42.120 --> 00:43:51.510
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.

266
00:43:51.930 --> 00:44:00.180
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.

267
00:44:00.720 --> 00:44:09.900
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.

268
00:44:10.620 --> 00:44:15.960
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.

269
00:44:16.470 --> 00:44:20.100
Zeeshan Ahmed: And that means measuring them and reconstructing the shape really well.

270
00:44:20.790 --> 00:44:34.440
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.

271
00:44:36.870 --> 00:44:50.040
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.

272
00:44:52.140 --> 00:45:00.810

Zeeshan Ahmed: Then the other big thing and systematics one needs to worry about his 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 average down if it's random. And if it's zero meat. 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

281
00:46:42.270 --> 00:46:44.070
Zeeshan Ahmed: Different sing and be contributions.

282
00:46:46.350 --> 00:46:47.940
Zeeshan Ahmed: Okay, so, um,

283
00:46:50.970 --> 00:47:01.410
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.

284
00:47:03.480 --> 00:47:15.060
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.

285
00:47:15.870 --> 00:47:24.210
Zeeshan Ahmed: And and because they had these big dishes, they have better resolution, they're able to see down to hire multiple

286
00:47:25.290 --> 00:47:33.870
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.

287
00:47:34.830 --> 00:47:41.970
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

288
00:47:43.170 --> 00:47:45.870
Zeeshan Ahmed: Better for systematics control. Okay.

289
00:47:47.010 --> 00:47:54.810
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.

290
00:47:55.110 --> 00:48:00.240
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

291
00:48:01.230 --> 00:48:13.980

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

292
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,

293
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.

294
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.

295
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

296
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.

297
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.

298
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.

299
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

300
00:49:43.020 --> 00:49:50.850
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.

301
00:49:51.090 --> 00:49:51.360
Zeeshan Ahmed: So,

302
00:49:51.390 --> 00:49:52.620
Lisa Kaufman: You should have five minutes left.

303
00:49:53.940 --> 00:49:55.500
Zeeshan Ahmed: Of five

304
00:49:55.530 --> 00:49:56.100
Lisa Kaufman: Five minutes.

305
00:49:56.790 --> 00:49:57.390
Zeeshan Ahmed: Okay, I

306
00:49:57.510 --> 00:49:59.340
Zeeshan Ahmed: Guess we're running oh yeah okay I

307
00:49:59.370 --> 00:50:10.500
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.

308
00:50:11.700 --> 00:50:23.190
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.

309
00:50:24.210 --> 00:50:33.510
Zeeshan Ahmed: Over here I just quickly highlight that these are the formulas that help you connect the ne t that we talked about in terms of the kilometers and the map depth.

310
00:50:34.050 --> 00:50:48.480
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

311
00:50:49.530 --> 00:50:54.450
Zeeshan Ahmed: We're gonna have to skip through a bunch of this. Let me just jump actually to

312
00:50:57.750 --> 00:51:04.080
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

313
00:51:05.550 --> 00:51:09.450
Zeeshan Ahmed: Um, so this is showing a progression over time of

314
00:51:11.250 --> 00:51:22.800
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.

315
00:51:23.310 --> 00:51:33.600
Zeeshan Ahmed: And the goal is to for the next generation build CMT s for which will have 500,000 kilometers. Okay.

316
00:51:35.340 --> 00:51:49.290
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.

317
00:51:50.790 --> 00:51:59.610
Zeeshan Ahmed: Range so that you can construct your tea and be very well. So, so this program is going to pursue inflation.

318
00:52:00.330 --> 00:52:09.000
Zeeshan Ahmed: Light relics neutrinos dark energy large scale structure. You'll also participate in a multi messenger astronomy, hopefully, lots of new discoveries

319
00:52:09.720 --> 00:52:24.990
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.

320
00:52:26.790 --> 00:52:37.710

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.

321
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.

322
00:52:47.160 --> 00:52:48.810
Zeeshan Ahmed: And and

323
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.

324
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

325
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.

326
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

327
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

328
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.

329
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.

330
00:54:09.900 --> 00:54:26.010
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

331
00:54:28.500 --> 00:54:37.830
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.

332
00:54:38.460 --> 00:54:46.830
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

333
00:54:47.400 --> 00:54:55.800
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.

334
00:54:56.640 --> 00:55:08.370
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

335
00:55:09.480 --> 00:55:21.840
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

336
00:55:22.530 --> 00:55:34.470
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.

337
00:55:35.160 --> 00:55:40.770
Zeeshan Ahmed: There's Python scripts and modules that you can play with with fake CSV data that's available over here.

338
00:55:41.250 --> 00:55:57.150

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 they're these papers that that are good introduction to belong mentors CB telescopes and so forth.

339
00:55:58.320 --> 00:56:11.010
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

340
00:56:12.120 --> 00:56:13.110
So let's stop.

341
00:56:15.510 --> 00:56:18.210
Lisa Kaufman: Thank you so much. See, sure, that really nice talking

342
00:56:19.800 --> 00:56:25.170
Lisa Kaufman: And we'll have 15 minutes for questions. Sit on will be moderating the question for you.

343
00:56:30.030 --> 00:56:45.150
dong su: 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

344
00:56:46.560 --> 00:56:48.720
dong su: There, there are actually two people ask the same question.

345
00:56:50.100 --> 00:56:56.880
dong su: Is why you need to take out the model and dipole before you can see we have the high order on assault.

346
00:56:58.050 --> 00:57:03.690
Zeeshan Ahmed: Okay. Now, that's it. That's a great question. I'm primarily all we're doing is we're

347
00:57:03.690 --> 00:57:18.960
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

348
00:57:20.400 --> 00:57:23.970
Zeeshan Ahmed: On top of the 2.73 the 2.73

349
00:57:25.170 --> 00:57:35.850
Zeeshan Ahmed: Is it your offset terms so that if you 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.

350
00:57:37.110 --> 00:57:40.470
Zeeshan Ahmed: we're subtracting the offset to be able to see this tiny fluctuations.

351
00:57:41.040 --> 00:57:42.210
On top of the 2.7

352
00:57:44.640 --> 00:57:56.580
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

353
00:57:58.230 --> 00:57:59.940
Zeeshan Ahmed: So we subtract off the part

354
00:58:00.990 --> 00:58:03.270
Zeeshan Ahmed: That is constant across the image.

355
00:58:04.380 --> 00:58:08.340
Zeeshan Ahmed: And then you're left with these these these tinier fluctuations.

356
00:58:11.190 --> 00:58:16.590
dong su: Okay, thanks. So the next question is, why is a CMT linear or

357
00:58:18.240 --> 00:58:18.720
Zeeshan Ahmed: Ah,

358
00:58:18.780 --> 00:58:20.790
Zeeshan Ahmed: Very good. That's an excellent question. Good.

359
00:58:21.090 --> 00:58:23.700
Zeeshan Ahmed: I, I have some slides specifically for

360
00:58:24.750 --> 00:58:25.380
Zeeshan Ahmed: For this I

361
00:58:25.590 --> 00:58:28.350
Zeeshan Ahmed: Think. Let's see if I can if I can find this

362
00:58:29.520 --> 00:58:31.080
Zeeshan Ahmed: Yeah, so this is interesting. So what

363
00:58:31.110 --> 00:58:32.880
Zeeshan Ahmed: ends up happening is

364
00:58:35.850 --> 00:58:41.820
Zeeshan Ahmed: So, this is this. This is a good cartoon for this. Okay, so at the time the CMT is in its

365
00:58:42.960 --> 00:58:50.250
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.

366
00:58:51.510 --> 00:58:56.160
Zeeshan Ahmed: By protons and neutrons plasma starts becoming neutral what's happening around and still is that

367
00:58:56.430 --> 00:58:59.130
Zeeshan Ahmed: You have something called Thompson scattered. You can read about this. There's, there's

368
00:58:59.130 --> 00:59:06.750
Zeeshan Ahmed: plenty, plenty of literature on this if you if you google Thompson scattering right what's happening is your, your, your

369
00:59:06.780 --> 00:59:07.800
Zeeshan Ahmed: Your photons.

370
00:59:07.830 --> 00:59:10.980
Zeeshan Ahmed: Your see me photons come in and Thompson scatter

371
00:59:12.750 --> 00:59:13.620
Zeeshan Ahmed: And if you

372
00:59:15.180 --> 00:59:18.000
Zeeshan Ahmed: If you read a bit more about Thompson scattering. You'll, you'll

373
00:59:18.090 --> 00:59:21.540
Zeeshan Ahmed: You'll learn the following things. One, you'll see that

374
00:59:22.830 --> 00:59:33.570
Zeeshan Ahmed: All any any if you have any kind of light coming in, even if it's on polarized, right. So we're we're showing this with a hot and cold spots and by convention, by the way the colors. The colors are squat, but just

375
00:59:34.950 --> 00:59:54.330
Zeeshan Ahmed: Going. I mean, that's just basically saying that blue is a 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

376
00:59:55.890 --> 01:00:06.450
Zeeshan Ahmed: If you end up polarizing light by this mechanism. It is only possible if you have what are called these particular anisotropy. So you need

377
01:00:06.480 --> 01:00:10.530
Zeeshan Ahmed: This quarter folder structure where you have maybe hot, hot, cold, cold.

378
01:00:11.580 --> 01:00:12.060
Zeeshan Ahmed: Or

379
01:00:12.120 --> 01:00:13.200
Zeeshan Ahmed: Hot, hot, cold, cold.

380
01:00:14.760 --> 01:00:15.090
Zeeshan Ahmed: To be

381
01:00:15.120 --> 01:00:15.990
Zeeshan Ahmed: Able to generate

382
01:00:16.020 --> 01:00:16.980
dong su: A neck polarization

383
01:00:17.040 --> 01:00:18.150
Zeeshan Ahmed: And this happens because

384
01:00:18.600 --> 01:00:20.010
Zeeshan Ahmed: The scattering occurs.

385
01:00:20.490 --> 01:00:30.750
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.

386
01:00:32.280 --> 01:00:36.630
Zeeshan Ahmed: And the polarization direction that comes out needs to be parallel. So

387
01:00:38.490 --> 01:00:49.770
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

388
01:00:49.770 --> 01:00:50.460
Zeeshan Ahmed: Here and then here.

389
01:00:50.520 --> 01:00:52.230
dong su: And therefore you're literally polarized that way.

390
01:00:53.460 --> 01:00:53.790
dong su: Okay.

391
01:00:54.210 --> 01:01:06.870
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.

392
01:01:07.170 --> 01:01:17.130
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.

393
01:01:18.240 --> 01:01:18.540
dong su: Okay.

394
01:01:18.630 --> 01:01:19.290

Zeeshan Ahmed: I hope that helps.

395
01:01:27.030 --> 01:01:30.240
dong su: Okay, thanks. So the next question is on page five

396
01:01:32.160 --> 01:01:40.860
dong su: So have the the peak of the multiple 250. So what's the physics behind the peak of the wise to 50

397
01:01:41.520 --> 01:01:51.780
Zeeshan Ahmed: Yeah, good. So this is an excellent question. So why is that what you know what what is the business of this peak. Um, so you have a

398
01:01:53.670 --> 01:01:55.770
Zeeshan Ahmed: First approximation of photon.

399
01:01:55.830 --> 01:01:56.550
dong su: Bearing on through it.

400
01:01:56.640 --> 01:02:06.900
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

401
01:02:07.350 --> 01:02:17.760
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

402
01:02:18.510 --> 01:02:26.790
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,

403
01:02:27.330 --> 01:02:45.840
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

404
01:02:47.340 --> 01:02:54.840

Zeeshan Ahmed: Sizes. And so when that decoupling occurs when the photons are all finally free. Then they have walked away.

405
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.

406
01:03:02.490 --> 01:03:05.730
Zeeshan Ahmed: And what what this what the scales of its most prominent features work.

407
01:03:10.050 --> 01:03:10.290
dong su: I hope

408
01:03:10.680 --> 01:03:13.770
Zeeshan Ahmed: And if and if not, we can find some offline material to

409
01:03:15.330 --> 01:03:17.220
Zeeshan Ahmed: To link and go

410
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

411
01:03:27.330 --> 01:03:27.900
And

412
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

413
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.

414
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.

415

01:04:12.960 --> 01:04:15.240
Zeeshan Ahmed: Is does not have to contend with the atmosphere.

416
01:04:16.290 --> 01:04:20.040
Zeeshan Ahmed: Right. So there's a huge chunk of noise that is taken out.

417
01:04:21.060 --> 01:04:32.880
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

418
01:04:34.170 --> 01:04:40.770
Zeeshan Ahmed: Which ends up, meaning that you can use a lot pure blood meters, but also the other important thing is that

419
01:04:41.760 --> 01:04:53.460
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.

420
01:04:53.940 --> 01:05:08.010
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

421
01:05:08.430 --> 01:05:12.450
Zeeshan Ahmed: Seals okay so if you're measuring a CL, you're doing it with incomplete information.

422
01:05:13.350 --> 01:05:29.670
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.

423
01:05:30.870 --> 01:05:37.260
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

424
01:05:38.400 --> 01:05:39.810
Zeeshan Ahmed: That has to do with

425
01:05:42.090 --> 01:05:58.470
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.

426
01:05:59.760 --> 01:06:15.210
Zeeshan Ahmed: To 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.

427
01:06:16.470 --> 01:06:24.120
Zeeshan Ahmed: So you want expect. So there are there are no planned space missions or several proposals.

428
01:06:25.170 --> 01:06:26.220
Zeeshan Ahmed: In at the moment.

429
01:06:27.600 --> 01:06:36.510
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

430
01:06:38.520 --> 01:06:45.450
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

431
01:06:45.930 --> 01:06:58.140
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

432
01:07:04.470 --> 01:07:09.510
dong su: Okay, thanks. So I'm actually well here. There's another question.

433
01:07:11.250 --> 01:07:25.710
dong 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.

434
01:07:26.400 --> 01:07:35.610
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

435
01:07:35.670 --> 01:07:43.050
Zeeshan Ahmed: And the lending potential is primarily giving you the scale of again the most prominent features in in all of that lensing.

436
01:07:43.920 --> 01:07:53.070
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.

437
01:07:53.760 --> 01:08:04.110
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

438
01:08:05.430 --> 01:08:07.830
Zeeshan Ahmed: structuring your membership to and

439
01:08:08.220 --> 01:08:08.490
dong su: That

440
01:08:09.240 --> 01:08:11.130
Zeeshan Ahmed: Would you end up seeing over here, remember, is

441
01:08:11.460 --> 01:08:13.860
Zeeshan Ahmed: You're not getting you're getting an integrated

442
01:08:14.400 --> 01:08:15.150
Zeeshan Ahmed: Path of

443
01:08:15.210 --> 01:08:18.870
Zeeshan Ahmed: Light does come through right not seeing the fluctuations is a function of time. You're seeing

444
01:08:19.260 --> 01:08:22.890
Zeeshan Ahmed: What the results in any fluctuation is and how rather how much

445

01:08:23.940 --> 01:08:30.120
Zeeshan Ahmed: Deviation, there is 100 Amish deflection. There is of the lights, you're basically trying to see

446
01:08:31.800 --> 01:08:33.390
Zeeshan Ahmed: Going from this image to that image.

447
01:08:34.500 --> 01:08:47.760
Zeeshan Ahmed: 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.

448
01:08:47.760 --> 01:08:47.970
Right.

449
01:08:49.590 --> 01:08:53.730
Zeeshan Ahmed: It doesn't have to exactly correspond to what you see in the beauty and EMP

450
01:09:00.180 --> 01:09:00.750
dong su: Okay.

451
01:09:00.840 --> 01:09:01.230
Lisa Kaufman: Thank you.

452
01:09:02.220 --> 01:09:02.790
Lisa Kaufman: I think that's

453
01:09:03.060 --> 01:09:04.860
dong su: The end of our time working

454
01:09:06.180 --> 01:09:09.390
Lisa Kaufman: Well, this is actually the end of our time. So if this can be the last question.

455
01:09:09.600 --> 01:09:11.520
dong su: Okay, yeah, maybe the rest of

456
01:09:12.810 --> 01:09:12.900
dong su: It.

457
01:09:14.100 --> 01:09:14.280

dong su: Yeah.

458
01:09:15.270 --> 01:09:16.590
Zeeshan Ahmed: Okay, thank you.

459
01:09:18.750 --> 01:09:19.380
Lisa Kaufman: Thank you.

460
01:09:19.830 --> 01:09:21.180
Thanks to all the speakers.

461
01:09:23.040 --> 01:09:24.150
dong su: Are you gonna ask this one.

462
01:09:25.260 --> 01:09:25.710
dong su: Yeah.

463
01:09:27.660 --> 01:09:27.840
dong su: Yeah.

464
01:09:27.900 --> 01:09:28.230
God

465
01:09:34.080 --> 01:09:35.670
Zeeshan Ahmed: Do I can cure saddam now.

466
01:09:37.170 --> 01:09:38.520
Lisa Kaufman: Yeah, looks like he's muted.

467
01:09:54.540 --> 01:09:56.070
Zeeshan Ahmed: I think I caught it offline. Maybe

468
01:09:56.280 --> 01:09:56.580
Okay.

469
01:10:03.210 --> 01:10:04.770
dong su: That's the whole point.

470
01:10:05.940 --> 01:10:06.780
Zeeshan Ahmed: Okay, thank you.

471
01:10:06.840 --> 01:10:07.260
Okay.

472
01:10:10.650 --> 01:10:12.150
Lisa Kaufman: Okay, I'm going to stop the recording now.