WEBVTT

1
00:00:03.990 --> 00:00:11.849
Richard Partridge: So I'm pleased to introduce Brian lance of Stanford, who's going to tell us about measuring gravitational waves. Right.

2
00:00:13.320 --> 00:00:24.900
Brian Lantz [h]: Great, thank you. I am really excited to be in this session, especially to be paired up with a talk by Daniel Holt's who I think gave a really nice.

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00:00:25.650 --> 00:00:35.550
Brian Lantz [h]: Introduction to all the Astronomy and Astrophysics that we can do with the current gravitational wave detectors. I think it really sets the motivation for

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00:00:36.840 --> 00:00:44.790
Brian Lantz [h]: Or continuing this work. I want to take sort of the opposite approach that he did and talk instead about the

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00:00:48.750 --> 00:00:52.290
Brian Lantz [h]: actually meant to do that for a couple of reasons.

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00:00:53.430 --> 00:01:02.760
Brian Lantz [h]: As Daniel alluded to, when he was showing the measurement of the first neutron star merger the machines are a little temperamental. And so understanding how the observatories work.

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00:01:03.210 --> 00:01:13.710
Brian Lantz [h]: I think gives you a better appreciation for how to do the analysis and evaluate the results. And the second is that, as you'll see at the end of this talk, we are

8
00:01:14.430 --> 00:01:31.500
Brian Lantz [h]: making plans to greatly increase the reach for these observatories on both in distance and in frequency and having an understanding of how the current machines work. I think sets a nice scale for the improvements that that we hope to do

9
00:01:33.390 --> 00:01:43.170
Brian Lantz [h]: And thirdly, maybe most important is that you know these machines are really cool. So I hope to maybe convince you about that a little bit.

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00:01:44.550 --> 00:01:52.440
Brian Lantz [h]: As I said, I'm Brian lance and tell you about how these machines have made the measurement of gravitational waves, a weekly event.

11
00:01:53.040 --> 00:02:02.580
Brian Lantz [h]: Of course I'm part of a lie ago the Lego scientific collaboration, which is an enormous collaboration. You can see, you know, the logos of the

12
00:02:03.210 --> 00:02:19.530
Brian Lantz [h]: Many universities and partners that we have around the world, funded by the National Science Foundation, a number of private foundations and many international partners, the Lego of courses is one of several

13
00:02:20.670 --> 00:02:30.900
Brian Lantz [h]: International detectors, we have the two Lego detectors in the United States. And I'm going to mostly focus my talk on those because that's the instrument that I'm most familiar with.

14
00:02:32.760 --> 00:02:42.600
Brian Lantz [h]: But I hope that you don't take away from that the conclusion that the network is not important, because the network is vitally important.

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00:02:43.140 --> 00:02:54.300
Brian Lantz [h]: And we're joined by the your good collaboration, which has a detector in Italy Legos partnered with India to build a third Lego detector in India.

16
00:02:54.810 --> 00:03:09.600
Brian Lantz [h]: There's an underground Japanese detector called Chicago, which has recently come online demonstrating some very interesting technology there and a short well a 600 meter long detector in northern Germany called the

17
00:03:11.010 --> 00:03:11.430
Brian Lantz [h]: Which

18
00:03:12.570 --> 00:03:23.010
Brian Lantz [h]: You can think of as either a small detector for gravitational waves or a very large laboratory for demonstrating some of the highest technology.

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00:03:23.610 --> 00:03:35.880
Brian Lantz [h]: Improvements that that we're trying to do to the other missions. Of course we became you know went from being a physics experiment to being an astronomical group on

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00:03:38.070 --> 00:03:39.840
Brian Lantz [h]: December September.

21
00:03:40.950 --> 00:03:50.880
Brian Lantz [h]: 14 of 2015 and the two Lego machines measured the first gravitational wave of Daniel talked about the black hole merger that we first saw

22
00:03:52.800 --> 00:04:06.000
Brian Lantz [h]: And he's talked earlier this session. Here you can see the the time series for that Daniel talked a lot about what we learned when we saw these 230 solar mass black holes merging into each other.

23
00:04:07.020 --> 00:04:14.970
Brian Lantz [h]: I want to bring your attention just maybe two or three features from these waveforms that are going to be relevant for the rest of the talk.

24
00:04:16.080 --> 00:04:28.350
Brian Lantz [h]: The first here's the strange. This is the proportional stretching of space time that you get from a gravitational wave that you see, I'd like of Hanford and like a Livingston

25
00:04:28.890 --> 00:04:47.310
Brian Lantz [h]: The peak strain that we're measuring is 10 to the minus 21 and as you can see from this wave form. This is just a band pass filtered wave form that strain that relative stretching is actually quite easy to see at the beginning of the first observing run for advanced Lego

26
00:04:49.080 --> 00:04:55.110
Brian Lantz [h]: Even though the second point is, even though that strain is very, very small.

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00:04:56.100 --> 00:05:06.180
Brian Lantz [h]: A number I like in comparison to what Daniel said this morning. If you take the distance from the Earth to the Sun and you oscillated the strain of 10 to the minus 21

28
00:05:06.570 --> 00:05:15.150

Brian Lantz [h]: Perhaps the length change you get is about the size of an atom. And that's the kind of strange. The proportional stretching of space that that we can see.

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00:05:17.190 --> 00:05:36.390
Brian Lantz [h]: The third thing to think about. And I think it's you know why I'm so excited to be part of the this at of classes is that this strain is nearly unmeasurable right this is a very, very small stretching of space time it's nearly invisible but

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00:05:37.470 --> 00:05:45.870
Brian Lantz [h]: The amount of energy that you see here, right, three solar masses of being converted into gravitational waves.

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00:05:50.070 --> 00:06:02.490
Brian Lantz [h]: See this event is enormous. Right. This was 50 times the luminosity in gravitational waves 50 times luminosity of the light coming off of all the stars in the entire physical universe and so

32
00:06:03.780 --> 00:06:15.300
Brian Lantz [h]: Just because it's hard to see, does not mean that it is unimportant or that it is small, which I think is a set or repeated theme that you're going to see all all through this week. Okay.

33
00:06:16.830 --> 00:06:19.470
Brian Lantz [h]: Right. So with those things to keep in mind.

34
00:06:20.640 --> 00:06:24.330
Brian Lantz [h]: Let's go and talk about how you actually make a measurement like this.

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00:06:25.440 --> 00:06:45.240
Brian Lantz [h]: So the Lego concept and beer go in Congress. And as you'll see a number of other machines coming up in the future. You've got some source over here uh pair of binary black holes are pilot or a neutron stars, perhaps a duck pond. It's emitting gravitational waves. And those way.

36
00:06:48.330 --> 00:06:59.550
Brian Lantz [h]: Distance observer kind of strange if you imagine that you have a ring of particles hanging out in space. And we've come through that believes that it's a transverse wave. So you can think about

37
00:06:59.880 --> 00:07:09.000

Brian Lantz [h]: Your, your doctor smile. Here she's watching, you know, watching outer space. And there's the wave comes through this ring of particles. First, it gets

38
00:07:09.480 --> 00:07:21.330
Brian Lantz [h]: Elongated one direction and compressed in the other direction and that ring of particles is going to oscillate back and forth for however many oscillations. There are in the gravitational wave

39
00:07:22.560 --> 00:07:37.920
Brian Lantz [h]: There to polarization for these gravitational waves. The H plus H cross. You can see the you know the difference in these two waveforms. And so if you could measure the distance from an object here to an object here and compare that.

40
00:07:39.240 --> 00:07:49.170
Brian Lantz [h]: Maybe use these to compare that to the distance between these two objects, then you could measure a gravitational wave. And that's exactly what we're trying to do with our big

41
00:07:49.920 --> 00:08:00.240
Brian Lantz [h]: Laser Interferometer so you can kind of think you know when that we've comes past. It's kind of like this, right, so first you know one arm gets a little longer. The other and it's shorter

42
00:08:02.070 --> 00:08:11.880
Brian Lantz [h]: And is the middle of a period of the cross and then three quarters of the period, you know, the other. Now the other arms longer and they're going to oscillate back and forth.

43
00:08:12.900 --> 00:08:14.490
Brian Lantz [h]: Until the waves come through.

44
00:08:17.730 --> 00:08:28.950
Brian Lantz [h]: It, one of the weirdest things about gravitational waves, though, is when you see an animation like this, what you see as though you know if these mirrors are moving, of course.

45
00:08:30.420 --> 00:08:45.480
Brian Lantz [h]: It's a general relativistic effect. And so the space time is stretching. These mirrors are not moving. It's just that the distance between them is is changing something that's still strikes me after all these years as a very, very odd idea.

46
00:08:46.500 --> 00:08:57.840

Brian Lantz [h]: Of course. Gravitational waves are hard to measure the space does not like to be stretched. Right. And so, you know, the original stream that we saw part in 10 to the minus 21

47
00:08:58.710 --> 00:09:07.770
Brian Lantz [h]: If you compare that to the length of these four kilometer arm cavities internet the length of this arm was changing by tend to them for 10 to the minus 18 years

48
00:09:08.640 --> 00:09:27.600
Brian Lantz [h]: And that's why it's taken so long to finally make a measurement Einstein predicted these waves back in 1916 Ray Weiss wrote a paper in 1973 describing hollow laser measurement system like this could actually work and beat you need the esoteric noise performance.

49
00:09:28.980 --> 00:09:36.960
Brian Lantz [h]: But it wasn't until almost 100 years after Einstein made the prediction was until 2015 and we finally made our, our first measurements.

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00:09:40.350 --> 00:09:46.980
Brian Lantz [h]: That the idea when you think about how these machines work. There are a lot of things that we do.

51
00:09:48.090 --> 00:10:00.000
Brian Lantz [h]: But you can sort of categorize the various approaches into four techniques. The first is really long arms and the second is you make the mirrors very, very quiet.

52
00:10:01.410 --> 00:10:06.450
Brian Lantz [h]: The third is you make a very precise measurement of the distance between the mirrors.

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00:10:07.470 --> 00:10:14.160
Brian Lantz [h]: And I'm going to talk about these three, a little bit more as we move forward. The fourth, of course, is that you have a network.

54
00:10:15.090 --> 00:10:21.330
Brian Lantz [h]: I'm going to make. So the thing about in network your two big benefits from a network. The first

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00:10:21.810 --> 00:10:30.960

Brian Lantz [h]: Is that by using the arrival time of the signals at the multiple detectors. You can use triangulation to figure out where your sources.

56
00:10:31.500 --> 00:10:44.250
Brian Lantz [h]: And so you really want to have online three good detectors, all of the time, so that you can reliably triangulate the source of interesting events like on your neutron stars.

57
00:10:46.200 --> 00:10:56.910
Brian Lantz [h]: The other benefit for a network is that often the signal to noise ratio of these events is pretty small. And so to help distinguish effects from local noise.

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00:10:57.480 --> 00:11:04.710
Brian Lantz [h]: From the effects of astrophysical signals, you'd like to be able to have a network. So you can see the same signal in a bunch of different detectors.

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00:11:08.280 --> 00:11:16.950
Brian Lantz [h]: So it's gave us the next long arms right so here's a couple of pictures of the Lego detectors, the arms here or four kilometers long.

60
00:11:17.640 --> 00:11:29.850
Brian Lantz [h]: Of course, since what we're trying to measure is a stretching of space. This each term, the more L. You have more arm length you have, the more absolute delta L length change get

61
00:11:31.350 --> 00:11:38.520
Brian Lantz [h]: I mean you compare that to the noise sources, the more absolute length change your have, the easier it is to make the measurement

62
00:11:40.320 --> 00:11:45.810
Brian Lantz [h]: Of the reasons that these these detectors are so expensive, right. We're World's Largest ultra high vacuums

63
00:11:49.080 --> 00:11:56.730
Brian Lantz [h]: Each four kilometers long, and four feet in diameter and filled with ultra high vacuum were filled with really extraordinary amounts of nothing at all.

64
00:11:57.690 --> 00:12:06.510

Brian Lantz [h]: Just a couple of pictures of that. Here's the detector being built in Louisiana. You can see that four foot diameter pipe stretching off into horizon under his little concrete.

65
00:12:07.530 --> 00:12:08.760
Brian Lantz [h]: Enclosure here.

66
00:12:11.070 --> 00:12:18.450
Brian Lantz [h]: There's a, you know, if you look at if you were to go out to the detector now looks a little looks a lot prettier the grasses, come back and

67
00:12:19.110 --> 00:12:33.330
Brian Lantz [h]: You can see the beautiful the beautiful building this out there is easier actually farmed trees, you know, the beautiful environment around the Louisiana Observatory stretching out here to the, to the end station.

68
00:12:35.070 --> 00:12:43.650
Brian Lantz [h]: If we could afford to have longer arms, we would the cost of these vacuum systems and these enclosures, and this land and this infrastructure.

69
00:12:50.070 --> 00:12:59.250
Brian Lantz [h]: We talk about the noise from various sources. One thing that's really useful to do is look at what we call the noise budget.

70
00:12:59.760 --> 00:13:12.120
Brian Lantz [h]: So this is the contribution of various noise sources at different frequencies. So here you have the frequency on the x axis. And on the y axis you have the stream which is the

71
00:13:14.070 --> 00:13:18.810
Brian Lantz [h]: Amplitude density of the strain. This is the proportional stretching

72
00:13:20.250 --> 00:13:30.030
Brian Lantz [h]: Per reports and if you're not familiar with amplitude spectral densities, you can just think to yourself, How much strain is there in a one hurts bandwidth

73
00:13:31.140 --> 00:13:40.380
Brian Lantz [h]: And then you can look at this and you can say, well, the most sensitive part and most sensitive frequency for advanced lygo should be here at a few hundred hertz.

74
00:13:41.010 --> 00:13:48.630
Brian Lantz [h]: And then we should be able to measure signals down to about 10 hertz and up to a few kilometers.

75
00:13:49.380 --> 00:13:58.890
Brian Lantz [h]: So often, and this is something that many people who first run into Lago are a little bit confused by when we're making a measurement of the

76
00:13:59.610 --> 00:14:09.900
Brian Lantz [h]: Arms, you know, we look at these arm length right here. You know, we can measure these to tear apart in 10 to the 21 but we're not actually measuring the absolute like

77
00:14:10.590 --> 00:14:22.050
Brian Lantz [h]: What we're measuring is the deviation from the original link and the difference of the deviation of this arm and that arm and those

78
00:14:23.430 --> 00:14:31.440
Brian Lantz [h]: Those deviations that differential deviations about zero make this measurement when one of the things that actually make this phone measurement possible

79
00:14:32.640 --> 00:14:52.350
Brian Lantz [h]: So at low frequencies of conflict look back at our noise budget, the fundamental things that limit advanced Lago ought to be the, the things in this purple curve and this red card. So this is the radiation pressure. So this is actually the photons bouncing off of the mirrors.

80
00:14:54.660 --> 00:15:02.190
Brian Lantz [h]: The thermal noise of the suspensions. So route the suspensions being driven back and forth because they're sitting at room temperature.

81
00:15:03.000 --> 00:15:14.280
Brian Lantz [h]: And then at the slightly higher frequencies, the thermal driven vibrations of the mirror coatings. I'm going to talk about all those as we go forward at higher frequencies.

82
00:15:16.290 --> 00:15:28.230

Brian Lantz [h]: We start to run into, into shot Moyes these. And interestingly, the sensing noise, both at low frequencies and the setting was at high frequencies might be

83
00:15:28.860 --> 00:15:34.440
Brian Lantz [h]: You know, you might think of this as radiation pressure moving the mirror around and so your inability to measure where the year is

84
00:15:34.920 --> 00:15:41.700
Brian Lantz [h]: Or you might think about this at sensing noise. The photon pressures in the light beam pushing the mirror around

85
00:15:42.210 --> 00:15:57.510
Brian Lantz [h]: So you have shot noise at high frequencies from your measuring of the photon and I'll talk about that and sensing noise at low frequencies from your radiation pressure was the plots like this. A couple more times as we're moving along.

86
00:15:58.770 --> 00:16:06.510
Brian Lantz [h]: The other interesting thing to do is then compare how well we actually do with our predictions. So this is where the advanced Lego

87
00:16:07.080 --> 00:16:22.440
Brian Lantz [h]: Noise curves. It's this black line. The green line is how well the initial Lego machine was able to perform and these red and blue lines where the performance of advanced Lego when we measured the first gratification.

88
00:16:23.700 --> 00:16:33.660
Brian Lantz [h]: And initial Lego ran for many years and never made it detection advanced Lego ran for three days before I saw one of the biggest gravitational waves signals ever measured

89
00:16:34.290 --> 00:16:44.730
Brian Lantz [h]: And when you look at how much distance there is between these noise or it's it's not very different, at least at 100 Hertz. As you move to lower frequencies, you start to see a very good

90
00:16:47.010 --> 00:16:51.810
Brian Lantz [h]: It doesn't look like it's very much here. But as you see later, it's actually really important

91
00:16:52.890 --> 00:17:04.650

Brian Lantz [h]: Another thing to think about is when we're running the machines like how does that, how does this spectrum actually compare to what the folks on the site and running the detector algorithms actually do

92
00:17:05.400 --> 00:17:16.380
Brian Lantz [h]: So this is a spectrograph Daniel Holt's showed you one of these earlier in the session. And so each of the vertical columns here is like a spectrum at a moment of time.

93
00:17:16.950 --> 00:17:29.160
Brian Lantz [h]: And so you can watch the spectrum as the time marches along here over the course of a day. Here you can see the most sensitive frequency around about, you know, a little over 100 hertz.

94
00:17:30.090 --> 00:17:45.630
Brian Lantz [h]: Hard to see anything on a plot like this, you can actually normalize each of these frequencies and you get a plot which looks like this. Or you can start to look for a little deviations in the time. So what you're looking for is a sudden blip that change is

95
00:17:49.290 --> 00:17:53.670
Brian Lantz [h]: Always at a, at a moment in time. So create a completely non random time at

96
00:17:54.810 --> 00:18:03.690
Brian Lantz [h]: UTC on August 17 of 2017 if you were to zoom in on this spectrum Graham and of course you have to change the color scheme.

97
00:18:04.920 --> 00:18:18.210
Brian Lantz [h]: What you would see is 30 seconds of spectrograph which looks like this and shows that beautiful inspiring church for the neutron stars but Daniel talked about so much earlier earlier today.

98
00:18:20.400 --> 00:18:28.980
Brian Lantz [h]: Yeah, so to neutron stars, you know, producing a killer Nova, a big burst of gamma rays and a very large burst of astronomy papers.

99
00:18:30.570 --> 00:18:30.900
Brian Lantz [h]: So,

100
00:18:31.950 --> 00:18:44.550

Brian Lantz [h]: Why do we use a Laser Interferometer to make a measurement like this and this is not this is this is comes from a beautiful animation that you guys can go and look

101
00:18:47.370 --> 00:19:03.570
Brian Lantz [h]: Look at dresses right here just captured from it. You can see you've got your being coming out of your laser gets the beam splitter edge down these two long arms comes back recombine to the beam splitter and a little bit of the light comes towards your comes towards your detector.

102
00:19:05.310 --> 00:19:14.070
Brian Lantz [h]: If you think about the electric field in these themes, you can think about the yellow one is the one that goes down the X arm and a blue going down the line arm.

103
00:19:14.610 --> 00:19:30.300
Brian Lantz [h]: When they come back, you can set the detector, so that these two electric fields returning from these two arms are out of phase, which means that they add to zero, and there is no light at your detector. If one arm gets a little longer.

104
00:19:31.380 --> 00:19:43.380
Brian Lantz [h]: Than what you see is that the phase of these two electric field changes and now they don't perfectly cancel and you start to get light at your detector and as you

105
00:19:44.310 --> 00:19:55.740
Brian Lantz [h]: Adjust the arm length a little bit going back and forth, or the gravitational wave coming past hopefully you can see my not an animation of a gravitational wave

106
00:19:59.340 --> 00:20:07.920
Brian Lantz [h]: As you fluctuate these arms, the light coming to this detector changes and you watch the light here as a monitor how long arms.

107
00:20:10.170 --> 00:20:21.360
Brian Lantz [h]: Which means that you now have a ruler right which is four kilometers long, and the tix on that ruler or a micron right there, the wavelength of light. So you can make a really, really sensitive detector. This

108
00:20:23.370 --> 00:20:29.760
Brian Lantz [h]: Now because this is supposed to be like a class, let me go into a little more detail right because

109
00:20:32.400 --> 00:20:40.680
Brian Lantz [h]: A micron 10 to the minus six meters is nothing like the performance of advanced Legos. How do we get there, right. So we talk through that.

110
00:20:41.700 --> 00:21:00.540
Brian Lantz [h]: A few minutes to talk about the how we accurately measure the length of these owners. So the first thing is if you had a one meter long laser Michaelson interferometer with a lot of laser power coming in, you can actually make a really good measurement

111
00:21:01.830 --> 00:21:11.460
Brian Lantz [h]: It turns out that the sort of fundamental performance for this is set by your photon counting statistics. And so you can imagine you're trying to measure these aren't whites.

112
00:21:11.910 --> 00:21:21.450
Brian Lantz [h]: By looking at the light on your detectors, you change the arm a light on your detector goes up and down like assignment you can you could imagine sitting right here. The mid fringe

113
00:21:21.870 --> 00:21:29.070
Brian Lantz [h]: And so if if we got a little more light we tell you that the arms a little longer, a little less light please your arms because a little bit shorter.

114
00:21:29.610 --> 00:21:41.850
Brian Lantz [h]: But there's this quantum uncertainty which says that if you expect to measure in photons in your measurement time that the Shop Boys will tell you that there's a spirit of an uncertainty to that.

115
00:21:43.530 --> 00:21:49.710
Brian Lantz [h]: And when you work through the math. You can get a relationship like this. Here's the power, looking at the number of photons.

116
00:21:51.180 --> 00:21:59.190
Brian Lantz [h]: HD lambda which relates of the energy per photon and the active fringe that you get

117
00:21:59.730 --> 00:22:14.760
Brian Lantz [h]: And when you work through this, what you can see is that at one, one, you can actually get all the way to 10 to the minus 16 meters, you can think about what's going on here. This uncertainty by

saying, Well, instead of having a nice clean line that she got this fuzzy line right and so

118
00:22:15.870 --> 00:22:25.320
Brian Lantz [h]: When I have some uncertainty in the number of photons and the number of photons changes. I don't know whether that's because of the quantum uncertainty moving in this direction.

119
00:22:25.830 --> 00:22:34.560
Brian Lantz [h]: Right up and down the detector power or if it's the arm life changing going this way. And so it's just a fundamental limit how well you can make a measurement

120
00:22:35.760 --> 00:22:42.180
Brian Lantz [h]: Of course, the more photons, you have, the better you can do that measurement. But even with one watt and one meter.

121
00:22:42.720 --> 00:22:49.260
Brian Lantz [h]: For the simple Michaelson interferometer something invented over 100 years ago right you can get all the way to 10 to the minus 16

122
00:22:50.160 --> 00:23:02.760
Brian Lantz [h]: Stream and a one hurts family down. The next thing to do, of course, if you move out to a four kilometers long arm right which makes you 4000 times more sensitive to strain. You can move to this line.

123
00:23:03.240 --> 00:23:14.310
Brian Lantz [h]: We're trying to get to the old one. In our first noise curve and then eventually to be advanced like a noise curve down here and you can see we're, we've actually gone a long way. Right.

124
00:23:16.860 --> 00:23:24.780
Brian Lantz [h]: The next thing you do is you start to do interesting enough for interferometry, so instead of that simple Michaelson, this is a better layout of the interferometer and you can see that we've got these

125
00:23:25.290 --> 00:23:30.330
Brian Lantz [h]: Funky cavities in here, what we do is we bounced the light back and forth a bunch of times.

126
00:23:30.870 --> 00:23:45.780
Brian Lantz [h]: Between these mirrors and you collect the phase you measure the gravitational wave for a longer time. So this is effectively

like making this arm, much, much longer I bouncing the light back and forth. And so at 20 bounces, you can see

127
00:23:51.270 --> 00:23:57.930
Brian Lantz [h]: In our picture string in fact mean bounce light back and forth about 300 times and so low frequencies to get a big improvement.

128
00:23:58.320 --> 00:24:12.390
Brian Lantz [h]: At a higher frequency, so we don't get the full improvement because the light is stored in the arm for longer than the period of the gravitational waves. So the arm out here. These high frequencies that are much longer than shorter or longer and shorter or longer and shorter

129
00:24:13.830 --> 00:24:19.200
Brian Lantz [h]: Compared you know in a single storage time for this cabin, which is why the performance gets worse.

130
00:24:20.550 --> 00:24:25.620
Brian Lantz [h]: It at high frequency or maybe you can say, which is why the performance does not continue to improve

131
00:24:28.050 --> 00:24:44.670
Brian Lantz [h]: Now one of the things you'll see as we talk about these characters is that there's a price to be paid for storing the light and these arms and that is we do something called make a fabric pro cavity. So this is a resonant optical cavity. It's not a bunch of

132
00:24:48.300 --> 00:24:57.900
Brian Lantz [h]: Bounces if this is sort of a plot of the cavity power versus our length and the. So the blue is the cavity power.

133
00:24:58.380 --> 00:25:05.460
Brian Lantz [h]: You can see that we have a lot of power right at the, you know, right on resonance. But if we move a nanometre away.

134
00:25:06.240 --> 00:25:14.730
Brian Lantz [h]: A white in the cabinet goes down dramatically and our signal which is shown here in the green, you can see is only effective right you're around

135
00:25:15.210 --> 00:25:31.320
Brian Lantz [h]: The optimum resonance condition. And so you have to put a lot of active server controls on to hold your cavity right here. In

fact, before kilometer arm categories are control to about 10 to the minus 14 meters RMS to make this thing work.

136
00:25:33.270 --> 00:25:33.630
Brian Lantz [h]: And

137
00:25:34.770 --> 00:25:35.250
Richard Partridge: Ryan.

138
00:25:35.580 --> 00:25:36.000
Brian Lantz [h]: Yes.

139
00:25:36.660 --> 00:25:40.620
Richard Partridge: It looks like your networking connection occasionally goes unstable.

140
00:25:40.890 --> 00:25:41.460
Brian Lantz [h]: Oh, no.

141
00:25:41.880 --> 00:25:45.750
Richard Partridge: Could you please turn off your video so that we get the audio.

142
00:25:46.950 --> 00:25:48.090
Brian Lantz [h]: Turn off the picture of me.

143
00:25:48.450 --> 00:25:49.560
Richard Partridge: Yeah for sure you

144
00:25:49.770 --> 00:25:51.180
Brian Lantz [h]: Know one wants to look at me anyway.

145
00:25:53.940 --> 00:25:58.530
Brian Lantz [h]: There we go. Maybe that will hopefully that'll help a little bit

146
00:25:59.430 --> 00:26:00.360
Brian Lantz [h]: Sorry about that.

147
00:26:05.340 --> 00:26:22.230
Brian Lantz [h]: Okay, let's let's keep going. So now we've got these long arm caddies, and you bounce the like back and forth effectively 300

times and now you can see that performance has gotten very close to where we need to be for the, for the first observing

148
00:26:25.110 --> 00:26:26.850
Brian Lantz [h]: You can see here at high frequencies.

149
00:26:28.050 --> 00:26:45.600
Brian Lantz [h]: We seem to be limited by shot noise. And so the thing you do is you put more power into the machine. So for one we were injecting 23 watts of laser power into the detector. The goal for advanced logo is actually 120 Watts coming into the machine.

150
00:26:46.620 --> 00:26:55.020
Brian Lantz [h]: And you go up to 23 wants your performance now improves pretty dramatically, your ability to resolve where you on the fringe does improve

151
00:26:57.810 --> 00:27:15.450
Brian Lantz [h]: But you still are limited by your photon counting year until we play another trick called Power recycling every resident we enhance the light at the beam splitter by building another optical cavity between the arms and something called the power cycle here.

152
00:27:17.100 --> 00:27:25.470
Brian Lantz [h]: That brings our performance now to this red line and you can see at least the theoretical performance for the sensing

153
00:27:25.950 --> 00:27:37.920
Brian Lantz [h]: You can see that our shot noise has gotten much better. But now we're actually seeing the impact, at least in the theoretical sense of the large numbers of photon pushing them years around this radiation pressure

154
00:27:39.390 --> 00:27:47.610
Brian Lantz [h]: There's one more big trick that we play, which is something called signal recycling. It's actually more appropriate called signal extraction

155
00:27:48.150 --> 00:28:08.100
Brian Lantz [h]: And this is a technique where you extract the detector. The gravitational waves signal from these arms you lower the resonance for the signal with it an additional mirror here, the single cycle, which makes you less sensitive in the most sensitive region in the bucket, but more sensitive

156

00:28:09.240 --> 00:28:13.380
Brian Lantz [h]: At the at the higher frequencies. And this is a trick you can play the tune the performance

157
00:28:15.150 --> 00:28:33.390
Brian Lantz [h]: Though that sort of a brief run through of a bunch of optical tricks. The other thing that we do among the other things that we do is we try to hold the mirrors very, very stillness is what I work on on a day to day basis and tell you a little bit about that.

158
00:28:34.560 --> 00:28:42.900
Brian Lantz [h]: If you looked at the end mirrors out here and you look you went to the Lego Observatory, what you would see is that 18 foot tall vacuum chamber.

159
00:28:43.440 --> 00:29:04.680
Brian Lantz [h]: With a multi stage isolation and suspension system holding this mirror and the goal is it the motion of this year at 10 Hertz is about four times 10 to the minus 19 meters in one hurts bandwidth which is about a billion times less than the motion of the ground at that frequency

160
00:29:06.750 --> 00:29:15.900
Brian Lantz [h]: We get this by having a whole bunch of stages. Here's a picture of the Lego vacuum system, you were to peer into this Chamber right here.

161
00:29:16.920 --> 00:29:22.650
Brian Lantz [h]: Make a cutaway for it, but you'd see something like this. The first two

162
00:29:24.510 --> 00:29:35.640
Brian Lantz [h]: Stages in the vacuum or this big active isolation table. So this is like an optical table that many of you may have seen in your optics classes or in your labs for your mouth optics two

163
00:29:36.750 --> 00:29:45.780
Brian Lantz [h]: Hours is the same thing only. It's quieter, you have the table itself is hung on these springs. So you get passive isolation and we put a bunch of settings.

164
00:29:48.510 --> 00:29:48.960
Brian Lantz [h]: Actually

165
00:29:49.980 --> 00:29:58.560

Brian Lantz [h]: Control it actively as well. Here's a picture of one of those going into the Lego Observatory and when you

166
00:29:59.190 --> 00:30:13.770
Brian Lantz [h]: trace through what these things are doing. We do a lot of active control to try and figure out how to make these things more quiet, just to give you a sense for that. Let me just walk through what happens when you turn on your controls.

167
00:30:15.120 --> 00:30:23.040
Brian Lantz [h]: This is a spectrum of the motion. The blue is the ground motion. So you can see here at one hurts the motion is

168
00:30:24.480 --> 00:30:29.070
Brian Lantz [h]: A little you know it's a fraction about what 30 or 40 nanometers in one hurts bandwidth

169
00:30:30.090 --> 00:30:45.240
Brian Lantz [h]: The red is the motion of a platform just hanging on it springs and so you get a lot of isolation up here at 10 Hertz, but not so much a low frequencies. And as you start to turn on the controls by adding damping an active feedback back to the first stage.

170
00:30:46.620 --> 00:31:02.370
Brian Lantz [h]: Active be better the second stage active feedback up from the ground motion, you can get over a factor of 1000 additional isolation to beat systems, which is a technique which is incredibly powerful when you're trying to build scientific instruments.

171
00:31:04.950 --> 00:31:13.830
Brian Lantz [h]: Then once you've got a really quiet table to hang a four stage mirror off of it, here's sort of a CAD drawing of the Lego optic the mirror down here. Your Business end is a

172
00:31:14.910 --> 00:31:21.030
Brian Lantz [h]: 40 kilograms piece of the world, some of the world's best few silica, also known as glass.

173
00:31:22.650 --> 00:31:34.320
Brian Lantz [h]: And it suspended from a four stage pendulum, the final stage of this is actually bonded together with pieces of glass. So there's a glass year on the on the penultimate stage.

174
00:31:34.890 --> 00:31:43.080

Brian Lantz [h]: A glass fiber, which runs down, which is monolithically bonded to the optic down below, using a technique actually that was developed.

175
00:31:43.500 --> 00:31:50.490
Brian Lantz [h]: At Stanford many years ago for the gravity probe the experiment, which I think is pretty cool. If you do your job right.

176
00:31:51.030 --> 00:31:59.880
Brian Lantz [h]: The isolation of this system is so good that the motion of this optic will be dominated, not by the coupling from the ground motion.

177
00:32:00.450 --> 00:32:08.970
Brian Lantz [h]: That because of its thermal be driven vibration. So because it's warm. It's just we're going around and that should be larger than emotion coupled from the ground.

178
00:32:10.740 --> 00:32:27.480
Brian Lantz [h]: We also coat, those with the best coatings and in fact at 100 Hertz. It's the thermal vibrations of those coatings which limit the performance of advanced log of something which is an active topic of research throughout the Lego scientific and the Virgo and the Congress collaborations.

179
00:32:29.070 --> 00:32:37.440
Brian Lantz [h]: You go back to my little spectra here here's that blue line for the seismic table motion this red line now shows the benefit that you get by hanging

180
00:32:37.770 --> 00:32:48.630
Brian Lantz [h]: The mirror from this stage pendulum to see the four residences here and tremendous isolation coming out here to high frequencies. So this is 10 to the minus 20 meters per routers.

181
00:32:50.310 --> 00:33:06.660
Brian Lantz [h]: Giving you a factor of, you know, more than factor of a billion in fact predicted from the ground motion. You can add some damping and compare that to the actual motion of login. And you can see a 10 Hertz, the actual performance of Lego is not limited anymore by the performance of the

182
00:33:07.890 --> 00:33:09.660
Brian Lantz [h]: coupling of the ground motion.

183

00:33:13.290 --> 00:33:23.190
Brian Lantz [h]: Which is, I think, really a testament to a lot of work and very good engineering, maybe a couple of publicity photos here. Here's an engineering prototype.

184
00:33:23.610 --> 00:33:35.820
Brian Lantz [h]: Of advanced Lego. You can see the four stages here of course these are aluminum dummies rather than real optics Betsy here for scale. She's the optics lead up at the Hanford Observatory.

185
00:33:38.370 --> 00:33:54.660
Brian Lantz [h]: The real suspensions look more like this going into the site. Here you can see the real optic and if you if you look really closely you can see the glass fibers that suspended. Here's a picture of the coating on those optics as those as there's mirrors are getting installed.

186
00:33:58.980 --> 00:34:07.500
Brian Lantz [h]: This is a plot of how well we've improved the performance over the first three observing runs. So the red is the performance and

187
00:34:09.060 --> 00:34:12.900
Brian Lantz [h]: Green is the performance in 2017 the blue is the performance and

188
00:34:14.220 --> 00:34:23.940
Brian Lantz [h]: At the turns out the Livingston Observatory and you push forward by adding more power squeezed light high frequencies to improve your shot noise.

189
00:34:24.570 --> 00:34:34.920
Brian Lantz [h]: And actually it low frequencies. It's all limited by technical stuff. So nothing that you saw in those earlier plots. But actually, things like scattered light.

190
00:34:36.300 --> 00:34:52.050
Brian Lantz [h]: Things that are vibrating in the machine poor readouts and stuff that slowly and gradually gets fixed by the hard working folks at the at the sites. It doesn't seem like a big improvement.

191
00:34:53.400 --> 00:34:54.150
Brian Lantz [h]: When you go from

192
00:34:55.680 --> 00:35:07.290

Brian Lantz [h]: But you might be surprised. Right. Here's a picture of the range to which you can see a binary neutron star or the Hanford and the Livingston Observatory about at mega parsecs. Right.

193
00:35:08.640 --> 00:35:09.900
Brian Lantz [h]: For the first observing run

194
00:35:11.280 --> 00:35:23.670
Brian Lantz [h]: And improve the sensitivity by a factor of two or three for the third observing run the range gets out 210 hundred and 20 240 mega parsecs. So

195
00:35:24.240 --> 00:35:33.570
Brian Lantz [h]: Know, roughly a factor of two. But the volume of space that you can see goes up, not by a factor of two. But of course, by a factor of eight.

196
00:35:34.260 --> 00:35:44.850
Brian Lantz [h]: And you make a factor to improvement in the range. And so when you look at the number of events. You can see what you see as a plot that is very dramatic. So here the first

197
00:35:45.360 --> 00:35:53.730
Brian Lantz [h]: The second and the two parts of the third observing run showing the number of events that we can see quickly started off with the Big Bang right here with

198
00:35:57.090 --> 00:36:08.460
Brian Lantz [h]: But in the third observing run, which is Daniel point out this morning just, you know, finished up in March. We've seen an enormous number of black hole mergers and a few neutron stars.

199
00:36:09.210 --> 00:36:18.630
Brian Lantz [h]: The, you know, total of 67 non retracted alerts and we're seeing black hole mergers, you know, more than once a week.

200
00:36:19.980 --> 00:36:24.390
Brian Lantz [h]: It's no longer really a science experiment. It really is a place where we can do astronomy.

201
00:36:26.280 --> 00:36:36.270
Brian Lantz [h]: And now let me change gears a little bit and talk about where we want to go forward. So you can see that even small improvements to the range, make a big impact.

202
00:36:36.780 --> 00:36:45.540
Brian Lantz [h]: To the, to the performance of your astronomy. We just finished our third observing run your logo of your go cartridges coming online.

203
00:36:47.250 --> 00:36:59.490
Brian Lantz [h]: In about a year and a half. We plan to start the fourth observing run with a slightly improved range of, maybe, you know, sort of 130 maybe 170 hundred and probably 170 mega parsecs.

204
00:37:01.080 --> 00:37:07.020
Brian Lantz [h]: And then building forward to new optical coatings and new

205
00:37:08.310 --> 00:37:16.530
Brian Lantz [h]: Detector physics with some squeezed light that you have your double the range out to 330 mega parsecs.

206
00:37:18.030 --> 00:37:28.620
Brian Lantz [h]: When you look at what that means for a spectrum now from the black line for dance logo. We're hoping to move to this purple line. So the Fed another factor of two.

207
00:37:29.850 --> 00:37:34.380
Brian Lantz [h]: And with that, you should be seeing mergers of binary black holes, maybe everyday.

208
00:37:35.550 --> 00:37:47.700
Brian Lantz [h]: binary neutron stars merging a few times a month. And when you think back to the kind of measurements that Daniel was able to do with one single binary neutron star.

209
00:37:48.240 --> 00:38:00.510
Brian Lantz [h]: And think, wow, if I had a whole year, or I was seeing a few of those a month, imagine the kind of astrophysics that we could get out of this. And I think within the next five or six years. That's where we're going to be

210
00:38:02.340 --> 00:38:13.530
Brian Lantz [h]: Of course, we always like to think big and so advanced Lego is now trying to push towards even bigger machines, the whole community is pushing this way. Here's a picture of two

211
00:38:15.300 --> 00:38:25.230

Brian Lantz [h]: machines that are now under very active discussion. This is called the Einstein telescope which is a European detector. Now they have 10 kilometer long

212
00:38:25.770 --> 00:38:37.260
Brian Lantz [h]: Underground arms in a triangle. So you can measure both the plus and that cross polarization that we mentioned briefly a little while ago.

213
00:38:39.630 --> 00:38:50.010
Brian Lantz [h]: A US machine being contemplated called Cosmic explorer looks a lot like advanced Lego except that now the arms are 40 kilometers long.

214
00:38:50.730 --> 00:39:05.880
Brian Lantz [h]: Or maybe 20 or maybe 15 there's an active design discussion going on trying to look at the cost benefit of this, the facility for the Einstein telescope is now under review in Europe and

215
00:39:07.650 --> 00:39:11.940
Brian Lantz [h]: If there had not been Kovac pandemic, we would have heard back on that already.

216
00:39:13.350 --> 00:39:29.790
Brian Lantz [h]: We do expect to hear whether the facility is going to be funded on in the immediate future within you know by the end of this year. And so a number of the ice European colleagues are very much on tenterhooks awaiting the the discussion of that.

217
00:39:30.930 --> 00:39:48.090
Brian Lantz [h]: The spectrum. The noise spectrum, you can see when you move to these really big machines, you know, here's advanced like advanced Lego the a plus where we're trying to get to. Now, and factors of five or 10 improvement to

218
00:39:49.350 --> 00:39:52.380
Brian Lantz [h]: The Einstein telescope and cosmic explorer.

219
00:39:53.400 --> 00:40:01.230
Brian Lantz [h]: Both giving you better sensitivity at the bucket as well as a broader bandwidth down here to lower frequencies.

220
00:40:03.450 --> 00:40:20.250
Brian Lantz [h]: When you think about how many black holes you can measure by doing that, it's often better to not think about number of

events per day by the volume of space that you can see to here's a plot showing the mass

221
00:40:21.300 --> 00:40:30.870
Brian Lantz [h]: Of the emerging event of you can see so 10 100 1000 solar masses of sorts frame object and the redshift.

222
00:40:32.220 --> 00:40:44.190
Brian Lantz [h]: When you look at this plot what this tells you is that you'll be able to see all of the mergers of the 10 to 100 solar mass black holes out to the time of the first star formation.

223
00:40:44.970 --> 00:41:07.230
Brian Lantz [h]: And when you think about the cosmology implications of that they aren't very dramatic. In addition, the signal to noise for the close by ones becomes also very, very good, allowing you to do really interesting modeling of the non you know of effects of general relativity and perhaps deviations.

224
00:41:08.370 --> 00:41:08.910
Brian Lantz [h]: From that

225
00:41:10.230 --> 00:41:25.110
Brian Lantz [h]: Course, we are not alone Lego virago cargo are not the only game in town. And it's really interesting to think about some of the other projects now that are going on to try and measure

226
00:41:26.010 --> 00:41:47.370
Brian Lantz [h]: Signals from gravitational waves in other ways, and other frequencies, Lisa, the Laser Interferometer Space Antenna I've got a few more slides about that. You can see it's got a sort of a characteristic strain performance here which is optimum down at a few hundred million or

227
00:41:48.420 --> 00:41:52.800
Brian Lantz [h]: A few 10s of know hurts, allowing you to see stuff like much heavier.

228
00:41:54.210 --> 00:41:55.980
Brian Lantz [h]: Than then the logger detectors.

229
00:41:57.570 --> 00:42:06.510
Brian Lantz [h]: I don't have any slides on the international pulsar timing array or the nano graph collaboration. If you're trying to use

230
00:42:08.070 --> 00:42:23.790
Brian Lantz [h]: The timing of distant pulse ours to measure gravitational wave signals down here at 10 to the minus eight parts or below I eat periods of a year or two or three or four

231
00:42:25.500 --> 00:42:31.680
Brian Lantz [h]: This detector. I just wanted. I just want to say a little bit about this. I'm not part of an anagram or ITA

232
00:42:32.070 --> 00:42:39.720
Brian Lantz [h]: But these are very interesting experiments. These are ongoing. Now it's almost surprising that we haven't seen anything from those yet.

233
00:42:40.590 --> 00:42:52.440
Brian Lantz [h]: This technology and some of the technology that Jason Hogan is going to talk about tomorrow in this band is a little different. These machines. Measure the length change between two arms.

234
00:42:53.850 --> 00:43:04.710
Brian Lantz [h]: Your national pulsar timing array, you think of distant neutron stars being a really good clock. And you can measure that clock by watching the radio signals arrive.

235
00:43:05.760 --> 00:43:13.560
Brian Lantz [h]: Compare it to a local clock here on the ground and if you see a modulation in the arrival time of those

236
00:43:14.640 --> 00:43:21.780
Brian Lantz [h]: Pulses from the neutron star, you can infer that gravitational wave has changed the distance between you

237
00:43:22.140 --> 00:43:41.280
Brian Lantz [h]: And those objects scattered through our galaxy which is a really interesting idea. And you'll see that that idea of measuring the distance between clocks are the relative phasing between clocks is going to show up tomorrow in Jason hagen's talk for for the matches experiment.

238
00:43:43.470 --> 00:43:54.240
Brian Lantz [h]: Let me go on and tell you a little bit about about Lisa. So this is the Laser Interferometer Space Antenna it's led by the European Space Agency with a plan launch of 2034

239
00:43:54.870 --> 00:44:09.690

Brian Lantz [h]: We think it's going to enable quite a bit of new gravitational wave astronomy measuring signals from like 100 micro hurts up to 100 megahertz is a requirement. The goal of course is a little broader Matt three separated spacecraft

240
00:44:10.830 --> 00:44:16.350
Brian Lantz [h]: One of the really exciting things about Lisa is that when you

241
00:44:17.430 --> 00:44:32.850
Brian Lantz [h]: Look at the performance that they've managed to achieve already. It's very exciting. So in 2015 they launched Elisa Pathfinder mission, which was a single satellite to demonstrate a bunch of the key technology for Lisa and

242
00:44:33.960 --> 00:44:42.000
Brian Lantz [h]: Here, instead of mirrors. They have these gold covered proof masses, the proof mass in this little housing and another one.

243
00:44:42.420 --> 00:44:51.510
Brian Lantz [h]: In the housing over here and you try and measure with the Lisa technology, the relative motion of these two proof masses.

244
00:44:52.350 --> 00:45:01.350
Brian Lantz [h]: The reason this is so exciting is that when you look at the performance that they've got this is a plot of the acceleration noise. The

245
00:45:02.010 --> 00:45:17.160
Brian Lantz [h]: Meters per second squared for rehearse as a function of frequency. So, how well can you resolve the forces pushing on these mirrors and where are they, and where they're sitting. This is the requirement for the Pathfinder mission.

246
00:45:18.690 --> 00:45:23.730
Brian Lantz [h]: This is the requirement for the acceleration noise and sensing for Lisa

247
00:45:24.420 --> 00:45:37.020
Brian Lantz [h]: And this is the performance that they were able to demonstrate, which is clearly superior, not only to the Pathfinder requirements would actually fit the Lisa requirements themselves, giving us a tremendous amount of confidence.

248
00:45:37.500 --> 00:45:40.770

Brian Lantz [h]: That this mission yet. But this thing is actually going to actually kind of work.

249
00:45:42.630 --> 00:45:55.050
Brian Lantz [h]: When you think about how that constellation of satellites works. It's kind of a neat idea. So here you have the earth orbiting around the sun. Lisa is three separated spacecraft

250
00:45:55.530 --> 00:46:09.030
Brian Lantz [h]: Now, instead of having a four kilometer or a 10 kilometer or 40 kilometer baseline these satellites or two and a half million kilometers apart, giving you much better performance at low frequencies, because your L is so big.

251
00:46:10.890 --> 00:46:24.930
Brian Lantz [h]: They're in an equal lateral triangle, giving you sensitivity to both gravitational wave polarization and this equal lateral triangle is actually tilted back off of the plane of the orbit of the Earth.

252
00:46:25.950 --> 00:46:34.890
Brian Lantz [h]: And about 60 minutes about 60 degrees up from that plane to if you watch an individual satellite. It starts off farther from the Sun and the Earth.

253
00:46:35.490 --> 00:46:46.800
Brian Lantz [h]: And a little above the orbital plane and as it this satellite moves around it moves in in the lips and ends up over here below. And inside

254
00:46:47.370 --> 00:46:56.130
Brian Lantz [h]: That orbit. And so when the three of them go around this triangle is essentially a stable equal lateral triangle orbiting around the sun.

255
00:46:56.910 --> 00:47:08.070
Brian Lantz [h]: And so as you move around. You can watch the pointing of this triangle towards different sources and it gives you localization for long lived long lived objects.

256
00:47:09.150 --> 00:47:16.860
Brian Lantz [h]: The way it works is there's sort of a what's called an optical phase meter and it compares the distance between the proof of proof mass on

257

00:47:17.490 --> 00:47:26.640
Brian Lantz [h]: One end of this are you know satellite and the proof mass on the other end of the arm of the other satellite, of course, each satellite has to prove mountains.

258
00:47:27.030 --> 00:47:36.600
Brian Lantz [h]: And so you watch the relative motion of these six, you know, two per satellite has this system moves around and you can imagine you know you launch

259
00:47:37.350 --> 00:47:40.530
Brian Lantz [h]: It turns out about to watch of laser power off of this satellite

260
00:47:41.340 --> 00:47:50.190
Brian Lantz [h]: travels along for two and a half million kilometers, you collect that light into about 30 centimeter telescope, you know, part of another satellite

261
00:47:50.730 --> 00:47:59.940
Brian Lantz [h]: And compare the, you know, measure that light with respect to a small proof mass, you know, on your optical cable in this satellite

262
00:48:00.390 --> 00:48:16.860
Brian Lantz [h]: So now you can think what you're saying, you know, compare that to what we were saying earlier about logo right so the arms are much, much longer which ought to give you much better performance other frequencies, there's much less power right because you want you launch to watts.

263
00:48:17.880 --> 00:48:26.280
Brian Lantz [h]: Two and a half million kilometers away, you only collect a few hundred people, lots of power. So your shot noise is severely limited

264
00:48:27.690 --> 00:48:33.930
Brian Lantz [h]: And so you can see, you know, the trade offs for these different kinds of detectors.

265
00:48:35.790 --> 00:48:52.530
Brian Lantz [h]: When you do that and look at the kind of observations that you can make thrilling exciting. So here's a noise performance for the expected noise performance for the Lisa project. You can see now the most sensitive frequency that bucket. He's down.

266
00:48:53.850 --> 00:49:06.900
Brian Lantz [h]: Just below 10 million hurts. And here is super impose a number of potential sources that you should be able to see. So the first our galactic binary. So these are orbiting white dwarfs.

267
00:49:08.040 --> 00:49:18.900
Brian Lantz [h]: Here's a highlight of I think nine known sources on on this plot, which you can use within the first few weeks to help calibrate the Lisa project and

268
00:49:19.230 --> 00:49:28.740
Brian Lantz [h]: Make sure that it's working. Make sure the calibrations are all right. Make sure that the whole instrument is behaving as you expect there are 10s of millions of binary

269
00:49:29.850 --> 00:49:32.400
Brian Lantz [h]: Like this in our galaxy, we think

270
00:49:34.020 --> 00:49:38.130
Brian Lantz [h]: And so as you run this machine, the number

271
00:49:39.150 --> 00:49:53.220
Brian Lantz [h]: That you should be able to observe within six months, you should be able to observe over 6000 of these white dwarf binaries and locate where they are on the sky 104 of them, how far away they are of

272
00:49:54.240 --> 00:50:13.140
Brian Lantz [h]: And the mass of 230,000 over a four year mission, you'll be able to track the orbits and tell interesting physical properties of thousands, thousands of these white dwarf binaries. In fact, there are so many sources.

273
00:50:14.250 --> 00:50:22.050
Brian Lantz [h]: That they start to form what's called a confusion limit right there are millions, because there are millions and millions of these it actually

274
00:50:22.470 --> 00:50:33.000
Brian Lantz [h]: It actually sets a noise floor for the detector which is a problem that Lego does not have actually Daniel actually mentioned this earlier this morning talking about resolving the

275
00:50:33.720 --> 00:50:41.520

Brian Lantz [h]: The background home right this is a problem. We all wish that we have so many sources to check can't tell them apart and

276
00:50:42.390 --> 00:50:52.470
Brian Lantz [h]: Another kind of thing you'll be able to see are the early phase of more of mergers of things like a binary black holes that Lego could see. So these are the blue.

277
00:50:52.950 --> 00:51:05.220
Brian Lantz [h]: Line here is an early track of the in spiral of 1509 14. So, you know, days, weeks, months, years before these objects merge and the Lego band.

278
00:51:05.790 --> 00:51:16.740
Brian Lantz [h]: Will be able to see them with with Lisa and perhaps tell where they are on the sky and when you would expect them to finally merge into the Lego band.

279
00:51:17.910 --> 00:51:31.800
Brian Lantz [h]: An excellent way to do, is that really multi messenger astronomy. If you see the same thing with two different instruments, a year apart, you know, maybe you guys can talk about this among amongst yourselves. So that really counts as multi messenger astronomy.

280
00:51:33.060 --> 00:51:33.390
Brian Lantz [h]: Or not.

281
00:51:36.210 --> 00:51:37.080
Brian Lantz [h]: But my five minutes.

282
00:51:39.570 --> 00:51:44.160
Richard Partridge: Yeah, you're just you're so on track. I didn't think you needed the five minute mark.

283
00:51:44.220 --> 00:51:47.580
Brian Lantz [h]: Okay, well good. Yeah, we get to just a couple more slides here.

284
00:51:52.140 --> 00:52:07.680
Brian Lantz [h]: Another thing that Lisa can see are the mergers of black holes. But of course, these are much bigger black holes so they emerge at a much lower frequency. So these would be things like the merger of

285
00:52:09.960 --> 00:52:32.820

Brian Lantz [h]: Hundred thousand million 10 million solar mass black hole binary systems, there is an interesting problem now in in cosmology, right, we can see with Lego and below mass x ray binary systems black holes up to about $100 masters, maybe more.

286
00:52:34.380 --> 00:52:44.550
Brian Lantz [h]: And we know that in the center of the galaxies like our galaxy, you know, there are black holes that are a million to a billion solar masses. But there's really very little observational evidence

287
00:52:44.880 --> 00:52:49.350
Brian Lantz [h]: Of what happens in the middle band these intermediate mass black holes.

288
00:52:49.950 --> 00:52:57.180
Brian Lantz [h]: You would think they must exist if you're going to form a black holes and center of galaxies, but we know almost nothing about them right now.

289
00:52:57.570 --> 00:53:12.150
Brian Lantz [h]: But with an instrument like Lisa, how to really cosmological distances, you can start to watch the in spiral and merger and actually make direct measurements of these intermediate large solar mass black holes.

290
00:53:14.130 --> 00:53:14.700
Brian Lantz [h]: The

291
00:53:16.710 --> 00:53:26.730
Brian Lantz [h]: Final source maybe to talk about something called extreme mass ratio in spirals. These em are I objects. So this is when you have something like

292
00:53:27.300 --> 00:53:40.290
Brian Lantz [h]: A stellar mass black hole attend 100 solar mass black hole orbiting and eventually merging into a really big black hole. Hundred and sort of 100,000 to a million solar mass black hole.

293
00:53:41.010 --> 00:53:51.210
Brian Lantz [h]: There'll be thousands of orbits for these extreme mass ratio events. And so you can use the gravitational leaves to track out

294
00:53:51.630 --> 00:54:00.030

Brian Lantz [h]: The space time as the smaller object orbits for thousands of times and the highly curved space around your massive object.

295
00:54:00.360 --> 00:54:13.410
Brian Lantz [h]: And watch those things come in. Look for deviations over hundreds of cycles of these non kept their orbits. Look for deviations from general relativity map out the space time see what other interesting things are going on there.

296
00:54:14.580 --> 00:54:20.280
Brian Lantz [h]: Watch what happens in these extremely relativistic regions on

297
00:54:21.660 --> 00:54:37.740
Brian Lantz [h]: The L three mission for Europe is the large, the third large mission is Lisa L two is something called Athena, which is an X ray instrument an Outer Space X ray instrument. And one of the things that's widely discussed

298
00:54:38.880 --> 00:54:50.100
Brian Lantz [h]: Between these two instruments is again you know correlating the measurements for the in spirals and mergers of giant black holes, looking at the big burst events as the

299
00:54:53.490 --> 00:54:55.680
Brian Lantz [h]: The accretion discs get disrupted.

300
00:54:57.060 --> 00:55:04.890
Brian Lantz [h]: As a huge amount of really fascinating astrophysics that we expect to be seeing from this observatory within the next 15 years

301
00:55:06.060 --> 00:55:09.780
Brian Lantz [h]: I let me finish up right here in a couple of final thoughts.

302
00:55:11.580 --> 00:55:19.200
Brian Lantz [h]: The era of gravitational wave astronomy, really, really has begun. We're seeing events now. Well, at the end of the last observing run every week.

303
00:55:20.310 --> 00:55:26.280
Brian Lantz [h]: Hopefully I've given you a little bit of a sense for how we go and peer into the nearly invisible universe.

304
00:55:27.210 --> 00:55:42.660
Brian Lantz [h]: The field is really moving very rapidly to see more events to see heavier events to see more distant sources and as you can see, there's really a lot that we've seen already, and much, much more to learn.

305
00:55:43.800 --> 00:55:45.120
Brian Lantz [h]: With that, let me stop.

306
00:55:46.560 --> 00:55:48.870
Brian Lantz [h]: And and trying to answer questions.

307
00:55:50.280 --> 00:55:59.790
Richard Partridge: Thank you, Brian, for it was just a really impressive time and some just incredible technology. I'm happy to give you the prize for most sensitive

308
00:56:03.240 --> 00:56:04.560
Richard Partridge: Charlie questions.

309
00:56:05.220 --> 00:56:12.360
charlie young: Okay thank you Brian wonderful talk with a number of questions. So let me just start with the first one.

310
00:56:13.470 --> 00:56:26.400
charlie young: Is it possible for gravitational wave form to impact both arms, the same way. I think the central question is can both arms appear to shorten at the same time rather than how to face.

311
00:56:27.510 --> 00:56:36.690
Brian Lantz [h]: Right, yeah. So this is an interesting thing, and it has a lot of implications for our ability to to locate sources, let me

312
00:56:38.340 --> 00:56:43.800
Brian Lantz [h]: Head back to an earlier slide. So maybe this one with our

313
00:56:45.780 --> 00:56:49.470
Brian Lantz [h]: With our to polarization so

314
00:56:50.610 --> 00:57:07.650
Brian Lantz [h]: If so, this machine obviously is set up to measure the plus polarization, right, the one that's aligned with the instruments for

the cross polarization both arms will stretch the same amount. And for these inner parameters you cannot see that at all.

315
00:57:09.120 --> 00:57:18.030
Brian Lantz [h]: Though for a particular instrument like this you are blind to half of the information. It turns out you're also blind.

316
00:57:18.510 --> 00:57:34.170
Brian Lantz [h]: If a signal comes in, of course, from the top, you can see it plus polarization single comes in from the top, you can see it very well. If a signal comes in from the side because it's a transverse wave. The two arms again or

317
00:57:35.190 --> 00:57:39.180
Brian Lantz [h]: respond in the same way and you have, you don't have any

318
00:57:40.560 --> 00:57:54.000
Brian Lantz [h]: Sensitivity for a signal coming in at the 45 for a single coming in along one arm. Of course, this arm isn't really going to be affected this arm gets the same signal. So you're about half of sensitive to a signal from here.

319
00:57:55.800 --> 00:58:00.240
Brian Lantz [h]: When you go back and look at the details of the

320
00:58:01.410 --> 00:58:07.770
Brian Lantz [h]: localization of the binary neutron star system, what you see is that they're clear signals in both of the Lego machines.

321
00:58:08.310 --> 00:58:19.560
Brian Lantz [h]: And there is no signal no noticeable signal. You can do some data processing and pull out a tiny signal. There's almost no signal at all in the machine, even though you should have seen it.

322
00:58:21.900 --> 00:58:35.280
Brian Lantz [h]: And that and that allowed us to conclude the collaboration. The collaborations to conclude that for the Virgo instrument, the signal is coming in from one of these four directions. And so you were actually able to do localization.

323
00:58:36.690 --> 00:58:52.230
Brian Lantz [h]: Even though you couldn't see the couldn't see the the source on that particular incident, because you knew it was there but you couldn't see it. So there's a lot of interesting stuff to go on. I'm

trying to go through the implications of the polarization and your ability to see them.

324
00:58:53.790 --> 00:58:54.240
Thank you.

325
00:58:55.320 --> 00:58:55.920
So,

326
00:58:57.240 --> 00:59:00.450
charlie young: Another question is, before vertical came online.

327
00:59:01.500 --> 00:59:08.130
charlie young: Why go able to do any triangulation at all based on the song signals. Yeah.

328
00:59:09.210 --> 00:59:12.000
Brian Lantz [h]: It's a friend of mine once called it by angle ation

329
00:59:13.020 --> 00:59:14.490
Brian Lantz [h]: Yes, a little bit.

330
00:59:16.350 --> 00:59:22.050
Brian Lantz [h]: We can, so of course you can usually pick out a ring on the sky. Right. So if you've got

331
00:59:24.330 --> 00:59:32.700
Brian Lantz [h]: You know, to detectors, like the ones in Hanford in Louisiana and the signal arrived, say, seven milliseconds earlier in Louisiana them Hanford

332
00:59:33.180 --> 00:59:41.760
Brian Lantz [h]: You can draw a ring on the sky from where those potential sources for the for the source must have been there's a little more information that you can get

333
00:59:42.390 --> 00:59:59.520
Brian Lantz [h]: nuts because you're most sensitive to detector which is to a single source which is directly above the observatory. So because the two Lego machines are 3000 kilometers apart, you know, their orientation to the sky is different.

334
01:00:01.230 --> 01:00:04.320

Brian Lantz [h]: And what you can see is that if it's a little more

335
01:00:05.910 --> 01:00:09.870
Brian Lantz [h]: You know, if you have a little more signal in Livingston than you do at Hanford

336
01:00:10.440 --> 01:00:20.220
Brian Lantz [h]: That can help you localize a little bit the region of the sky. You know, it must be a little more overhead for underneath Livingston, that it came from. So that's how we

337
01:00:20.760 --> 01:00:29.700
Brian Lantz [h]: Turned the ring on the sky people look back at the that paper. It looks more like a banana on the sky where we've localized it a little bit within that ring.

338
01:00:31.620 --> 01:00:42.810
charlie young: Thank you. The next question has to do with slide 15 where you show the sensitivities of like a vehicle so

339
01:00:47.460 --> 01:00:50.520
charlie young: And the question is, can you explain the difference

340
01:00:52.950 --> 01:00:55.200
Brian Lantz [h]: This slide here 59

341
01:00:58.950 --> 01:00:59.250
Brian Lantz [h]: Right.

342
01:00:59.310 --> 01:01:09.570
charlie young: Yes, I can we, how do we understand the difference in the reach in terms of 990 mega pass 120 and so on.

343
01:01:14.640 --> 01:01:23.010
Brian Lantz [h]: Yeah, so, you know, at the beginning of course Lego. You know, we just got online sooner for that explains it. But that doesn't tell you what's going on here.

344
01:01:24.600 --> 01:01:29.400
Brian Lantz [h]: The Lego arms are a little longer there four kilometers, instead of three, four years ago.

345
01:01:34.440 --> 01:01:41.850

Brian Lantz [h]: And con Agra so that that's most of the difference between Lego enberg of just the arm link.

346
01:01:42.900 --> 01:01:47.610
Brian Lantz [h]: For con Agra the machine that machine is actually a cryogenic detector.

347
01:01:48.840 --> 01:01:55.560
Brian Lantz [h]: And so the way it you know it's noise floor is impacted by more than just the length. It also has

348
01:01:57.330 --> 01:02:01.680
Brian Lantz [h]: Impacts of low frequencies from the local cryogenic sources.

349
01:02:02.850 --> 01:02:10.080
Brian Lantz [h]: And its ability to how to handle high power. So that explains a lot of the difference. I'm Congress

350
01:02:13.920 --> 01:02:19.050
Brian Lantz [h]: Backup if you have a cryogenic machine. It's hard to put a lot of power into it. And so your shot noise gets limited

351
01:02:21.180 --> 01:02:32.970
charlie young: Yeah, thank you for that. The next question is which update detectors, you have described will be able to measure primordial gravitational waves caused by inflation.

352
01:02:35.790 --> 01:02:50.100
Brian Lantz [h]: So it's not impossible that Lego would see primordial signals, it's very unlikely the models which generate primordial black hole primordial

353
01:02:51.150 --> 01:02:52.410
Brian Lantz [h]: ripples in

354
01:02:53.430 --> 01:02:57.990
Brian Lantz [h]: In Space Time. Rarely, rarely do they impact the Lego band, but

355
01:02:59.490 --> 01:03:04.830
Brian Lantz [h]: Something like the international pulsar timing array should should be able to see those

356
01:03:07.170 --> 01:03:10.440
Brian Lantz [h]: And when you look at the cosmic ray

357
01:03:11.700 --> 01:03:14.070
Brian Lantz [h]: Cosmic ray, the

358
01:03:17.190 --> 01:03:21.990
Brian Lantz [h]: The radio measurements, looking at, you know, like the bicep.

359
01:03:23.220 --> 01:03:31.080
Brian Lantz [h]: Result, which turned out to not be right. But that idea is still quite valid or you look at difference between the be mode.

360
01:03:32.730 --> 01:03:36.150
Brian Lantz [h]: signals of the primordial radio signal microwave signals.

361
01:03:37.800 --> 01:03:39.720
Brian Lantz [h]: Later left over, you know, caused by

362
01:03:40.800 --> 01:03:46.020
Brian Lantz [h]: Caused by primordial black holes by primordial gravitational waves. Excuse me.

363
01:03:47.040 --> 01:03:53.340
Brian Lantz [h]: Those are the two most likely sources. So things that much at much lower frequencies and different skills.

364
01:03:55.980 --> 01:03:56.850
charlie young: Okay, thank you.

365
01:03:57.990 --> 01:04:03.360
charlie young: Next question has to do with the mirrors. What is the coating on the mirrors.

366
01:04:04.650 --> 01:04:13.920
Brian Lantz [h]: The Lego mirrors are so it's a dielectric coding. It's not a, you know, often like the mirror in your bathroom. It's got a layer of aluminum splattered on

367
01:04:14.940 --> 01:04:36.660

Brian Lantz [h]: The deposited onto the back these layers are there dielectric. So it's alternating layers of silica and titanium doped tantalum, those have a different index every fraction. So by stacking them up. You can form coherent reflections and transmissions of those

368
01:04:38.430 --> 01:04:46.500
Brian Lantz [h]: For a plus a tremendous amount of work is going into understanding the mechanical properties as well as the optical properties of those

369
01:04:47.760 --> 01:05:05.280
Brian Lantz [h]: For a plus. We do not, it might be a modified version of the silica cantaloupe layer pairs. We might also look at silicon germanium or Germania with a doping that question. I think will be answered in the next year or so.

370
01:05:07.740 --> 01:05:10.680
charlie young: Thank you. We could do we have time for one more question.

371
01:05:15.120 --> 01:05:16.680
charlie young: Okay, I take that as a yes.

372
01:05:18.090 --> 01:05:21.090
charlie young: The next question is about slide number 55

373
01:05:24.450 --> 01:05:28.020
charlie young: Right. So the question is, between the observing runs

374
01:05:30.450 --> 01:05:37.620
charlie young: The spikes move around a little bit and some get broader some can narrower what's going on.

375
01:05:38.400 --> 01:05:55.080
Brian Lantz [h]: Yeah, so all of the spikes in a spectrum. And let me, let me say I'm mostly they're going away right joke you look at, oh one that all of this stuff and bumps and ripples you compare that to oh three, you can see that the spectra 403 is much cleaner.

376
01:05:57.000 --> 01:06:02.910
Brian Lantz [h]: And this represents really thousands and thousands of hours of work by folks on site.

377
01:06:03.480 --> 01:06:15.270

Brian Lantz [h]: Trying to get rid of them. So a few interesting ones like this one actually isn't real. This is a calibration line. And so these have been taken out for later Queen spectra just you don't get confused.

378
01:06:15.990 --> 01:06:24.390
Brian Lantz [h]: This thing it's 60 Hertz is some kind of coupling from the world because all the power in the US at 60 hertz and the couples and everything.

379
01:06:25.920 --> 01:06:30.720
Brian Lantz [h]: In many, many ways you can still you can see it's still present, you know, three but much smaller.

380
01:06:32.310 --> 01:06:49.410
Brian Lantz [h]: These lines out here at 500 Hertz are actually those the resonant modes of the glass fibers will be called the violin and holding up the holding up the optic, those are driven thermal and those are just a feature of the spectrum.

381
01:06:50.940 --> 01:07:01.530
Brian Lantz [h]: Stuff like this is nasty thing right here just above 60 hertz or this junk right here just below 60 Hertz, where the crab pulse our lives.

382
01:07:02.760 --> 01:07:14.280
Brian Lantz [h]: This is some kind of technical vibration which couples into the instrument. These are often things like a little piece of metal some some light some tiny fraction of light.

383
01:07:14.820 --> 01:07:26.100
Brian Lantz [h]: You know, has a diffuse scatter off of the optic catches a glint off of a piece of metal in the vacuum system somehow recombined with a beam and then when you bang on the vacuum system.

384
01:07:27.240 --> 01:07:38.280
Brian Lantz [h]: That little glint. The thing moves around and shows up in your spectrum. And so you can see that a lot of that stuff has been removed by identifying what those things are.

385
01:07:38.310 --> 01:07:39.810
Brian Lantz [h]: covering them up removing them.

386
01:07:40.350 --> 01:07:41.070
Brian Lantz [h]: amping them.

387
01:07:42.300 --> 01:07:53.070
Brian Lantz [h]: And things like that. We're very, you know, we are both incredibly irritated by how bumpy this spectrum is and at the same time very proud of how smooth.

388
01:07:54.390 --> 01:07:56.340
Brian Lantz [h]: The folks on sites have managed to get it.

389
01:08:00.240 --> 01:08:02.430
charlie young: Okay, thank you. Um,

390
01:08:03.000 --> 01:08:03.510
Richard Partridge: I think you

391
01:08:04.530 --> 01:08:11.820
Richard Partridge: Know, we're at our time limit, then pressing question. So are we ready to close the session.

392
01:08:14.100 --> 01:08:18.000
charlie young: I think that's about all the questions that have been posted. Thank you.

393
01:08:18.540 --> 01:08:22.890
Richard Partridge: Okay, well, I want to thank all of this morning speakers for

394
01:08:23.910 --> 01:08:29.880
Richard Partridge: wonderful presentations. And at this time I invited stop the recording.