WEBVTT

1
00:00:04.049 --> 00:00:17.699
Richard Partridge: And I'm pleased to introduce our first lecture for the third day of the Summer Institute I Daniel holds of your research Connor will be telling us about gravitational wave binaries.

2
00:00:18.810 --> 00:00:20.940
Richard Partridge: Daniel, please go ahead and share your screen.

3
00:00:38.220 --> 00:00:47.190
Daniel Holz: Okay. Um, alright, so I'm really delighted to be here, virtually and

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00:00:48.900 --> 00:00:53.760
Daniel Holz: giving this talk to chance to tell you a little bit about what's going on.

5
00:00:55.170 --> 00:00:56.520
Daniel Holz: Gravitational wave side.

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00:00:58.020 --> 00:01:01.950
Daniel Holz: Of course I'd much rather have us all be there in person, but

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00:01:03.870 --> 00:01:06.270
Daniel Holz: You know, zoom will have to suffice from

8
00:01:07.830 --> 00:01:19.260
Daniel Holz: So my my task is to give you an overview of grub Trisha way bindings so that I'm going to kind of focus on that, but I'm going to talk about other things along the way.

9
00:01:20.820 --> 00:01:27.570
Daniel Holz: So to start, I should emphasize that you know gravitational waves and touch with us races.

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00:01:29.340 --> 00:01:38.940
Daniel Holz: Really belongs in this in this sort of lecture series since it's about almost invisibles and gravitational waves are

11
00:01:39.990 --> 00:01:45.780

Daniel Holz: Invisible. I mean, we don't see them we we probe them with gravity only

12
00:01:46.830 --> 00:01:59.040
Daniel Holz: I mean, of course, there are indirect ways to find out about them. But really they're not visible directly and they're also weekly couple. And I'll talk a little bit more about that, but fundamentally these

13
00:02:01.410 --> 00:02:13.560
Daniel Holz: These gravity and count on vacation waves are we coupled, which means they're very hard to detect. But it also means they carry a lot of information and we'll discuss that as we go.

14
00:02:14.400 --> 00:02:21.810
Daniel Holz: So I'm my goal is to kind of give you a high level overview of some of the things that are going on and then to just

15
00:02:23.340 --> 00:02:36.420
Daniel Holz: It'll be kind of a poster session type of thing where I just give you describe certain results that we've gotten recently. It's such a broad field. There's no way to do it justice at this point.

16
00:02:37.440 --> 00:02:43.170
Daniel Holz: But I'll try to give you a flavor for some of the things that are happening. So that's my goal.

17
00:02:45.120 --> 00:02:45.750
Okay.

18
00:02:48.360 --> 00:02:54.210
Daniel Holz: All right, so I'm gonna start at the very, very highest level, just so that we're all on the same page, which is that

19
00:02:55.380 --> 00:03:14.700
Daniel Holz: This is based in john I'll Tony and we summarize your relativity with this cute phrase space tells matter how to move and matter tell space time how the curve. And a lot of the theory is encapsulated in that, you know, tells you that it couple the nonlinear and

20
00:03:15.720 --> 00:03:17.250
Daniel Holz: Complicated, in some sense,

21

00:03:18.270 --> 00:03:24.000
Daniel Holz: And so that is that underlies what we're doing now that picture is useful.

22
00:03:25.650 --> 00:03:36.990
Daniel Holz: For for the topic we're talking about, which is specifically gravitational waves and black holes. So the idea, obviously, is that space and time are linked into space time

23
00:03:38.070 --> 00:03:55.890
Daniel Holz: This space time can become infinitely warped. So going back to the previous thing matter tell space time how to curve. If you have very dense matter cause causes of warping. And that's more than can, in some sense, become infinite can very strong and those are black holes.

24
00:03:57.150 --> 00:04:06.960
Daniel Holz: Also space time tells matter how to move. If you have to black holes are compact objects neutron stars near each other as they go around.

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00:04:07.650 --> 00:04:17.100
Daniel Holz: The space time of one is sort of telling the other where to go. They, they wrap around each other they emit waves and those are gravitational waves and

26
00:04:17.760 --> 00:04:27.810
Daniel Holz: Just, I think it's helpful to have a good heuristic for gravitational waves. And I found that this is a good heuristic, which is imagine you have a duck on a pond.

27
00:04:29.400 --> 00:04:34.980
Daniel Holz: So if the duck doesn't move the pond. The surface of the pond is it's glassy, it's totally still

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00:04:35.730 --> 00:04:50.040
Daniel Holz: Now, if the duck moves there ripples that emanate from the doc and go to the edges of the park. And in fact, if you were at the edge of the pond and can measure the ripples carefully, you could infer Oh there's a doctor. The doctor is moving, it's going in this direction.

29
00:04:51.150 --> 00:04:56.370
Daniel Holz: Maybe you could figure out the massive the duck certain properties of the duck by analyzing intervals.

30
00:04:57.690 --> 00:05:08.910

Daniel Holz: So this is just like rotational Wayne's, what you do is you replace the duck with two black holes are true neutron stars you replace the surface of the lake with space time

31
00:05:09.420 --> 00:05:19.200
Daniel Holz: And then it's basically the same thing as objects accelerate they in the ripples if they're not accelerating. No, no. Ripples space time is still

32
00:05:19.650 --> 00:05:28.770
Daniel Holz: But as they move they make ripples and by measuring those ripples, you can infer properties of the source and you can think of it as, you know, the ripples.

33
00:05:29.700 --> 00:05:37.170
Daniel Holz: Are what are updating you know the gravitational field whenever you move if you decide to go across the room.

34
00:05:37.530 --> 00:05:52.470
Daniel Holz: And then, you know, some galaxy far away has to know that you've now moved and so gravitational waves go out to tell that galaxy, you know, you've now moved and so that's that's what's going on. Gretchen with, in some sense, or how the universe keeps track of where everything is.

35
00:05:53.670 --> 00:06:01.200
Daniel Holz: Okay, so okay gravitational waves exist there were, they were predicted by Einstein in 1917

36
00:06:02.580 --> 00:06:15.030
Daniel Holz: But they're very weakly coupled. It's part of the theme of this this week. Now, just to get a sense of this. And this is another one of these things. It's very hard to convey. I mean, I still have trouble.

37
00:06:15.810 --> 00:06:27.840
Daniel Holz: wrapping my mind around just how weak, these are these are if we have very loud gravitational waves. Very loud passing you know through through the earth now.

38
00:06:28.800 --> 00:06:39.690
Daniel Holz: To get a sense of the scale to we're talking about. You could imagine if you were monitoring the distance to the nearest star on our son. The next year. Start off with some Tori four light years away.

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00:06:40.260 --> 00:06:47.850

Daniel Holz: If you were monitoring that distance and gravitational waves are passing what graduates do is they change relative distances in different directions.

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00:06:48.300 --> 00:06:55.080
Daniel Holz: And the amount of changing that distance is for Alpha Centauri is the equivalent of the width of a human hair.

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00:06:55.680 --> 00:07:07.140
Daniel Holz: So you have to think, what we want to do to detect gravitational waves is be able to monitor something the equivalent of monitoring the distance Alpha Centauri. And notice that it's wobbling back and forth by the width of a human.

42
00:07:09.720 --> 00:07:10.980
Daniel Holz: It. That's hard to do.

43
00:07:12.360 --> 00:07:13.290
Daniel Holz: Now that

44
00:07:17.010 --> 00:07:20.670
Daniel Holz: Technical difficulties. There we go. Okay.

45
00:07:21.720 --> 00:07:24.720
Daniel Holz: That's really difficult. How do we do this.

46
00:07:26.340 --> 00:07:35.040
Daniel Holz: Okay, we've built my ego and Virgo. And these are micro center foreigners and we shoot lasers and they're shining errors and then they're just go back and forth. And we're basically

47
00:07:35.310 --> 00:07:52.590
Daniel Holz: Timing photons. We compare how long it takes a full time to go down one arm compared to the other arm and we can do comparisons are not to figure out different connotation way this there um it's astounding that that this can be done at all this. Not sure I'm not talking about that.

48
00:07:53.970 --> 00:08:00.570
Daniel Holz: Brian will be talking more this afternoon and telling you all about how how these detectors work.

49
00:08:01.830 --> 00:08:10.980

Daniel Holz: It's there. It's really amazing and even now, I still can't believe they actually work it's it's remarkable and the amount of physics in these instruments is my mother.

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00:08:12.750 --> 00:08:29.490
Daniel Holz: Oh, I should also mention that Jason Hogan will be giving a talk tomorrow about a completely different way. But very novel exciting way to to measure gravitational waves using them in a foreign country it's, you know, very ambitious and you'll get a sense of that tomorrow.

51
00:08:31.260 --> 00:08:39.900
Daniel Holz: At this point, there are through the tomatoes are the two Legos one in Halford Washington wanting living from Louisiana. And then there's the Virgo detector in Italy.

52
00:08:40.530 --> 00:08:46.740
Daniel Holz: These are I kind of the most sensitive instruments ever built. Now you know slack is all about particle physics.

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00:08:47.670 --> 00:08:56.730
Daniel Holz: You might see a lot of people claim is the most sensitive instrument ever been. I think these are way more sensitive. It's all about metrics. Fortunately, I don't have to argue this again.

54
00:08:58.260 --> 00:08:59.160
Daniel Holz: Pick your urine.

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00:09:00.270 --> 00:09:06.390
Daniel Holz: Later today. Okay, so that's it for instruments. I'm going to now focus a little bit on science.

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00:09:08.010 --> 00:09:15.780
Daniel Holz: That you know the scientific results that we've gotten out of these instruments you know this story. So I'm going to go through it fairly quickly.

57
00:09:16.410 --> 00:09:30.390
Daniel Holz: We first learned turn these instruments on the legal instruments at the kind of advanced or near advanced sensitivity in September 2015 and we heard this, and I hope the sound comes through.

58
00:09:33.480 --> 00:09:34.140
Daniel Holz: Their sound.

59

00:09:57.600 --> 00:10:06.540
Daniel Holz: So just to give you a sense of what's being cloud instance, you'll see more of these on the x axis of stress time on the Y axis is frequency

60
00:10:07.050 --> 00:10:19.920
Daniel Holz: And the, the colors here indicate the if you like the amount of energy, the manpower at this at this particular time at this frequency. So each slice is like a 40 and transform

61
00:10:21.240 --> 00:10:34.950
Daniel Holz: And. And what you can see as you go along here is that there's not much hear what you're hearing in the early part is just noise and then you can start to see that there is something coming above the noise.

62
00:10:35.730 --> 00:10:45.660
Daniel Holz: And and what it does is it sweeps up and it gets brighter, which means louder. So this is something that's sweeping up and frequency and sweeping up an amplitude

63
00:10:46.020 --> 00:10:57.120
Daniel Holz: And that's what we call a chirp. It's the loop very distinctive chirp that you got from gravitational waves. And you'll notice that this happened, both at Hanford and Middle Eastern at the same time.

64
00:10:57.870 --> 00:11:10.350
Daniel Holz: And and you know it's if you've if you've been in the field for a while. This is what you were hoping for is this sort of very clear loud said no and and there it is.

65
00:11:10.800 --> 00:11:20.700
Daniel Holz: And so, so when this happened. This was, you know, our big discovery. There's a big discovery also mentioned in this video just for everyone that's

66
00:11:21.180 --> 00:11:28.980
Daniel Holz: You know, really paying attention there too. It's play twice. It comes twice at low frequency which is the actual frequency

67
00:11:29.280 --> 00:11:42.930
Daniel Holz: Now we've just taken the gravitational waves. We've increased the amplitude by 20 orders of magnitude and then put them into our speakers and low frequency, you can just barely hear the thump. And then we just frequency shifted so it's clear to your ear.

68
00:11:45.240 --> 00:11:45.600
Daniel Holz: I was

69
00:11:48.210 --> 00:12:01.800
Daniel Holz: It was a big deal. You know, we analyze the signals. I'll talk more about that we infer that it was two black holes are always 30 solar masses on the system was about 40 mega prospects away and for

70
00:12:02.400 --> 00:12:13.140
Daniel Holz: Under 409 parsecs away and for a fraction of a second. The system emitted more energy than all the stars in the universe combined. And let me just focus on that.

71
00:12:13.620 --> 00:12:22.530
Daniel Holz: Just because it's really hard to wrap one's mind around all of these things. So, you know, in that quarter of a second when these black holes were merging.

72
00:12:23.970 --> 00:12:45.510
Daniel Holz: You know the power being radiated was more than all the light from all the stars in the observable universe combined so extremely extraordinarily luminous I come among the most luminous birth sources that ever happened in the universe outside of the Big Bang. But, um,

73
00:12:46.650 --> 00:12:51.780
Daniel Holz: Yeah, unless you have a gravitational detector, you don't notice it at all. It's two black holes and there might be no fault.

74
00:12:52.380 --> 00:12:57.750
Daniel Holz: So it's really a remarkable system and it's a major advanced detector.

75
00:12:58.560 --> 00:13:05.970
Daniel Holz: And so this was a confirmation and have you know the prediction for gravitational waves that are better kind of independent measurements.

76
00:13:06.210 --> 00:13:13.830
Daniel Holz: Of this, we were pretty confident existed, but this was a direct sort of laboratory measurement as gravitational waves pass. So that was a big deal.

77
00:13:14.100 --> 00:13:20.730

Daniel Holz: And it was also sort of a direct detection of black holes and a direct confirmation of general relativity in the description black holes.

78
00:13:21.000 --> 00:13:32.190
Daniel Holz: But of course we can spend a lot of time talking about black holes, they're phenomenal amazing profound objects and physics and and this shows that they really exist, the way I described

79
00:13:33.150 --> 00:13:44.160
Daniel Holz: I mean this. The say okay, you know, in very short order, there was a Nobel Prize and now it's already in all the textbooks and it feels like it's a historical thing its own

80
00:13:46.320 --> 00:13:47.580
Daniel Holz: So move on.

81
00:13:48.810 --> 00:13:53.670
Daniel Holz: And now, you know, talk about what happens next. So that's kind of the preface.

82
00:13:54.660 --> 00:14:00.120
Daniel Holz: And quite a number of things have happened since then. And right now I'm going to focus on

83
00:14:00.480 --> 00:14:12.630
Daniel Holz: probably the single most exciting thing that's happened in the field, and I'm sure you've all heard a lot about this. So again, I'm going to kind of give you a pretty quick overview and just highlight a few things that I find interesting.

84
00:14:13.680 --> 00:14:21.840
Daniel Holz: And so what I'm talking about is what happened on August 17 2017 and here is the same frequency versus time plot.

85
00:14:23.010 --> 00:14:32.310
Daniel Holz: And this is for the hand for detector and what you're I should be, oh sorry what your I should be drawn to is this curve.

86
00:14:33.480 --> 00:14:37.620
Daniel Holz: And it's you know it's this beautiful chirping signal.

87
00:14:39.030 --> 00:14:47.280

Daniel Holz: And if you were paying attention to their previous movie, this is actually tripping up too much higher frequency. This is in the hundreds of hurts here.

88
00:14:49.440 --> 00:14:58.500
Daniel Holz: It's, it's, it's your I can just pick it out you know we we spent years developing all these search algorithms to pick up very faint signals in the noise.

89
00:14:59.700 --> 00:15:06.420
Daniel Holz: And here you don't need anything you can just look at it. Now what was weird is this happened, but we got no alerts.

90
00:15:07.230 --> 00:15:21.420
Daniel Holz: There was no claim, you know, we have all these automated software, you know, it didn't announce a detection and but this is even by I. The fact that you can see it so clearly means it's really loud. It's very surprising that our software to attach it

91
00:15:22.530 --> 00:15:24.570
Daniel Holz: So actually read the

92
00:15:25.920 --> 00:15:31.770
Daniel Holz: Post Office University Chicago went and looked at the Livingston data and notice this.

93
00:15:33.330 --> 00:15:37.110
Daniel Holz: This is what the Livingston data looks like. And

94
00:15:38.130 --> 00:15:43.110
Daniel Holz: There's this huge triangular thing here. Extremely Loud

95
00:15:44.490 --> 00:15:56.280
Daniel Holz: And that dominates. You know what's happening at that point. This is the technical term is it's a glitch. And this is these glitches happen all the time.

96
00:15:57.810 --> 00:16:09.600
Daniel Holz: We're not quite sure what causes them it's maybe fibers realigning or something. This is an extremely sensitive instrument, just remember this whole thing about Alpha Centauri moving. By the way, every human hair.

97
00:16:10.350 --> 00:16:18.930

Daniel Holz: It's, you know, we're sensitive to you know everything. So people sneeze and it's very sensitive stuff like this happens.

98
00:16:19.500 --> 00:16:26.370
Daniel Holz: Now what you're I should be gone to is underneath there's an even clear trial that there's something there.

99
00:16:27.030 --> 00:16:37.410
Daniel Holz: And so, well you know what we can do is remove the clutch and this is what you find, and you find this extremely long, beautiful, perfect chirping trail.

100
00:16:38.190 --> 00:16:47.160
Daniel Holz: And I mean that is just, I mean not incredibly loud and just it's just so perfect. I mean, if you look at this

101
00:16:47.670 --> 00:16:58.890
Daniel Holz: I mean, this is an incident Daffy the sort of thing that was predicted, but it's qualitatively different if you might remember I I played you the sound of the 1509 14

102
00:16:59.640 --> 00:17:18.930
Daniel Holz: And that was a fraction of a second guess your I can easily pick out this trial this tripping track for 30 seconds and and we can actually, you know, we can dig it out using an analysis tools, much, much earlier than that. This is a very different beast from 15 or 914

103
00:17:20.370 --> 00:17:27.210
Daniel Holz: And so this is gonna. This is kind of summarizes the state of affairs, when we discovered

104
00:17:27.660 --> 00:17:36.630
Daniel Holz: This this 117 or it's on a team. So what I'm showing here are the actual waveforms. So you do a best fit you pick out the parameters. This is the way for you find

105
00:17:37.230 --> 00:17:54.750
Daniel Holz: In turn, in time, and this is the part of the waveform that's in there in the leg. Oh, man. So 15 online 14 you see comes in band. It does a few oscillations and then emerges and you can see the amplitude here is relatively high compared to the others. This was very loud.

106
00:17:56.430 --> 00:18:01.920

Daniel Holz: And then here are some of the other things. I mean, at this point, where you have your many more and but it gives you a sense

107
00:18:02.670 --> 00:18:10.500
Daniel Holz: If you, if you're in bed longer. That means you're merging at higher frequency. You can kind of see that the frequencies here are higher than now here.

108
00:18:10.980 --> 00:18:28.170
Daniel Holz: I'm actually go to higher frequency that means you're going to lower mass, if you like, if you're, you know, lower mass, you can get closer and going around faster before you hit the horizons and merge. And so as you go further along in this you're going to lower and lower.

109
00:18:29.310 --> 00:18:38.610
Daniel Holz: So just by looking at this, you can look at the amplitude, get a sense of how loud, they are and you can look at how far to the right, they merge and that gives you a sense of what the mass

110
00:18:39.300 --> 00:18:47.250
Daniel Holz: Okay, so I'm not going to show you the way for for 1717 and it's actually going to play the sound as well. Here we go.

111
00:18:57.150 --> 00:18:58.830
Daniel Holz: This is going to keep on going for a while.

112
00:18:59.940 --> 00:19:06.240
Daniel Holz: So you can see this is very, very different and the amplitude is not as high.

113
00:19:07.200 --> 00:19:21.090
Daniel Holz: It's still alone, let alone for a while, at the end, it'll get higher, but there are many, many cycles and we get to integrate up all those cycles. So the signal to noise of this event is actually even higher. You know 914 this noises

114
00:19:22.140 --> 00:19:24.660
Daniel Holz: Basically, as far as these factors.

115
00:19:26.160 --> 00:19:28.530
Daniel Holz: You should start to be a rebel.

116
00:19:44.340 --> 00:19:53.820

Daniel Holz: There you go. Okay, that's the trick. That's what we heard we heard it in both detectors extremely loud very clear truly remarkable.

117
00:19:56.490 --> 00:20:13.200
Daniel Holz: So now to get you oriented at that point. We've had a number of black holes. These are kind of visualize and blue here, the x axis is meaningless. The y axis is just to help visualize the y axis is a massive solar masses. And so here is

118
00:20:14.250 --> 00:20:19.830
Daniel Holz: Something like a 30 with a 20 to 30 days. I think that's 5914

119
00:20:21.030 --> 00:20:38.550
Daniel Holz: Yeah, anyway. Um, so here at some of the events, we've had so far. And here are x ray binary. And so it's a different way to measure black hole masses those coming lower in general. And then these are all neutron star masses. Okay.

120
00:20:39.570 --> 00:20:50.340
Daniel Holz: And so the question is when we do the analysis on 1717. What do we find, and this is what we find we find the masses of these two orange dots.

121
00:20:51.030 --> 00:21:01.530
Daniel Holz: And painful right where the neutron stars are so I feel a lot of internal debate, we decided to call them neutron stars and claim this is a binary star.

122
00:21:02.040 --> 00:21:08.970
Daniel Holz: Like fun the gravitational wave data alone. I'll get to this. It's actually hard to know if they're neutron stars are black holes and I'll talk more about that.

123
00:21:10.530 --> 00:21:15.750
Daniel Holz: Also, draw your eyes to two other things because this is interesting in terms of astrophysics.

124
00:21:16.860 --> 00:21:23.790
Daniel Holz: The first is that if you're locked and you're trying to start seeing to Peter added around to solar masses. Maybe a little more

125
00:21:25.110 --> 00:21:30.360
Daniel Holz: On this agrees with theory or think there's kind of a maximum, maximum neutron stars, depending on the equation estate.

126
00:21:32.610 --> 00:21:36.090
Daniel Holz: Black Hole since have a minimum mass at around five

127
00:21:37.050 --> 00:21:45.570
Daniel Holz: And it looks like there might be a gap. This is called the last gap between the most massive neutron star and the least massive black hole, and that's

128
00:21:45.960 --> 00:21:53.970
Daniel Holz: Very interesting and gives you clues about the formation mechanisms of the systems. And so, you know, that's something we'd really like to understand better

129
00:21:55.080 --> 00:22:00.570
Daniel Holz: And also point out that up above, you know, this plot that component masses.

130
00:22:01.830 --> 00:22:03.330
Daniel Holz: Peter out at about 40

131
00:22:04.770 --> 00:22:12.600
Daniel Holz: And appears to be a gap above and I'll talk more about that later as well. So even just from this plot, it's always there's already quite a bit of interesting

132
00:22:13.770 --> 00:22:14.400
astrophysics.

133
00:22:16.170 --> 00:22:16.530
Alright.

134
00:22:18.270 --> 00:22:24.060
Daniel Holz: That's not the end of the story. You all i'm sure familiar with this, but I'm going to give you my spin on this.

135
00:22:25.440 --> 00:22:35.310
Daniel Holz: So the next thing, and this is very important. Actually people that stock, of course, played a major role in this, because the Fermi satellite was was a big part of this day I'm

136
00:22:35.730 --> 00:22:49.980

Daniel Holz: In the bottom. I'm showing the standard frequency versus time plot for gravitational waves in the top I'm showing counts per second. So luminosity and gamma rays as a function of time. I mean, these are all synced up

137
00:23:07.980 --> 00:23:15.720
Daniel Holz: Sure. And then about two seconds later that been was that little bow was the sound of gamma rays. That was the gamma rays hitting

138
00:23:16.860 --> 00:23:17.700
Daniel Holz: You know, the firm is

139
00:23:19.170 --> 00:23:20.640
Daniel Holz: And here's another picture on that.

140
00:23:21.810 --> 00:23:29.250
Daniel Holz: And so what you see is the Trump. There's a merger. That's not the black line here and then sometime later there's a burst of gamma rays.

141
00:23:29.670 --> 00:23:37.530
Daniel Holz: And it may not look incredibly impressive on this clock, but this is actually a very high Significance gamma ray burst on and

142
00:23:38.220 --> 00:23:49.650
Daniel Holz: It turns out it comes from the same part of the sky and you can do all this analysis and show that it's less than I want a million chance that it's happening by, by chance, so this is a real Association.

143
00:23:50.700 --> 00:23:57.030
Daniel Holz: Okay, so that's extremely excited. We've now got a binary system membership revocation woods and we've detected some folk

144
00:24:00.090 --> 00:24:02.550
Daniel Holz: That's not the end of the story, there's even more.

145
00:24:04.050 --> 00:24:15.390
Daniel Holz: And that's not we actually discovered a killing all the associated with a source and here it is. You can see the star kind of appear and then disappear.

146
00:24:16.860 --> 00:24:22.410
Daniel Holz: This is data from the Dark Energy towering. And actually, a lot of people at soccer and Stanford were also involved in this.

147
00:24:23.400 --> 00:24:31.770
Daniel Holz: You know, this was something there is a group of us that collaborated to use the dark energy camera to search for counterparts of gravitational waves.

148
00:24:32.550 --> 00:24:44.430
Daniel Holz: We look for counterparts had black holes in and find anything but the goal. The whole goal was to detect a killer Nova, and to be able to do science with that. And sure enough, the very first binary neutron star.

149
00:24:45.150 --> 00:24:58.200
Daniel Holz: We discovered this killing. So we were one of a few teams that disk, you know, found this and got to do follow ups and do a lot of science with it, it's really remarkable this this appearances really mind blowing.

150
00:24:59.970 --> 00:25:19.800
Daniel Holz: Okay, so this is a lot of talk about 17 right 17 so on. I mean, there's so much to say about I'm going to again just highlight a few results. But the big picture is this was absolutely revolutionary. It's the first time we're getting gravitational waves and light from the same object.

151
00:25:20.880 --> 00:25:30.660
Daniel Holz: And by combining that we were you learn a lot about Gemma Tony about nuclear physics astrophysics cosmology. It's really, it's this gold mine literally a gold mine.

152
00:25:31.620 --> 00:25:41.730
Daniel Holz: And and so I'm going to highlight a few results. But, you know, we could spend the entire week just talking about this event and there would still be lots to say okay

153
00:25:42.810 --> 00:25:46.860
Daniel Holz: So I'm going to pick a few topics I've kind of pick things that are

154
00:25:48.210 --> 00:25:56.970
Daniel Holz: More along the theme of this week, but are there lots of other things to talk about. I'm happy to answer questions in the q&a

155
00:25:57.630 --> 00:26:09.450

Daniel Holz: So these are the sorts of questions you can ask. So the first one, the most obvious. The thing we all did a, you know, almost immediately like within an hour. Everyone had these limits.

156
00:26:10.470 --> 00:26:12.090
Daniel Holz: Taunton photons travel at the same

157
00:26:14.400 --> 00:26:14.880
Daniel Holz: And

158
00:26:22.110 --> 00:26:29.790
Daniel Holz: So here's the picture you should have in mind we we had the gravitational waves that they came and then the system merged.

159
00:26:30.570 --> 00:26:42.990
Daniel Holz: And then two seconds later, we got a gamma ray burst. So the question is, you know, what happened there. Two seconds a light can go pretty far in two seconds so that doesn't sound like they're happening quite at the same time.

160
00:26:44.310 --> 00:26:52.350
Daniel Holz: The number is that the source is far away hundred million years years is the light travel time

161
00:26:53.430 --> 00:27:06.750
Daniel Holz: This, this is the source that's 40 megabytes. So this source. It took quite a while for for the gravitational waves and the gamma rays. So you can imagine, let's imagine that they were admitted at the same time, let's say,

162
00:27:07.920 --> 00:27:24.630
Daniel Holz: For 100 million years they're traveling and by the time they get to Earth. There's a 1.7 second delay which means okay maybe the galleries are going a little slower but if they're going a little slower. They're going one part and tend to the 15th. So it's basically the same speed.

163
00:27:26.700 --> 00:27:32.640
Daniel Holz: If you could also imagine, well maybe it takes a while for the gamma rays to be admitted and Barry says

164
00:27:33.060 --> 00:27:39.150
Daniel Holz: 1.7 seconds is actually quite reasonable so probably what happened is you have the neutron stars crash into each other.

165
00:27:39.360 --> 00:27:46.860
Daniel Holz: It took a while to develop a relativistic jet and then you get shocking and that emits gamma rays, and then we see those and that's about 1.7 seconds later.

166
00:27:47.340 --> 00:27:58.140
Daniel Holz: And not all kind of fit, but you can imagine that said it takes 10 seconds and the galleries actually faster and that my catching up the whole time. If they're faster they're still only faster by one part in 10 to the 50

167
00:27:59.610 --> 00:28:09.600
Daniel Holz: So, just the fact that these things arrived within 1.7 seconds constraints that and claim it this way that photons go at the speed of gravity.

168
00:28:10.140 --> 00:28:16.020
Daniel Holz: To the you know better than one part of the 50 which is a major development in a field.

169
00:28:16.950 --> 00:28:26.970
Daniel Holz: And you might say, well I you know I kind of expected that. But then we keep in mind is, first of all, we have to go out and measure this stuff. And this is the first time we really had a measurement like this.

170
00:28:27.750 --> 00:28:33.930
Daniel Holz: But also, I'm there. You know, there are reasons to think that something is funny about gravity.

171
00:28:34.410 --> 00:28:41.970
Daniel Holz: Because of dark matter and dark energy and things you've been hearing about this week. And so people like to modify the account to account for this.

172
00:28:42.270 --> 00:28:56.460
Daniel Holz: And there are many classes. Many theories were, what you do is you effectively change this, the speed of light or the speed of gravity, you give the grab a ton of mass, you can mess with this stuff.

173
00:28:58.650 --> 00:29:00.090
Daniel Holz: Now if you do that.

174
00:29:01.380 --> 00:29:16.110

Daniel Holz: The end up traveling at different speeds and this, this one measurement was enough so so this one, you know, within minutes of having this gamma ray burst and done an association and being confident that it's a real Association.

175
00:29:17.460 --> 00:29:26.850
Daniel Holz: Huge classes at the retreat. So this is a major event. And we've gone from basically no constraints or 15 orders of magnitude. It's pretty good. That doesn't happen every day.

176
00:29:27.960 --> 00:29:33.570
Daniel Holz: Okay. Sounds good grammar tons of photos to have about the same speed. Yeah. Better than 1.2 hundred 50

177
00:29:36.060 --> 00:29:38.580
Daniel Holz: Okay, I'm just to give you a sense of

178
00:29:39.840 --> 00:29:47.700
Daniel Holz: You know, sort of novel test you can do and you can ask to get tons and photons travel through the same universe and so

179
00:29:48.600 --> 00:29:59.490
Daniel Holz: Let me try to convince you why this is an interesting question. So the idea here is I've talked about how people love to modify gravity. One of the very popular ways to modify is imagine that

180
00:29:59.940 --> 00:30:11.310
Daniel Holz: There are actually many extra dimensions in our universe and and there are many flavors of this, but one flavors that you imagine that there are extra dimensions, there's, there's

181
00:30:12.660 --> 00:30:21.750
Daniel Holz: You can confine the electromagnetic fields and light, you know quantum mechanics, if you like to, to a brain.

182
00:30:22.290 --> 00:30:28.170
Daniel Holz: And three dimensional three plus one dimensions and then gravity leaks out into the book.

183
00:30:28.980 --> 00:30:36.540
Daniel Holz: At some higher dimension and there are lots of appealing things about theories that include this. So if this is what's going on.

184
00:30:37.440 --> 00:30:46.020

Daniel Holz: If they're really if gravity is really operating in higher dimensions. Then as grab a time travel. I think that translates travel. Some of the energy will leak out into these higher dimensions.

185
00:30:46.590 --> 00:30:56.700
Daniel Holz: And if that happens, the amplitude of the gravitational raise will be decreased. And so what we can do is look at how effectively help break the sources in light.

186
00:30:57.630 --> 00:31:08.550
Daniel Holz: In for a distance from light. Compare that to how loud. The sources and gravitational waves. And that gives us a constraint on the number of dimensions extra dimensions that gravity might be looking into

187
00:31:09.210 --> 00:31:16.710
Daniel Holz: And there's some equations here. I'm not going to go through these and the message, the top one is the inverse square law, but here.

188
00:31:17.610 --> 00:31:24.390
Daniel Holz: One interesting thing about graduate sources is that we measure the strain which you can kind of think of as like measuring the he feel

189
00:31:24.750 --> 00:31:35.520
Daniel Holz: And energy goes is strange square or E squared. And so this is the inverse square law. But, you know, we've taken the route because while I'm looking at each show it's one over this.

190
00:31:36.330 --> 00:31:44.280
Daniel Holz: Instead of one over d squared. And you modify this if you have extra dimensions and there's lots of details here. I can talk about later for questions.

191
00:31:45.570 --> 00:31:51.720
Daniel Holz: This is so I should say this was worth led by Chris Provo, who is now a postdoc at JPL.

192
00:31:52.740 --> 00:32:08.460
Daniel Holz: And what we did was we just analyze the data and ask what is how many dimensions that we find. So this is a plot of, you know, our pastors on the number of space time dimensions as inferred from 1708 17 and

193
00:32:09.120 --> 00:32:16.650

Daniel Holz: Here is for three space plus one time and you can see that we confirm that therefore space time dimensions.

194
00:32:17.220 --> 00:32:33.660
Daniel Holz: You might say, you look around the room, you already knew that. But this is that cosmological scales 40 mega parasites, we've confirmed that everything that's it's just, it's, it's very cute. And it just pops right out of this, this one that it's a completely novel.

195
00:32:35.850 --> 00:32:46.920
Daniel Holz: You can also measure that you know is that, you know, is there a time during class and you can kind of go through something similar and show that there isn't. I won't spend time on this right now. But again, you can look at decides

196
00:32:48.630 --> 00:32:53.640
Daniel Holz: Okay, so do grab tons of photons shining through the same universe. So, yes, yes. Thank you.

197
00:32:56.550 --> 00:33:08.280
Daniel Holz: Yeah, okay. It's really fun to modify gravity. I'm a GR person in general, I like to assume it's correct and see what the repercussions are so from now I'm just going to assume jr's

198
00:33:10.260 --> 00:33:14.670
Daniel Holz: Um, so one of the things we can do is measure the question of state of neutron stars.

199
00:33:15.420 --> 00:33:23.010
Daniel Holz: I'm running a little late. I'm actually going to skip this. But again, you can ask the questions basically you're measuring how squishy. The neutron stars are

200
00:33:23.490 --> 00:33:32.880
Daniel Holz: As they go around each other and the title fields cause them to squash and by measuring that you're measuring the equation estate and we show that you can do this.

201
00:33:33.810 --> 00:33:39.030
Daniel Holz: quite effectively and and infer fundamental properties of nuclear physics.

202
00:33:39.720 --> 00:33:53.370
Daniel Holz: Super nuclear density. So this is, you know, here's kind of saturation dancing nuclear density and we can make constraints higher

than that something you can't do like the lab you know at this temperature. This is really unique and you can only do it.

203
00:33:54.630 --> 00:34:03.390
Daniel Holz: Basically from neutron stars. So it's very exciting. But I don't have time to go into. So one day I spend a few minutes on

204
00:34:04.230 --> 00:34:15.870
Daniel Holz: Is how the universe makes money and your time starts. This is one of the fundamental questions from the astrophysics perspective would really like to understand how does the universe. Do they make these systems that we're detecting

205
00:34:17.730 --> 00:34:18.180
Daniel Holz: And

206
00:34:19.230 --> 00:34:29.940
Daniel Holz: Spend a lot of time on this because this is actually work I did I was on sabbatical at Stanford and and this one's a project I did while I was there, I was logged by system, a daughter, Chloe.

207
00:34:30.240 --> 00:34:36.330
Daniel Holz: Who was a postdoc at slack and Stanford and who's actually coming to Chicago as a postdoc in the fall.

208
00:34:38.400 --> 00:34:49.590
Daniel Holz: Modulo the pandemic and also a number of other people were involved in including john pay phone, who is an under Stanford undergraduate and Risa Wexler who's director of Titanic.

209
00:34:51.060 --> 00:34:51.960
Slack and Stanford.

210
00:34:53.040 --> 00:35:04.110
Daniel Holz: And my fish back my glad to see you. Chicago. So here's the basic idea. We want to know how these binaries are made and the observation is that

211
00:35:04.740 --> 00:35:11.400
Daniel Holz: Binaries occur in galaxies and the galaxies have a lot of information about their history if you observe them.

212
00:35:11.700 --> 00:35:22.530

Daniel Holz: You can get information about you know their properties and you know how long they've been around what they're made out of. And that helps you infer how the banners and sounds are being

213
00:35:24.240 --> 00:35:25.110
Daniel Holz: And so

214
00:35:26.490 --> 00:35:36.420
Daniel Holz: I think I'll skip over some of these details but you know we characterize this as a star formation. Right. And every time distribution. Again, you can ask me questions later on, probably

215
00:35:37.020 --> 00:35:40.050
Daniel Holz: I mean, I'll go through this plot, and this will give you some sense of how this works.

216
00:35:40.770 --> 00:35:52.230
Daniel Holz: Which is you can imagine there three quantities that galaxies. You know, there are three properties at galaxies have, we have a star formation me how many stars each galaxy is making per year.

217
00:35:52.740 --> 00:36:01.470
Daniel Holz: And have a stellar mass. How many stars are in the galaxy. So you think of those, that's kind of an integral of all the stars I were formed for the life of the godson and then

218
00:36:02.670 --> 00:36:11.550
Daniel Holz: There's a dark matter mass as well. And that's the dominant mass of the galaxy. So you could ask if I have a host Galaxy Tab binary system.

219
00:36:12.000 --> 00:36:22.050
Daniel Holz: And do they do these binaries prefer some galaxies over others. So for example, let's suppose that that binaries by neutral stores are formed.

220
00:36:22.890 --> 00:36:33.600
Daniel Holz: When the stars are formed, and then they merge very quickly. Well then, then if you look at the host galaxies, the host galaxies will prefer actually have lots of star formation.

221
00:36:34.410 --> 00:36:45.180
Daniel Holz: And if binary neutron stars are actually forum somehow through dark matter processes Dinah trace trace the dark matter and the galaxies, not the star formation. Right. And what we showed is that

222
00:36:45.660 --> 00:36:49.860
Daniel Holz: We're just some small number of hosts galaxies, you can start to infer

223
00:36:50.460 --> 00:37:06.030
Daniel Holz: How, what the processes are whether binary and your trust or you prefer a tracking stolen us or star formation or dark matter or maybe none of the above and and that's remarkable. All we need is a few host galaxies and we can start to learn about these very complicated processes.

224
00:37:07.770 --> 00:37:08.190
Daniel Holz: And

225
00:37:09.240 --> 00:37:17.190
Daniel Holz: We happen to have this perfect event to work with, which is 1717 where there it is. And you can see this

226
00:37:17.520 --> 00:37:29.580
Daniel Holz: You know, very nice host galaxy and GC 4993 and so we can use that to try to learn something about the processes by which 1708 17 that binary was made and

227
00:37:29.970 --> 00:37:39.600
Daniel Holz: Just from that one goes galaxy. We already got to say, well, it looks like there's kind of a longer delay time that between when the binary was formed.

228
00:37:40.080 --> 00:37:53.340
Daniel Holz: And when it actually merged was something like six giga years. That's this kind of darker spot in the bottom right, and that's amazing just with this one host cancer. We can already start to infer something about the formation

229
00:37:55.230 --> 00:38:02.940
Daniel Holz: So it's a lot of detail here, but it's very neat. And it's kind of a new way to do astrophysics of graduate sources.

230
00:38:04.740 --> 00:38:15.810
Daniel Holz: Okay. Um, this is one of the topics I'm most excited about. So spend a few slides on this, which is how we can use metrics right sources to measure the Hubble costly.

231

00:38:17.280 --> 00:38:26.490
Daniel Holz: Here is a plot which kind of summarizes some of the, you know, issues in this field. And so this is by Wendy Friedman, she showing

232
00:38:27.330 --> 00:38:34.560
Daniel Holz: Over time on measurements of their horrible constant. This is, you know, the Hubble key project, and it had this

233
00:38:34.920 --> 00:38:41.850
Daniel Holz: You know, which at the time was considered very good measurement and here it is we rolled out that it was 30, you're probably know that if I

234
00:38:42.630 --> 00:38:59.940
Daniel Holz: Put this plot, even back, you know, many years back, initial measurements were much higher the hundreds Hubble's initial measurement was way off. And then it's been marching down and then there have been lots of controversies over the years. Now what's interesting is that now these two

235
00:39:00.960 --> 00:39:12.270
Daniel Holz: Parts of the clock seem to be divergent supernovae, or what we call local measurements measurements that are based on observations nearby seem to find higher values of the humble constant and the CMT

236
00:39:12.660 --> 00:39:17.370
Daniel Holz: early universe measurements have lower values and you're going to hear a lot about this.

237
00:39:17.910 --> 00:39:31.350
Daniel Holz: It could be a hint of a revolution in our understanding of the cosmological Steiner model. Or it could just be systematics we don't know out and that's going to give a talk just focused on this. So you're going to hear plenty

238
00:39:32.550 --> 00:39:41.220
Daniel Holz: What I want to just mention is that gravitational waves offer a new way to constrain this and find information with you know

239
00:39:42.420 --> 00:39:48.990
Daniel Holz: Very what I think it was extremely incredibly clean Pro. And so the idea is that

240
00:39:49.740 --> 00:39:57.990

Daniel Holz: You know black holes are very simple objects. The only described by mass and spin and you know maybe charge if you're very ambitious.

241
00:39:58.320 --> 00:40:09.390
Daniel Holz: And that's it fully describe so a binary system is actually very simply describing relativity and it's calibrated by the theory of relativity itself. So from

242
00:40:09.870 --> 00:40:22.950
Daniel Holz: The GR from GR you can write down the questions. I tell you, if you have these masses. This is how loud, the source will be. And so if you can measure how loud. The sources and your detector, you can figure out how far away the source.

243
00:40:25.500 --> 00:40:30.000
Daniel Holz: Here, a lot of details. I'm just going to skip over that again we can talk about the questions so

244
00:40:30.330 --> 00:40:37.830
Daniel Holz: What God gives you is if you have a banner sustain you measure the gravitational waves. You see how loud. They are you get a distance. There's no distance not or you just

245
00:40:38.100 --> 00:40:44.910
Daniel Holz: Measure the distance out to cosmological distances. That's remarkable. That's sometimes very hard to do, or in other ways and astrophysics.

246
00:40:45.840 --> 00:40:55.770
Daniel Holz: You don't get an entre you don't get a redshift and there. That's part of the nature of general relativity. So you have to get a metric some other way.

247
00:40:56.160 --> 00:41:03.660
Daniel Holz: And you can do it with properties of the system, statistically, I'll talk more about that, like, the easiest and cleanest is if you just have an electromagnetic counterpart.

248
00:41:03.990 --> 00:41:13.080
Daniel Holz: You have a counterpart, you can measure redshift directly. So from the electromagnetic kind of product you get Rochester. If you're nearby. It's a recession velocity be

249
00:41:13.470 --> 00:41:23.040

Daniel Holz: And that distance comes from the graduation rates and it's you can solve this equation to get Babel classic. And then there's a more complicated version of this as you go farther away. But it's still the same idea.

250
00:41:25.230 --> 00:41:32.730
Daniel Holz: 1717 is the ideal standard tiring. I mean, this is something we talked about for years, if only one day we could get

251
00:41:33.090 --> 00:41:43.320
Daniel Holz: You know, some system and it would be learner. We can get there, we could do this phenomenal measurement. And to be honest, I wasn't sure it would ever happen. And then some to 817 and

252
00:41:44.010 --> 00:41:46.020
Daniel Holz: Within 24 hours, we had a measurement

253
00:41:47.010 --> 00:42:00.510
Daniel Holz: And it's, it's because something like 17 was so loud. Well actually got a pretty good distance matching it and we had that optical counterpart. So we identified the host galaxy and very, I didn't know you I could Google the host galaxy.

254
00:42:01.050 --> 00:42:10.500
Daniel Holz: And get each redshift. So I had wretched distance, you can make your plot for the constant. In fact, and just a caveat.

255
00:42:11.010 --> 00:42:23.040
Daniel Holz: It was too good. It was too close. So there are actually some issues procure the motions and variable asked me to do some work to get a really robust answer. But we went through all this. And this is what we found.

256
00:42:23.490 --> 00:42:31.680
Daniel Holz: And I still just can't believe we've made this plot, this is the Hubble consensus process. And so this, this is our, you know, kind of our

257
00:42:32.160 --> 00:42:38.190
Daniel Holz: Measurement of what the Hubble costume is about the Hubble content, you see a pizza at around 70

258
00:42:38.940 --> 00:42:44.040
Daniel Holz: Which happens to be right in between the values from cosmic microwave background and supernovae.

259
00:42:44.730 --> 00:42:53.460
Daniel Holz: But we're pretty good on certain since the very first system first time we've done it. It's amazing that it works at all. I mean this could have picked somewhere else and a kind of

260
00:42:53.940 --> 00:43:02.970
Daniel Holz: confirms that science is working, which is great. I'm also point out those this long tail that has to do with the distance, and conditions you can see

261
00:43:03.990 --> 00:43:15.180
Daniel Holz: But it means this whole thing is very long. Yes, in which means as we get more sources and actually converges quite quickly gosselin's converge know much too slow. It's the worst case.

262
00:43:15.870 --> 00:43:29.520
Daniel Holz: They have you thought tales and it's terrible. And this will converge much much quicker and not something we show here on this is work led by my former student and show your chain also with my official ah

263
00:43:30.540 --> 00:43:36.120
Daniel Holz: And what we've done is we kind of projected phone and we show that with some small number.

264
00:43:36.690 --> 00:43:42.390
Daniel Holz: ten's of binary systems where we've gotten I will constantly we can measure the Holocaust and we have a ton of part

265
00:43:42.960 --> 00:43:49.830
Daniel Holz: Where you got to a few percent medical intervention and I'll just remind you this is calibrated by channel relativity. So it's very robust

266
00:43:50.100 --> 00:43:58.740
Daniel Holz: Keep that in mind when Adams talking about the other measurements of the Hubble constant. Yeah, this is a difficult thing to do. This is a very clean way to do it.

267
00:43:59.070 --> 00:44:08.220
Daniel Holz: On the problem is we need more sources. And if we don't get the additional sources, we're stuck with what we have so far, which is a 10 or 15% measurement, which is not nearly as interesting.

268

00:44:09.540 --> 00:44:09.780
OK.

269
00:44:10.890 --> 00:44:13.800
Daniel Holz: So again items talk will be helpful.

270
00:44:15.870 --> 00:44:19.290
Daniel Holz: All right, so, um, I have about 10 minutes left.

271
00:44:19.860 --> 00:44:31.950
Daniel Holz: So I'll just kind of step back a little bit. We have lots of repetition. Right. The touchdowns. At this point, this is up there. I just, this is as of May, here are announced detection. So the lot. The blue

272
00:44:32.520 --> 00:44:42.060
Daniel Holz: The blue circles here all the black holes. We've discovered there are quite a few as I'll talk about their action many more in the cabinet. We should be announcing soon.

273
00:44:43.350 --> 00:44:48.480
Daniel Holz: And so now you can really start to do population astrophysics, which has been

274
00:44:49.350 --> 00:44:56.370
Daniel Holz: One of our real focus in the community. We've gone from Oh look, we have 5914 I spend a lot of time on that.

275
00:44:56.730 --> 00:45:09.540
Daniel Holz: Oh, we have 17 year old 17 and spent a lot. Now we're assigning it to. We have enough sources we can analyze as a population. And that's, you know, very excited. And it's a different sort of way to learn about physics astrophysics.

276
00:45:10.530 --> 00:45:14.730
Daniel Holz: So I'm going to give you some examples of some of the things we we learn from the population.

277
00:45:16.620 --> 00:45:23.850
Daniel Holz: So what I'm going to do is just pick a few your topics and kind of do a very brief overview of those topics.

278
00:45:24.900 --> 00:45:32.010

Daniel Holz: And so the first is, you know, where r ly goes big black holes. So the one thing you might notice

279
00:45:42.270 --> 00:45:49.290
Daniel Holz: So one thing you notice from this plot, and I mentioned this before, is that, you know, the component black hole. So each of these

280
00:45:49.500 --> 00:45:59.580
Daniel Holz: Is her to smaller black holes, they merge and the trade a bigger Michael. If you look at the smaller black holes like they kind of come all the way up to this line at around 40

281
00:46:00.450 --> 00:46:12.270
Daniel Holz: But then they're not a buck and we've detected. Quite a few. And they're just kind of pairing up there. And what's interesting is actually work sensitive way above this line. And in fact,

282
00:46:13.050 --> 00:46:30.420
Daniel Holz: Those are the loudest sources. And so we detect those the farthest so the fact that will not seeing anything up here means they're very, very few because if there were any out there, we would have detected them because they're sold out. So, so we noticed

283
00:46:32.670 --> 00:46:33.450
Science

284
00:46:39.300 --> 00:46:50.490
Daniel Holz: We noticed that there are missing. And we could fit the population and and quantify what the maximum masses of the population. And so this is work I did with

285
00:46:51.450 --> 00:46:59.250
Daniel Holz: My student my official um and what we did was we noticed yesterday appears to be a cut off in that population and

286
00:46:59.910 --> 00:47:09.090
Daniel Holz: As a side note there he had said that I'm there should be a cut off. Because of this, these things called parents to very supernovae as your shipping.

287
00:47:09.570 --> 00:47:20.160
Daniel Holz: Address stars are bigger and bigger. At some point they got there's a phase where they're slow so had an interior got it goes through this instability.

288
00:47:20.970 --> 00:47:35.010
Daniel Holz: And it blows itself up so violently that it doesn't form of by Ansel theory had said that at some point, there would be no more black holes and be a gap and upper deck.

289
00:47:36.060 --> 00:47:47.640
Daniel Holz: And we now find evidence. And this is now as we do that additional population analyses, we're kind of characterizing we're, we're, you know, what is this edge look like, and is it sharp or is it

290
00:47:48.090 --> 00:48:02.370
Daniel Holz: You know, is there a slope to it and maybe there's some things above, but not many. You know, we're trying to characterize this. It's fascinating. And it has. We think has made to the astrophysics of how these black holes are formed in the first

291
00:48:05.280 --> 00:48:12.210
Daniel Holz: One other thing that comes out of this is that you can come up with a new method to constrain cosmology using standard sirens.

292
00:48:12.840 --> 00:48:16.380
Daniel Holz: I mentioned that there's as far as you need a counterpart to get the Russia.

293
00:48:17.220 --> 00:48:32.040
Daniel Holz: But if there is a again gap, there's an edge. And you can think of that, in the same way that you can think of a Georgian features and electromagnetic sources you take a spectrum. And there's a feature and you can infer the red shirt.

294
00:48:32.640 --> 00:48:41.100
Daniel Holz: You can do the exact same thing here using just the distribution of masses and infer where the gap is and that gives you information about redshift as well.

295
00:48:42.000 --> 00:48:54.000
Daniel Holz: And so we share this was work led by well far the flat iron Institute and Stony Brook and we showed that even with just a few years of data.

296
00:48:54.690 --> 00:49:05.400
Daniel Holz: At advanced sensitivity. You can constrain you can constrain the, the, you know, HMC the expansion history to the level of, you know,

297

00:49:06.030 --> 00:49:14.640
Daniel Holz: 2% I retro point seven five which is a very interesting matchup because that's where you go from dark matter dominated to dark energy dominated

298
00:49:15.570 --> 00:49:22.290
Daniel Holz: And here's a completely new way to to constrain cosmology using these Rochester light sources.

299
00:49:22.860 --> 00:49:28.530
Daniel Holz: There are a lot of caveats. You'd have to understand how this gap works and whether it evolves and

300
00:49:28.980 --> 00:49:43.350
Daniel Holz: There's lots more that can be said about this, but it's extremely promising it's entirely new. And the idea didn't exist now four years ago. It's just a new thing, because we have this population, you can start to come up with new ways to do science.

301
00:49:44.760 --> 00:49:45.360
Richard Partridge: Minutes.

302
00:49:45.990 --> 00:49:46.770
Daniel Holz: Okay, thank you.

303
00:49:48.360 --> 00:49:54.270
Daniel Holz: Okay, are there other questions, you're going to ask, such as does the rate of mergers evolve over time.

304
00:49:55.530 --> 00:50:07.650
Daniel Holz: And so we have this merger way we're starting to see all these monitors. Most of them are nearby, but you can ask, do we have any evidence that more of them are happening as we go to higher Richard

305
00:50:08.880 --> 00:50:15.270
Daniel Holz: And the point here is that we think and I alluded to this with the with the binary host

306
00:50:15.690 --> 00:50:26.340
Daniel Holz: Connection stop when we look at the host galaxies, we think that that these black holes and the neutron stars are being formed from the depths of stars.

307
00:50:26.880 --> 00:50:41.820

Daniel Holz: And so these should you know relate to when stars are performing and done. And there was a lot more activity earlier in the universe that ratio is one to two. That's where we think most of the stars were born.

308
00:50:42.510 --> 00:50:49.050
Daniel Holz: And so there's an expectation that that's where a lot of action happens. And that's probably where most of the murders were happening.

309
00:50:50.220 --> 00:51:00.810
Daniel Holz: And so as we go to high redshift, we should start to see evidence for that. And there are ways to analyze for that and we start to have tantalizing hence that this is happening as we get more of a population more constrained

310
00:51:03.000 --> 00:51:16.500
Daniel Holz: There's black hole spans are extremely fascinating as well. I'm actually going to skip this. But Eric spends can tell you, between dynamical and isolated formation, how these again it's details on how the black holes are being formed.

311
00:51:18.900 --> 00:51:25.260
Daniel Holz: Related to that, you can ask this question of whether black holes are being made out of small black holes. It's related to the spin question.

312
00:51:26.910 --> 00:51:36.750
Daniel Holz: So this was a question we asked, and we find preliminary evidence that at least not all black holes are being made at a smaller black holes.

313
00:51:37.140 --> 00:51:43.320
Daniel Holz: The reason this is interesting is if you're a child about primordial black holes and you think like a water hose might be promotional

314
00:51:43.650 --> 00:51:51.840
Daniel Holz: And there's a reasonable chance that they're being built up out of smaller and smaller black holes. What's fascinating about that is if you take two black holes in your merge them.

315
00:51:52.350 --> 00:51:57.030
Daniel Holz: And there's so much orbital angular momentum that the final black hole is spinning

316
00:51:57.720 --> 00:52:03.720
Daniel Holz: Must be spinning, and that's what we're showing here. This is the distribution of the spin parameter and it's around point seven

317
00:52:04.320 --> 00:52:20.010
Daniel Holz: Where one is extreme or occur, you're spinning. If you like at the speed of light. And so point seven is very rapidly spinning and we don't think that all the black holes that we've detected so far rapidly spreading. This is something that the population will teach you about

318
00:52:21.720 --> 00:52:26.070
Daniel Holz: I think maybe I'll spend a little time on this, and then wrap up.

319
00:52:27.360 --> 00:52:36.690
Daniel Holz: Which is this is some work led by Tom Koster, who's a postdoc at the Florida Institute, but it gives you a sense of

320
00:52:37.350 --> 00:52:44.490
Daniel Holz: Other things we can do. For example, in this, we said, well, we have all these binaries we've measured locally.

321
00:52:45.150 --> 00:52:51.750
Daniel Holz: Or seeing all these binary murders. But as I've just been saying we think there are a lot more as you go to high Russia.

322
00:52:52.650 --> 00:53:01.800
Daniel Holz: And those we can identify individually, but the whole population should be creating this background hump call, which we call the sarcastic background.

323
00:53:02.250 --> 00:53:15.360
Daniel Holz: So you can ask how we detected the home. We have not detected it so far. The fact that we haven't detected it means there can't be all that many at high ratchet because we would have the type of the home. We haven't and so

324
00:53:16.560 --> 00:53:23.850
Daniel Holz: The green plot here is as a function of venture. What are the possible rates that are consistent with the detections we have so far.

325
00:53:24.450 --> 00:53:31.290

Daniel Holz: And you can see they're all over the place that it could have increased very rapidly. It could have decreased. We don't know.

326
00:53:31.770 --> 00:53:45.060
Daniel Holz: But if you throw in the fact that we haven't heard the hum you cut off all the high ones. And so that's a very interesting additional information and by combining these we argue, you're going to get a much better handle on what's happening.

327
00:53:46.920 --> 00:53:53.190
Daniel Holz: And you'll hear a lot more about that tomorrow from Geraldine, who is an expert on on sarcastic.

328
00:53:55.620 --> 00:54:03.840
Daniel Holz: Okay. Um, so I'm just going to end with, you know, where are we now, we're in the third observing and we're just finished we're analyzing the data.

329
00:54:04.080 --> 00:54:14.220
Daniel Holz: Or we ended a little early, because of the pandemic, but we got a lot of good data we've had something like 60 alerts of binary black hole and bury your transfer banks.

330
00:54:14.700 --> 00:54:20.970
Daniel Holz: And we're much more sensitive than we were previously we've published three discoveries, which I'm just going to flash up

331
00:54:22.560 --> 00:54:33.600
Daniel Holz: We had 1904 25 or trends, a binary neutron star event, um, unfortunately we don't localize it. Well, we didn't get any light. So there's no multi messenger astronomy.

332
00:54:33.990 --> 00:54:44.370
Daniel Holz: What was interesting about this one. Is it was slightly more massive. And most of the band neutron stars were aware of. So it's curious. It's just unusual and that could be quite interesting.

333
00:54:46.470 --> 00:54:47.400
Daniel Holz: We also announced

334
00:54:48.780 --> 00:54:52.830
Daniel Holz: Which is a binary black hole event or what's interesting about this is that

335

00:54:53.310 --> 00:55:04.320
Daniel Holz: It was a big black hole 30 solar masses with a much smaller backhaul only eight solar masses. This is a for tech first time with confidently detected a binary where the masses are not the same.

336
00:55:05.070 --> 00:55:11.280
Daniel Holz: And so you can look there's a paper I wrote called picky partners, where we argue all

337
00:55:11.850 --> 00:55:21.000
Daniel Holz: You know, we learned a lot about astrophysics based on these mass ratio is this is the first time we really have an interest in mass ratio. So this is fascinating. We need to understand how this was for

338
00:55:21.960 --> 00:55:34.170
Daniel Holz: Um, and then here is the third, the last event that we've announced so far from all three which is perhaps the most fascinating. This was a black hole with another object.

339
00:55:34.410 --> 00:55:46.950
Daniel Holz: Which is either the most massive neutron star with other detected or the least massive black hole that we've ever detected. Either way, it's fascinating. It seems to be right in the mascot that I alluded to that lower mascot.

340
00:55:47.490 --> 00:55:55.590
Daniel Holz: Yeah, this is, you know, quite incredible. And this is exactly that sort of thing. We're hoping it attack. To learn more about these populations.

341
00:55:57.330 --> 00:56:11.820
Daniel Holz: There should be a lot more results from all three coming soon. And, you know, we'll see where they lead and just and here is the research group is actually his or her doctor is now a postdoc at Oregon and here's the rest of the group.

342
00:56:13.380 --> 00:56:22.020
Daniel Holz: Just we had a nice get together. A couple of weeks ago and went for bubble tea and it felt really nice to see him kind of all

343
00:56:23.430 --> 00:56:24.750
Daniel Holz: Alright, so to me.

344
00:56:26.460 --> 00:56:29.520
Daniel Holz: The error of graduate messenger astronomy has arrived.

345
00:56:30.540 --> 00:56:35.910
Daniel Holz: Just in the last few years. This wine from all hypothetical turn now it's just happening.

346
00:56:36.420 --> 00:56:43.380
Daniel Holz: On the ground cash wave instruments are being upgraded. You'll hear more about this later this week we hope to turn on in about 18 months.

347
00:56:44.130 --> 00:56:53.580
Daniel Holz: We should be much more sensitive, there should be a deluge of events. There's going to be incredible science and hopefully there'll be lots of good surprises as well.

348
00:56:54.810 --> 00:56:55.410
Daniel Holz: And there

349
00:56:57.000 --> 00:56:57.900
Daniel Holz: For two questions.

350
00:56:59.430 --> 00:57:09.360
Richard Partridge: Thank you very much for your interesting lecture. So another turn it over to Charlie. Yo, who's managing the question and answer period.

351
00:57:10.920 --> 00:57:25.290
charlie young: Thank you Richard and Thank you Daniel very interesting lecture. We have a lot of questions, we'll just go through a few of them, and the rest, we will take care of offline and then post all the questions and the answers to the agenda.

352
00:57:26.520 --> 00:57:30.690
charlie young: So here comes the first question on slide 13

353
00:57:32.790 --> 00:57:36.390
charlie young: The energy that you're referring to is a purely gravitational

354
00:57:42.060 --> 00:57:42.720
Daniel Holz: So,

355
00:57:44.370 --> 00:57:45.030

Daniel Holz: This slide.

356
00:57:46.710 --> 00:57:47.190
And

357
00:57:48.270 --> 00:58:00.000
Daniel Holz: This is probably this this slide. Okay. Um, the energy here is pure rotational so so if you just look at the luminosity and rotational waves.

358
00:58:01.350 --> 00:58:01.920
Daniel Holz: It's

359
00:58:03.060 --> 00:58:16.170
Daniel Holz: I think it's tend to the 55% of time anyway. I can't remember the exact number, but it's on the order you know it's it's it's just it's astronomical

360
00:58:17.220 --> 00:58:31.740
Daniel Holz: So, but pure gravitational wave energy. Another way to say it is for that event. The 3030 solar mass event. And this is kind of the GR units. I'm more familiar where there was something like three solar masses.

361
00:58:33.300 --> 00:58:44.400
Daniel Holz: Of energy we're releasing gravitational waves. So if you took the masses of the initial black holes and the NASA, the final black hole there was about three sunglasses missing.

362
00:58:45.570 --> 00:58:51.090
Daniel Holz: That went into gravitational wave energy that then went through the universe. And that's where we detected

363
00:58:52.410 --> 00:59:01.620
Daniel Holz: Yes, you know, three, four sons worse of energy mc squared into gravitational waves, it's staggering.

364
00:59:02.880 --> 00:59:03.900
Daniel Holz: In a fraction of a second.

365
00:59:04.830 --> 00:59:07.650
charlie young: Okay, thank you. So another question.

366

00:59:08.790 --> 00:59:21.090
charlie young: Suppose there is a black hole knew where the gravitational wave originates. How does this extra black other black hole perceived the gravitational wave as it passes.

367
00:59:22.200 --> 00:59:31.620
Daniel Holz: Yeah, okay. So it's a great question. Imagine you have a binary. And let's assume there's another black hole nearby. And I should say that's not a completely hypothetical

368
00:59:32.190 --> 00:59:43.170
Daniel Holz: Issue. There was a lot of activity now about high walk, what I call the hierarchical triples or higher order systems where you're having binary and then there's a companion to the binary orbit.

369
00:59:43.800 --> 00:59:49.590
Daniel Holz: And so you can imagine three black holes where you have to in a tight binary and a third farther away and

370
00:59:49.740 --> 00:59:56.940
Daniel Holz: So the first question is, will that change the the waveform. The, the orbits of the to interview.

371
00:59:57.450 --> 01:00:05.760
Daniel Holz: The interview the two bottles inside and then that depends on that on what the orders of the third object. If it comes nearby.

372
01:00:06.270 --> 01:00:15.780
Daniel Holz: And it can distort the system it can generate a centricity so the orbit, instead of being circular my tissue waves have a tendency to circular orbit.

373
01:00:16.770 --> 01:00:23.280
Daniel Holz: It could end up very eccentric and that's something that we could, in principle, measure and that would be extremely exciting.

374
01:00:23.550 --> 01:00:34.260
Daniel Holz: It's not something we particularly expected or look for for we're starting to look for that. And everybody, great to see that that will give you some evidence that there's something else going on something about the foundation

375
01:00:36.750 --> 01:00:42.870
Daniel Holz: It has to be close for that to happen. If it's far away the gravitational effect of that.

376
01:00:43.620 --> 01:00:53.250
Daniel Holz: Third black hole is just completely overwhelmed by the nearby gravitational wave effects of the two black holes and so unless there's something very near my doesn't do much.

377
01:00:53.760 --> 01:01:02.430
Daniel Holz: Um, there's one exception to that which might be interesting, which is you can imagine gravitational lensing. And there's been a lot of talking about renting and the sources.

378
01:01:02.730 --> 01:01:17.460
Daniel Holz: And you could imagine some lensing effects of gravitational waves. If you have another black hole, but that gets to be quite fine tune. I can talk more about that if there's interest that you know that's something which eventually we may be able to

379
01:01:19.680 --> 01:01:24.030
charlie young: Okay, thank you. Another question. This is about slide 32

380
01:01:25.080 --> 01:01:33.210
charlie young: Where we conclude that the number of space time dimensions. The question is, are all extra dimension theories root out artist result.

381
01:01:34.770 --> 01:01:42.750
Daniel Holz: So no, that's a very good question. I mean, I was excited for a while because I thought maybe that's what really put constraints on this.

382
01:01:43.380 --> 01:01:50.910
Daniel Holz: There are many different flavors of extra dimension, there is. So for example, in the canonical string theories

383
01:01:51.390 --> 01:02:01.620
Daniel Holz: That extra dimensions are called up very small and and and these gravitational waves, the wavelengths are much, much larger than then the

384
01:02:01.980 --> 01:02:09.630
Daniel Holz: Size, if you like, of those dimensions. So the waves don't notice those extra dimensions and pass right through. So if your answer dimensions are small.

385

01:02:10.290 --> 01:02:24.240
Daniel Holz: And then this doesn't constrain them at all. What this does is it's constraints, a large dimension surge of extra large dimensions, then this. This provides you know, interesting constraints on you know on the scales.

386
01:02:25.980 --> 01:02:26.640
That's a good question.

387
01:02:27.750 --> 01:02:41.460
charlie young: Thank you. This question is about page 27 where we put constraints in the speed between photons and Gravity Forms. The question is, can we use this to constraint, a mass of the graph data.

388
01:02:42.900 --> 01:02:47.970
Daniel Holz: We can. I mean, it does give you their their their different ways to constrain that mass

389
01:02:48.930 --> 01:03:04.020
Daniel Holz: One is this way and another is through dispersion relations, you can look for frequency dependent effects and both of them provide interesting constraints. I don't know the number off the top of my head. But if you look at

390
01:03:05.310 --> 01:03:12.960
Daniel Holz: Some of the papers associated with Centenary tentative you'll see them presented there so you get a direct constraint on on the mass of the gravitas.

391
01:03:14.340 --> 01:03:18.210
charlie young: Great. Thank you. Can we go to Slide 19 please

392
01:03:21.120 --> 01:03:27.330
charlie young: I think at this point, you mentioned that there's a gap between neutron stars and black holes. Can you explain that again.

393
01:03:27.990 --> 01:03:38.130
Daniel Holz: Yeah, so, so this is a phenomenal, phenomenal logical observation. So this is something where people have kind of looked at these populations and they've noticed

394
01:03:39.090 --> 01:03:49.860
Daniel Holz: That the black holes seem to stop at around five and they don't continue down neutron stars we expect. There's a maximum massive neutral have a neutron star.

395
01:03:50.370 --> 01:04:00.060
Daniel Holz: So you can, you know, build neutron star, you know you you add this is saying a supernova collapses, it explodes and you leave a neutron star behind

396
01:04:01.890 --> 01:04:15.930
Daniel Holz: You can keep adding matter to the neutron star, for example through fallback of material and there's a limit the neutron stars not infinitely staff. It depends on the question I said if you keep adding matter at some point it should collapse to a black hole.

397
01:04:17.520 --> 01:04:29.910
Daniel Holz: So we theory says, There must be a maximum master neutron stars. Now if you think of the description I just gave you. It seems like you could take the maximum neutron star, just add

398
01:04:30.330 --> 01:04:36.600
Daniel Holz: One more time. And then the whole thing or collapse into a black hole and therefore, there should not be a gap.

399
01:04:38.310 --> 01:04:43.980
Daniel Holz: But know the data. There's some evidence that there is a gap. And the question is why would that happen.

400
01:04:45.210 --> 01:04:57.390
Daniel Holz: And so that seems to have to do if there is a gap with how black holes are formed and black holes are also formed in these you know supernova events you get collapse and an explosion.

401
01:04:58.230 --> 01:05:05.550
Daniel Holz: And the question is, is there something about the nature of that event. And I remember, it's very different. If you're forming a neutron star from the call.

402
01:05:06.060 --> 01:05:16.680
Daniel Holz: If you start collapses on and it finds a neutron star at the center, then all this material kind of can bounce off the neutron star, which is very dense.

403
01:05:17.880 --> 01:05:27.180
Daniel Holz: And then you know eject if it's a black hole. There's no surface you're just following and so that doesn't happen. So the physics of

404
01:05:27.960 --> 01:05:35.400
Daniel Holz: You know, a supernova that creates a neutron star could be different from the physics of one that creates a bottle and that could lead to a gap.

405
01:05:36.210 --> 01:05:47.430
Daniel Holz: We have arguments. I've written some papers with climbers, including Chris fire on masala and Chris Belgian ski in Poland.

406
01:05:48.330 --> 01:05:57.570
Daniel Holz: And, you know, we've argued that there's something about the 10 scale of the supernova events that might distinguish and naturally form a gap.

407
01:05:58.440 --> 01:06:05.070
Daniel Holz: But we don't really know. We don't have that much data. And that's something that we're hoping gravitational waves will help with

408
01:06:05.490 --> 01:06:15.570
Daniel Holz: And if there are binaries that are low mass. If there are three and three or four and four selling mass black but hold on. We will attack them.

409
01:06:16.500 --> 01:06:27.990
Daniel Holz: They're not as loud as the bigger one. So they have to happen near nearby. It's just a matter of time. We'll keep absorbing and the hope is well either fill in the gap or will constrained

410
01:06:28.920 --> 01:06:39.420
Daniel Holz: And that's one of the more exciting results that may come out of, you know, logo is, is there a gap or not, I'm here, and if so, how do we characterize it. What is it teaching us

411
01:06:40.170 --> 01:06:49.620
Daniel Holz: And the very last again I talked about is a black hole with with an object that appears to be right around here, right in the middle of the gap.

412
01:06:50.280 --> 01:06:52.590
Daniel Holz: And so that's extremely intriguing.

413
01:06:53.490 --> 01:07:03.270

Daniel Holz: It's very hard to make any big statements based on one event. So we'll have to see where the statistics lead, but it's very suggestive. And so we'll see what happens. And

414
01:07:03.600 --> 01:07:12.960
Daniel Holz: The next observing run. I think will really help clarify whether or not there's a gap and what its properties are. And just as an aside,

415
01:07:13.800 --> 01:07:26.580
Daniel Holz: Since I'm the one talking, I get to talk about my work, I just put out a paper called matter matters does matter, matter. I think it does matter, matter with a question mark. This is worth read us

416
01:07:27.150 --> 01:07:36.120
Daniel Holz: And my official and we specifically address this question of whether on how we were characterized this gap.

417
01:07:36.450 --> 01:07:47.400
Daniel Holz: In the data and analyze it and look for evidence and we argue that there's preliminary evidence that there is a gap because it's very unlikely that the tech summit generate 17 down here.

418
01:07:48.060 --> 01:07:58.110
Daniel Holz: And the tact and nothing in the middle because there's a lot more volume our sensitivity here. So there's a week evidence for a gap, but the future will should really know

419
01:07:59.910 --> 01:08:07.050
charlie young: Maybe I can ask one question. As a follow up to this is around this page, what is the horizontal axis here.

420
01:08:07.590 --> 01:08:15.750
Daniel Holz: Yes. So this is, it's just, it's just for visual interest and there's no information on the horizontal axis is just

421
01:08:16.080 --> 01:08:28.890
Daniel Holz: So it's a slightly confusing way to show that at the Y axis is still you know the the masses of the binaries and solar masses and the x axis is just a way to spread them all out, so they're not on top of each other visual

422
01:08:30.480 --> 01:08:41.430

charlie young: There's no information there. Right. Thank you. So here's a question about success, since we are describing things in general relativity framework.

423
01:08:41.790 --> 01:08:52.020
charlie young: Why do we speak about Gravity Forms and associated with the quantum field theory framework for which general relativity. We don't have yet. Yeah.

424
01:08:52.170 --> 01:08:59.310
Daniel Holz: Okay, great, crushing and PowerPoint so fun. The GR perspective. They're just gravitational waves.

425
01:09:00.240 --> 01:09:17.190
Daniel Holz: I use all the time, cuz I you know I think of this, especially since its associated with slack and it's a bunch of particle physicist, I try to use the language of particle physics. And so there I think people often think of them as, you know, grab at times, but it's a fair point that

426
01:09:18.240 --> 01:09:27.930
Daniel Holz: That's, you know, if we we think there's something where required ties GR and we're expecting about trench ways to be quantization suspension particle up

427
01:09:29.280 --> 01:09:36.360
Daniel Holz: Right, it's, you can just think of it, you can replace it with gravitational waves. It's much easier in terms of like the time of flight measurements.

428
01:09:36.690 --> 01:09:45.270
Daniel Holz: To think of it in terms of, oh, here's a graph baton and a photon because they're kind of analogous but you can think of it as here's a gravitational wave front.

429
01:09:45.630 --> 01:10:02.190
Daniel Holz: And a photon and we're just asking you know what what the speed so so that's that's a fair point. And, and, you know, really, you can replace everything with gravitational waves. Whoever said it's it's it's the same. So yeah, OK.

430
01:10:02.700 --> 01:10:03.360
Richard Partridge: Ok I

431
01:10:03.690 --> 01:10:22.230

Richard Partridge: Think we need to wrap it up. But one of the fake Daniel for stimulating the lecturer and our participants for many excellent questions and we will be taking a telomere break will be stopping recording here.

432
01:10:23.280 --> 01:10:26.580
Daniel Holz: Okay. Hi, everyone. Thank you. Thanks for the questions.

433
01:10:28.260 --> 01:10:28.440
Thank