WEBVTT

1
00:00:02.520 --> 00:00:03.090
Lisa Kaufman: Okay, great.

2
00:00:05.430 --> 00:00:11.190
Scott Dodelson: Okay, thanks for inviting me and nice to see none of you.

3
00:00:12.750 --> 00:00:22.020
Scott Dodelson: Would be nice to see some of you. I see. So they asked me to talk about cosmic neutrinos and unfortunately we can't do this interactively

4
00:00:23.160 --> 00:00:30.240
Scott Dodelson: And so I think I'm going to try to not take up too much time so we can have some time a little bit more time at the end.

5
00:00:31.380 --> 00:00:33.660
Scott Dodelson: So let's get started. Um,

6
00:00:34.770 --> 00:00:43.170
Scott Dodelson: You have the you should have the access to the file. Let me just show it to you and we'll walk through it together.

7
00:00:52.230 --> 00:00:53.760
Scott Dodelson: Okay, separate. Can everyone see this

8
00:00:56.550 --> 00:00:57.300
Scott Dodelson: Oh, you can't answer.

9
00:00:57.360 --> 00:00:58.320
Lisa Kaufman: We can we can

10
00:00:59.880 --> 00:01:00.300
Scott Dodelson: Well,

11
00:01:00.960 --> 00:01:10.230
Scott Dodelson: Okay, so then the. This is a series of standard picture you seen this a lot of times of the constituents of the energy density in the universe, and there's

12
00:01:10.800 --> 00:01:20.760

Scott Dodelson: People say that there's dark energy. People say that there is dark matter there definitely is hydrogen, helium, there are stars and are heavy elements. And it turns out we can say with

13
00:01:21.150 --> 00:01:29.190
Scott Dodelson: A fairly, fairly high level of confidence that they're also our cosmic neutrinos and that's what I'd like to discuss. I'm in the way of

14
00:01:35.250 --> 00:01:43.860
Scott Dodelson: So that here's a kind of a for context. Thank you, we discussed earlier in the week cosmology early times can

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00:01:44.700 --> 00:01:53.970
Scott Dodelson: Correspond to high temperatures, a lot higher energy. So this going vertically from top to bottom corresponds to going from time to equal to zero until today.

16
00:01:54.660 --> 00:02:03.240
Scott Dodelson: And so neutrinos really have played a role at many, many at box. So that's why they're of continuous continual fascination to cosmologists

17
00:02:03.570 --> 00:02:08.610
Scott Dodelson: At the very highest energies. It's conceivable that there are right handed neutrinos that

18
00:02:09.060 --> 00:02:16.320
Scott Dodelson: Produced the seesaw mechanism and the masses are likely to be in the 10th, the 10th GB Ranger even higher. So that's kind of

19
00:02:16.830 --> 00:02:20.760
Scott Dodelson: Potentially a portal to energy that can never be probed accelerators.

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00:02:21.240 --> 00:02:32.580
Scott Dodelson: And similarly for cosmology those right hand and nutrients may play a role in producing the battery on a symmetry in the universe, because if they can decay producing electron asymmetry. If you go down to

21
00:02:33.240 --> 00:02:37.770
Scott Dodelson: A nice soon. You can see my cursor. If you're down to about a GV or so.

22
00:02:38.430 --> 00:02:50.550
Scott Dodelson: That spell around during the last week phase transition can transform that leptons asymmetry into a bearing on a symmetry. So that's kind of something that's been studied a lot in our potential or potential

23
00:02:51.390 --> 00:02:59.580
Scott Dodelson: Observational ramifications of that throughout this whole epoch that we, although neutrinos our normal neutrinos are very

24
00:03:00.240 --> 00:03:11.340
Scott Dodelson: Are very weakly interacting that densities are so high that, as we'll see in a second, the neutrinos are maintained, I basically part of the cosmic plasma. So it's not just electrons and

25
00:03:12.090 --> 00:03:19.470
Scott Dodelson: And photons and protons. It's also neutrinos, they're interacting very rapidly with other stuff. So they're basically an equilibrium

26
00:03:20.370 --> 00:03:31.680
Scott Dodelson: Around 105 years. So if light sterile neutrinos exists. They were produced. So we might see them today if lights down neutrinos have mass in the kV range. They might be the dark matter.

27
00:03:32.640 --> 00:03:42.570
Scott Dodelson: Um, I'll focus mainly on observational signatures, namely will how we can actually detect the neutrinos by looking at the CMT and we'll hear more about that from zetia later today.

28
00:03:43.110 --> 00:03:49.170
Scott Dodelson: And then also how neutrinos. It can be detected the masses can be detected by looking at the growth of structure.

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00:03:49.830 --> 00:03:56.730
Scott Dodelson: And just to throw out one provocative idea that is not yet born fruit, the neutrino mass scale is similar to the mass scale of the

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00:03:57.150 --> 00:04:06.600
Scott Dodelson: What the energy density driving the current epoch of acceleration usually attributed to dark energy. So it's conceivable that some one of you will come up with the model that explains that coincidence.

31
00:04:08.130 --> 00:04:21.480
Scott Dodelson: OK, so moving on, let's let's discuss why it is that neutrinos. We were part of the cosmic plasma early on. So think about it. I will walk you through the the

32
00:04:22.140 --> 00:04:28.050
Scott Dodelson: The math, but that are the physics, but it's a pretty simple calculation. So what you want to do is you want to compare the

33
00:04:28.800 --> 00:04:36.270
Scott Dodelson: Rate for producing new tuners let's say they didn't exist. Initially, the rate for producing them with the typical time scale or the typical

34
00:04:36.600 --> 00:04:47.880
Scott Dodelson: The typical time scale in the universe, the time. So one of the top rate is the reaction rate for electrons times the cross section for producing neutrinos. So you can calculate that.

35
00:04:48.390 --> 00:04:54.030
Scott Dodelson: And the thing to compare it to. Is the Hubble rate and number eight, very early on was very high. But the

36
00:04:54.480 --> 00:05:06.330
Scott Dodelson: The reaction, it was even higher. So above if you do the math above about it if you me V neutrino that rate was higher than the expansion rate and therefore neutrinos were part of the cosmic plasma which means

37
00:05:06.690 --> 00:05:16.980
Scott Dodelson: That their distribution. There were completely equilibrated they have just as the photons today have a very pristine black body distribution. Similarly, the Fermi the

38
00:05:18.180 --> 00:05:26.430
Scott Dodelson: Neutrinos had a fairly direct distribution and their temperature was exactly equal to the, the temperature of the electrons and photons. That's what equilibrium means

39
00:05:27.660 --> 00:05:36.900
Scott Dodelson: When the temperature drop to blow a few MTV, the neutrino stop talking to the rest of the plasma. So what does that mean, it means okay they were no longer

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00:05:37.710 --> 00:05:42.720
Scott Dodelson: scattering off of them. But their distribution is applauded here, the black curve.

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00:05:43.200 --> 00:05:49.710
Scott Dodelson: It's, it's, if nothing else is happening. We just say the same would be this since they're not interacting. No, they just have the same exact distribution.

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00:05:50.100 --> 00:05:58.440
Scott Dodelson: Something was happening though the universe is expanding. So a neutrino with electronic five and maybe when the universe doubled in size.

43
00:05:58.770 --> 00:06:05.910
Scott Dodelson: Its energy would drop as you learned earlier to two and a half and maybe. So what happens to the spectrum. It's get shifted to the left.

44
00:06:06.300 --> 00:06:16.500
Scott Dodelson: So as neutrinos decoupled from the plasma. They actually the shape same, exactly the same. It's still I'm exactly the same from from your direct distribution. It's just that the temperature goes down.

45
00:06:17.130 --> 00:06:26.400
Scott Dodelson: So in fact, we know that. And that's exactly what happens with the photons and we know that that we know very well with the photon temperature is today. So we can calibrate off of that, and we

46
00:06:26.790 --> 00:06:37.890
Scott Dodelson: Can I predict that the number of neutrinos and anti-neutrinos for a given species is 115 there are getting 15 in in a region, the size of my fist or so.

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00:06:38.250 --> 00:06:49.950
Scott Dodelson: So that is a very definite prediction of the standard model of cosmology and that means that I'm the flux going through the the screen.

48
00:06:50.940 --> 00:06:56.340
Scott Dodelson: Well, if we were a person that would be the screen would be a meter big, but we're not in person. So let's say call it

49
00:06:56.940 --> 00:07:09.990

Scott Dodelson: 10 soon 10 centimeters big. So anyway, that the flux going through the was, I guess not quite 100 trillion spent a quadrillion cosmic neutrinos passing through the screen your screen every second. So there's tons of neutrinos around

50
00:07:11.760 --> 00:07:21.000
Scott Dodelson: So under a question is how we're going to detect those and people have been a lord with the possibility of detecting them.

51
00:07:21.660 --> 00:07:33.720
Scott Dodelson: Directly, but that turns out to be extremely difficult. So we're going to talk a little bit about indirect detection, but first let me point out that what I've said so far applies to active neutrinos, the normal three

52
00:07:34.800 --> 00:07:42.600
Scott Dodelson: The, the electron new on atomic tree. Now, there's the possibility of having STARING ON chinos, and there's the possible ability that those are light.

53
00:07:43.260 --> 00:07:54.690
Scott Dodelson: If that's true, then they too are produced in the early universe their production rate is different because they don't interact directly instead it's via oscillations and the rate has given them the upper left here.

54
00:07:55.320 --> 00:08:01.950
Scott Dodelson: With the mixing angle that relates the sterols to the to the actives I want you can see is that

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00:08:03.240 --> 00:08:11.880
Scott Dodelson: The for a large for a large range of parameters space there are, they're not produced it also in the bottom left, they're not produced at all. But if they

56
00:08:12.720 --> 00:08:19.800
Scott Dodelson: If they if the if the mixing angle is large enough for the mask were differences large enough, then the

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00:08:20.340 --> 00:08:27.720
Scott Dodelson: Than that, then they're produced basically is saying, with no would have the same abundance is the active neutrinos. So that would mean is

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00:08:28.080 --> 00:08:32.430

Scott Dodelson: Is the way we tend to parameters that let's say there was one lights down the tree. Now,

59
00:08:32.790 --> 00:08:46.170
Scott Dodelson: If its parameters were in this upper right range then instead of being three neutrino species, they were before and and Trina species. So we often refer to access non relativistic particles as contributing to this effective number of

60
00:08:46.590 --> 00:08:55.620
Scott Dodelson: Relativistic light relativistic species that was so sometimes called an effective. So if there is one light Sturm neutrino. That would mean and effective would be roughly four

61
00:08:58.890 --> 00:09:06.270
Scott Dodelson: Okay, so how are we going to detect them, they leave a subtle imprint on the sky blue Daniel mentioned earlier this week.

62
00:09:06.810 --> 00:09:25.770
Scott Dodelson: Stuff about the CM being will learn about it more, this afternoon. So it's a picture of what the universe look like when it was 380,000 years old. So let's just to be on the same page. Let's be clear about what picture means it's literally a picture, right, because the photons from

63
00:09:27.090 --> 00:09:36.120
Scott Dodelson: That were very, very that were so what happened in 380,000 years old as the electrons stop talking to the to the protons because all the protons were captured a neutral hydrogen

64
00:09:37.140 --> 00:09:39.780
Scott Dodelson: Side of photons stop talking to them. So the

65
00:09:40.890 --> 00:09:51.120
Scott Dodelson: So the photons traveled freely after that time. And what that means is photons that were relatively nearby us at where we are today have passed by us.

66
00:09:51.540 --> 00:10:01.710
Scott Dodelson: Photons that were very, very far away haven't reached just yet. So the only photons. We see come from a shell around us that such that the photons just are reaching us today.

67
00:10:02.040 --> 00:10:06.600

Scott Dodelson: So this picture this this CM be thing that people have seen is

68
00:10:07.110 --> 00:10:20.190
Scott Dodelson: Is the flux of photons from all directions from that shell and that's what the picture is right just booked on traveling freely to you from from an object. So we see what the universe was like when it was 380,000 years old.

69
00:10:21.360 --> 00:10:28.500
Scott Dodelson: And that's where we can make. We can make our money. So what was the universe, like we can apply basic physics to understand it.

70
00:10:29.310 --> 00:10:45.030
Scott Dodelson: So the neutrinos were not part of the cosmic plasma. They were not interacting strongly. However, the electrons, protons and photons were all tightly coupled. This was before the electrons and protons combine to form neutral hydrogen and

71
00:10:46.980 --> 00:10:54.450
Scott Dodelson: And so there were there scattering tightly together. If you had a clump of them there, they all move together. That is a single fluid.

72
00:10:55.560 --> 00:11:03.900
Scott Dodelson: And therefore they were subject to a restoring force if you had a dense region that was over dense over the course of time, it would

73
00:11:04.560 --> 00:11:13.470
Scott Dodelson: The Odense the many extra stuff particles in that region would flow out of there and would create an under dense region and vice versa. So just like a

74
00:11:14.280 --> 00:11:18.450
Scott Dodelson: String. If you pluck it, it goes from high to low desert Desert Storm force.

75
00:11:19.020 --> 00:11:33.570
Scott Dodelson: And that restoring forest leads to acoustic constellations and that means if you sit on a given point, you'll see the density go up and down. All are turning ugly if you sit at a given time, you'll see that the density fluctuate in space.

76
00:11:34.650 --> 00:11:44.520

Scott Dodelson: So that's one feature of what the universe was like at that time. Another feature is that on small scales the photons essentially do a random walk.

77
00:11:45.210 --> 00:11:52.140
Scott Dodelson: And they suppress the perturbation. So here's an example. The electrons are the blue are the black stuff and the photon is

78
00:11:52.890 --> 00:11:57.750
Scott Dodelson: The single photon is a red thing, and this is the path. The photon takes in a given time.

79
00:11:58.140 --> 00:12:05.880
Scott Dodelson: That same universe expands by a factor of two or so. So scattering off tons of electrons. And each time it scatters it changes directions.

80
00:12:06.180 --> 00:12:14.370
Scott Dodelson: And it undergoes tons and tons of scattering but basically any any perturbation on this scale of lambda d

81
00:12:14.880 --> 00:12:32.220
Scott Dodelson: The damping scale is going to be suppressed. So there'll be an exponential suppression in the in the spent in the in the distribution of of of of stuff of photons ON SCALES smaller than the stamping scale.

82
00:12:34.440 --> 00:12:39.720
Scott Dodelson: And other scale to keep to keep track of. Here is the mean three path that between us scanners.

83
00:12:40.740 --> 00:12:54.510
Scott Dodelson: Okay, so what does that mean for this for what we observe. Well, if you took a note of a musical spectrum you see exactly the same thing you'd see a fundamental mode at Miss case it's at looks like about 700 hertz and

84
00:12:55.650 --> 00:13:01.290
Scott Dodelson: And you see a bunch of higher harmonics. So that's what you see when you have acoustic oscillations.

85
00:13:01.560 --> 00:13:09.600
Scott Dodelson: And then the highest terminus would be damned out because things are suppressed for whatever reason for you know where mechanical reason, the case of a musical instrument.

86
00:13:09.930 --> 00:13:20.430
Scott Dodelson: So in this case, that's exactly the same thing, there's a there's a fundamental mode. And then there's the higher harmonics. And then there's going to be the damping. In this case, due to the fact that the photons can random walk out of us small region.

87
00:13:21.270 --> 00:13:24.660
Scott Dodelson: So, as you probably know, this is exactly what the spectrum we see looks like.

88
00:13:25.740 --> 00:13:33.060
Scott Dodelson: There's this acoustic scale, the fundamental mode. That's about a half a degree or so and then there's, um, as you move to the right.

89
00:13:34.140 --> 00:13:39.480
Scott Dodelson: There's um, the, the, there are these higher harmonics and eventually, there's the

90
00:13:39.870 --> 00:13:53.760
Scott Dodelson: The fluctuations damp out so I can get to very small Angular scales, say, a 10th of a degree or so the fluctuations become exponentially suppressed. So you can see, you can see that very clearly in the spectrum that probably you've all seen at one point or another.

91
00:13:59.370 --> 00:14:07.770
Scott Dodelson: Let's think a little bit about these two scales was, as you can imagine, with all the money that's been spent on the CB we can measure these

92
00:14:08.160 --> 00:14:16.380
Scott Dodelson: Features very well. And therefore, therefore, if they really are really effectively to skin cells in the problem we can measure, you know, there are

93
00:14:16.980 --> 00:14:25.770
Scott Dodelson: That sky, you saw, there's tons and tons of pixels. We can measure two parameters extremely well. So thinking about those two scales is pretty important.

94
00:14:26.520 --> 00:14:35.970
Scott Dodelson: Let's, let's try to understand how they are related to one another. So the acoustic scale is the wavelength fat, the wavelength between I'm

95
00:14:36.750 --> 00:14:47.820
Scott Dodelson: That it's essentially the distance that that a photon could travel the blood, the plasma could travel in a in a given in a given time, actually, by the time of of recombination.

96
00:14:48.210 --> 00:14:52.170
Scott Dodelson: So that is sometimes called the sound. The Sound Horizon at recombination.

97
00:14:52.470 --> 00:15:04.980
Scott Dodelson: And roughly speaking, that's just the speed of sound, which is roughly the speed of light. At the time, times because there's so many more photons and other stuff times time. So that means it's the acoustic scale is proportional to one power of the time.

98
00:15:06.240 --> 00:15:16.770
Scott Dodelson: The damping scales, a little bit different. The damping scale is a random walk. So that means it's on proportional to the mean free path, times the square root of the number of scatters.

99
00:15:17.610 --> 00:15:28.770
Scott Dodelson: And if you think about it, the number of scatters is the total distance a photon would travel in a given time t divided by the main three path right that's that's just the number of times it scatters.

100
00:15:29.190 --> 00:15:36.570
Scott Dodelson: And so therefore the the damping scale is proportional to the square root of the time at for example recombination.

101
00:15:37.140 --> 00:15:44.490
Scott Dodelson: And that means the ratio of these two scales should be proportional to the age of the universe at Rick combination

102
00:15:45.030 --> 00:15:51.360
Scott Dodelson: Recombination is dictated by the time at which electrons and protons combined to form neutral hydrogen

103
00:15:51.870 --> 00:16:03.060
Scott Dodelson: So what is what what what dictates the ratio of these two scales is the age of the universe at that temperature at that temperature of roughly a third of an electron folder so

104
00:16:03.900 --> 00:16:13.680

Scott Dodelson: So that at that temperature that what what the age of the universe is dictates what the ratio of these two skills is, which is something we can measure. So another. Another way of saying this.

105
00:16:13.920 --> 00:16:20.790
Scott Dodelson: Is since we can measure the left hand side here that this ratio extremely well we can measure the age of the universe that recombination extremely well.

106
00:16:22.410 --> 00:16:31.950
Scott Dodelson: And that's the thing that neutrinos tend to affect. So let me explain how that works. Thank you probably learned from Daniel probably newer you learned from Daniels discussion that I'm

107
00:16:32.400 --> 00:16:45.120
Scott Dodelson: Einstein's equations tell us that the expansion rate of the interest is proportional to the energy Denton square to the energy density maneuvers. So the more stuff there is, the faster the universe expands.

108
00:16:45.900 --> 00:16:52.080
Scott Dodelson: The age of the universe goes the other way, the energy Asian universe is inversely proportional to the expansion rate.

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00:16:52.710 --> 00:16:59.280
Scott Dodelson: So for example, if you have, if you add neutrinos, then what are you doing, you're increasing the expansion rate.

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00:16:59.760 --> 00:17:11.670
Scott Dodelson: And therefore you're dropping the age of the universe. So if you increase the number of neutrinos from zero to three, the age of the universe goes down from say 400,000 to 380,000

111
00:17:12.450 --> 00:17:17.460
Scott Dodelson: And similarly, if you would add a fourth neutrino if there would be a sterile neutrinos, it would go down even further.

112
00:17:18.840 --> 00:17:31.200
Scott Dodelson: So what does that mean for our scales, it means if the if the age of the universe went down if there were more neutrinos, then the damping scale would go up. That means, there would be more damping.

113
00:17:32.820 --> 00:17:41.370

Scott Dodelson: So in words, the more neutrinos. There are, the more damping, there is. And therefore, the less power there will be on small scales.

114
00:17:41.700 --> 00:17:49.980
Scott Dodelson: So these are the small scales and what you if there's no neutrinos would be more power. If there are three neutrinos, there would be less power for neutrinos even less.

115
00:17:51.810 --> 00:17:55.920
Scott Dodelson: So that's where we stand. Theoretically, where do we stand experimentally.

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00:17:57.270 --> 00:18:07.350
Scott Dodelson: Over the course of 30 years we've come a long way and measuring the anisotropy is in the microwave background. So we started off with a very low resolution.

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00:18:07.800 --> 00:18:12.600
Scott Dodelson: Experiment that covered the full sky and over the course of

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00:18:13.290 --> 00:18:26.310
Scott Dodelson: Three decades, I just, this is just a selection of the dozens, maybe closer to 100 by this point of experiments that have been done on the CB. This one's just here because I made that map but um but there's tons of

119
00:18:27.240 --> 00:18:35.640
Scott Dodelson: There's tons of experiments and they're all moving up into this right upper upper thing and that's something that will hear about again more facetiousness afternoon.

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00:18:36.420 --> 00:18:43.440
Scott Dodelson: And so one of the probably the strongest constraints currently come from the plank experiment, at least in this area.

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00:18:43.920 --> 00:18:50.940
Scott Dodelson: And what they what they've been able to show are these data points here. This is from this is actually from like 2015 data.

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00:18:51.330 --> 00:19:06.930
Scott Dodelson: And what they show is clearly know neutrinos is ruled out. So this is a an indirect, but it's still a detection of the cosmic

neutrino background, the fact that the point is some on this curve are clearly do not allow neutrinos.

123
00:19:07.710 --> 00:19:15.990
Scott Dodelson: So the so clearly true that the cosmic neutrinos exist. And you can imagine that we could even do better than that we could to help to say

124
00:19:16.350 --> 00:19:25.440
Scott Dodelson: Weigh in on the question of whether or not sterile nutrients exists. And just to go back for a second. There's a lingering anomaly in accelerator data.

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00:19:25.890 --> 00:19:34.320
Scott Dodelson: That another slight other data that point to this star as a possible reason for a certain neutrinos that would that would imply

126
00:19:34.650 --> 00:19:45.660
Scott Dodelson: If there are, if these anomalies are correct. That would imply that this should be, and we should see for these nutrients are an effective would be for. So let's see how that plays out with the most recent data.

127
00:19:46.680 --> 00:19:59.010
Scott Dodelson: So this is playing from a year or two ago. And so the gray Khan, said the time that points are just using one subset of the plant data.

128
00:19:59.520 --> 00:20:18.840
Scott Dodelson: And you can see that fairly conclusively they rule out for neutrinos. If you add in more data that is especially from the by an acoustic constellations. I'm not sure if they're too much. And those are not so but it a little more cosmological data you get a tighter constraint.

129
00:20:20.070 --> 00:20:35.730
Scott Dodelson: That that is the, the, quote, don't look at this, the quote is submit equal force run about Six Sigma and then I think you'll hear from Adam Reese next week. There's this lingering thing. There's a question whether or not there's the

130
00:20:36.780 --> 00:20:44.040
Scott Dodelson: Tension between a direct measurement of H naught and the CB measurement of H naught and then some kind of

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00:20:44.580 --> 00:20:50.010
Scott Dodelson: unruly people say you could reconcile those two with by adding several neutrinos, because you see

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00:20:50.820 --> 00:21:05.100
Scott Dodelson: You as their own tree knows that kind of helps with that record with that attention a little bit. So if you believe that tension and you really want to add another ellipse into your into your cosmological model than this would be one way to reconcile those things.

133
00:21:06.900 --> 00:21:20.370
Scott Dodelson: Okay, so that's in terms of life terms of how we probe those we also can probe the masses of the active neutrinos. And we do that by looking at structuring the universe. And for this, it's important to understand

134
00:21:21.750 --> 00:21:25.380
Scott Dodelson: That one of the probably the I said the greatest success of the

135
00:21:26.100 --> 00:21:35.850
Scott Dodelson: Customer a lot of cosmology over the past 50 years is the understanding of how we got from a universe, which was pristine and completely almost completely homogeneous.

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00:21:36.360 --> 00:21:47.280
Scott Dodelson: To a universe which today is very non uniform. The room you're sitting in on has an over density of tend to the 30th compared to an average place in the universe.

137
00:21:49.170 --> 00:21:57.630
Scott Dodelson: So how did we get from a place where that room had the same exact number of atoms within apart and 10,000 has any other room in the universe.

138
00:21:58.380 --> 00:22:07.800
Scott Dodelson: To a place where we're just so incredibly non uniform today and the fundamental thing that we've discovered is that evolution was driven by gravity these very, very

139
00:22:08.310 --> 00:22:28.320
Scott Dodelson: Small over densities gradually became more and more evidence due to gravity eventually forming galaxies, stars, planets and people. So, that is, if we had to pass down one sentence to to our, our kids, I guess, or grandkids, we would. I would say we should pass this down to them.

140
00:22:30.060 --> 00:22:39.390
Scott Dodelson: Anyway, so what does this mean for neutrinos. What it means for neutrinos is that they have the potential of impact and quantitatively this evolution of

141
00:22:40.590 --> 00:22:52.800
Scott Dodelson: How structure grow in a homogeneous growing universe. So to understand how that could happen. Here's part of the energy density relative to the total energy efficiency today of neutrinos as a function of

142
00:22:53.670 --> 00:23:03.030
Scott Dodelson: Of time or temperature. So this is early time. This is late time, the right hand side is very far right access today with the temperature of 2.7 degrees Kelvin.

143
00:23:03.660 --> 00:23:12.330
Scott Dodelson: So the black curve shows the matter in the universe. The, the, I'm baryons and the thing that people called dark matter.

144
00:23:12.750 --> 00:23:25.200
Scott Dodelson: And then the dashed blue curve is what the neutrinos would look the density of neutrinos would look like if they were mass less. Remember I think hopefully you learn from your know that relativistic stuff.

145
00:23:26.790 --> 00:23:35.010
Scott Dodelson: Loses density more because not only is the debt is the number density of particles getting diluted, but the energy per particle is getting diluted.

146
00:23:35.310 --> 00:23:49.440
Scott Dodelson: So they fall as t to the fourth instead of his t q so that their energy density, even though it was within 10 of the norm other matter at recombination by today it's it's completely it's completely irrelevant.

147
00:23:50.640 --> 00:24:07.380
Scott Dodelson: However, if neutrinos have mass, then that's not true anymore. Then they scare, just like the rest of matter and as at the time of recombination. They could be almost abundant energy as abundant energetically as the rest of matter. They today could be say up to 10% of the

148

00:24:08.610 --> 00:24:17.490
Scott Dodelson: Quite 10% of the of the matter. So that, so the possibility exists that these on these neutrinos today could make up

149
00:24:17.970 --> 00:24:28.770
Scott Dodelson: I'm quite a bit of the could could make up quite enough of the matter of entity to make a difference. And the reason that make a difference is that they cluster differently if you have I'm

150
00:24:29.970 --> 00:24:36.990
Scott Dodelson: Matt, if you just have mass list neutrino. So you just have all the matter in the universe is what's called cold, cold, cold dark matter, then you get to

151
00:24:37.470 --> 00:24:45.720
Scott Dodelson: simulate that with a, with an end body simulation, then you get structure that looks something like this. Very clumpy on small scales, whereas if neutrinos.

152
00:24:46.950 --> 00:24:52.500
Scott Dodelson: Account for a large fraction of the matter than the small scale structure gets wiped out because the neutrinos, they're not

153
00:24:53.430 --> 00:25:05.790
Scott Dodelson: Relativistic but they're still moving pretty fast, so they can basically you know this. A lot of nutrients in this region can spread themselves out and they get us. So the small scale stuff just gets moved out and you're only left with the large scale structure.

154
00:25:08.100 --> 00:25:14.640
Scott Dodelson: So that's something can see it visually here, in this case, we use a very large neutrino massive, it's not really

155
00:25:15.210 --> 00:25:34.920
Scott Dodelson: A lot of neutrinos. In this case, but, um, but more general and, more generally, even if even if the neutrino math neutrino contribution to the masses relatively small, then it makes a difference in what Daniel described as the power spectrum of matter. So a few things about this plot.

156
00:25:36.780 --> 00:25:49.440
Scott Dodelson: This is shows the power spectrum as a function of wave number I think Daniel introduced this on Monday. And so the wave number small wave numbers is large scale large numbers small scales.

157

00:25:50.520 --> 00:25:51.750
Scott Dodelson: And this is a

158
00:25:53.160 --> 00:26:00.480
Scott Dodelson: Dimension this quantitative measure of how clumpy the universe is so anything above one becomes nonlinear

159
00:26:01.200 --> 00:26:16.050
Scott Dodelson: And anything below on means it's relatively smooth. So that's one way to read this plot that this particular dimension. This combination is the wave number cube times what Daniel undefined is the power spectrum which is roughly the density square

160
00:26:17.070 --> 00:26:26.850
Scott Dodelson: And the overtime to the square with over density. The density in the given place divided by the main density, minus the mean density divided by the main density and it's the for a transformer

161
00:26:27.990 --> 00:26:37.620
Scott Dodelson: So that's the, that's the power spectrum. And this is the dimension. This combination that turns that power spectrum into something very useful. That is a quantifies whether something is

162
00:26:38.250 --> 00:26:46.410
Scott Dodelson: Homogeneous below this line or energy nice above this line. And what you see is on small scales. The universe is in homogeneous.

163
00:26:47.460 --> 00:27:01.230
Scott Dodelson: And what you also see is that if the neutrinos contribute quite a bit, then it becomes less than it becomes more homogeneous because there's structure gets suppressed on small scales, if there are more neutrinos goes

164
00:27:02.610 --> 00:27:10.740
Scott Dodelson: To one final comment out this plot, you might be tempted to say, oh, wait a minute. If the neutrinos are less massive they're more relativistic Fisher wipeout structure more

165
00:27:11.100 --> 00:27:24.150
Scott Dodelson: That's not true. So what happens is if the neutrinos are less massive it's true. They can travel further, but they can't the comprise a smaller fraction of the total mass of the of the of the matter, and therefore they have less than an impact.

166

00:27:24.570 --> 00:27:30.240
Scott Dodelson: So this is counterintuitive, but the larger the massive neutrinos, the more they suppress structure.

167
00:27:30.780 --> 00:27:43.110
Scott Dodelson: So that's something to just keep in mind, not because they don't, they still travel very far, whether it's truly travel less than these guys. But they still travel far enough to suppress the structure on the scales and what that what ends up happening is they

168
00:27:44.250 --> 00:27:48.990
Scott Dodelson: That they since they have that they contribute more than the energy density, they have more of an impact.

169
00:27:51.240 --> 00:28:03.660
Scott Dodelson: Okay, so how are we going to observe this, this is kind of a theory plot that just shows you that theoretically if we could measure the mat distribution of matter in the universe and take the Fourier transform plot the square the

170
00:28:04.230 --> 00:28:13.560
Scott Dodelson: The overtime studies, we could you know tell the difference between known neutrino. The university continues have no master, which they have a large mass

171
00:28:14.220 --> 00:28:24.930
Scott Dodelson: In react in reality of course, we cannot measure the matter because most of it is dark. So we have to resort to different techniques. And fortunately, there are about a dozen techniques for doing that here so white paper we

172
00:28:25.440 --> 00:28:36.690
Scott Dodelson: Produced about 10 years ago, which is actually pretty useful and we must did about 10 different methods and things. I think you'll hear about from Z Shar the top three here.

173
00:28:37.140 --> 00:28:49.230
Scott Dodelson: And maybe I'll spend a bit of time on this, but mentioned that these two things are things we're actively working on now in the dark energy survey DS will be worked on in the Reuben survey.

174
00:28:49.770 --> 00:28:52.440
Scott Dodelson: It's nice to see that a lot of these things are

175
00:28:53.130 --> 00:29:02.010

Scott Dodelson: This is now what's called busy so things have been renamed W first been named room. They've been a lot of things are on track. So that's, that's a good sign for the community.

176
00:29:02.280 --> 00:29:13.770
Scott Dodelson: That things that were kind of pies in the sky 10 years ago are actually going to be operating in your lifetime, and you'll be in your I mean as you start your careers and you'll be I'm reaping the benefits of

177
00:29:14.850 --> 00:29:31.890
Scott Dodelson: The work and maybe we could we helped a little bit by advocating for these things. Okay, anyway. So let me just give an example of how you might use say this a probe to measure the matter spectrum in the universe and have about 20 minutes left, so I think we're good.

178
00:29:34.950 --> 00:29:50.580
Scott Dodelson: Okay, so here's an example. This is a from the boss survey. And it's this this particular analysis was led by Ashley Ross, who is a colleague of mine, but a terrific scientist and

179
00:29:52.110 --> 00:30:01.170
Scott Dodelson: It's just, but this just one of one analysis of many. So this is I'm looking for galaxies in boss and this is a map of what

180
00:30:02.670 --> 00:30:16.290
Scott Dodelson: Of what the galaxies. They on the side of the galaxies that they chose to look at these galaxies. We can always locate galaxies on the sky, that's not particularly hard with much, much harder to do.

181
00:30:17.250 --> 00:30:24.480
Scott Dodelson: That's not true. It is hard to tell what's the galaxy and what to start. So that is hard, but it's, you can do it. Um, what's much harder at least

182
00:30:25.170 --> 00:30:35.790
Scott Dodelson: In terms of money is getting figuring out how far away they are and the boss survey was able to take specter of galaxies. And that was an enabled them to figure out

183
00:30:36.390 --> 00:30:38.730
Scott Dodelson: The redshift of galaxies, how much they the different

184
00:30:39.390 --> 00:30:49.590

Scott Dodelson: Say the OH two lines, for example, we're read shifted and armed with those redshift. They can estimate how far away, each galaxy was from us. So that means they're turning a 2D map into a 3D map.

185
00:30:49.890 --> 00:30:54.720
Scott Dodelson: Which is extremely powerful and and therefore able to do quite a bit can logically

186
00:30:55.440 --> 00:31:09.090
Scott Dodelson: So what they do when they, when they get this data is they essentially pixelized the survey. So if any pixel they compute the number of galaxies that should be there. If the universe was just completely homogeneous.

187
00:31:09.420 --> 00:31:15.240
Scott Dodelson: And the number that are actually there and they call that ratio. The over density called capital delta here.

188
00:31:16.320 --> 00:31:27.360
Scott Dodelson: And this is it looks. Looks simple but it's actually a ton of work that people like actually put into these things because figuring out how many galaxies. You expect in a given pixel depends on things like

189
00:31:28.020 --> 00:31:38.370
Scott Dodelson: You know, like whether there was a media or going through on a night you observed and maybe part of the pixel wasn't observed and stuff like that. So there's all kinds of complications and that hidden in that unexpected.

190
00:31:39.450 --> 00:31:47.940
Scott Dodelson: And then you form a quadratic estimator. So the power spectrum, as I mentioned is essentially the square of this delta, but in order to

191
00:31:48.660 --> 00:31:57.570
Scott Dodelson: Get extracted get an estimate or that's optimal in the sense that it has the lowest noise and it's not biased. You have to play games and people spent

192
00:31:58.200 --> 00:32:13.650
Scott Dodelson: Guess it's close to 3030 because it's been 25 years now. It's 30 years trying to get optimal estimators for this for this for this power spectrum. And there's a lot of them ways that people think of I'm

193

00:32:14.670 --> 00:32:25.020
Scott Dodelson: Doing this the way that I've written who's is one is one way that is you take the real space deltas and just take the symbol for a transforms and square

194
00:32:25.410 --> 00:32:40.470
Scott Dodelson: But because of this math stuff and edge effects and stuff. You got to be more clever than that. So, after doing that they get this. They take this data. Their estimated power spectrum. A lot of the work these days is

195
00:32:41.640 --> 00:32:47.100
Scott Dodelson: Related to getting the covariance matrix that is the essentially the errors on the on estimator.

196
00:32:47.640 --> 00:32:53.880
Scott Dodelson: And if you think of it, one way to think about this in terms of theory is that this is a two point function, the power spectrum.

197
00:32:54.390 --> 00:33:10.380
Scott Dodelson: And the covariance matrix is there for a four point function. And there's tons, tons elements. So sometimes it's not that easy to compute numerically. So, and it's not easy to compute analytical either. So this is a kind of a big area of effort, these days. Similarly with theory.

198
00:33:11.490 --> 00:33:18.240
Scott Dodelson: Seems simple because, you know, I just showed you a simple plot of the theory of the power spectrum, but then you have to remember that was the matter power spectrum and

199
00:33:18.660 --> 00:33:23.760
Scott Dodelson: Boss measure measures galaxies. So how to relate one to the other. And then you have to worry about the fact that

200
00:33:24.120 --> 00:33:34.050
Scott Dodelson: The redshift is not necessarily a good indicator of distance because galaxies may be moving with respect to the Hubble Flow. So things are pretty complicated in each one of these boxes.

201
00:33:35.010 --> 00:33:42.840
Scott Dodelson: And then you do the simple thing. You just combine it and you sample it at millions of points in a multi dimensional parameter space we're up to about

202

00:33:43.440 --> 00:33:54.480
Scott Dodelson: 30 and DS and are actually more but but you can. It's dozens of parameters and then you spit out one of the parameters will be the neutrino mass. And based on all this

203
00:33:55.290 --> 00:34:06.090
Scott Dodelson: Is the result from Java at all from I think that from that data set. And what they find is an upper limit of about. You can see it's about point three v or so. And since then.

204
00:34:06.900 --> 00:34:14.460
Scott Dodelson: There's been about 100 or so papers combining different data sets and roughly speaking, the upper limit now is about point two electron volts.

205
00:34:15.840 --> 00:34:26.640
Scott Dodelson: So that's one way where we can really help inform the neutrino community about some of the mysteries of Neutrino Physics that you heard about from Andre from early on this week.

206
00:34:27.840 --> 00:34:40.770
Scott Dodelson: I'm in terms of projections, as I said, some of these things have been relabelled the, um, the projections, I think, are holding up pretty well lensing. The length of galaxies think has gotten in maybe a bit more

207
00:34:41.490 --> 00:34:51.960
Scott Dodelson: Expected or desired is the expected error and electron volts. So, by the way, we know that the sub from the oscillation experiment that some industry knows masses has to be at least point oh six CV.

208
00:34:52.320 --> 00:34:57.000
Scott Dodelson: So something like this translates to a, you know, three or four sigma detection. So that's

209
00:34:57.570 --> 00:35:06.930
Scott Dodelson: Kind of where we're headed. And you'll have to wait facetious. I don't know if he will actually I'll mention in a second. What I think CBS for will give

210
00:35:07.410 --> 00:35:20.580
Scott Dodelson: But, um, this gives you a sense of what the current value is. We think we can do factor of 10 or so better than we were. We currently set. So that's kind of exciting in terms of will actually be able to should end up being a detection.

211
00:35:22.740 --> 00:35:28.800
Scott Dodelson: And here's another pictorial way of saying this again this goes back to the preparation, we did about 10 years ago the

212
00:35:29.250 --> 00:35:46.860
Scott Dodelson: Current cosmology at that point was about point five maybe now we're down to about point two or so that that what this shows is that the as you as you know, there are two measured parameters in isolation experiments and there are three masses. So there's one free parameter

213
00:35:47.970 --> 00:35:48.870
Scott Dodelson: If you take the

214
00:35:49.950 --> 00:36:04.560
Scott Dodelson: That free parameter be to be the lightest on neutrino mass then depending on whether the hierarchy is normal, the green curve or inverted, you get a definite prediction for the some of the neutrino masses, and this is why I said, since we know what

215
00:36:05.610 --> 00:36:08.970
Scott Dodelson: Those other two oscillation parameters are even if the lightest massive zero

216
00:36:09.360 --> 00:36:19.890
Scott Dodelson: The some indigenous internal medicine has to be at least point out 60 be in the normal hierarchy in. It can be as large as point want it can be, it has to be as large as point one in the inverted hierarchy.

217
00:36:20.640 --> 00:36:31.260
Scott Dodelson: So we are hoping for is that what everyone's looking for the inverted hierarchy which case we get a real solid detection of the sometimes you know masses and

218
00:36:31.740 --> 00:36:45.480
Scott Dodelson: This this this cosmology experiments in this sense are complimentary to the direct experiments, say for by Cat said, for example by Catrin so this is circa 2020. This is our estimate from seven years ago.

219
00:36:46.800 --> 00:36:52.530
Scott Dodelson: I think that limit that they came out with last year was point five. Is that right, anyway. There was so

220
00:36:53.070 --> 00:37:00.660
Scott Dodelson: They they're pretty much on target to get to where they're expected to go maybe they'll be your two behind our projections, but that's that's on target.

221
00:37:01.020 --> 00:37:08.790
Scott Dodelson: So this is, um, this, this is an interesting an interesting space to watch. So for example if if Catrin one interesting thing I'd like to

222
00:37:10.020 --> 00:37:14.970
Scott Dodelson: Keep you aware of is the possibility that Katrin detects something and we do not

223
00:37:16.170 --> 00:37:22.650
Scott Dodelson: So we're thinking of that possibility is something we should be thinking about because cosmology.

224
00:37:23.100 --> 00:37:31.530
Scott Dodelson: seems really successful because it predicts everything correctly. But you have to remember that it's it's made stuff up in order to be successful. It's made up dark matter.

225
00:37:31.800 --> 00:37:41.580
Scott Dodelson: It's made up of inflation and it's made up dark energy. So you could say successful or you can say we've just piled on ellipses on top of ellipses. So if I'm not if there becomes another

226
00:37:41.910 --> 00:37:52.200
Scott Dodelson: Kind of anomaly that shows up, for example, starting with neutrinos. If that accelerator and I'm really turns out it turns out to be true and cosmology says it's about six sigma

227
00:37:52.620 --> 00:38:01.050
Scott Dodelson: Then you could start to add games in the storm neutrino subtract sector or you could start to really go back to the basics and we need people like you to read be rethinking the basics. I think

228
00:38:02.700 --> 00:38:11.670
Scott Dodelson: There's another way that neutrino complimentary with them that cosmology is complimentary with I'm in Torino experiments.

229
00:38:12.210 --> 00:38:26.310

Scott Dodelson: So here on the x axis I put the some of the neutrino masses. And as I've said a one possibility is that will get a measurement here. So this could be for the either the inverted or for the on normal hierarchy. The the

230
00:38:27.390 --> 00:38:37.200
Scott Dodelson: The some instruments could just be measured could be point one. If you depend. It doesn't matter which hierarchy still be there and we will we will detect that if that's true with the next decade or so.

231
00:38:37.650 --> 00:38:46.620
Scott Dodelson: With very high Significance and the y axis is the mass that goes into trina's double beta decay that determines the

232
00:38:47.430 --> 00:39:02.820
Scott Dodelson: The lifetime for nutrients double beta decay, which is a you know, a very high priority because if it's detected that points to the neutrinos being my around particles that would be extremely exciting to detect that would be an amazing discovery to the tech that

233
00:39:04.050 --> 00:39:10.560
Scott Dodelson: Here's the future projection for where an Expo is going to be and so

234
00:39:11.340 --> 00:39:18.450
Scott Dodelson: One thing that it's there are several things interesting here. First of all their complimentary we measure the x axis, they measure the y axis. Second of all,

235
00:39:18.990 --> 00:39:30.060
Scott Dodelson: If we measure this and they measure that we're not only we're pointing to this point in parameter space, but we actually end up measuring one of the

236
00:39:30.750 --> 00:39:38.790
Scott Dodelson: Mirena phases in the neutrino mass matrix, which would be kind of amazing to think about. But I think more importantly

237
00:39:39.450 --> 00:39:50.700
Scott Dodelson: Let's say an XO gets to, you know, a limit of point two years. I'm like that. Let's say that's where they they get to this point O. T. They say we don't see anything.

238
00:39:51.360 --> 00:40:02.070

Scott Dodelson: And then I'm the experimental is go to the funding agencies and say, okay, we need a billion dollars to measure the the the neutrino was double beta decay.

239
00:40:03.600 --> 00:40:08.700
Scott Dodelson: And they'd say, You're out of your mind, you haven't yet seen it yet, we're not giving you a billion dollars to measure this thing.

240
00:40:09.330 --> 00:40:16.410
Scott Dodelson: But they can point to us and say, wait a minute. We know a detection is right along the horizon, because we know

241
00:40:16.710 --> 00:40:23.010
Scott Dodelson: That, um, that it's got the end this parameter and beta beta has got to be cosmology tells us we live in this region.

242
00:40:23.310 --> 00:40:31.200
Scott Dodelson: And that means the lowest and beta beta can be is is here. So we know we're going to measure with this experiment. So if we if you

243
00:40:31.590 --> 00:40:45.030
Scott Dodelson: You know, Jared Kushner fund this experiment you win the Nobel Prize. So you could definitely should definitely fund this. So that's something that I think in it. I think is actually the most synergistic thing between cosmology and the experiments.

244
00:40:46.710 --> 00:40:53.160
Scott Dodelson: Okay, so let me just close by mentioning another possibility for how neutrinos might impact cosmology.

245
00:40:54.450 --> 00:41:05.820
Scott Dodelson: The Sterling Trina sector is wide open in the sense that we know very little about it. And so one possibility is that this gentleman right handed neutrino grab a mass in the kV range.

246
00:41:07.020 --> 00:41:15.570
Scott Dodelson: And actually there's been some and if it did, then it turns out that that's a perfect dogmatic candidate and it's actually the reason why it's perfect.

247
00:41:16.470 --> 00:41:27.090

Scott Dodelson: Um, it was because it's pretty, it's very easy to predict what what their abundance should be and also neutrinos exist right so it's kind of, um,

248
00:41:28.050 --> 00:41:37.800
Scott Dodelson: You know, everything else that people propose. I mean, we don't know the Stormtroopers exists, but at least neutrinos exist. So, I mean, I think there's some

249
00:41:38.820 --> 00:41:50.310
Scott Dodelson: There's an almost every model almost every model of neutrinos will not. Maybe that's I think that's true. Most neutrino Miles have right hand in neutrinos, either in as

250
00:41:50.880 --> 00:42:00.780
Scott Dodelson: An indirect mass part or is in the seesaw mechanism. So almost all Miles have right hand and neutrinos. So I think that's a

251
00:42:01.410 --> 00:42:05.970
Scott Dodelson: That's a pretty good guess that right in truth exists. And if you grant me that then

252
00:42:06.450 --> 00:42:18.990
Scott Dodelson: You also have to remember, we have no idea what their masses. So saying that they would have a mass in the kV range is not necessarily crazy. And of course, we have this document all these anomalies that point to the existence of dark matter.

253
00:42:19.770 --> 00:42:25.500
Scott Dodelson: So all this by way of justifying the proposal that kV neutrinos could be dark matter.

254
00:42:26.760 --> 00:42:39.450
Scott Dodelson: And in fact of the past half decade or so, there's been evidence or hints anyway. Excellent. I know anomalies that suggested that that, um, there might be something there. There's an excess in

255
00:42:40.170 --> 00:42:53.850
Scott Dodelson: A stack signal for many galaxy clusters from Andromeda from several other cosmic sources of a signal that would correspond to a neutrino of seven kV to came to a photon and a lighter

256
00:42:54.480 --> 00:43:03.300

Scott Dodelson: An inactive neutrinos. So that's what that's what I'm we would. That's what we've seen an excess in this region, the fact that they're in the same place is kind of interesting.

257
00:43:04.110 --> 00:43:07.860
Scott Dodelson: So there's something that's exciting. Why did I spend so much time in that slide.

258
00:43:08.490 --> 00:43:14.160
Scott Dodelson: Um, well guess what about 30 years ago I wrote a paper about this some kind of still invested in this idea

259
00:43:14.610 --> 00:43:27.000
Scott Dodelson: Um, the mechanism that we proposed Larry and I proposed probably doesn't work for their production because it's been rolled out by other limits. But there are other ways people since I've come up with clever ways of producing

260
00:43:27.630 --> 00:43:34.020
Scott Dodelson: Sterile neutrinos and the anomalies with here. So there's still potentially, at least according to

261
00:43:35.340 --> 00:43:41.670
Scott Dodelson: Some people. I'm a possible candidate for dark matter. So this is something that I'm

262
00:43:42.810 --> 00:43:49.110
Scott Dodelson: That I think is at least worth keeping in mind as you try to synthesize all this information about cosmology.

263
00:43:50.010 --> 00:43:54.360
Scott Dodelson: Okay, I want to close with a personal opinion. That's kind of leaked through a lot of what I've said

264
00:43:55.170 --> 00:44:03.270
Scott Dodelson: You've seen this plot a million times, and the version. The reason I like this version is because it's, it, it's kind of like a stone.

265
00:44:03.930 --> 00:44:09.810
Scott Dodelson: Tablet. And so that kind of makes me think of the you know the 10 commandments. It's, you know, you can't break them, they're

266
00:44:10.350 --> 00:44:18.810

Scott Dodelson: They're just just set in stone. There's nothing that we can do about this, we have to live with dark energy dark matter. This is the model and we have to learn to live with it.

267
00:44:19.230 --> 00:44:37.320
Scott Dodelson: And if there's some problem with it. We just add new stuff we just add add stuff. And so that's why I think it's come to be part of our heritage and we have good reason for that. I mean, there's tons of data that support this this model I'm at the simplest level neutrinos could

268
00:44:38.940 --> 00:44:51.360
Scott Dodelson: disrupt this a little bit, or at least flesh this out by saying if if it's true that the sterile neutrinos have kV master. They could be synthesizing the neutrino sector with the dark matter sector that would be tremendously interesting

269
00:44:52.380 --> 00:44:55.500
Scott Dodelson: And more importantly, just kind of

270
00:44:56.760 --> 00:44:59.580
Scott Dodelson: Maybe it's not philosophically, but it's a psychologically

271
00:45:00.240 --> 00:45:02.520
Scott Dodelson: Um, if you go back in history of neutrinos.

272
00:45:02.880 --> 00:45:12.030
Scott Dodelson: Everyone always thought they knew everything. And they ended up not knowing everything they thought there was no neutrinos. Oh, there's a neutrino they thought there was one generation neutrinos. Oh, there's three generations and Seamus

273
00:45:12.270 --> 00:45:18.990
Scott Dodelson: They thought there's no mass. Oh there's math. So it's like it's it's your channels are literally a lesson in how we're always wrong when we think we're right

274
00:45:19.350 --> 00:45:27.150
Scott Dodelson: So that's I think another a hint. Perhaps that, at least to me that this picture is just wrong.

275
00:45:27.780 --> 00:45:37.170

Scott Dodelson: And then, um, and that leads to my my my feeling is my own personal feeling that we think we have a simple cosmological model that fits everything. And maybe we don't

276
00:45:37.590 --> 00:45:44.820
Scott Dodelson: And it's, it's possible that one of you will think about more compelling way to explain all this data without introducing things like dark matter and dark energy.

277
00:45:45.210 --> 00:45:52.500
Scott Dodelson: And it's also possible that in material discovery will will kind of be the thing that really breaks breaks this some this cosmic egg.

278
00:45:53.610 --> 00:45:54.600
Scott Dodelson: Okay, and that's all I had.

279
00:45:58.260 --> 00:46:09.960
Lisa Kaufman: Thank you, Scott for that really wonderful and entertaining talk. I really enjoyed it. So we'll hand it over, then, to see Don who will moderate the Q AMP. A. And since we finished early. We have plenty of time for questions.

280
00:46:11.940 --> 00:46:23.340
dong su: Okay, so we do have a quite a few questions. I hope that, see how many we can get through. So the first question is on page, page five

281
00:46:25.830 --> 00:46:30.030
dong su: If you can keep the slides up. Maybe it's easier to look and paste through them.

282
00:46:32.250 --> 00:46:33.930
Scott Dodelson: I'm sure

283
00:46:37.170 --> 00:46:39.450
dong su: So on page five

284
00:46:43.350 --> 00:46:44.100
dong su: There is a

285
00:46:47.250 --> 00:46:48.720
dong su: There's a mentioned about the

286

00:46:50.040 --> 00:46:57.900
dong su: peak at hundred meds. So the question is why the production or why the production is that Peter hundred me

287
00:47:00.120 --> 00:47:03.270
Scott Dodelson: Ah, yeah. I don't remember actually. The the

288
00:47:03.390 --> 00:47:03.870
Scott Dodelson: I mean,

289
00:47:03.930 --> 00:47:13.440
Scott Dodelson: The point is that if they don't interact the qualitative plan. I don't, I don't know specifically why it does peak there but I very early times the

290
00:47:14.550 --> 00:47:16.530
Scott Dodelson: The, the isolation. It's not

291
00:47:16.590 --> 00:47:23.430
Scott Dodelson: It's not interactions. Right, so they don't really gain so much from the fact that the

292
00:47:25.980 --> 00:47:26.280
Scott Dodelson: That true

293
00:47:27.840 --> 00:47:28.500
Scott Dodelson: Um,

294
00:47:29.760 --> 00:47:38.640
Scott Dodelson: Yeah, I actually don't know. No, I don't remember well enough. I mean, I learned I plotted this 25 years but I just don't remember why but but

295
00:47:38.670 --> 00:47:40.380
Scott Dodelson: Roughly speaking on

296
00:47:40.770 --> 00:47:46.650
Scott Dodelson: The awesome. It's the oscillations between the active in the soil that that determinant not scattering and that really changes.

297
00:47:47.280 --> 00:47:47.910
Scott Dodelson: In almost all

298
00:47:48.480 --> 00:47:51.450
Scott Dodelson: An almost all processes where you produce things

299
00:47:51.750 --> 00:48:06.060
Scott Dodelson: It's the production. The production rate is really high early on, but because this is not sorry not scattering processes because this is not a scattering process it qualitatively Changes the rate at which the things happen and i think i think what happens is the

300
00:48:07.380 --> 00:48:14.130
Scott Dodelson: This this effective mixing angle becomes extremely small at on very high temperatures.

301
00:48:18.030 --> 00:48:18.240
Scott Dodelson: Right.

302
00:48:18.750 --> 00:48:28.680
dong su: I think we probably don't need to worry about that in the end you you enter the the answers in the text in the Google doc for the eventual q&a anyway. So we have another chance.

303
00:48:32.190 --> 00:48:37.980
dong su: So let's move on to the next question. On page 14

304
00:48:41.700 --> 00:48:51.510
dong su: The why that seems as if a large number of neutrinos. The spectrum also ship to higher frequency, in addition to being a low power.

305
00:48:53.700 --> 00:49:01.530
Scott Dodelson: Right, good question. Again, I don't I don't dance on top of my head, but it is true that, um,

306
00:49:02.100 --> 00:49:12.300
Scott Dodelson: I didn't focus on the smaller shifts. I just focused on the ratio of these two scales, but really every parameter changes things a little bit. So think about the

307
00:49:12.840 --> 00:49:27.660
Scott Dodelson: So I said that this the frequency. So basically, what you're saying is the first scope the acoustic scale shifts the acoustic scale is the integral of the sound speed over time.

308
00:49:28.830 --> 00:49:41.910

Scott Dodelson: So one way to think about that is if time goes up, then the acoustic scale should go up as well. So does that work here. Let's see if we said that the time was up. There's no neutrinos.

309
00:49:42.720 --> 00:49:48.390
Scott Dodelson: The acoustic scale should get larger and that's that's actually true. So I do have the answer to that question.

310
00:49:48.390 --> 00:49:51.690
Scott Dodelson: So look at the no neutrinos slide. So remember the neutrino curve.

311
00:49:52.020 --> 00:50:04.380
Scott Dodelson: So remember, if there's no neutrinos, the age of the universe is larger. And that means the acoustic scale is larger. If the acoustic scale is larger. That means that

312
00:50:05.670 --> 00:50:11.820
Scott Dodelson: The first peak and the subsequent weeks will be a larger scales, which correspond to move into the left

313
00:50:16.020 --> 00:50:16.500
Okay.

314
00:50:22.620 --> 00:50:25.020
dong su: Yeah, maybe that's keep moving.

315
00:50:26.490 --> 00:50:43.500
dong su: On page 17 on the question or someone saying is, maybe still not quite clear that the plant data seem to exclude the possibility of sterile. The force for sterile sterile to another 14 you know

316
00:50:44.910 --> 00:50:54.630
dong su: Or is it the data and not quite saying that or including the car by whether the data is is excluding the fourth neutrino either sterile already

317
00:50:55.800 --> 00:51:01.920
Scott Dodelson: Yeah, so a lot of the plank data by itself is is um

318
00:51:02.520 --> 00:51:10.560
Scott Dodelson: Is I don't know what the thing that I've quoted, I believe, is from the arm the black

319
00:51:10.920 --> 00:51:15.030
Scott Dodelson: Contours which use some other cosmological data as well.

320
00:51:15.450 --> 00:51:20.970
Scott Dodelson: And that's the quote that is excluded at six sigma. So, the black contours.

321
00:51:21.330 --> 00:51:22.080
Scott Dodelson: You can almost

322
00:51:22.110 --> 00:51:31.920
Scott Dodelson: count it out so 123456 you can kind of see that it's good. Six Sigma for the for an effective equal to four.

323
00:51:32.550 --> 00:51:53.220
Scott Dodelson: I'm having said that, I'm as you can see a lot depends on what is a good example of one of those kind of games and cosmology days. What did you include so it kind of makes sense to check and see if the CMT data alone as I'm as

324
00:51:53.310 --> 00:51:54.210
Scott Dodelson: The term by these

325
00:51:54.690 --> 00:51:59.130
Scott Dodelson: That's what depicted by these dots, just the CSV data alone.

326
00:52:00.420 --> 00:52:20.580
Scott Dodelson: Whether that's consistent with what's called ba. Oh, here the cosmological data and have a structured data and crazy. They are. And so, combining them makes sense. No, it does not make sense to combine a value the dashed curve combines the black with

327
00:52:20.760 --> 00:52:22.050
Scott Dodelson: The gray and that

328
00:52:22.230 --> 00:52:35.730
Scott Dodelson: Probably does not make sense, at least not to me because you're combining data that seems to be at odds with each other. So of course you're going to end up in the middle. So it's kind of a game here. I mean, it's just it's a science, but it's a game to figure out

329
00:52:37.140 --> 00:52:45.810

Scott Dodelson: What it's kosher to combine and what it's not kosher to combine. I would argue that the, I mean, just by I. It does not look to me like it's kosher to combine

330
00:52:47.040 --> 00:52:49.500
Scott Dodelson: Those, those two datasets. Yeah.

331
00:52:52.320 --> 00:52:53.040
dong su: Okay.

332
00:52:54.750 --> 00:52:56.970
Scott Dodelson: So sorry brain to close. So then

333
00:52:57.480 --> 00:52:58.620
Scott Dodelson: If the question is

334
00:52:59.460 --> 00:53:03.930
Scott Dodelson: What to take away from Cosmo cosmology data, I would take away. Yes.

335
00:53:04.380 --> 00:53:15.960
Scott Dodelson: Then the one third lies during the show is excluded is excluded and therefore if many Boone, or whoever sees that that comes back to what I saying at the end that really is cause for everyone to rethink what's going on.

336
00:53:19.440 --> 00:53:19.860
dong su: Okay.

337
00:53:21.450 --> 00:53:30.120
dong su: Let's move on to the next one is actually back to the acoustic again. So have they been like sound, the second and the third piece.

338
00:53:31.620 --> 00:53:33.570
dong su: Is actually not 10

339
00:53:34.350 --> 00:53:42.570
dong su: So in the power of spectrums. I don't pay. I think the question says paid for but address page 10 I think yes, or some more there.

340
00:53:43.830 --> 00:53:49.350
dong su: So the why the for the third pick in particular is not an

341
00:53:50.970 --> 00:53:51.480
Scott Dodelson: Easy question.

342
00:53:53.040 --> 00:54:12.630
Scott Dodelson: Um, yeah. So maybe if you don't mind, I advertise. We just came out of Safari instrument and I just came out with the new version of modern cosmology that goes through this in quite a bit of detail. I'm sorry about that. But the answer is bounds so that

343
00:54:13.800 --> 00:54:18.030
Scott Dodelson: If, if there were no baryons then the I'm

344
00:54:19.260 --> 00:54:26.580
Scott Dodelson: Sorry, the more baryons there are so what what what this isn't a harmonic oscillator, it's you know, it's a forcing thing that's the

345
00:54:27.000 --> 00:54:30.870
Scott Dodelson: simplest case it's a forced harmonic oscillator. It's forced by gravity.

346
00:54:31.470 --> 00:54:37.890
Scott Dodelson: So a forced harmonic oscillator, typically what happens is you expect the odd and even peaks to be

347
00:54:38.220 --> 00:54:45.180
Scott Dodelson: Be at different heights and you can work out the math of that, if you want, because it basically it's it's oscillating around zero. And we're squaring it so the

348
00:54:45.930 --> 00:54:51.030
Scott Dodelson: The minimum say of the oscillation will be closer to the zero line than the maximum. So that's why you expect

349
00:54:51.480 --> 00:55:07.620
Scott Dodelson: The first speaking. The third piece to be high and the third peak in the fifth peak to be high and all the odd weeks behind all the even pics to be low. So the question is, so actually the, the other way around. The question is why is the third peak.

350
00:55:08.940 --> 00:55:15.480
Scott Dodelson: Not where the first peak is and answers because what you said in the question. It's actually damned. So, if not for damping, it would be up here.

351
00:55:16.200 --> 00:55:25.350
Scott Dodelson: Does that make sense so so that that's that that you actually do see the damping quite clearly here. And the reason why the reason. Yeah.

352
00:55:26.670 --> 00:55:39.480
dong su: And then your question was, because you use the sound of the analogy that yes, all that the sound of them and so soon, we should be looking compared to that. And then in that case, is it not them, but I think that where the passion.

353
00:55:39.510 --> 00:55:45.060
Scott Dodelson: Yeah, I think, I think if someone knows music more about midnight doing probably knows this, but I don't think

354
00:55:46.650 --> 00:55:53.280
Scott Dodelson: I'm obviously there's a forcing function. The case of musical instruments, because you're hitting them but um

355
00:55:54.360 --> 00:56:02.280
Scott Dodelson: I don't think that is I actually don't know. So I don't know whether I don't know if I'm going to say it, but in this case I do know quite a bit about it. And it turns out

356
00:56:02.730 --> 00:56:08.580
Scott Dodelson: That they should be there should be an odd, even, peak disparity and when I was talking about the baryons is

357
00:56:09.120 --> 00:56:16.200
Scott Dodelson: That the baryons kind of decrease the sound speed and therefore decrease the frequency of the oscillations.

358
00:56:16.560 --> 00:56:28.020
Scott Dodelson: And the lower the frequency, the more, the greater the disparity between the odd and even peak. So you can actually measure the barrier and density extremely accurately measuring the ratio of the first to the second peak.

359
00:56:31.320 --> 00:56:31.590
You know,

360
00:56:33.570 --> 00:56:45.060

dong su: Okay, so actually well on here. The next question is also related to some of the spectrum. So the question is that actually doesn't matter if you can stay on this page.

361
00:56:45.720 --> 00:57:01.680
dong su: Says neutrino. How do neutrinos further damage the acoustic oscillation. What neutrino can impact this spectrum as damping and also it at this point. Haven't neutrinos already broken equilibrium with the other

362
00:57:04.950 --> 00:57:13.980
Scott Dodelson: Okay, it was back to the last question. Hundred percent neutrinos are not interacting at all. So they're not interacting has nothing to do with the way they interact

363
00:57:14.460 --> 00:57:25.860
Scott Dodelson: All. It has to do with is how they contribute to the energy density of the Universe and therefore, and remember the energy density in the universe contributes to how fast the universe expands.

364
00:57:26.940 --> 00:57:33.690
Scott Dodelson: So does that I know the person, no one else can you can't say whether that makes sense. So, so, Don, you have to, you have to be the

365
00:57:33.780 --> 00:57:35.430
Scott Dodelson: Proxy here. Does that make sense.

366
00:57:37.080 --> 00:57:39.810
dong su: Of yes i think that that

367
00:57:41.100 --> 00:57:43.380
dong su: I think is in fact also that so

368
00:57:45.480 --> 00:57:45.960
Scott Dodelson: Okay.

369
00:57:46.410 --> 00:57:49.650
dong su: So the first part of the time being, I think the first part, I'm not sure if

370
00:57:50.280 --> 00:57:59.790

dong su: You heard that very nice is that the for the neutrinos in two weeks. Extent are in what way that the spectrum damping might might happen for the

371
00:58:01.200 --> 00:58:04.980
dong su: Tree knows if they, the number of neutrinos more or whatever, how would look like.

372
00:58:06.000 --> 00:58:21.720
Scott Dodelson: Right, so it has nothing to do with the interactions. It has to do solely with the effect on the expansion. So as we loosely derived here, the ratio. These two Scales. Scales as proportional to the age of the universe at recombination to the one half power.

373
00:58:22.500 --> 00:58:25.650
Scott Dodelson: And that age is what the neutrinos do effect.

374
00:58:26.100 --> 00:58:36.750
Scott Dodelson: So the neutrinos affect how old the universe's are the time temperature relation, the relationship between the temperature of the universe and the age of the universe. Why do they affect that.

375
00:58:37.200 --> 00:58:51.990
Scott Dodelson: Because they affect the expansion of the universe and on the Einstein's equations relate the expansion of the universe to the stuff that's in it. So anything that's in it. Neutrinos or dark energy or anything will will affect the expense.

376
00:58:52.020 --> 00:58:55.920
Scott Dodelson: With the affect the expansion rate. So, in fact, we've been calling these things neutrinos.

377
00:58:56.760 --> 00:58:59.940
Scott Dodelson: But, and so this is a good time to segue to what I think.

378
00:59:00.180 --> 00:59:16.020
Scott Dodelson: The way zetia will present it. It's actually not necessarily neutrinos. It could be any a thing. It was around at the time that increased would ever was around it would increase the density and therefore increase the expansion rate and therefore

379
00:59:16.200 --> 00:59:20.100
Scott Dodelson: If anything that increases the expansion rate what ends up happening is

380
00:59:20.970 --> 00:59:21.900
Scott Dodelson: It ends up

381
00:59:23.340 --> 00:59:30.120
Scott Dodelson: Ends up reduce decreasing the time decreasing age because the age is inversely proportional to the experience, right.

382
00:59:30.360 --> 00:59:40.680
Scott Dodelson: So you fat if you add any particle, not just neutrinos. Then you decrease the age of the universe at recombination and that leaves an impact on the ratio of these two scales we can measure

383
00:59:41.730 --> 00:59:42.450
Scott Dodelson: Does that make sense.

384
00:59:43.980 --> 00:59:45.390
dong su: Yeah, okay.

385
00:59:46.590 --> 00:59:50.190
dong su: Alright, so let's move on to the next one.

386
00:59:53.040 --> 01:00:02.280
dong su: On page 26 so

387
01:00:03.840 --> 01:00:11.370
dong su: Here's what can they expect a number of galaxies in in a pixel be a pain from embody simulation.

388
01:00:14.310 --> 01:00:23.490
Scott Dodelson: Ah, yeah, that's easy. Um, well, it's easy, because I'm sorry. Okay. Sorry. Um, it's easy to count them. The matter of

389
01:00:24.000 --> 01:00:32.820
Scott Dodelson: The Hammond. How many dark matter particles, there aren't in it and body simulation. What it does is it uses only dark matter particles and it

390
01:00:33.510 --> 01:00:49.890
Scott Dodelson: Starts them off with the initially pretty homogeneous state and it evolves them via gravity and so you couldn't do and they do indeed pixelized those simulations and count how many dark matter particles are in each box. I think maybe that what the question is asking is,

391
01:00:50.280 --> 01:00:52.410
Scott Dodelson: Okay, fine, but what about galaxies, how are

392
01:00:52.410 --> 01:00:54.330
Scott Dodelson: Those dark matter particles related to

393
01:00:54.330 --> 01:01:06.900
Scott Dodelson: Galaxies and this is what i. So, in other words, making a theoretical prediction for this is very difficult. So it does. It involves, as you say, I'm

394
01:01:08.040 --> 01:01:22.740
Scott Dodelson: Making a making a prediction for for using sometimes in body simulations to predict how the power spectrum looks like on small scales, but also understanding the relationship between galaxies and

395
01:01:23.700 --> 01:01:39.990
Scott Dodelson: And the matter. So there's one thing that helps us here and that is we don't really have to do embodies simulations. If much nonlinear include much nonlinear physics. If we stay to the left of this line that is anywhere where

396
01:01:40.170 --> 01:01:54.240
Scott Dodelson: The company. This is less than one. We're basically it's basically linear. So you don't have to worry about all these nonlinear effects that are captured in the simulations. So for and if you stick to case a less than point one, then you're all nonlinear friends are very

397
01:01:54.240 --> 01:02:05.310
Scott Dodelson: Very small. So that basically means you don't necessarily have to worry so much about um about nonlinear effects and and so I think one thing. And the second thing which is pretty

398
01:02:06.150 --> 01:02:14.940
Scott Dodelson: Has turned out to be true. And this, this involves going beyond and body simulations to do hydrodynamic simulations include baryons and star formation and stuff.

399
01:02:15.450 --> 01:02:26.130
Scott Dodelson: Is that on large scales again to the left of about point one or so the relation between the matter and the galaxies is fairly regular and that's an atom enormous

400

01:02:26.880 --> 01:02:33.810
Scott Dodelson: Effort of people to try to understand that that relation its ongoing on how galaxy forms and it was a fascinating question.

401
01:02:34.650 --> 01:02:50.430
Scott Dodelson: But for the zero to answer is that unmarked scales that relation between the galaxy density and the matter density is just linear. So it can be is typically captured, but just a single bias parameter parameter which is called the bias.

402
01:02:53.760 --> 01:02:59.820
dong su: Right. So I think that the question was, the expected number of galaxies can be obtained it was

403
01:03:00.540 --> 01:03:06.030
Scott Dodelson: OK, right. So that's different, the expected number of data galaxies in a survey.

404
01:03:07.230 --> 01:03:12.480
Scott Dodelson: Isn't isn't is not, I'm sorry. That's all right. Okay. Sorry. So that's not I'm

405
01:03:13.080 --> 01:03:19.680
Scott Dodelson: Predicting the survey that that that's not from simulations, that's just from the survey that is you look in the sky and you say, you can. How many galaxies. You have you have

406
01:03:20.220 --> 01:03:27.150
Scott Dodelson: You know 4 Million Galaxies and you just say okay this pixel is the surveys, this big the pixels this big

407
01:03:27.510 --> 01:03:43.560
Scott Dodelson: And so there should be you know 4 million divided by the times that ratio in not pixel. If the universe homogeneous unless there's things like part of the pixel couldn't be observed. So that really has nothing to do with in body simulations. It's more to do with observational facts.

408
01:03:45.390 --> 01:03:55.980
dong su: Okay, yeah, that sounds pretty clear. Um, so the next question on page 22

409
01:04:04.080 --> 01:04:04.500
dong su: So,

410
01:04:05.520 --> 01:04:06.540
dong su: At what point

411
01:04:07.590 --> 01:04:18.270
dong su: Would we be able to tell if the small scale structure is one or the other, a wooden the fact that neutrinos are known to have matters already

412
01:04:19.560 --> 01:04:21.960
dong su: Massive already eliminate some of the often

413
01:04:23.940 --> 01:04:24.420
Scott Dodelson: So can you

414
01:04:29.550 --> 01:04:30.630
Scott Dodelson: repeat the question, please.

415
01:04:31.410 --> 01:04:32.940
dong su: Right, so the question.

416
01:04:34.470 --> 01:04:35.940
dong su: Um, let's see.

417
01:04:37.590 --> 01:04:50.070
dong su: At what point would we be able to tell if the small scale structure is one or the other, wouldn't the fact that neutrinos are known to have mass already eliminate some dolphins.

418
01:04:51.990 --> 01:04:52.500
Scott Dodelson: Ah,

419
01:04:52.620 --> 01:04:53.820
Scott Dodelson: The problem knows that.

420
01:04:54.000 --> 01:05:04.020
Scott Dodelson: You know, yeah, if, if this was, this would probably be observable. But the problem is this. I think we ran this mass for 10 years having massive 10 electron volts.

421
01:05:04.410 --> 01:05:19.140

Scott Dodelson: You know factor of 100 or so, bigger than the current limit. So the simulation between an neutrinos, with no mass and point one electron volts is you can't you just can't tell anything by it.

422
01:05:19.170 --> 01:05:21.030
Scott Dodelson: So that's why you have to resort to these

423
01:05:21.630 --> 01:05:29.940
Scott Dodelson: Numerical things like the power spectrum. The statistics in order to get to extract out the information. There's just no way to just look at it by until the difference

424
01:05:33.330 --> 01:05:37.500
dong su: Right. Yeah. I think the question that were given the known neutrino methods with

425
01:05:37.530 --> 01:05:43.920
dong su: Some of the possible of these already been ruled out so you don't have to worry of them because they're not already a piece of certain

426
01:05:44.820 --> 01:05:53.160
Scott Dodelson: Yeah. So as I said, depending on who you talk to, roughly speaking, the current limit is point two. So anything any some of the masses above point two is ruled out.

427
01:05:57.630 --> 01:05:58.050
dong su: Okay.

428
01:05:59.580 --> 01:06:04.020
dong su: Let's maybe move on to the next one. This one has no patient number so

429
01:06:05.340 --> 01:06:15.030
dong su: Does the ratio, the ratio of abundance of neutrinos very matter of fact, the evolution of the universe. Okay, so that's a more general

430
01:06:16.320 --> 01:06:20.850
Scott Dodelson: And the ratio of the number of nutrients to the various masses, you're saying is that what is

431
01:06:21.030 --> 01:06:23.580
dong su: The question, the ratio ratio, the abundance of

432
01:06:23.610 --> 01:06:25.740
dong su: The Filipinos of various different types

433
01:06:26.250 --> 01:06:28.080
Scott Dodelson: Right, well that changed.

434
01:06:28.380 --> 01:06:47.550
Scott Dodelson: Yeah, I mean, I'm not sure anyone's actually looked at that I'm experimentally. It might be a fun thing to look at because theoretically, it's the prediction is that they're within a percent or so, all the same, they have the same abundance that electron, the talent and the neutrino so

435
01:06:48.600 --> 01:06:50.220
Scott Dodelson: Actually, I'm not sure.

436
01:06:51.480 --> 01:06:55.860
Scott Dodelson: And I yeah so it's of course we don't we don't detect them directly it's indirect.

437
01:06:55.860 --> 01:06:56.580
dong su: Detection

438
01:06:57.420 --> 01:07:01.020
Scott Dodelson: All we can really measure is the sum of all of them.

439
01:07:02.040 --> 01:07:16.140
Scott Dodelson: So we're, we're not we're not really weighing in and we and we measure it to be consistent with effectively, you know, three one plus one plus one. It could be, you know, there's two of one type one of them know that you know there's twice as many electronic neutrinos, as we think

440
01:07:17.730 --> 01:07:23.100
Scott Dodelson: Just as many town neutrinos and no neon neutrinos that could be we hadn't rolled out that possibility.

441
01:07:23.580 --> 01:07:26.220
Scott Dodelson: But that seems there's no

442
01:07:26.340 --> 01:07:28.290
Scott Dodelson: Way I would be able to understand that.

443
01:07:28.290 --> 01:07:35.850
Scott Dodelson: Theoretically, and we don't have an experimental way of distinguishing those because we all, we all we care about is their, their contribution to the energy

444
01:07:36.900 --> 01:07:39.330
Scott Dodelson: Or always measures the contribution the energy

445
01:07:40.530 --> 01:07:44.550
dong su: Yeah. Okay, so the next one is on Page 33

446
01:07:45.750 --> 01:07:49.410
dong su: There are some access access and basically the asking

447
01:07:51.030 --> 01:07:53.490
dong su: Is are some kind of matter. How many sigma is the

448
01:07:53.490 --> 01:07:53.910
Asset

449
01:07:55.830 --> 01:07:56.940
Scott Dodelson: Um,

450
01:07:57.750 --> 01:07:59.310
Scott Dodelson: Yeah, I don't think that

451
01:08:00.180 --> 01:08:00.690
Right.

452
01:08:02.970 --> 01:08:17.850
Scott Dodelson: The number of my head is three sigma but i think that i think there's been enough claim detections from enough different places that the statistics at this point are not so much the issue. The issue is more the systematics that

453
01:08:17.850 --> 01:08:27.810
Scott Dodelson: Is calling get an access means you have to have a model for what you know people slack are really experts in this. I'm not but

454
01:08:29.040 --> 01:08:34.170
Scott Dodelson: You have to have a model of what the signal should be. And that model typically involves things like

455
01:08:34.860 --> 01:08:51.570
Scott Dodelson: Lines from metals and stuff like potassium and all these metals and, you know, there's all these different lines and access means you think you have that model, you know, extremely well in hand. And that, I think that's the that's that's the

456
01:08:51.600 --> 01:09:06.660
Scott Dodelson: Biggest suspicion about a nice to my mind about whether or not this is correct, not so much the statistics, it's, I mean, it's not a 10. Second thing, but it's been seen at the three single level from enough different places that it's pretty, it's that and statistical front is pretty interesting.

457
01:09:07.830 --> 01:09:08.070
Scott Dodelson: Yeah.

458
01:09:08.430 --> 01:09:18.690
dong su: OK, so maybe one last one back of one of the earlier questions also on page 30 athlete right right before here 3231 of

459
01:09:20.940 --> 01:09:25.590
dong su: Can you clarify about using the lateral week phase transition wireless see

460
01:09:26.640 --> 01:09:27.030
dong su: I'm

461
01:09:27.270 --> 01:09:30.450
Sorry 3132 31

462
01:09:32.070 --> 01:09:35.070
Lisa Kaufman: Sit down and Scott, this will have to be the last question, because for

463
01:09:35.070 --> 01:09:38.580
dong su: It. Yeah, that was intended to be the last question is

464
01:09:39.150 --> 01:09:42.930
Scott Dodelson: Using the ELYSEE Selectric phase transition. Sorry.

465
01:09:44.550 --> 01:09:51.540

dong su: Right. So I think the question is that, can you part about using the electoral week as transition for Alex see

466
01:09:55.110 --> 01:09:57.210
dong su: Exactly what it is relating to the

467
01:10:03.450 --> 01:10:17.100
Scott Dodelson: Yeah, I don't know the I made an offhand comment at the beginning that the seller ons that happened around electric phase transition could transform the neutrino trends come true Baronet symmetry and also

468
01:10:18.210 --> 01:10:27.270
Scott Dodelson: That's well that would be in for a scale well above the LA. He scale, but I don't remember. Sorry if I said something about the election. I don't remember.

469
01:10:30.030 --> 01:10:38.040
dong su: Yeah okay so we can probably deal with that later offline as well. That's the end of the question which would pose right now. Yeah. Thanks very much.

470
01:10:38.850 --> 01:10:39.210
Scott Dodelson: Okay.

471
01:10:39.390 --> 01:10:44.070
Lisa Kaufman: Thanks, everyone. Thanks again, Scott. We know you're busy with your collaboration me

472
01:10:44.460 --> 01:10:45.780
Scott Dodelson: Thanks again. I

473
01:10:46.110 --> 01:10:47.100
Lisa Kaufman: Will talk all

474
01:10:47.160 --> 01:10:51.150
Lisa Kaufman: Right, we're going to stop the recording and we'll have a an eight minute break before next time.