WEBVTT

1
00:00:03.419 --> 00:00:16.139
mark convery: So today we're very pleased to have with our first speaker slacks own Aaron Goodman, who will give us first of two lectures on dark energy. So Aaron is going to share your screen and

2
00:00:18.330 --> 00:00:18.900
mark convery: Take it away.

3
00:00:23.490 --> 00:00:24.480
Aaron Roodman: Alright, thanks, Mark.

4
00:00:26.340 --> 00:00:29.340
Aaron Roodman: So it's a pleasure to talk to you this morning. I hope everyone's doing well.

5
00:00:30.660 --> 00:00:34.380
Aaron Roodman: My lectures are entitled present and future dark energy pro

6
00:00:35.820 --> 00:00:39.900
Aaron Roodman: And what I'm going to do is today.

7
00:00:41.760 --> 00:00:43.170
Aaron Roodman: I will talk about

8
00:00:44.520 --> 00:00:46.830
Aaron Roodman: The present and talk about

9
00:00:47.970 --> 00:00:56.730
Aaron Roodman: Some recent measurements of dark energy. And since this is a summer school and not a seminar. I'm going to dive into one particular measurement

10
00:00:58.140 --> 00:01:06.330
Aaron Roodman: In in more detail and then tomorrow, the second lecture I'm going to focus on the future and I'm going to talk about

11
00:01:06.870 --> 00:01:18.300
Aaron Roodman: One of the talk about a new telescope project that I'm part of and give you some insight into how we're building that project and how we're going to optimize it. So either energy

12
00:01:19.350 --> 00:01:21.300
Aaron Roodman: Okay. So then let's launch in

13
00:01:24.180 --> 00:01:26.700
Aaron Roodman: And start with the discovery of accelerated expansion.

14
00:01:28.380 --> 00:01:32.220
Aaron Roodman: So in the late 90s, two different groups.

15
00:01:33.600 --> 00:01:42.870
Aaron Roodman: Started looking for type one, a supernova. So the top, the top image is a before and after and a difference.

16
00:01:44.070 --> 00:01:48.090
Aaron Roodman: Showing the capture of a supernova and

17
00:01:49.410 --> 00:01:58.950
Aaron Roodman: It's not any supernova. It's a certain time type on a supernova, which are discovered to have a common level of brightness and

18
00:01:59.700 --> 00:02:14.460
Aaron Roodman: With some important work to looking at the time behavior. The time history of each supernova are going to actually correct the brightness and make them even more regular and so those formed a standard candle.

19
00:02:15.510 --> 00:02:21.450
Aaron Roodman: That could be used to study the expansion universe. And so this this plot.

20
00:02:23.550 --> 00:02:30.750
Aaron Roodman: Which is compilation of the supernova found by the two groups, the highs, the supernova team and the Supernova Cosmology team.

21
00:02:32.250 --> 00:02:50.580
Aaron Roodman: shows the difference between the brightness the supernova minus the expected brightness. It's in magnitude. So this is fainter, this is brighter as a function of redshift and comparing nearby supernova to those that higher redshift Richards and around a half

22
00:02:51.870 --> 00:03:12.360

Aaron Roodman: Of what was seen is that the supernova were fainter than expected. If the universe was only made of matter and the curve. The zero per here is the case where the density universe was too low, lower than a critical density of the one in which case the universe was expected to expand forever.

23
00:03:14.160 --> 00:03:19.260
Aaron Roodman: Um, and the data was actually not consistent with that it was more consistent with this top line.

24
00:03:21.510 --> 00:03:33.180
Aaron Roodman: Which one found from the universe. This 30% matter and the rest. Something else dark energy. And so this work, a representative to discovering that the

25
00:03:34.470 --> 00:03:36.390
Aaron Roodman: Expansion universe was accelerating.

26
00:03:37.650 --> 00:03:53.580
Aaron Roodman: And led to the Nobel prize or to the three. The three liters of this work in 2011. In fact, I think it will hear from Adam Reese, one of those Nobel laureate, so later this afternoon, talking about his most recent research studying the whole printer.

27
00:03:55.710 --> 00:04:05.040
Aaron Roodman: So this is how we discovered that the expansion universes actually accelerating and that there has to be a component of the universe that we call dark energy.

28
00:04:06.810 --> 00:04:07.260
Aaron Roodman: So,

29
00:04:08.490 --> 00:04:20.100
Aaron Roodman: Let's start at the beginning. What do we know about dark energy. Well, actually, even before I want to just make a comment about the term. And I think the term, you know, for non scientists. The term is often confusing.

30
00:04:22.140 --> 00:04:30.000
Aaron Roodman: Because we have another term that you heard about these lectures. Dark matter are turned into the to the kind of matter in the universe.

31
00:04:30.450 --> 00:04:38.430

Aaron Roodman: That don't currently identify but doesn't shine and stars is an atom's is forks and isn't leptons at something else.

32
00:04:39.270 --> 00:04:50.820
Aaron Roodman: So dark energy sounds similar, but of course it's a totally different phenomenon. So dark energy really is just determined. It's given for the cause. Weeks already an expansion. It's actually due to to a

33
00:04:52.110 --> 00:05:06.630
Aaron Roodman: Lecture by Mike Turner, just after this discovery was made previously called the vacuum energy and perhaps that some more accurate term because that's really what it looks like. And it is essentially

34
00:05:07.980 --> 00:05:17.670
Aaron Roodman: Einstein's original cost washer constant or at least that's the structure that it has. So okay, so now that's the term dark energy. What do we know

35
00:05:19.020 --> 00:05:33.090
Aaron Roodman: About it. Okay, so we really only know a few things. First, we know the magnitude of lambda or omega lambda. And so I hope you'll recall from Daniel ruins lectures at the start of the school.

36
00:05:33.750 --> 00:05:46.350
Aaron Roodman: Omega lambda is the critical dense is the fraction of the critical density that is held by the energy density of dark energy. So, omega wave, um,

37
00:05:47.790 --> 00:05:48.420
Aaron Roodman: The

38
00:05:49.770 --> 00:05:53.700
Aaron Roodman: The value. So the 70% is equivalent to

39
00:05:55.440 --> 00:06:00.630
Aaron Roodman: An energy density in the universe of three and a half proton mass equivalents per cubic meter.

40
00:06:01.860 --> 00:06:07.860
Aaron Roodman: So it is so we know that number as a dilute as a fairly dilutes quantity

41
00:06:09.150 --> 00:06:10.560

Aaron Roodman: Spread throughout the universe.

42
00:06:12.090 --> 00:06:21.270
Aaron Roodman: The second thing we know is the equation of state. So you remember from thermodynamics or system mechanics, the equation of state is the pressure to density ratio.

43
00:06:22.740 --> 00:06:29.520
Aaron Roodman: non relativistic matter. It's quite close to zero. Just a little bit of both. Zero for photons. It's a third

44
00:06:31.320 --> 00:06:43.230
Aaron Roodman: Or a vacuum energy. It's going to be negative and for dark energy, the data so far is consistent with it being minus one. And that's what you expect from a cosmological constant

45
00:06:44.070 --> 00:06:51.540
Aaron Roodman: So of course, that's weird. And that's one of the weird aspects of a vacuum energy or dark energy is that it has negative pressure

46
00:06:52.350 --> 00:07:11.400
Aaron Roodman: And that's equivalent to the fact that as the universe expands the density of dark energy stays constant unlike regular matter or radiation or anything else where the density of course goes down as the universe expands dark energy.

47
00:07:12.690 --> 00:07:19.710
Aaron Roodman: Or vacuum energy density stays constant and that's totally equivalent to the fact that you have a negative pressure

48
00:07:21.930 --> 00:07:33.510
Aaron Roodman: What else do we know well actually we assume one other thing I guess there's no evidence against this. It's hard to imagine this wouldn't be true is that the dark energy is homogeneous. Obviously, if it's connected in any way to the vacuum.

49
00:07:34.680 --> 00:07:36.960
Aaron Roodman: You know that's that's one of our most important

50
00:07:38.490 --> 00:07:42.180
Aaron Roodman: Assumptions about the universe is that is that it's homogeneous.

51

00:07:43.470 --> 00:07:58.740
Aaron Roodman: But really we it's assumed mostly the others. There's not really incisive evidence yet, but this is not the case. And you got will change and will be will be evidence the measurements directly probing this in the future. Okay, so that's what we know.

52
00:08:00.180 --> 00:08:01.560
Aaron Roodman: What do we measure so

53
00:08:02.880 --> 00:08:08.610
Aaron Roodman: This is from review article first understand skolnick from from I guess it's two years ago now.

54
00:08:09.780 --> 00:08:17.160
Aaron Roodman: That updates the supernova data with a collection called pantheon. So that's have multiple groups.

55
00:08:18.330 --> 00:08:28.050
Aaron Roodman: Representing you know at the time. All the supernova pathologically observe supernova and combining that data. And so the curves.

56
00:08:29.670 --> 00:08:43.080
Aaron Roodman: Here show our most favorite region and parameter space for a mega matter and the mega lambda, the constraint from microwave background and the flatness, the universe is this line which is just the

57
00:08:44.640 --> 00:08:57.150
Aaron Roodman: The total density is the critical density. The original discovery of the accelerated expansion before these curves and here's the new data, which is, you know, if you look at that data, it is

58
00:08:58.800 --> 00:09:02.310
Aaron Roodman: It is quite compelling today, leading to these very small

59
00:09:03.840 --> 00:09:19.980
Aaron Roodman: Preferred regions in parameter space. And then if we we can look in if we if we allow the equation of state to be different than minus one. So here we're assuming it's minus one, but feel out to be different than minus one, we get these

60
00:09:21.030 --> 00:09:26.940
Aaron Roodman: These regions of parameter space. So this is in W creation state animated matter.

61
00:09:28.140 --> 00:09:29.880
Aaron Roodman: Fraction critical density and matter.

62
00:09:31.050 --> 00:09:44.670
Aaron Roodman: So it's, it's the most preferred region is pretty close 2.3 and minus one. And you can see that the data points to the equator state n minus one to

63
00:09:45.180 --> 00:09:59.940
Aaron Roodman: You know, between five and 10% in this in this combination of different measurements which include my quick background very on acoustic oscillators also there. I'll talk a little about that tomorrow. And then the supernova data has shown here.

64
00:10:00.960 --> 00:10:10.230
Aaron Roodman: So at this point we actually do know a lot. We know these two parameters describing dark energy to pretty reasonable precision.

65
00:10:12.630 --> 00:10:14.160
Aaron Roodman: Okay, now what don't we know

66
00:10:16.080 --> 00:10:28.290
Aaron Roodman: And you will. Well, so what don't. First is, there's a typo. Sorry. It should be a minus one year. Sorry, is equal to minus one to mine precision.

67
00:10:30.090 --> 00:10:39.450
Aaron Roodman: Well, we don't know that 1%. You might even ask what you know what precision is good enough. That's actually an important question that doesn't have a clear answer.

68
00:10:42.120 --> 00:10:49.140
Aaron Roodman: Is W constant over cosmic time. Often, we could write it's we could

69
00:10:51.120 --> 00:10:54.000
Aaron Roodman: surmise that w depends on

70
00:10:55.200 --> 00:10:57.750
Aaron Roodman: Cosmic time. So the expansion parameter a

71
00:11:00.060 --> 00:11:05.070

Aaron Roodman: simplest thing is to assume a linear form and we can try to measure this slope.

72
00:11:06.450 --> 00:11:18.060
Aaron Roodman: And see if w is really constant you expect it to be constant depending on the model, but it's a very that will tell you an enormous amount about what dark energy gives so

73
00:11:19.320 --> 00:11:22.200
Aaron Roodman: Constraints of this parameter actually quite poor.

74
00:11:23.640 --> 00:11:36.780
Aaron Roodman: So those are two things we go now. And the third maybe most important is we don't know what dark energy is and I think there's a lecture for a mark dragon I believe this afternoon he will talk about this question, but

75
00:11:38.310 --> 00:11:50.220
Aaron Roodman: The three possibilities are that the dark energy is just a cosmological constant. In that case, W will be exactly minus one and will never change. So the slope is zero.

76
00:11:52.230 --> 00:11:58.290
Aaron Roodman: Could be a quantum field of some sort. Then there's the least the possibility that it changes with cosmic calm.

77
00:11:59.490 --> 00:12:02.880
Aaron Roodman: And it could be a model could require a modification of general relativity

78
00:12:03.900 --> 00:12:14.640
Aaron Roodman: So you'll hear more about that. I would say even though the cosmos with constant books like The simplest explanation and is consistent with the data. We definitely don't know the answer to this, but

79
00:12:16.290 --> 00:12:26.370
Aaron Roodman: The next thing we don't know is why is the value so small and the comparison that people make is to the value of the vacuum energy

80
00:12:26.850 --> 00:12:49.860
Aaron Roodman: Compared to the plank mass to the fourth power. And if you do kind of a very simple minded calculation of the vacuum energy and you cut off at the Planck scale. This is the, this is the value you would

nicely expect it's you. You could ask questions about whether that calculation is valid.

81
00:12:51.180 --> 00:12:54.510
Aaron Roodman: But as an order of magnitude, you might expect it to be reasonable.

82
00:12:56.430 --> 00:13:01.260
Aaron Roodman: But it's well hey way off. So why is the value so small. We don't know.

83
00:13:02.280 --> 00:13:15.240
Aaron Roodman: And then I would actually add one more thing that we dumbed down and that is will vacuum energy current Backman keep it current dark energy. Well that persist into the indefinite future

84
00:13:16.830 --> 00:13:20.220
Aaron Roodman: I think that's actually kind of a curious question. We don't know the answer.

85
00:13:21.840 --> 00:13:32.460
Aaron Roodman: Alright, so how do we measure dark energy. Well, we can only measure it through the expansion of the universe, because it's, it doesn't have any particle interactions in a super dilute

86
00:13:33.870 --> 00:13:43.260
Aaron Roodman: That's the only way we can measure it. So we have to study the expansion of the universe, and we want us that the studies kind of break into two categories, and this

87
00:13:43.890 --> 00:14:00.300
Aaron Roodman: One geometrical tests. And that's what the standard candles of supernova are very on acoustic isolation is also a geometric test and it really depends on comparing the distance proper distance as a function of redshift in different ways.

88
00:14:02.130 --> 00:14:13.140
Aaron Roodman: The other method. And this is what I'm really going to focus on almost exclusively for going forward in this lecture is tests that use gravity and, in particular, what is

89
00:14:14.580 --> 00:14:27.930
Aaron Roodman: Termed structure of growth of structure. So structure means any non homogeneity of matter in the universe today galaxies

clusters of galaxies, etc. And so you have those evolve over constantly Tom

90
00:14:29.070 --> 00:14:30.000
Aaron Roodman: And

91
00:14:31.620 --> 00:14:52.410
Aaron Roodman: The, the simplest description of them in terms of the Fourier transform of the density contrast so delta is the density contrast sitting Daniel told you about that in the opening lectures and if you for you transform that you can actually get a fairly simple evolution equation.

92
00:14:53.850 --> 00:15:09.420
Aaron Roodman: For that density contrast and it also evolves over customer time growing from small contrast to the current large contrast we have today and that that change depends on

93
00:15:10.590 --> 00:15:21.810
Aaron Roodman: The actual nature of dark energy. So, this curve from the review article from Josh Freeman and company FEW YEARS BACK shows how that evolution, we change if dark matter.

94
00:15:23.220 --> 00:15:32.100
Aaron Roodman: Very with equation state from minus one, two, minus 30 it's on a log plots are actually accurate measurements in this region.

95
00:15:34.290 --> 00:15:35.100
Aaron Roodman: Will

96
00:15:38.370 --> 00:15:42.840
Aaron Roodman: Probe, the nature of dark energy and a very accurate way so

97
00:15:44.070 --> 00:15:49.770
Aaron Roodman: This division is an absolute and actually some of these methods do also depend a little bit on geometry.

98
00:15:50.550 --> 00:15:55.650
Aaron Roodman: But the methods that use gravity are looking at week gravitational lensing and particular its powers factor.

99
00:15:56.280 --> 00:16:09.900

Aaron Roodman: And also looking at galaxy clusters. If they're massive audience and I'm going to focus in this lecture on the week lens in which to date or the most incisive measurements we have using gravity to study the expansion of the universe.

100
00:16:11.610 --> 00:16:18.630
Aaron Roodman: Okay, so this is a plant that effectively. It's the same one that Daniel show to the beginning of the week.

101
00:16:20.220 --> 00:16:38.880
Aaron Roodman: Comparing the results of the temperature Matt from plum showing the small amount of structure attend to the minus five structure in the universe, and as he of 1000 and comparing that to a simulation due to some of my colleagues at Stanford.

102
00:16:40.440 --> 00:16:46.050
Aaron Roodman: Is showing how dark matter evolves in the universe. And so this beautiful simulation.

103
00:16:47.940 --> 00:16:49.710
Aaron Roodman: Where every everything that

104
00:16:51.840 --> 00:16:52.590
Aaron Roodman: Is seen here.

105
00:16:53.700 --> 00:16:56.400
Aaron Roodman: Let's, let's go back while I'm talking to watch it again.

106
00:16:58.170 --> 00:17:09.300
Aaron Roodman: Shows the evolution of structure in the universe and everything, shown here is dark matter, actually, and you start with a fairly uniform universe and the first little instant

107
00:17:09.870 --> 00:17:17.730
Aaron Roodman: And gradually developed this spectacular film entry structure as well as these lumps of dark matter, which are the sites were galaxies women.

108
00:17:19.140 --> 00:17:31.170
Aaron Roodman: Ultimately in this simulation and galaxy clusters form and they were the biggest galaxy clusters have 1000 galaxies and masses of 10 to 15 solar master. So to truly enormous object.

109
00:17:33.780 --> 00:17:47.430

Aaron Roodman: And if you understand the makeup of the universe, not of dark matter, the type of dark matter. The amount or the density of dark energy and it's equation and state.

110
00:17:47.910 --> 00:17:59.760
Aaron Roodman: You should be able to predict how the universe evolves from here to here. So how the structure of the universe evolves from this very uniform universe early on.

111
00:18:01.260 --> 00:18:13.140
Aaron Roodman: To the, to the on talking, you can watch people watching it to the highly structured universe we have today. Now there's one thing I want to point out, and that is that the

112
00:18:14.220 --> 00:18:23.640
Aaron Roodman: Amount of matter in any particular spot in the universe doesn't really convey any cosmological information it's random, in some sense, and in fact

113
00:18:24.060 --> 00:18:37.950
Aaron Roodman: Randomness comes in at inflation at the end of inflation. So the very first incident universe that the density fluctuations are seated that by the end of inflation.

114
00:18:39.780 --> 00:18:59.370
Aaron Roodman: And that's a quantum process. It's a random process. And so the density in any particular spot is random, but what isn't, rather than is the power spectrum of those density fluctuations that contains fast fascinating information about the start of the universe about the end of inflation.

115
00:19:00.420 --> 00:19:01.290
Aaron Roodman: And then does not rain.

116
00:19:02.340 --> 00:19:10.020
Aaron Roodman: So, so the information will come from looking at power spectra, not the density and anymore location.

117
00:19:11.520 --> 00:19:12.930
Aaron Roodman: It's an important point to remember

118
00:19:14.040 --> 00:19:15.600
Aaron Roodman: And in fact, the

119

00:19:17.310 --> 00:19:26.610
Aaron Roodman: It's worth taking a look at what does the power spectrum actually look like. So this is a this is a plot is actually a complicated plan. So it's been a minute on

120
00:19:27.540 --> 00:19:41.490
Aaron Roodman: Of the matter, matter power structure. So in this case, it's all matter, dark matter and what is usually turn baryonic matter. So, that's atoms that make up the ass clowns and makeup galaxies.

121
00:19:43.710 --> 00:19:53.580
Aaron Roodman: And it's a look at that matter over many different scales. So the x axis is the way of number. So it's one over the length scale.

122
00:19:54.960 --> 00:20:03.150
Aaron Roodman: So let's see. So these are large, so that small scales smoke a large Angular scales.

123
00:20:04.230 --> 00:20:08.220
Aaron Roodman: Here's the power spectrum. It's got units so

124
00:20:09.780 --> 00:20:17.490
Aaron Roodman: You have to watch yourself in the literature, there's two kinds of our second one with units and one that's universe multiplied by a few

125
00:20:19.710 --> 00:20:20.760
Aaron Roodman: And then it's

126
00:20:23.100 --> 00:20:32.520
Aaron Roodman: It's the power spectrum today and redshift zero. So the theoretical curve is shown here. The solid curve is the circle linear case.

127
00:20:33.780 --> 00:20:47.310
Aaron Roodman: But the universe is not linear in the evolution of the power sector because gravitational interaction also affects the lumpiness of magic, especially at small scales scales.

128
00:20:49.650 --> 00:20:50.280
Aaron Roodman: At or

129
00:20:51.480 --> 00:20:59.280

Aaron Roodman: Of the size of individual galaxies or the distance between neighboring galaxies or maybe between neighboring groups of galaxies.

130
00:21:00.120 --> 00:21:09.900
Aaron Roodman: We can calculate some of that effect that nonlinear effect. And that's shown in this dotted and that's what the universe really looks like the dotted curve.

131
00:21:10.470 --> 00:21:31.590
Aaron Roodman: But what's been done here is to subtract that piece off using theoretical estimates of its size to get this idealized linear days and then to correct individual measurements in the same way. So the move them from the real measurement, the real values to these inferred linear values.

132
00:21:33.360 --> 00:21:41.640
Aaron Roodman: In addition, there are also scaled such that they're even though some of the measurements come from the microwave background. So the plonk measurements which are

133
00:21:42.210 --> 00:21:56.130
Aaron Roodman: blue, orange and green, those are those are transformed to the power spectrum today, even though those measurements are made obviously z of 1000 at the time that the

134
00:21:58.350 --> 00:22:03.720
Aaron Roodman: The photons in the universe decoupled from matter. And so we can see the photons from the big thing.

135
00:22:05.640 --> 00:22:16.320
Aaron Roodman: Um, but what's also shown our dark energy survey your one results. Those are. I don't know what this color is an issue. And that's what I'm actually going to talk to you today about the dark energy circuit.

136
00:22:17.370 --> 00:22:27.150
Aaron Roodman: They're also results from very on acoustic isolation show. So the data all agrees pretty well and the power, spin it matches the theoretical

137
00:22:28.230 --> 00:22:41.640
Aaron Roodman: Understanding of what the power spectrum of matters should look like today. The other thing you'll notice is that there are really no features on there is this there is some point at which the some scale at which the our spectrum.

138
00:22:43.170 --> 00:22:45.060
Aaron Roodman: Is largest but

139
00:22:46.080 --> 00:23:00.300
Aaron Roodman: Except for a small feature here which you really can't see on this curve is the baryonic this constellation were no features. So unlike other measurements, where you have sharp spectral features to focus on. You don't have that this case.

140
00:23:01.170 --> 00:23:10.260
Aaron Roodman: That changes the nature of the information. The information that we get from studying we cleansing we gravitational lensing and the matter, matter power spectrum is still very incisive

141
00:23:10.770 --> 00:23:21.870
Aaron Roodman: But it's important to remember it doesn't it smooth in this way. Okay, so now let's let's let's launch into the specifics, I want to talk about that is weak gravitational lensing.

142
00:23:23.250 --> 00:23:28.950
Aaron Roodman: So, as you all these figures are taken from the Wikipedia page and we cleansing whoever wrote that page. If you're doing a nice job.

143
00:23:29.850 --> 00:23:39.870
Aaron Roodman: It's a, it's a good place to start if you want a little bit more of the details of course at this point. Most cosmology textbooks have sections on the gravitational lensing.

144
00:23:41.430 --> 00:23:46.560
Aaron Roodman: And it's, it's such an important and powerful pro because it's sensitive to all mad.

145
00:23:49.140 --> 00:23:50.010
Aaron Roodman: And

146
00:23:52.620 --> 00:24:15.000
Aaron Roodman: Unlike studying galaxies alone, which, in which case you're just looking at stars a fraction of the matter. And first, if we are, if we have a gravitational pro something that sensitive to gravity that will be sensitive to all map. That's in a nutshell, that's why this method is so powerful.

147
00:24:16.650 --> 00:24:27.240

Aaron Roodman: And in, in what we observe is that sort of fantasy in this cartoon. Imagine there's some lump of matter here.

148
00:24:28.500 --> 00:24:40.620
Aaron Roodman: And we look at galaxies behind that long. So we're here. This is where we put our telescopes here. Here are these more distant galaxies and what we observed is that the shape

149
00:24:41.760 --> 00:24:58.770
Aaron Roodman: And orientation of those galaxies is changed by the gravitational interaction of this long matter, how does that occur. Exactly. Let's look at this diagram to see. So again, here's our lump of matter. Here's a distant galaxy. Here's us with our telescope

150
00:25:00.060 --> 00:25:12.330
Aaron Roodman: And the source. So that's the distant galaxy. When we say it's light goes along, and then is bent by this lump of matter in this way. And so the

151
00:25:12.990 --> 00:25:25.350
Aaron Roodman: We observe the image to be here and it should be here, and we also see the shape of the galaxy change. You can just barely see it, that sort of spread out.

152
00:25:26.190 --> 00:25:40.980
Aaron Roodman: And the change in shape which we break into three components. And just a little bit of nomenclature for you, kappa is the convergence. That's the change in signs and generally

153
00:25:42.210 --> 00:25:46.140
Aaron Roodman: If there's a if there's a lot of matter and

154
00:25:47.700 --> 00:25:50.670
Aaron Roodman: Close to the line of sight will observe

155
00:25:52.020 --> 00:25:57.960
Aaron Roodman: Kappa, the positive. So, the size of the galaxy grows. It's magnified by this land.

156
00:25:59.640 --> 00:26:02.460
Aaron Roodman: So green is the is the true

157
00:26:03.630 --> 00:26:08.160

Aaron Roodman: shape and size and the black lines show what happens with gravitational lensing.

158
00:26:09.270 --> 00:26:18.390
Aaron Roodman: But in addition, the size the size can grow. But in addition, the shape can change. And the reason that occurs is that

159
00:26:19.620 --> 00:26:31.110
Aaron Roodman: Our sources are not point objects as galaxies third standard objects. And so the strength of the gravitational lensing is different on one side of the galaxy than the other.

160
00:26:32.190 --> 00:26:40.440
Aaron Roodman: And that gives you a tidal effect. So the dependence is the second goes as the second derivative of the gravitational potential

161
00:26:42.480 --> 00:26:51.060
Aaron Roodman: And that can change the shape and it depends on where the galaxy is with respect to the lump of matter.

162
00:26:52.740 --> 00:27:11.700
Aaron Roodman: And we we divine that change in shape. So that's called gamma. That's the shear and we can divide it into two parts. One is when the shape changes, kind of, up, down, left, right, and whatever coordinate system are using and the other is in the changes at 45 degrees.

163
00:27:12.840 --> 00:27:16.110
Aaron Roodman: And those are different derivatives of the gravitational potential

164
00:27:17.460 --> 00:27:28.140
Aaron Roodman: In addition, the dependence of that change as well that changes dependent on the distances. So it depends on the distance

165
00:27:29.430 --> 00:27:50.850
Aaron Roodman: From us to the lands that's decent D. It depends on the distance from us through the source. These have asked, and it also depends on the distance between the lens and the source in this way. So it's maximal when the lens is halfway between us and the source and has this kind of dependence.

166
00:27:52.770 --> 00:27:55.320
Aaron Roodman: So that's what we're looking for. Now,

167
00:27:56.790 --> 00:28:04.500
Aaron Roodman: Okay, we're gonna try to do a poll. So, my colleague Daniel grid, but did the first electricity did a bunch of these and

168
00:28:05.220 --> 00:28:18.150
Aaron Roodman: It worked pretty well. I'm going to try. I just have a one today. And so I want to ask you the question. So let's see if this works, how can we measure the week gravitational effect on galaxy shape.

169
00:28:19.290 --> 00:28:25.710
Aaron Roodman: When we don't know the unless so the true you know shape of the galaxy.

170
00:28:26.340 --> 00:28:38.220
Aaron Roodman: Right, because we don't know that we're not, we can't. We don't have images taken nearby. We don't know what the galaxies really look like. So how do we measure this week gravitational effect. So here, you're here. Your choices.

171
00:28:39.510 --> 00:28:44.190
Aaron Roodman: We could select only galaxies that are likely to be around and then

172
00:28:45.810 --> 00:28:50.160
Aaron Roodman: Measure how not round. They are we could assume that all galaxies are randomly oriented.

173
00:28:52.050 --> 00:29:10.020
Aaron Roodman: We could infer the unless shape of the galaxies from their color. We also measure galaxy color or we could infer the shape of the galaxies from their rotational velocity. So take a we're kind of halfway through. This is a decent time to take a short

174
00:29:11.340 --> 00:29:12.060
Aaron Roodman: catch our breath.

175
00:29:13.200 --> 00:29:22.950
Aaron Roodman: You can go to this website polivy.com slash. It's my name here in Redmond 286 or you can tax.

176
00:29:23.970 --> 00:29:24.690
Aaron Roodman: This

177

00:29:26.430 --> 00:29:31.560
Aaron Roodman: String to this number on your phone to join and then you enter a, b, c, or d

178
00:29:33.450 --> 00:29:37.470
Aaron Roodman: So give that a try. I'm going to give people

179
00:29:40.110 --> 00:29:43.950
Aaron Roodman: Good people 15 seconds. Maybe 20 seconds to give it a shot.

180
00:29:45.270 --> 00:29:48.810
Aaron Roodman: So how do we measure the second don't know the true shape of the galaxies.

181
00:29:56.760 --> 00:30:02.610
grzegorz madejski: Alright, if you could put the link on the TV in the chat window. Somebody else

182
00:30:03.750 --> 00:30:04.560
grzegorz madejski: Could just click on it.

183
00:30:06.360 --> 00:30:07.410
Aaron Roodman: Let me see if I can

184
00:30:08.130 --> 00:30:09.600
Aaron Roodman: You see if I can do that.

185
00:30:09.870 --> 00:30:11.640
grzegorz madejski: If they're already mitochondria did it.

186
00:30:12.990 --> 00:30:13.890
Aaron Roodman: Okay, thank you.

187
00:30:14.970 --> 00:30:16.440
Aaron Roodman: Alright, so let's

188
00:30:18.750 --> 00:30:19.320
Aaron Roodman: Okay.

189
00:30:21.480 --> 00:30:22.800
Aaron Roodman: I see people

190
00:30:24.600 --> 00:30:27.330
Aaron Roodman: Lots of people are entering

191
00:30:30.090 --> 00:30:31.710
Aaron Roodman: Give people. One more minutes.

192
00:30:42.210 --> 00:30:46.080
Aaron Roodman: I have percentage. I don't know how many people have really answered. It's not that many. But

193
00:30:51.270 --> 00:30:53.970
Aaron Roodman: Okay, I'll give you 10 more seconds.

194
00:31:09.150 --> 00:31:12.030
Aaron Roodman: Alright that was 10 so. Okay, let's see, can we see

195
00:31:14.640 --> 00:31:20.190
Aaron Roodman: So here are the here are your answers are there still moving around. That's exciting.

196
00:31:23.970 --> 00:31:24.690
Aaron Roodman: So,

197
00:31:25.950 --> 00:31:29.460
Aaron Roodman: Okay, so it looks like the top two answers.

198
00:31:31.770 --> 00:31:32.910
Aaron Roodman: I hope you can see that I'm

199
00:31:34.740 --> 00:31:36.600
Aaron Roodman: Still sharing. Yeah. All right.

200
00:31:38.040 --> 00:31:38.340
Aaron Roodman: Okay.

201
00:31:38.370 --> 00:31:49.230
Aaron Roodman: Awesome. The top two answers are be assume galaxies are randomly oriented or D and for the unless shape of galaxies from rotational velocity

202

00:31:50.310 --> 00:31:55.320
Aaron Roodman: Okay, so that's good. That is excellent. Um, so the answer.

203
00:31:57.840 --> 00:32:04.140
Aaron Roodman: For all week cleansing measurements today is be we assume the galaxies are randomly oriented.

204
00:32:05.880 --> 00:32:16.800
Aaron Roodman: And then it's a statistical measurement we need to look at a lot of galaxies. And so the random orientations cancel.

205
00:32:18.150 --> 00:32:21.180
Aaron Roodman: Because we're basically taking the meaning the residual

206
00:32:22.590 --> 00:32:23.100
Aaron Roodman: And

207
00:32:24.270 --> 00:32:41.700
Aaron Roodman: Since around the horn. So if you look at enough galaxies. They're random orientations cancel and the mean has the residual information about the gravitational potential that forms the change in shape of the galaxies and you can detect the effect

208
00:32:42.810 --> 00:32:54.930
Aaron Roodman: So that's the, that's one of the challenges with the measurement. The, the typical elasticity, or the RMS the assistant is maybe point 2.3

209
00:32:56.040 --> 00:33:04.920
Aaron Roodman: And the effective gravitational lensing is less than 1% so baby point oh five new a lot of galaxies that can't to to

210
00:33:07.350 --> 00:33:11.370
Aaron Roodman: To cancel out that big point two five or so.

211
00:33:12.810 --> 00:33:32.580
Aaron Roodman: Rms and just see the little bit past the little half a percent residual change now D is not totally wrong. Okay, so see you cannot tell the shape of galaxies from their color, sadly, um, you can kind of tell if they're elliptical or or spiral. But that doesn't really tell you the shape

212
00:33:33.900 --> 00:33:45.360

Aaron Roodman: ellipticals or elliptical, they, they have some shape spirals, of course, actually we don't know the orientation of the spirals, but there is there is a proposal on

213
00:33:46.260 --> 00:33:55.740
Aaron Roodman: That if you could measure the rotational velocity of galaxies and for certain kinds of galaxies. You could infer enough of their online shape.

214
00:33:56.820 --> 00:34:11.880
Aaron Roodman: So, Natalie. And so that's a complicated measurement. It is not really been demonstrated yet, but it's a really, it's a very clever idea. So, d isn't totally wrong. It's just not what people have been able to do yet. Okay, good. That worked well I'm

215
00:34:14.820 --> 00:34:16.890
Aaron Roodman: Great. So let me. Let's see. I'm going to go back

216
00:34:19.110 --> 00:34:28.950
Aaron Roodman: To the slide. Okay, let me let me move along. So I want to tell you about the measurements. We've made with the dark energy survey which is the project I've been working on.

217
00:34:29.640 --> 00:34:39.960
Aaron Roodman: Some a member of this group for the last dozen years. It's a big international collaboration of people that built. So we built the dark energy camera Deccan

218
00:34:40.770 --> 00:34:58.890
Aaron Roodman: And we've conducted a very large survey and one of the most interesting results is a gravitational Isaac, so I'm gonna tell you more about it. Okay, so the dark energy survey uses the Blanco four meter telescope. Here's the mirror the four meter mirror

219
00:34:59.910 --> 00:35:13.650
Aaron Roodman: And the Sarah to low low inter American Observatory in July. So here's the dome, I would want the telescope lives and our group built a new camera whole deck cam dark energy camera.

220
00:35:15.300 --> 00:35:23.010
Aaron Roodman: Here's one of the corrective lenses or you can see it's it's a pretty big beast. The camera is actually here.

221
00:35:23.520 --> 00:35:32.160

Aaron Roodman: Mounted on the top end of the telescope. So you can see the primary merrier. There's the giant horseshoe that's used to move it so scroll across the sky.

222
00:35:33.150 --> 00:35:43.650
Aaron Roodman: And the cameras, you know, this giant cylinder and this lens is actually, you can't see it, but it's it's here and the heart of the camera is the imager.

223
00:35:44.280 --> 00:35:55.860
Aaron Roodman: And that's half a giga pixel imager shown here, you can see each of the separate CCD then they've got the imager. And here is actually one of the first images on the sky.

224
00:35:57.660 --> 00:35:58.350
Aaron Roodman: There are

225
00:35:59.730 --> 00:36:00.810
Aaron Roodman: There are 62

226
00:36:01.890 --> 00:36:10.920
Aaron Roodman: CC knees each of those is an eight megapixel. This is an enormous camera. The field of view is two degrees. Diane

227
00:36:12.150 --> 00:36:14.610
Aaron Roodman: So you can see this one spectacular image.

228
00:36:16.680 --> 00:36:27.210
Aaron Roodman: And we took images for five and a half years we finished the year and a half ago and surveyed a big swath 5000 square degrees at the southern hemisphere, Scott.

229
00:36:31.200 --> 00:36:46.830
Aaron Roodman: Um, here's a so that survey we use five different filters. So I'll talk a little bit about more about this tomorrow. But basically, each image has taken a narrow wave band with these funny names.

230
00:36:47.250 --> 00:36:57.960
Aaron Roodman: We took 10 different images per filter over five and a half years 5000 square degrees. I'll show that footprint in a second. There's some special fields we took even more images for suit.

231
00:36:59.010 --> 00:37:06.840

Aaron Roodman: What I'm going to tell you about today are cosmology results. They're actually from a year and a half ago from the first year of data.

232
00:37:07.980 --> 00:37:19.140
Aaron Roodman: We're working now on the data from the first three years, the survey and those results, hopefully will be out soon. Daniel ruin my colleague that you heard from the band and he's actually one of the leaders of that.

233
00:37:20.280 --> 00:37:26.430
Aaron Roodman: Effort to study week reputational data sample. And here's a plant Daniel made

234
00:37:27.390 --> 00:37:45.660
Aaron Roodman: Or a graph detonated of a just a little bit of a region of the sky showing the quality of the dark energy survey data. This is actually a galaxy cluster here. And every one of these dots, pretty much is a galaxy these bright things are stars. Those are stars.

235
00:37:46.770 --> 00:37:56.850
Aaron Roodman: You know, that's a star. There are a few stars here some of these rounder objects or or possibly stars, but most of what you're seeing here are galaxies.

236
00:37:58.230 --> 00:37:58.740
Aaron Roodman: Now,

237
00:38:01.260 --> 00:38:10.890
Aaron Roodman: If you take our data. You can use it to build a map of all the matter in the universe in the direction of our images.

238
00:38:11.370 --> 00:38:20.340
Aaron Roodman: That math is shown here. So the first the data will will show is only a subset of our footprint. But this is the footprint. We use

239
00:38:21.300 --> 00:38:36.030
Aaron Roodman: And the color bars, you're telling you how much matter is a natural reaction compared to the to the average amount of matter in the universe. And you can see these hot and cold regions are dense and under dense region for u verse

240
00:38:37.260 --> 00:38:52.950

Aaron Roodman: Galaxy clusters are shown in these gray dots. You can see the galaxy clusters trace the dark matter. Well, and circles and boxes are some particularly interesting peaks and voids in this matter.

241
00:38:54.360 --> 00:39:04.350
Aaron Roodman: So this is kind of the, the closest one can get to visualizing the week gravitational effect is to take the measured effect on galaxies and

242
00:39:05.880 --> 00:39:17.940
Aaron Roodman: With basically a very particular convolution in for the map of matter in the universe. Now this is highly smooth, but it really does contain

243
00:39:19.110 --> 00:39:22.620
Aaron Roodman: A lot of information about where matter is the universe.

244
00:39:23.670 --> 00:39:39.960
Aaron Roodman: Okay. Now I do want to mention some of the challenges of making a measurement with week gravitational lensing. So I've already mentioned, the effect is small that galaxies have shaped. We don't know their true shape and the week gravitational effect changes that shaped

245
00:39:40.980 --> 00:39:44.700
Aaron Roodman: By roughly half a percent. That's a typical number now.

246
00:39:45.840 --> 00:39:58.260
Aaron Roodman: The additional challenge. And so here's another image from the dark energy survey different part of the sky and you'll notice there's a couple these spectacular. Well, these are relatively nearby galaxies.

247
00:39:59.310 --> 00:40:06.120
Aaron Roodman: But most of what you see are these tiny smudges. Here's a zoom and

248
00:40:07.590 --> 00:40:10.260
Aaron Roodman: Each one of these little smudges is the galaxy.

249
00:40:11.670 --> 00:40:20.400
Aaron Roodman: And so you can't really see whether there's fire over elliptical. You can even make a guess based on their color. It's only you can know for sure.

250

00:40:21.510 --> 00:40:31.560
Aaron Roodman: And they're so far away. You don't see any of the structure you see for more nearby councils. That's what we're using those are the galaxies, we're using to study week gravitational lensing.

251
00:40:32.520 --> 00:40:44.040
Aaron Roodman: Now to measure the shape of those galaxies. You need to know the response of the atmosphere, the telescope and the imager.

252
00:40:45.420 --> 00:40:53.820
Aaron Roodman: Which are not perfect turbulence in the atmosphere can change the shape of all objects aberrations in the telescope

253
00:40:54.690 --> 00:41:05.640
Aaron Roodman: And other features of the imager can also change the shape of objects we characterize that by something called the point spread function. So what that means is if you have a point object.

254
00:41:06.810 --> 00:41:09.030
Aaron Roodman: How is it spread out in your data.

255
00:41:10.200 --> 00:41:28.770
Aaron Roodman: It's not perfectly round and you have to remove that effect, which is an instrumental effect from your measurement of the shape of all galaxies and you can do with stars. Stars are a perfect point object they stars. They're so small and so far away, they should have no size.

256
00:41:30.660 --> 00:41:37.860
Aaron Roodman: But they appear like this. And so here's a star. Well, actually I have to. I'm lying slightly. It's probably star don't know for sure.

257
00:41:39.030 --> 00:41:40.620
Aaron Roodman: Statistically, it's probably start

258
00:41:41.910 --> 00:41:50.760
Aaron Roodman: When you use the stars to evaluate the point spread function which changes spatially across the image and changes every image.

259
00:41:51.870 --> 00:41:56.700
Aaron Roodman: Largely because we're taking these images from the ground. We have to go through the light goes through the atmosphere.

260
00:41:57.660 --> 00:42:11.280
Aaron Roodman: So we use those stars to characterize the points for function. We have to apply correction based on that to each of these tiny not so well measured galaxies. That's Challenge number one in doing this measurement

261
00:42:13.080 --> 00:42:14.940
Aaron Roodman: Now I'm

262
00:42:16.350 --> 00:42:22.110
Aaron Roodman: Okay, so I think I'm actually given the time. I'm not going to go through this in as much detail as I hoped, but

263
00:42:22.800 --> 00:42:38.280
Aaron Roodman: The idea. And this is really just kind of schematic is that we have to measure the point spread function or some true shape what we observed is different. So in some sense, we have to do involve back to the true shape.

264
00:42:39.360 --> 00:42:46.530
Aaron Roodman: That cannot be done perfectly. And so when we measure the sheer we that may

265
00:42:47.580 --> 00:42:52.080
Aaron Roodman: Be only a fraction of the true cheer and this

266
00:42:54.180 --> 00:43:02.880
Aaron Roodman: This multiplicative bias might not be exactly one might deviate from one a little that isn't important systematic in the measurements.

267
00:43:03.480 --> 00:43:19.080
Aaron Roodman: Now there's a new method called meta calibration due to described in these two papers, um, that actually is a big advance in determining the true shear and getting an M as close as possible to one.

268
00:43:20.400 --> 00:43:42.300
Aaron Roodman: It involves a D convolution, which normally doesn't work well for such dim objects, but it is a clever method that that uses a D convolution and eerie convolution and gives you a way of measuring the sheer reliably from an ensemble and determining this multiplicative correction accurately.

269
00:43:43.530 --> 00:43:50.550

Aaron Roodman: It's an important development and one of the as I said one of the tricky features of doing this measurement. The other difficulty.

270
00:43:51.630 --> 00:43:54.780
Aaron Roodman: Is that we need to know the distance to the galaxies.

271
00:43:55.890 --> 00:44:17.400
Aaron Roodman: And we're measuring dark energy surveys case the data. I'll show you is from about 30 Million Galaxies will ultimately have several hundred Million Galaxies is that we cannot take a Spectrum. Spectrum of every galaxy. We have to infer the disk, the redshift distance based on measurements.

272
00:44:18.630 --> 00:44:34.590
Aaron Roodman: That are so called third metric measurement. So they're just meshed into the flux in different ways bands. So here are four of our five waistbands shown here. So this is a function of wavelength this block goes from about 3500 nanometers. Well, it's an extra room so

273
00:44:36.450 --> 00:44:40.800
Aaron Roodman: 3500 rooms up to 10,000 to one micron.

274
00:44:42.480 --> 00:44:58.890
Aaron Roodman: The way bands G R RI z are shown with the throughput that you get taken into account the atmosphere which causes these features as well as the quantum efficiency of our sensors and the throughput of the filters.

275
00:45:00.660 --> 00:45:17.700
Aaron Roodman: Compared to a typical galaxy. So here's a typical galaxy of the redshift 2.4 and there's a feature here where the bomber lines the bomber lines of hydrogen start to kick in. Now, if the ratio for zero that feature will be down here at around 4000 agents.

276
00:45:19.110 --> 00:45:30.270
Aaron Roodman: 400 nanometers. But as the galaxies rich if that feature moves the right, it moves to the red if the galaxy or 0.8 redshift point eight that feature move here.

277
00:45:31.500 --> 00:45:51.810
Aaron Roodman: And at 1.15 that we move here. So it changes for the relative flux in these different filters and we can use that to infer redshift. Now it's imperfect, because these are wideband and we also don't know the true spectrum of the galaxy. And galaxies of different spectrum.

278
00:45:52.890 --> 00:45:56.280
Aaron Roodman: So it's an imperfect method, but it does give us the information we need.

279
00:45:57.540 --> 00:45:58.140
Aaron Roodman: It's

280
00:46:00.600 --> 00:46:02.940
Aaron Roodman: One of the things we have to do though is calibrate it

281
00:46:04.140 --> 00:46:12.300
Aaron Roodman: I'm going to skip this because I'm running out of time, but that calibration, we have to use the data in a different way to calibrate the

282
00:46:12.810 --> 00:46:27.930
Aaron Roodman: Quality of our friendships. So here's from the darkening survey data here is the redshift distribution shown when we divide the data into different big bins of redshift. And you can see it there broad distributions there.

283
00:46:28.950 --> 00:46:35.670
Aaron Roodman: If we if we think the redshift is between point six five and point nine, it really might have this distribution.

284
00:46:36.300 --> 00:46:47.400
Aaron Roodman: But it turns out that all we need to know is the mean and perhaps the, the width of these distributions and that's good enough to do the refunds and measurements we want. Okay, what are those measurements so far.

285
00:46:48.660 --> 00:47:03.090
Aaron Roodman: I said at the outset that they are a smooth. Well, here they are. So what's what's plotted here is the data. Here's the power spectrum and share. And it's a certain combination of share

286
00:47:05.430 --> 00:47:17.550
Aaron Roodman: Of pairs of galaxies and it's effectively the sheer. Sheer power spectrum and the data. You can see it. Is it smooth, there's no there's no real people.

287
00:47:18.480 --> 00:47:37.260
Aaron Roodman: But the information is in the magnitude and there's information to when we cross correlate between different redshift it. So

here's the first redshift ban against itself. Second against itself. There's information to if we compare the first redshift in against the fourth Richard

288
00:47:38.640 --> 00:47:43.830
Aaron Roodman: Were to power spectra one conformed depending on whether and how you combine the data.

289
00:47:45.510 --> 00:48:06.750
Aaron Roodman: And this quantity C plus minus depends ultimately on the matter, matter power spectrum. That's the nonlinear shown here. It also depends on the combination of distances. So he is chi is the proper distance do to Lansing. So that's five times.

290
00:48:07.830 --> 00:48:19.920
Aaron Roodman: Five is kind of a pipeline that's effectively the combinations of distance I show ends on omega matter and it depends on the multiplicative bias from the sheer measure

291
00:48:21.540 --> 00:48:39.750
Aaron Roodman: And because it has that those dependencies. It's more powerful to combine the sheer. Sheer power spectrum with two other powers factor one between the position of galaxies and the lenses of galaxies. So kind of the position of this galaxy.

292
00:48:41.040 --> 00:48:46.380
Aaron Roodman: And the lens of this one. So here's the data shown here, and then has a different dependence.

293
00:48:47.490 --> 00:48:51.060
Aaron Roodman: It. Um, it depends on

294
00:48:52.290 --> 00:48:56.550
Aaron Roodman: A single power of a mega matter and a single power of

295
00:48:58.200 --> 00:49:10.260
Aaron Roodman: The lending box. And so because of those coming linearly one has independent information about them that can be used to break a little bit to break the degeneracy between

296
00:49:10.650 --> 00:49:19.800
Aaron Roodman: Sis a systematic effect. And what we want to measure which is inside here, it introduces though another parameter which is called the galaxy by us.

297
00:49:20.430 --> 00:49:37.620
Aaron Roodman: To help reduce that we look at a third power spectrum. And that's between the location of galaxies only that doesn't depend on the week lensing. But it has a different dependence on this galaxy bias galaxy bias comes in square. It's in both Eastern

298
00:49:38.730 --> 00:49:49.170
Aaron Roodman: And by combining those three power spectra. We've got more information now to combine all that data together. You have to know how the data is correlated

299
00:49:49.890 --> 00:50:00.240
Aaron Roodman: It's correlated, because it's the same galaxies, we're using in each case. And it's correlated, because we're only using one part of the universe or is something called Cosmic variance. There is

300
00:50:01.170 --> 00:50:08.070
Aaron Roodman: Variance in our data due to the fact that we have only one universal one little part of the universe to study.

301
00:50:09.600 --> 00:50:12.390
Aaron Roodman: Finding that covariance matrix actually quite difficult.

302
00:50:13.620 --> 00:50:27.390
Aaron Roodman: But in really beautiful paper, led by was with House using mostly calculations we derive a covariance matrix being all those measurements, it's shown graphically here it looks quite spectacular.

303
00:50:28.740 --> 00:50:32.850
Aaron Roodman: And using that we can combine the three different covariance matrix is here are results.

304
00:50:34.320 --> 00:50:34.650
Aaron Roodman: Here.

305
00:50:34.710 --> 00:50:35.730
mark convery: In about five minutes.

306
00:50:36.540 --> 00:50:38.520
Aaron Roodman: Okay, good. I think I'm on track. Thank you.

307
00:50:39.540 --> 00:50:42.000
Aaron Roodman: Here are results. So this shows the

308
00:50:43.110 --> 00:50:53.400
Aaron Roodman: The most favorite region and parameter space given different assumptions from this data and we call it three by two point because we have three different to point our spectrum.

309
00:50:55.260 --> 00:51:00.840
Aaron Roodman: Um, the parameters are mega here and this is assuming

310
00:51:02.550 --> 00:51:17.670
Aaron Roodman: Dark Energy has omega of minus one and doesn't change. Here are our region. So look at the blue region which is the combination in Omega matter and something called sigma eight or and sigma eight

311
00:51:18.690 --> 00:51:24.750
Aaron Roodman: Is this is the, the amplitude of the power structure. It's our way of

312
00:51:25.740 --> 00:51:42.390
Aaron Roodman: Parameter rising. The, the magnitude of that matter, matter power spectrum that I showed you, and we look at two different combinations we have sigma eight and then this combination sigma a mega matter which which basically removes the correlation between them.

313
00:51:44.070 --> 00:52:02.220
Aaron Roodman: If we allow the dark energy equation of state parameter W to very we get these contours. So it's so again look at the blue, which is the combination of all three. Three by two point data and you can see it does

314
00:52:03.600 --> 00:52:11.430
Aaron Roodman: Omega or w of minus one looks good and sap has values of around point eight

315
00:52:12.960 --> 00:52:16.560
Aaron Roodman: And the three different measurements are consistent. So we feel confident combining

316
00:52:17.850 --> 00:52:24.660
Aaron Roodman: And here's what we find compare comparing our data against block. So let's look at this one for that I think is a really compelling Kurt

317
00:52:25.260 --> 00:52:39.750

Aaron Roodman: Ballou shows are contours and the green shows the block results where we've dialed the magnitude of our spectrum that is found can microwave background forward in time.

318
00:52:40.770 --> 00:52:47.730
Aaron Roodman: Effectively to compare against measurements made with galaxies that are a redshift of one or below.

319
00:52:49.380 --> 00:52:58.470
Aaron Roodman: They're pretty consistent. They're not perfect but statistically, they are consistent and if you combine them, you would get this this contract.

320
00:53:01.260 --> 00:53:05.010
Aaron Roodman: And here's, here's another view of that in in more parameters.

321
00:53:06.300 --> 00:53:06.900
Aaron Roodman: Now,

322
00:53:07.980 --> 00:53:16.500
Aaron Roodman: It's consistent, but they don't perfectly agree, especially in the value of sigma eight, the amplitude of the matter, matter of commerce.

323
00:53:17.610 --> 00:53:26.940
Aaron Roodman: Now we have more data and results to come. Here's the footprint from our, our full data sample. I want to just mention I have one more minute.

324
00:53:28.020 --> 00:53:39.210
Aaron Roodman: Um, we're not the only people making this the only group making this measurement today or two others. One of them just came out with the results in the last month. That's the kids one thought kids.

325
00:53:40.200 --> 00:53:52.080
Aaron Roodman: Collaboration, they have a thousands for any reason data over nine filter bands. It's actually quite nice in that way. And here's their results. So the results. I just showed you are the yellow

326
00:53:53.580 --> 00:53:59.220
Aaron Roodman: The kids results, combined with one extra source of information, which does make their punchers smaller

327

00:54:00.510 --> 00:54:10.350
Aaron Roodman: From another project is the blue, and I'm sorry that's their early results with the blue and their newer results is the red and here's why.

328
00:54:11.460 --> 00:54:20.730
Aaron Roodman: And so if we compare and this is from their recent paper we compare our results just to bring the kids results which are red.

329
00:54:21.450 --> 00:54:31.350
Aaron Roodman: They're pretty consistent with sh. This particular combination around the point seven seven and the results from the microwave background or up here at about point eight two

330
00:54:32.310 --> 00:54:38.880
Aaron Roodman: They don't agree perfectly and this tension, this difference which is comparing

331
00:54:39.450 --> 00:54:51.090
Aaron Roodman: Results today versus results at the time the microwave background is really an interesting one. And if that attention holds up a good point to something we don't understand about the evolution of the universe.

332
00:54:51.660 --> 00:54:59.010
Aaron Roodman: Okay, so with that I'm going to include a I'm going to consume my lecture and I will take questions. Thanks.

333
00:54:59.700 --> 00:55:09.240
mark convery: Great, thank you very much. Aaron for very interesting lecture just as a reminder, Aaron will give the second in the series of lectures. Tomorrow. Tomorrow morning at the same time. So be sure to

334
00:55:09.750 --> 00:55:10.530
mark convery: Tune in for that.

335
00:55:10.860 --> 00:55:14.700
mark convery: And with that, I'll pass it over to suit on who's handling the questions.

336
00:55:17.550 --> 00:55:26.790
dong su: Hi Aaron, thanks for the nice lecture. So let's get on with the questions. So the first one is on page three, so keep the slides up

337

00:55:28.140 --> 00:55:29.850
dong su: High through the right

338
00:55:31.110 --> 00:55:31.470
dong su: Place.

339
00:55:36.720 --> 00:55:36.960
Aaron Roodman: Okay.

340
00:55:37.260 --> 00:55:48.150
dong su: So, so why you saying homogeneous, does it mean perfectly homogeneous nearly, nearly perfect old hopeful homogeneous only on some certain lens scale.

341
00:55:49.290 --> 00:55:57.150
Aaron Roodman: Right. It's a great, it's an interesting question. So what we assume is that is absolutely homogeneous perfectly homogeneous in all directions and

342
00:55:58.740 --> 00:55:59.550
Aaron Roodman: And and

343
00:56:01.050 --> 00:56:08.730
Aaron Roodman: So that's what you say we don't have any real evidence. Yeah. One of the ways you can you can address that is to look at

344
00:56:10.320 --> 00:56:23.400
Aaron Roodman: Any of the effects that measure the accelerated expansion in different directions. I'm doing that with supernova looking in different directions at supernova and seeing the results compare

345
00:56:24.480 --> 00:56:25.560
Aaron Roodman: Is a great way to do it.

346
00:56:26.970 --> 00:56:29.790
Aaron Roodman: There's, there isn't enough darn tough supernova to really do it.

347
00:56:30.870 --> 00:56:40.290
Aaron Roodman: Accurately in you know in many directions. Yeah, that may change with the project. I'm going to tell you about tomorrow, Ruben Observatory.

348

00:56:44.010 --> 00:56:47.640
Aaron Roodman: But yeah, we assume it's perfectly homogeneous. Don't be afraid of it.

349
00:56:48.960 --> 00:56:52.770
dong su: Okay, the next one is I found the next page on page four.

350
00:56:54.150 --> 00:57:01.590
dong su: On the the headings you refer moza OCD em and WC DNS or what are the those names different

351
00:57:02.940 --> 00:57:13.050
Aaron Roodman: So let's see. Um, I always forget what why this says, oh, but what's assumed on the left side is the W is minus one.

352
00:57:15.840 --> 00:57:16.410
Aaron Roodman: Exactly.

353
00:57:17.700 --> 00:57:24.540
Aaron Roodman: And on the right. So when people say WC BM, it's, it's the

354
00:57:26.430 --> 00:57:38.640
Aaron Roodman: It's assuming that the vacuum energy or dark energy is constant over constant time. But that w doesn't have to be exactly minus one, you can have a different value.

355
00:57:40.170 --> 00:57:57.480
Aaron Roodman: And so then we can see how consistent, the data is with different values of w and that's what the contours show and and just in case people don't don't know that the standard is that the first contour cover 68%

356
00:57:59.040 --> 00:58:05.970
Aaron Roodman: Of sort of probability space and the second contour, I guess, is 90% roughly one and two, sigma equivalence

357
00:58:07.500 --> 00:58:12.840
dong su: Right. Okay. Thanks. Let's move on to the next one is on page eight,

358
00:58:16.620 --> 00:58:26.160
dong su: When you say that. So what the the spectrum is in smooth. What's the significance of this background beans move something on me.

359
00:58:27.750 --> 00:58:28.770
Aaron Roodman: So, so

360
00:58:30.060 --> 00:58:39.900
Aaron Roodman: I so the significance is that if you have something that has a sharp spectral feature of the above, it's easier to measure.

361
00:58:42.270 --> 00:58:52.500
Aaron Roodman: If it's smooth in this way, then you then it's a little harder to measure and what you what you can measure is the amplitude. So kind of the height.

362
00:58:53.280 --> 00:59:03.660
Aaron Roodman: And if your measurements cover a wide enough range of of case space or angular space you can measure something about the the change over that.

363
00:59:04.830 --> 00:59:08.280
Aaron Roodman: Over that baseline or over that bandwidth

364
00:59:09.900 --> 00:59:15.960
Aaron Roodman: But it means the main events are going to be more challenging because you don't have a C sharp spectral V years

365
00:59:18.120 --> 00:59:18.570
dong su: Okay.

366
00:59:19.770 --> 00:59:24.450
dong su: And then the next one is on the next slide actually fight night.

367
00:59:27.270 --> 00:59:28.770
dong su: So there's a case of

368
00:59:29.790 --> 00:59:40.230
dong su: The cases in which case does convergence is negative, and what kind of matter of configuration in the length that give the result.

369
00:59:41.610 --> 00:59:48.270
Aaron Roodman: So, right. So convert so negative convergence means that the object, it turns out, smaller

370
00:59:50.220 --> 01:00:00.630

Aaron Roodman: That can happen if you're close to avoid okay so if you're if you're close to a positive a region that has a lump of matter and

371
01:00:02.070 --> 01:00:11.910
Aaron Roodman: You know the technical would actually Halo. So basically region that has more than normal your conversions. When you positive will see the object magnified.

372
01:00:13.350 --> 01:00:23.910
Aaron Roodman: But if you're if you're near a region that has a void, it has less matter than average, then you can get you can get negative convergence.

373
01:00:26.610 --> 01:00:27.060
Okay.

374
01:00:28.260 --> 01:00:39.780
dong su: Thanks. So let's move on to the next one. So one measuring the shape of lens, the galaxies that does it. How much does it depend on their face on a drawn and some of the second angle.

375
01:00:42.060 --> 01:00:47.610
Aaron Roodman: So okay, so, so I mean this effect is

376
01:00:49.740 --> 01:00:50.010
Aaron Roodman: Is

377
01:00:51.390 --> 01:01:03.600
Aaron Roodman: In some senses additive okay to first order the sheer so these measures it, which is the elliptic, it is additive. The you can take the true either publicity.

378
01:01:04.140 --> 01:01:14.400
Aaron Roodman: And add or subtract the additional shear from gravitational lensing. Now there's some small corrections that second order, but at first order the tour just additive

379
01:01:16.830 --> 01:01:27.900
dong su: Right, so I'm trying to actually pause on the question a little bit is I think there may be asking the why is it the easier to do certain types and the weather when you

380
01:01:28.890 --> 01:01:38.700

dong su: Or you preferentially preferentially measure a certain type of better than the other. So that are you sampling them all the orientation in a in a sensible way.

381
01:01:39.570 --> 01:01:41.310
Aaron Roodman: Okay, so. So, all right.

382
01:01:42.660 --> 01:01:53.160
Aaron Roodman: So that the real part of damn for the two components kind of the uptown component and 45 dream about it, those are those are unequal footing.

383
01:01:54.720 --> 01:02:12.960
Aaron Roodman: Convergence is a little less useful and and we really everything I showed was really from sheer measurements and conversions is less useful because there's no things don't average to zero. If you look at the shape of galaxies as we

384
01:02:14.610 --> 01:02:25.860
Aaron Roodman: If you look at the art. If you imagine the online shape of galaxies. The elasticity will average to zero and okay we'll lose our cartoon, you know, there may be some

385
01:02:26.730 --> 01:02:41.520
Aaron Roodman: Difference in the size that you notice it, but the orientation averages out to zero. And that's why you can you share the same is not true of convergence, because there's the sizes of galaxies just buried

386
01:02:42.600 --> 01:02:52.260
Aaron Roodman: And there's no, there's nothing that averages down to zero. So that's why I share is more useful, the two components are useful because when we form the power spectrum.

387
01:02:52.650 --> 01:03:03.390
Aaron Roodman: So let's look at our cartoon here what we're really forming is we're saying okay when some Angular baseline. Let's combine let's let's say Angular baseline is what I'm showing with my mouse.

388
01:03:04.560 --> 01:03:12.270
Aaron Roodman: So we'll combine down this galaxy and that galaxy and we can form two components, depending on whether the shares are aligned or anti align

389
01:03:14.790 --> 01:03:23.880

Aaron Roodman: And there's more information, a little bit more information on the line case in the anti line case. But that's why there are two powers vector hope maybe that I hope that answers some of the question.

390
01:03:24.630 --> 01:03:33.960
dong su: Right, yeah, maybe we can actually do a little bit more offline as well. Let's just try to move on to the next one. Um, so in on Patreon site 14

391
01:03:35.820 --> 01:03:38.310
dong su: There's a nice picture of various type of

392
01:03:39.390 --> 01:03:51.840
dong su: Object you're looking at. So one of the redshift the nicer looking God's galaxies in the white feel picture and the redshift. The blurry doc looking out for us in the zoom picture.

393
01:03:53.580 --> 01:03:56.790
Aaron Roodman: Which is super sexy that say that question again for me.

394
01:03:56.850 --> 01:04:02.700
dong su: I think for the wretched wretched the nicer looking God's leading the wide, wide field of view picture.

395
01:04:04.410 --> 01:04:10.440
dong su: Then the also the the blurry looking galaxy in the picture.

396
01:04:11.010 --> 01:04:17.970
Aaron Roodman: Well, okay, so not i'm not sure exactly what the question is. But the, you know,

397
01:04:19.920 --> 01:04:33.750
Aaron Roodman: Yeah, so, so these images. So this image is sort of a is is made from a combination of images in the different filter bands obviously are our images or

398
01:04:34.920 --> 01:04:40.320
Aaron Roodman: There's no. The only color information we have is from the filter we use

399
01:04:41.460 --> 01:04:47.610
Aaron Roodman: And so these images for display are made from demining those

400
01:04:49.290 --> 01:04:57.330
Aaron Roodman: Images and different filters in kind of what you call a false color combination. So the colors you're kind of arbitrary, you know,

401
01:04:57.810 --> 01:05:08.130
Aaron Roodman: In how we combine the different colors. It's meant to be kind of close to what you'd see with your eyes. Although your eyes would have to be sensitive to infrared near infrared light.

402
01:05:09.030 --> 01:05:25.380
Aaron Roodman: To see it. See it looking like this. So there's you know redshift comes by taking the flocks. Let's say from this galaxy and looking at the flux in each of the filter in each of the images in different filters.

403
01:05:26.610 --> 01:05:34.140
Aaron Roodman: And putting it through a sophisticated algorithm that then is calibrated and that's how we would find the rhetoric.

404
01:05:35.580 --> 01:05:42.630
dong su: Yeah. Okay. So then let's move on to the next one, next one is on Page 10 I'm

405
01:05:43.650 --> 01:05:47.100
dong su: Assuming assume the galaxies are randomly orientation.

406
01:05:48.570 --> 01:05:51.600
dong su: Or must know the distribution of different shape of galaxies.

407
01:05:52.650 --> 01:05:59.790
dong su: Then the question is how to, how do people know that distribution of and Lance shape of the county

408
01:06:00.420 --> 01:06:03.270
Aaron Roodman: So we don't need to know that because

409
01:06:04.530 --> 01:06:09.480
Aaron Roodman: I'm because the effect of week lensing is additive

410
01:06:10.770 --> 01:06:12.690
Aaron Roodman: So you could imagine you've got

411
01:06:13.800 --> 01:06:14.430
Aaron Roodman: The

412
01:06:15.990 --> 01:06:19.500
Aaron Roodman: The intrinsic shape, plus the week lens in shape.

413
01:06:20.550 --> 01:06:38.850
Aaron Roodman: So it's a shape. So the magnitude of the first part doesn't matter if you average over many galaxies that first term averages to zero. And all that's left is the gravitational lensing effect. That's it. So that's another important feature of how we can extract information with this method.

414
01:06:40.980 --> 01:06:42.600
dong su: Yeah, okay.

415
01:06:43.680 --> 01:06:45.900
dong su: So let's move on to the next one.

416
01:06:49.440 --> 01:06:56.130
dong su: With a week Lansing telescope in space. Eventually achievable, or the generally better do them from the ground.

417
01:06:57.450 --> 01:07:08.550
Aaron Roodman: So I I'll comment on that tomorrow. There actually are two space face projects telescope projects. One, the European Space Agency and one from NASA

418
01:07:09.900 --> 01:07:25.890
Aaron Roodman: Who's an important part of their mission is studying the gravitational lensing. We're doing it from space has some very significant advantages and it has other significant disadvantages. I'm not going to go into great detail, but I'll, I'll say a little bit more about that tomorrow.

419
01:07:27.150 --> 01:07:34.950
dong su: Okay, of the next one is your favorite experiment on PS. So, so what is the

420
01:07:36.840 --> 01:07:40.920
dong su: wavelength range and the the redshift covered by the yes

421

01:07:42.420 --> 01:07:43.770
Aaron Roodman: So, um,

422
01:07:45.600 --> 01:07:59.220
Aaron Roodman: Let's see. So the wavelength ranges from around 350 nanometers up to 1000 meters. So it's the visible Banda light with that goes into the UV a little bit and into the near infrared

423
01:08:00.300 --> 01:08:15.930
Aaron Roodman: And redshift range that's really usable as kind of from point two to 1.2 there's certainly galaxies that that are more distant than that, it becomes difficult to determine their redshift asked, you know, let's call it 1.2

424
01:08:18.360 --> 01:08:18.660
Yeah.

425
01:08:19.950 --> 01:08:23.460
dong su: Okay, so on the, on page 17 there's a

426
01:08:25.860 --> 01:08:31.740
dong su: Lot quarter on page 17 on how worthy retro of the known galaxy previously I'll paint.

427
01:08:33.540 --> 01:08:43.020
Aaron Roodman: Oh, okay. So I didn't have much time to talk about this. And so this is the calibration of red shirts and then there are a couple different ways. We have

428
01:08:43.440 --> 01:08:56.790
Aaron Roodman: To, to make sure we understand systematically the redshift of different ensembles of galaxies. Now in this method we take an ensemble, which is selected by a point estimator.

429
01:08:57.510 --> 01:09:06.360
Aaron Roodman: For the redshift, and we want to ask what is the distribution of red shifts in that ensemble. So that might be one of the different

430
01:09:07.590 --> 01:09:08.730
Aaron Roodman: We call them demographic

431
01:09:08.730 --> 01:09:19.350

Aaron Roodman: Bins is or is there a name for them. And that's the different colors, shown here. Now we can cross correlate them against another sample galaxies with no redshift now.

432
01:09:20.430 --> 01:09:33.270
Aaron Roodman: If you had a lot of galaxies measured with full spectra. You could do this to me. Well, but spectra are very expensive and currently we don't have enough galaxies of

433
01:09:33.840 --> 01:09:52.800
Aaron Roodman: This kind and these are dim galaxy which is the problem we don't have enough of them with full spectroscopic Richards, we do have a sample. It's a sample we call red magic. That's the name that people that invented the algorithm gave to it, putting my colleague, it's like money right

434
01:09:54.090 --> 01:10:03.210
Aaron Roodman: And those galaxies we measure the redshift with this photo metric method, but the galaxies have a certain

435
01:10:04.890 --> 01:10:24.960
Aaron Roodman: Color distribution that makes it much makes their friendships, much more reliable from the telemetry. So it's a subset of galaxies colors are much more constrained and understood and so they're redshift are much better than the average galaxy.

436
01:10:26.160 --> 01:10:41.190
Aaron Roodman: And so we're kind of bootstrapping. We've we can study those galaxies against spectra and then we can sell a study most galaxies against the special read magic ounces. That's the trick we played in this in this world.

437
01:10:41.850 --> 01:10:44.520
mark convery: And not okay we got one more quick one.

438
01:10:46.140 --> 01:10:55.380
dong su: Yes, this one last question on the same page so you someone called you, you only we only need to know the width of these distributions, what you meant by that.

439
01:10:56.130 --> 01:10:56.850
Aaron Roodman: Oh, so

440
01:10:57.900 --> 01:11:02.670
Aaron Roodman: So it turns out that and we cleansing don't need

441
01:11:04.860 --> 01:11:10.290
Aaron Roodman: Because it's a statistical measurement and post we're averaging over millions of galaxies.

442
01:11:11.460 --> 01:11:20.610
Aaron Roodman: And we're dividing our galaxies into these telegraphic bins. It turns out that all you really need to know to do the measurement well

443
01:11:21.180 --> 01:11:28.590
Aaron Roodman: Is the mean and the and the which is the first moment. And then the second moment which is the width of these distributions.

444
01:11:29.220 --> 01:11:47.550
Aaron Roodman: It doesn't really depend on the detailed shape of the distribution that much. So it's it's it's a system. It's a comment about the systematics of the measurement and where most of the information is it's mostly in the meat and width of the distributions.

445
01:11:48.150 --> 01:11:51.150
dong su: Okay, thanks very much. I got that we're out of times then Techstars

446
01:11:51.180 --> 01:11:59.850
mark convery: Okay, thank you very much variation talk and we'll look forward to your second lecture tomorrow on the same topic, and I'll stop the recording.