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WEBVTT

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00:00:03.000 --> 00:00:13.290
thomas rizzo: Okay, great. I'm extremely happy to have Adam Reese here
from Johns Hopkins, who's going to tell us about the dark energy and the
Hubble tension, take it away.

2
00:00:14.490 --> 00:00:15.179
Adam Riess: Okay.

3
00:00:15.990 --> 00:00:18.000
Adam Riess: Hello out there. Wherever you are.

4
00:00:18.210 --> 00:00:29.520
Adam Riess: And so I'm going to tell you about recent efforts to measure
the expansion rate of the universe, also known as the Hubble constant and
how they have been regularly.

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00:00:30.840 --> 00:00:43.680
Adam Riess: Coming out higher than then you might have expected. So this
is a work from the shoes team that I'm going to be mostly talking about
and a couple of review articles or recent articles in the lower left
there.

6
00:00:44.880 --> 00:00:54.240
Adam Riess: When a backup quite a bit and provide some sort of context
and background sort of at a colloquium level before getting into the

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00:00:54.660 --> 00:01:05.580
Adam Riess: Most recent measurements. So one of the only ways we have of
learning about the composition age and fate of the universe is by
watching it expand around us.

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00:01:06.330 --> 00:01:12.870
Adam Riess: We know the universe to be homogeneous and isotopic on large
scales that's even through observations.

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00:01:13.620 --> 00:01:28.080
Adam Riess: And that combined with general relativity allows us to derive
what is essentially the equation emotion for the universe, how the scale
factor A, the size of the grid that you see in my expansion. Let me get
that thing to expand again.

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00:01:29.100 --> 00:01:36.180
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Adam Riess: How, how that grid size a changes with time. That's what the expansion is and that that equation.

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00:01:36.480 --> 00:01:45.900
Adam Riess: Is the freedmen equation in the lower right there to differential equation that describes how he changes with time. That's the kinematic behavior of the universe.

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00:01:46.260 --> 00:01:57.000
Adam Riess: On the left hand side of the equation on the right hand side is all the physics of the universe. The mostly sources of gravity, whether it's a matter or energy

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00:01:57.600 --> 00:02:07.860
Adam Riess: But also curvature because of the complex geometry that the universe could have and we would like to measure a of t and learn about the right hand side of the equation.

14
00:02:08.310 --> 00:02:13.260
Adam Riess: We can't directly observed a but we can observe redshift, which is just the inverse

15
00:02:13.830 --> 00:02:27.750
Adam Riess: We can't directly observed time in the universe, but we can measure distances and through the speed of light, we can relate distances to time. So in the observers frame. Therefore, we measure redshift and distance to learn about a of t.

16
00:02:28.320 --> 00:02:44.550
Adam Riess: And universe. Now, many years ago when we thought the only important term on the right hand side was the mass density of the Universe then cosmology was simple, because the first two derivatives of A would tell you pretty much what you needed to know.

17
00:02:45.390 --> 00:02:52.290
Adam Riess: The first derivative a.is what we call the Hubble constant, the rate at which the universe expands today.

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00:02:52.770 --> 00:03:05.070
Adam Riess: It sets the size scale and aid scale for the universe, because you know you can show up at any time in history of the universe. And so it would have to be that this number is actually telling you about the present context.

19
00:03:06.330 --> 00:03:16.590

Adam Riess: The second derivative of A is the deceleration parameter and in a matter dominated universe, the amount of deceleration relates very simply to the mass density of the Universe.

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00:03:16.920 --> 00:03:25.050
Adam Riess: Which then relates to the ultimate fate of the universe, whether the universe will expand forever if omega matter is less than one.

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00:03:25.770 --> 00:03:34.440
Adam Riess: Or if the universe will stop expanding if omega matter is greater than one and start collapsing. And so in

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00:03:35.190 --> 00:03:47.760
Adam Riess: For decades, really astronomers cosmologist wanted to measure these quantities, but the 1990s and into 2000s was really a unique time to make these measurements, because

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00:03:48.180 --> 00:03:54.630
Adam Riess: It's when we first developed very precise long range distance indicators, what I call standard candles.

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00:03:55.260 --> 00:04:06.570
Adam Riess: Throughout the stock to make the kinds of measurements to quantify these numbers. So a few words about standard candles standard candle is really any object that

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00:04:07.290 --> 00:04:14.490
Adam Riess: You can standardize or understand its luminosity, to be able to measure its distance from its brightness.

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00:04:15.150 --> 00:04:24.780
Adam Riess: And I'm going to talk about two of what I think are the best long range distance indicator standard candles that we have today. The Type one A supernovae, these are

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00:04:25.650 --> 00:04:30.330
Adam Riess: A white dwarf stars which reach the Chandra sake car limit either probably

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00:04:31.020 --> 00:04:38.700
Adam Riess: Through transfer of mass from a binary and when they explode. They give us a very uniform explosion. About a billion souls luminosity.

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00:04:39.210 --> 00:04:44.250
Adam Riess: I'm going to talk about another kind of star to less luminous than type when a supernovae, but more common.

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00:04:44.640 --> 00:04:58.290
Adam Riess: These are Cepheids variables. These are super giant stars which are pulsating there's an instability in their atmosphere which causes them to constantly overshoot the condition of hydrostatic equilibrium

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00:04:58.710 --> 00:05:13.440
Adam Riess: And the period of that oscillation relates to the density and the mass of the star, which then relates very closely to its luminosity. This is empirically determined, but it's well understood from theory.

32
00:05:13.710 --> 00:05:26.790
Adam Riess: And this gives you a standard candle. That's about 100,000 solar luminosity. So, in both cases very luminous, we can see them very far away that makes them great long range distance indicators in practice there can be complexities

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00:05:28.230 --> 00:05:36.300
Adam Riess: Not all type when a supernovae have exactly the same luminosity, but there are empirical relations which have been measured

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00:05:37.380 --> 00:05:40.890
Adam Riess: to standardize their luminosity relating

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00:05:42.030 --> 00:05:51.480
Adam Riess: To empirical information. Basically, the rate at which the explosion to KS correlates very well with the luminosity sometimes

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00:05:52.440 --> 00:06:06.210
Adam Riess: There is dust in galaxies that host these kinds of objects and so generally that dust, not just dims but also change the colors in a known way. And so we can

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00:06:07.200 --> 00:06:13.050
Adam Riess: Calculate and correct for the amount of dust by measuring the colors of these objects.

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00:06:13.800 --> 00:06:22.230
Adam Riess: So by the mid 1990s, it became possible to measure the expansion rate of the universe that that helpful diagram distance versus

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00:06:22.710 --> 00:06:33.570
Adam Riess: Redshift relation using the Type one A supernovae, the points in green are from the first big survey in the South Dakota. Lolo survey, which is a very important survey.

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00:06:34.770 --> 00:06:42.630
Adam Riess: And in the north for my thesis and I collected about 20 of these type one A supernovae, and so

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00:06:43.080 --> 00:06:54.030
Adam Riess: Between the use of the supernovae. The advent of CDs, the use of the light curve shape luminosity correlations and the dust color.

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00:06:54.450 --> 00:06:59.370
Adam Riess: Correlations it was possible to derive distances that were good to about 6%

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00:07:00.030 --> 00:07:07.590
Adam Riess: However, in order to measure the Hubble constant, one needs not just a relative distance, but an absolute distance that is

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00:07:07.860 --> 00:07:16.200
Adam Riess: You really need to run a tape measure out to a type one, a supernova that's obviously hard to do. I will say more about that later in the talk.

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00:07:16.770 --> 00:07:24.900
Adam Riess: But just understand that the effort to do this lagged behind the ability just to measure relative distances from relative brightness.

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00:07:25.650 --> 00:07:40.560
Adam Riess: And so in order to measure Q, not the deceleration parameter one simply needs to measure to hire redshift or greater look back times greater distances to be able to see that second derivative, the change in the expansion rate.

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00:07:40.980 --> 00:07:49.800
Adam Riess: This, of course, was done by two teams famously 1998 and they found looking at high redshift supernovae compared to nearby ones.

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00:07:50.070 --> 00:08:01.350
Adam Riess: That the deceleration parameter itself was negative. That is the universe is accelerating distant supernovae are fainter than you would have expected were it not for that.

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00:08:02.370 --> 00:08:16.350
Adam Riess: Phenomenon. And this was quite remarkable. However, at the time, astronomers worried that a prep somehow distant supernovae were just intrinsically dimmer. Are there was some dust.

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00:08:17.010 --> 00:08:33.120
Adam Riess: In front of them grey das perhaps that we hadn't accounted for. And so over the next few years. Oops, sorry, I didn't want to jump that far, it became important to measure up to even higher redshift to distinguish between some kind of dimming and

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00:08:34.020 --> 00:08:47.550
Adam Riess: What would instead be the earlier deceleration of the expansion, because when the universe is younger, it's more compact and therefore matter even if there is

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00:08:48.600 --> 00:08:53.160
Adam Riess: A small amount of it now, would have been dominant in the past and cause that deceleration.

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00:08:53.640 --> 00:09:00.240
Adam Riess: So over the next decade or two many more supernovae were collected by various teams from the ground.

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00:09:00.510 --> 00:09:13.980
Adam Riess: As well as using the Hubble Space Telescope at higher redshift, and indeed the original signal held up very well, including evidence of this turnover. That is indicative of a mixed dark matter, dark energy universe.

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00:09:14.370 --> 00:09:25.170
Adam Riess: Of course, at the same time, there were many measurements from the cosmic microwave background Barry on acoustic oscillations and other tools so that this became very well established and so

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00:09:25.500 --> 00:09:36.330
Adam Riess: Here we are, some 20 years later after that initial discovery, the latest, greatest sample of supernovae is the the Pantheon sample from Dance Coleman, who was a graduate student of mine.

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00:09:37.320 --> 00:09:47.220
Adam Riess: And you could see the constraints in the Omega matter omega lambda space say very well inside the original Discovery Data the evidence for dark energy now.

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00:09:47.580 --> 00:09:55.560
Adam Riess: Is just from supernovae alone is probably about six sigma. But the evidence becomes much, much stronger when you include the other probes.

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00:09:56.310 --> 00:10:04.710
Adam Riess: So of course, and I think you've been talking about this a little bit in this summer school this really raises the question, why is it that the universe is accelerating.

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00:10:05.130 --> 00:10:15.990
Adam Riess: We don't know. But we've broken the problem until a much more sort of empirical way of looking at it is to look at what is the equation of state of dark energy, the ratio of

61
00:10:16.260 --> 00:10:33.270
Adam Riess: Pressure to energy density that would cause the acceleration and so possibility. Number one is that we have a vacuum energy aka the cosmological constant. This is a feature of quantum mechanics. And yet, in general relativity produces repulsive gravity.

62
00:10:34.410 --> 00:10:47.190
Adam Riess: The test for this is to see if the equation status minus one at all times. It could be. We have a dynamical dark energy. So here, the energy is not vacuum energy so much as the potential energy of a scale or field.

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00:10:47.970 --> 00:10:56.130
Adam Riess: If that were the case, you would expect that scale our field to be changing and time and space so that you might not see the equation or state being minus one.

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00:10:56.790 --> 00:11:08.550
Adam Riess: We have sort of existence proofs for both of these possibilities in the Higgs field which is more like a static energy and inflation, which we believe happened, and we believe

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00:11:09.660 --> 00:11:19.380
Adam Riess: Was due to a scale or field. The third possibility, being a modification to general Timmy, particularly on large scales. So how do we proceed.

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00:11:20.160 --> 00:11:29.430

Adam Riess: Besides measuring the equation and state, one of the most powerful ways forward really is to assume option one because it's the easiest to calculate

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00:11:29.790 --> 00:11:40.260
Adam Riess: And then look forward departures from that. And so I'm going to tell you about what is sort of maybe the grandest a test of lambda cm, which is to

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00:11:40.620 --> 00:11:47.400
Adam Riess: Go from end to end in the universe predicting the expansion rate of the universe today and measuring it so

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00:11:48.000 --> 00:12:01.680
Adam Riess: With this new standard model of cosmology vanilla lambda CDN. There are six parameters and a number of our thoughts and so what we generally do is, although we don't

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00:12:02.220 --> 00:12:12.330
Adam Riess: Understand the nature really well of dark matter or dark energy. What we do is we assume they take the most vanilla forums so dark matter, we assume it's

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00:12:13.740 --> 00:12:25.410
Adam Riess: Collision less doesn't decay. So it's perfectly stable perfectly cold for dark energy, we assume it's a cosmological constant. And then we take the the

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00:12:26.010 --> 00:12:30.540
Adam Riess: Cosmological Model, as it would have looked at Richard throw up 1000. So what you see here in the upper left.

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00:12:30.810 --> 00:12:40.230
Adam Riess: And we use that model to predict the physical size of fluctuations in the plasma of the early universe. The foremost of these is the Sound Horizon, the distance

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00:12:40.950 --> 00:12:47.040
Adam Riess: That a fluctuation can travel from the big bang until the universe becomes transparent.

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00:12:47.550 --> 00:12:57.300
Adam Riess: That sets of characteristics size of the fluctuations, but also for example the berry on density is something you can calculate from the model. We then compare the

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00:12:57.840 --> 00:13:10.650
Adam Riess: Predicted size of the fluctuations, or that whole power spectrum of fluctuations to the actual observations of it on the Angular scales from the cosmic microwave background and in that comparison.

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00:13:11.430 --> 00:13:18.690
Adam Riess: We actually then calibrate what those six free parameters ought to be. So at that point, the model is calibrated

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00:13:19.440 --> 00:13:28.110
Adam Riess: And then of course the model itself changes over time, or at least I should see the constituents of the universe change quite dramatically their densities.

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00:13:28.500 --> 00:13:37.830
Adam Riess: To the present time, and we can use the model as calibrated at redshift of 1000 to predict the entire expansion history of the universe.

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00:13:38.220 --> 00:13:43.230
Adam Riess: There are some guardrails along the way. In this process, we can use a high redshift supernovae.

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00:13:43.560 --> 00:13:53.370
Adam Riess: And Barry on acoustic oscillations, just to check some aspects of the model. But what we don't know is whether we have the right calibration overall of the model and so

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00:13:53.640 --> 00:14:07.860
Adam Riess: The model using the cosmic ray background then predicts the Hubble constant, the expansion rate of the universe today to be 67.4 plus or minus point five. So that's a very precise prediction.

83
00:14:08.880 --> 00:14:19.110
Adam Riess: You know, to better than 1% and so powerful and and test them this whole story of the cosmological model is to measure the expansion rate directly today.

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00:14:19.980 --> 00:14:23.910
Adam Riess: And so that's what I'm going to talk about in the rest of this talk.

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00:14:24.570 --> 00:14:31.350

Adam Riess: We started a project about 15 years ago called The shoes project to try to do that to improve upon measurements.

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00:14:31.740 --> 00:14:37.380
Adam Riess: Of the Hubble constant and the way we plan to do that is if you recall earlier I talked about the use of

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00:14:37.860 --> 00:14:47.730
Adam Riess: Type one a supernova dimension. The expansionary of the universe. And I said, you know, if you want to actually measure the Hubble constant, you need to run a tape measure out to a type one, a supernova because

88
00:14:48.540 --> 00:14:56.070
Adam Riess: To measure the Hubble constant you need absolute distances, not just relative distances. So we began building a distance ladder.

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00:14:57.270 --> 00:15:07.110
Adam Riess: To run that tape measure out to supernovae, starting with geometry that is a tape measure, but then out to some intermediate stars Cepheids variables and then type when a supernovae.

90
00:15:07.740 --> 00:15:13.440
Adam Riess: You can't go directly with geometry to supernovae, because they're too far away for any of our geometric methods.

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00:15:14.190 --> 00:15:24.840
Adam Riess: And so we saw ways to reduce systematic errors by collecting the data in a way that was more consistent. I'll talk about that. And by observing in the near infrared

92
00:15:25.500 --> 00:15:35.940
Adam Riess: We saw ways to keep track of systematic errors in a way that was more complete than past measurements. And so this project is now gone for

93
00:15:37.350 --> 00:15:52.350
Adam Riess: 17 cycles of the Hubble Space Telescope. So as I said about 15 or 16 years has been granted about 1000 orbits. Overall, which is probably makes it the biggest project in the history of the Hubble Space Telescope.

94
00:15:53.910 --> 00:16:01.110

Adam Riess: Okay, so let me tell you a little bit about distance ladders, in principle, they're great, because they are simple and they're totally empirical

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00:16:01.740 --> 00:16:12.090
Adam Riess: So what do I mean by that. Well, we usually start out at there's really three steps. Step one is I said we run a tape measure out too well, we'd like to run a tape measure out to Cepheids

96
00:16:12.660 --> 00:16:21.720
Adam Riess: These are the pulsating stars that we've seen most galaxies, including our own. And in this case, that might be parallax to measure the geometric parallax of a separate

97
00:16:22.110 --> 00:16:28.410
Adam Riess: And that's usually done on scales of killer parsecs are mega parsecs either inside our galaxy or galaxy in your body.

98
00:16:29.010 --> 00:16:38.220
Adam Riess: And then we look at more distant galaxies maybe 10 to 40 mega parsecs away where which hosted type one A supernovae recently.

99
00:16:38.850 --> 00:16:48.150
Adam Riess: And we use the Hubble Space Telescope to find Sethi and variables in those galaxies, the redshift of those galaxies does not enter the problem at all. It is just the fact that

100
00:16:48.870 --> 00:16:54.270
Adam Riess: The supernovae and Cepheids are assumed to be Co located in a galaxy and so therefore

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00:16:54.780 --> 00:17:09.780
Adam Riess: They're at the same distance. And then finally, in step three type when I supernovae are seeing out into the expanding universe. And that's where we relate their distances to their wretches to measure the expansion rate of the universe. So a couple of notes.

102
00:17:10.830 --> 00:17:18.330
Adam Riess: Distance ladders do not make use of astrophysical modeling. This is totally empirical, they don't really make use of general relativity

103
00:17:19.530 --> 00:17:37.170
Adam Riess: And they don't use the cosmological model. This is all, as I said, geometric and empirical to measure the expansion rate of the

universe. However, a good measure and practices are critical. And probably the most important thing of all is that there are

104
00:17:38.370 --> 00:17:48.780
Adam Riess: Two sets of observations of the same kind of object in a distance ladder. For example, Cepheids near in an intermediate distances or 20 supernovae and intermediate in faraway distances.

105
00:17:49.050 --> 00:17:58.710
Adam Riess: And it's critical that the measurements and the objects themselves are the same. Otherwise, you know, you've broken the idea of a simple empirical measurement

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00:17:59.550 --> 00:18:08.370
Adam Riess: Okay, so let me say a few words about the first step. The first step would be, for example, measuring parallax in the Milky Way to separate variables.

107
00:18:09.180 --> 00:18:23.850
Adam Riess: In principle, this is straightforward. In practice, it's hard because Sophia variables are killing parsecs away, meaning that the parallax angles are Millie arcseconds fractions of a milli second or in other words

108
00:18:25.170 --> 00:18:29.790
Adam Riess: For a second variable that's a few killer parsecs away. That would be typical

109
00:18:30.240 --> 00:18:41.490
Adam Riess: The annual motion of that second variable due to the motion of the Earth around the sun. That's what we're measuring and parallax is about one 100th of a pixel. That's a very small

110
00:18:42.180 --> 00:18:50.430
Adam Riess: Thing to measure the problem comes down to really being able to measure the centroid of that star relative to other stars.

111
00:18:50.760 --> 00:18:57.660
Adam Riess: Let's say now. And six months later to measure the parallax. When we can only centroid a star to a hundredth of a pixel

112
00:18:58.140 --> 00:19:11.550
Adam Riess: We developed a workaround. A number of years ago, and that was to spatially scan the telescope. This allows us to turn those points that are hard to centroid into lines where we can get many measurements.

113
00:19:11.850 --> 00:19:21.600
Adam Riess: Of the separation of stars thousands of them. So we literally let the telescopes scan and obtain a scanned images like you see.

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00:19:22.260 --> 00:19:30.450
Adam Riess: There's a little patch of one of those images, there's a great deal of information in the scanned images and particularly as it relates to the separation of stars.

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00:19:31.020 --> 00:19:44.790
Adam Riess: We then extract those scan lines one by one and align them in time. The first thing we're able to see is that there's Jupiter in the telescope, but the Jupiter is removed when we compare the separation between any two stars.

116
00:19:45.210 --> 00:19:57.600
Adam Riess: And so, what we get is a very clean measurement of the separation of stars that gets us to a precision of about 20 to 40 micro arcseconds that's about one 1,000th of a pixel on the Hubble Space Telescope.

117
00:19:58.410 --> 00:20:10.770
Adam Riess: And then over the course of four years, we observed the back and forth motion of the selfie variables as you see here I subtracted off the drifting motion. And so what you see is just the parallax.

118
00:20:11.220 --> 00:20:23.370
Adam Riess: The amplitude of each of these zigzagging curves is the parallax. The inverse of that, of course, is the distance. And so we measured the mean luminosity of a set of these to about 3%

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00:20:24.000 --> 00:20:43.560
Adam Riess: Meanwhile, there's a telescope. Another telescope in space called Gaia, which is a European mission that's been measuring the paradoxes of thousands know millions of stars and we picked out 50 Cepheids from that's from those measurements as well, which we were tired of the Hubble using

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00:20:44.610 --> 00:20:53.910
Adam Riess: More of the spatial scan observations, but this time dimension, the brightness of the stars. And so, this gave us another independent 3% calibration.

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00:20:54.270 --> 00:21:01.710

Adam Riess: Of the luminosity subset few variables. And then on top of a pre existing calibration by parallax.

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00:21:02.310 --> 00:21:16.530
Adam Riess: Of the Illuminati is of separate. So here's three flavors of the Sethi and variables using us now empirically to relate the period of the oscillation of these pulsating stars to their luminosity.

123
00:21:17.220 --> 00:21:25.530
Adam Riess: But now measured over a wide range of periods, the same range of the separate variables we see in distant galaxies.

124
00:21:25.830 --> 00:21:33.090
Adam Riess: When Gaia reaches its final precision, we expect this step to be good to about 0.4% and the Hubble constant

125
00:21:33.480 --> 00:21:46.140
Adam Riess: So parallax is just one way to run a tape measure out to separate variables to calibrate their luminosity geometrically. There are two other methods which have been commonly used recently.

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00:21:46.680 --> 00:21:59.490
Adam Riess: Besides parallax. One of those is called detached Eclipsing binaries you observe a star orbiting another star you measure the time between the eclipses.

127
00:21:59.850 --> 00:22:16.350
Adam Riess: And you measure the radio velocity of the stars and the Doppler effect that gives you a measurement of the physical size of the star and you measure the angular size with through a relationship between temperature

128
00:22:17.220 --> 00:22:27.150
Adam Riess: And brightness and angular size of the star that's been calibrated through interferometry, and this gives you a geometric distance measurement

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00:22:27.810 --> 00:22:42.720
Adam Riess: To some nearby galaxies that hosts Cepheids another well known method is to measure the capillary and motion of water clouds through radio observations of their amazing a mission meters.

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00:22:43.680 --> 00:22:55.890

Adam Riess: In order to geometrically measure the distance and this has been done exquisitely wealth to one nearby galaxy in particular NGC 40 to 58 which also hosts many Sofia various

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00:22:56.700 --> 00:23:03.150
Adam Riess: Okay, so that's step one. We have many ways to measure geometrically, the distance to Cepheids. Step two.

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00:23:03.390 --> 00:23:14.070
Adam Riess: Is to look for nearby galaxies which recently hosted a type one, a supernova, like you see here, and then go back with the Hubble Space Telescope years later and look for separate variables.

133
00:23:14.340 --> 00:23:24.810
Adam Riess: Now I told you earlier in the talk. Each type when a supernova is good to about 6% in distance. So this is really the rate limiting step for measuring the Hubble constant is that 6%

134
00:23:25.170 --> 00:23:43.170
Adam Riess: over square root of n, the number of galaxies to what you can do this. And in the past. This has been done mostly by our team to about 19 galaxies nearby and we expect to exhaust the possible sample which is limited in distance to see the Cepheids

135
00:23:44.340 --> 00:23:55.680
Adam Riess: To a sample of about 38 so about a doubling of a sample that we expect to come out later this year or hopefully sometime in around six months or so.

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00:23:56.430 --> 00:24:08.760
Adam Riess: And these supernovae are just like the ones a little bit further out as we measured and to our found and measured in these nearby galaxies.

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00:24:09.630 --> 00:24:19.860
Adam Riess: Here are the period luminosity relationships of the safety of variables in these hosts galaxies that are using to measure the distance

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00:24:20.160 --> 00:24:33.420
Adam Riess: To the Type one A supernovae to calibrate their luminosity, as well as what I call the anchor galaxies, the galaxies, whose geometric distance has been measured by the techniques that I described earlier in the talk.

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00:24:34.800 --> 00:24:42.090

Adam Riess: Okay, so one of the ways we've been able to reduce systematic errors and really make this, I think, a very precise physics measurement

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00:24:42.330 --> 00:24:55.950
Adam Riess: Is by using the same telescope to measure the separate variables in the two locations on the distance ladder, both in the geometric anchor and in the type one, a supernova hosts. This allows us to cancel out.

141
00:24:56.700 --> 00:25:12.060
Adam Riess: Questions of absolute calibration of the flux of the telescope itself and fact we try to match all the properties of the samples of Cepheids so that there's really no lever arm to speak of for systematic errors.

142
00:25:13.380 --> 00:25:26.850
Adam Riess: And we make our observations in the near infrared because Cepheids are better distance indicators in the near infrared because the issue of dust becomes even less even quite negligible dust passes.

143
00:25:27.780 --> 00:25:34.980
Adam Riess: Sorry infrared near infrared light passes very easily through dust because of the physical size of dust grains being what they are.

144
00:25:35.340 --> 00:25:44.010
Adam Riess: And so you see this example in the Large Magellanic Cloud. This is the relationship between period and luminosity for some 70

145
00:25:44.670 --> 00:25:52.650
Adam Riess: Cepheids in the Large Magellanic Cloud and down below you see in the optical the scatter can be quite large, because of dust clouds.

146
00:25:52.980 --> 00:26:04.800
Adam Riess: In the large mental and a cloud, but by the time you get to the near infrared you're seeing through the desk very easily. And so you get these very tight relationships. And so we do our work in the near infrared for that reason.

147
00:26:05.340 --> 00:26:16.260
Adam Riess: Step three is similar to what I showed you before, which is just to measure the intercept of the Hubble Diagram, that is, you're measuring any characteristic brightness.

148
00:26:16.710 --> 00:26:22.470

Adam Riess: What the redshift is or a characteristic redshift what the brightness is of a type one, a supernova to determine

149
00:26:22.950 --> 00:26:34.020
Adam Riess: The intercept of the Hubble Diagram. And then finally, you do all of these steps simultaneously in a multi linear regression. We have a set of measurements we have a regression matrix.

150
00:26:35.070 --> 00:26:40.530
Adam Riess: free parameters which are really just empirical correlations and from this, you end up driving

151
00:26:41.580 --> 00:26:52.080
Adam Riess: Really two numbers, which is the absolute luminosity of a type when a supernova, and the intercept of the Hubble Diagram of type on a supernovae, which together relate directly to the Hubble constant

152
00:26:53.430 --> 00:27:08.610
Adam Riess: And you can take a look if you want to follow in more detail. The steps in the papers that I referenced in the very first slide. So what do we get or what does the data look like it more or less looks like this. These are the three steps that I talked about shown in three nested

153
00:27:09.930 --> 00:27:21.090
Adam Riess: Distance versus distance diagrams. So step one, as I said, we use geometry on the x axis to calibrate Cepheids and you can see the very good agreement between those

154
00:27:22.500 --> 00:27:38.340
Adam Riess: And then in step two. In 19 galaxies are there have been times when a supernovae, we observed Cepheids so the Cepheids now calibrated on the x axis here calibrate the type on a supernovae, and then hundreds of type one A supernovae in the Hubble expansion.

155
00:27:39.720 --> 00:27:55.260
Adam Riess: Are us then to relate their distances to register to determine the Hubble constant and best result we get today is 73 and a half plus or minus 1.4 including systematics so that's a total uncertainty of 1.9%

156
00:27:56.280 --> 00:28:03.060
Adam Riess: If you remember back from earlier in this talk. This number might seem different to you than the number predicted

157
00:28:03.570 --> 00:28:18.360

Adam Riess: Using the cosmic microwave background to calibrate lambda c d m and then using lambda CDN to predict the expansion rate today. And that is true. They, they differ by about 4.2 sigma. So, this is what is known as the Hubble tension that

158
00:28:19.230 --> 00:28:23.220
Adam Riess: Was the subject of this talk. So like any

159
00:28:23.910 --> 00:28:36.630
Adam Riess: Time you see something that is a mess. You want to dig in and look at a breakdown of where the amiss rises or how robust. The result is. And so what I broken out are the seven different

160
00:28:37.050 --> 00:28:43.650
Adam Riess: Sources of geometric calibration of the luminosity of the seven variables, basically. Step one.

161
00:28:44.370 --> 00:28:57.930
Adam Riess: In seven independent measures. So there were the majors in NC 40 to 58 method. The detached Eclipsing binaries in the Large Magellanic Cloud and now there are five flavors of parallax measurements.

162
00:28:58.380 --> 00:29:07.650
Adam Riess: The historic one one my team did scanning the Hubble Space Telescope and three different ones that have come from the European space satellite Gaya

163
00:29:08.310 --> 00:29:21.720
Adam Riess: These range from, you know, 72 to 76. But you see, this is not the source of the discrepancy nothing moves you down in the really into the territory of what

164
00:29:22.320 --> 00:29:35.910
Adam Riess: The early universe is predicting and these results themselves. When you look at their individual on certain. These are all consistent at about the two sigma or better level which is not, you know, unusual given seven different measurements.

165
00:29:37.410 --> 00:29:45.150
Adam Riess: Now the discrepancy itself the tension can be seen as a 20% or two tenths of a magnitude and astronomer units.

166
00:29:46.320 --> 00:29:58.680

Adam Riess: Difference in the brightness of any of these kinds of objects. And so we looked at lots of systematic uncertainties lots of things you could vary in the analysis, you could vary some

167
00:29:59.070 --> 00:30:08.700
Adam Riess: Assumptions about the nature of the dust in other galaxies, whether it is like the Milky Way dust or it's some kind of different dust that doesn't affect things very much

168
00:30:09.060 --> 00:30:21.030
Adam Riess: You could change the way you fit the second period luminosity relationship, whether it's a single linear relationship or two linear relationships or whether you cut it off at short periods or at long periods.

169
00:30:21.390 --> 00:30:26.130
Adam Riess: How you fit supernova like curves where you start the Hubble Flow which kinds of galaxies.

170
00:30:26.670 --> 00:30:37.590
Adam Riess: You will allow into your sample for host of type when you supernovae, none of these things really very the answer very much. And that's particularly because we've made such an effort to match.

171
00:30:38.100 --> 00:30:46.950
Adam Riess: The measurements at the two different rungs on the distance ladder, and I would say it's fair to say nobody has found yet a way to analyze this data.

172
00:30:47.400 --> 00:30:53.130
Adam Riess: To bring it in accordance with the early universe of questions. I'm frequently asked

173
00:30:53.700 --> 00:31:01.980
Adam Riess: If I thought I would just give me answers to them right off the top. Could it be that we live in a giant void and so that the expansion rate of the universe locally.

174
00:31:02.340 --> 00:31:11.310
Adam Riess: Is different than you would have expected cosmetically. Well, unfortunately, this has to be an enormous void. And I don't mean just in physical size, although that true, but in depth.

175
00:31:11.580 --> 00:31:20.280

Adam Riess: So you have to basically increase the local expansion rate by 9% whereas theory tells us to expect fluctuations due to large scale structure.

176
00:31:20.520 --> 00:31:28.170
Adam Riess: Of about 0.6% so that would make it like a 20 sigma fluctuation, plus we see no evidence for that when we actually look at the

177
00:31:29.130 --> 00:31:39.240
Adam Riess: Hubble Diagram type when a supernova going out very far, is our telescope a linear enough or is calibrated linear enough to really make this measurement. The answer is yes.

178
00:31:39.840 --> 00:31:51.090
Adam Riess: We we're trying to reach you 1% measurement. We're only a 2% now, but the linearity of the telescope has been calibrated to contribute a 0.3% uncertainty in this

179
00:31:52.020 --> 00:32:03.030
Adam Riess: Is there some effect crowding, for example of distance Cepheids that is compromising their accuracy, the answers. I would say no we published a paper. Earlier this year, showing

180
00:32:03.450 --> 00:32:12.300
Adam Riess: Independent effect of such speculated crowding, which is to change the amplitude of the variations of the Cepheids are

181
00:32:12.960 --> 00:32:18.690
Adam Riess: Are not there. In fact, we could rule out the the that level, or even a significant level of

182
00:32:19.650 --> 00:32:28.020
Adam Riess: Extra crowding, is there a difference in the supernovae themselves at the two ends of the distance ladder, and here I have to say no at the level of the tension.

183
00:32:28.530 --> 00:32:46.590
Adam Riess: There can be a residual correlations of order sort of 0.3% of the Hubble constant shown by a couple of papers. Recently, but it would be very difficult to make this as much as really one or 2% in the Hubble constant, let alone the full 9% that we see.

184
00:32:48.300 --> 00:33:03.510

Adam Riess: And new results. Continue to sort of increase the evidence of this. It's not just our measurements, but measurements from a whole host of other techniques I decided, actually I'm going to skip this slide because I wanted to jump ahead to showing you

185
00:33:04.830 --> 00:33:10.230
Adam Riess: This in another in a more graphical way. So let me just skip that for instance, and I'll get back there. So,

186
00:33:10.560 --> 00:33:18.540
Adam Riess: These measurements of the local Hubble content have been improving over the last 20 years from the Hubble Space Telescope, they were good to 10% from the

187
00:33:18.960 --> 00:33:29.070
Adam Riess: HST key project in 2001. This is the error budget, the various components of uncertainty and sort of by attacking each one of them in different iterations.

188
00:33:29.550 --> 00:33:39.930
Adam Riess: We've gotten down to the present 2% looking ahead in the next six months by doubling the sample and for the next data release from Gaia, we expect this to get even better.

189
00:33:40.440 --> 00:33:44.670
Adam Riess: Should you be surprised by the local result, I don't think so.

190
00:33:45.420 --> 00:33:50.760
Adam Riess: Over the last 20 years this approach of measuring selfie variables and type when a supernovae.

191
00:33:51.030 --> 00:33:59.700
Adam Riess: Is the most replicated by other teams. And why is that because the Cepheids are the longest range distance indicators short of the type one A supernovae.

192
00:33:59.970 --> 00:34:03.120
Adam Riess: And so the two together get you out the farthest

193
00:34:03.360 --> 00:34:16.680
Adam Riess: With the greatest precision in the fewest number of steps, while allowing you to make measurements in a very consistent way. And so for 20 years with different teams using different methods of the measurements are different data sets.

194
00:34:17.430 --> 00:34:24.810
Adam Riess: Different ways of analyzing the data using different instruments on the Hubble Space Telescope, you've seen consistently this

195
00:34:25.440 --> 00:34:40.110
Adam Riess: sort of set of values so that our latest value today, while the errors are smaller because there are more measurements and they are done with tighter systematics control they sit right in them really middle of where these measurements have been

196
00:34:41.400 --> 00:34:48.600
Adam Riess: Now how does this compare to other techniques for measuring the expansion rate of the universe. There was a conference last year at Kitt

197
00:34:48.960 --> 00:35:00.750
Adam Riess: And Santa Barbara where proponents of various methods came together to discuss these there are 20 supernova distance ladders that use separate variables. Those are the ones I talked about

198
00:35:01.620 --> 00:35:06.870
Adam Riess: There's two other kinds of stars that have been used in the same role as separate variables there less luminous

199
00:35:07.470 --> 00:35:17.580
Adam Riess: But, and they sort of less established, I would say very interesting Myra variables and the tip of the red giant branch calibrated in different ways.

200
00:35:18.270 --> 00:35:28.620
Adam Riess: Or lensing and alternative to type when I supernovae is a technique called surface brightness fluctuations, which involves measuring how smooth or lumpy.

201
00:35:29.400 --> 00:35:36.570
Adam Riess: The fluctuation in surface brightness of a galaxy is this is a statistical effect that allows you to measure the distance

202
00:35:37.110 --> 00:35:49.050
Adam Riess: To those galaxies and then single wrong techniques where you're not building a ladder at all. You're going all the way I did one step. This has been done with strong lensing from the holy cow team, and more recently.

203
00:35:49.500 --> 00:36:03.750
Adam Riess: Majors directly into the Hubble Flow from the maser cosmology project. And when you average these results or even if you don't average them, it's quite clear that these are sitting consistently between around 70 to 75

204
00:36:05.040 --> 00:36:19.530
Adam Riess: You can form an average. But you have to be careful not to use a double use any data. And so you can take one thing from Category one, a type one, a supernova distance ladder one from category to Category three and four.

205
00:36:20.010 --> 00:36:31.080
Adam Riess: And still have room for a peremptory challenge. One thing you can just decide to throw away because you know everybody doesn't like some kind of data or some kind of method I that seems entirely reasonable

206
00:36:31.470 --> 00:36:39.660
Adam Riess: So these are these various combinations with peremptory challenges. So you can do it without type 20 supernovae without lensing.

207
00:36:40.140 --> 00:36:46.680
Adam Riess: Without surface brightness fluctuations. You can only use Cepheids for distance ladder or my arrows or tip of the red giant branch.

208
00:36:46.950 --> 00:36:54.810
Adam Riess: The values change around a little bit, but they don't get you a lot closer to the ones from the early universe. So this is the the most precise from plank.

209
00:36:55.560 --> 00:37:05.790
Adam Riess: But other cosmic microwave background data sets, combined with Barry on acoustic oscillations because barren acoustic oscillations are essentially

210
00:37:06.090 --> 00:37:13.560
Adam Riess: The fluctuations in the cosmic microwave background seen in galaxy surveys, but they need to be calibrated from the cosmic microwave background.

211
00:37:14.160 --> 00:37:24.000
Adam Riess: Those all give you a much lower value for the Hubble constant. And so this really is putting a finer point on this Hubble tension that I talked about.

212
00:37:24.510 --> 00:37:33.480
Adam Riess: This is a matrix of those combinations that you saw these are all the late universe ones versus the early universe. And when I say early universe. I mean,

213
00:37:33.690 --> 00:37:41.880
Adam Riess: Uses early universe version of lambda CDN to calibrate the phenomenon that you're observing so you can predict the value of the Hubble constant

214
00:37:42.420 --> 00:37:50.220
Adam Riess: These differ by anywhere from four to six units in the Hubble constant or in standard deviations anywhere from

215
00:37:51.180 --> 00:38:03.810
Adam Riess: Three to six and asked sigma i think the ones to focus on involve plank, because we have no reason to not use the most precise cosmic microwave background data set. And so here you can see that the differences really

216
00:38:04.680 --> 00:38:17.820
Adam Riess: Are somewhere between four and a half and 6.3 sigma and that depends on, as I said, which peremptory challenges you use. So if you don't like lensing. For instance, you'd be at about five sigma

217
00:38:18.870 --> 00:38:22.950
Adam Riess: Were the use of some of these other methods that I talked about here.

218
00:38:24.210 --> 00:38:33.570
Adam Riess: So what is causing this tension, I don't know, we, I don't think anybody really knows. It's a very interesting open problem right now.

219
00:38:34.140 --> 00:38:41.850
Adam Riess: You know, certainly. Anybody wouldn't normally think about systematic errors, but we've seen. I think enough independent indications of the same thing that

220
00:38:42.450 --> 00:38:50.700
Adam Riess: If you're going to suggest systematics, you know, you have to be extremely clever and I can't think of one that affects all these different measurements, but

221

00:38:51.000 --> 00:38:57.570
Adam Riess: I think we're getting hopefully we're getting past the point where people can just wave their arms and say oh systematics unknown unknowns.

222
00:38:57.990 --> 00:39:06.690
Adam Riess: Because you have to explain how those systematics can affect different kinds of experiments physics is hard to, I mean the most

223
00:39:07.110 --> 00:39:18.960
Adam Riess: The most fruitful approach has been to think about modifying the early universe. The, the cosmological model and early times I direct you to this recent review of efforts to do that. The Hubble hunters guide.

224
00:39:19.500 --> 00:39:28.050
Adam Riess: Many of these ways of modern modifying the early universe will mess up something else in the cosmic microwave background, which makes it a no go.

225
00:39:28.530 --> 00:39:40.020
Adam Riess: The most successful ideas I think have involved either injecting energy in the early universe or adding more radiation like degrees of freedom in the early universe to expand the universe faster.

226
00:39:40.560 --> 00:39:45.420
Adam Riess: Causing it to enter transparency earlier shrinking the Sound Horizon.

227
00:39:46.260 --> 00:39:53.820
Adam Riess: But it's tricky. As I said, without messing up something else in the cosmic microwave background. Another idea that I think looks interesting, is some kind of small scale.

228
00:39:54.330 --> 00:40:04.860
Adam Riess: Nonlinear in homogeneous cities in the berry on density before recombination people tried this with magnetic fields various things I'm far from an expert.

229
00:40:05.340 --> 00:40:21.540
Adam Riess: In these methods, but there is near a paper nearly every other day on the archive with an idea of how to do this. I would just simply say some ideas look more fruitful than others. None of them looks like the slam dunk far better than other ideas.

230

00:40:23.310 --> 00:40:30.600
Adam Riess: Meanwhile, it's worth keeping your eyes on another tension which seems to be a rising, which may or may not be related

231
00:40:31.050 --> 00:40:36.720
Adam Riess: Which is the sigma eight tension sigma eight is a parameter that describes the

232
00:40:37.470 --> 00:40:45.960
Adam Riess: Amount of matter fluctuation on a certain physical scale, of course, the universe is very smooth. In the beginning shortly after the Big Bang.

233
00:40:46.350 --> 00:40:59.760
Adam Riess: But the cosmological model once calibrated by the cosmic microwave background tells you how fluctuations will grow through gravity and therefore what the sigma eight or the the clumpiness of the universe to be today.

234
00:41:00.240 --> 00:41:04.080
Adam Riess: Like you saw with the hub attention. We can also measure it today.

235
00:41:04.500 --> 00:41:15.780
Adam Riess: That's been done either through lensing or peculiar velocity measurements. There are two studies in the last year that each deviated from the prediction by about three sigma independently.

236
00:41:16.470 --> 00:41:29.880
Adam Riess: And in the same direction. And in fact, you know, really. Another one or two from lensing that are not as strong as that but are a couple of sigma in the same direction. And so this is certainly something worth paying attention to.

237
00:41:31.050 --> 00:41:46.500
Adam Riess: You know, some people think the right idea. If there is one to explain these would solve both of them, some not, you know, it's, it's hard to say, but to important to keep on your radar screen. Um, I also encounter people who don't

238
00:41:47.520 --> 00:41:53.550
Adam Riess: Believe these tensions, simply because there's no explanation on and, you know, to my mind, that's a little backwards.

239
00:41:54.090 --> 00:42:00.150

Adam Riess: There have been many times in the history of science we have identified a phenomenon that was clearly interesting

240
00:42:00.990 --> 00:42:08.400
Adam Riess: But we didn't yet understand the why of it you know the procession of mercury. The Solar Neutrino problem. The missing Barry on a problem.

241
00:42:08.790 --> 00:42:15.780
Adam Riess: You know, even today's, you know, flat rotation curves and accelerating universe are observational phenomenon where they still

242
00:42:16.140 --> 00:42:27.420
Adam Riess: You know, a fairly weak physics explanation in terms of the real detail in the form of dark matter and dark energy. So I think it's important not to sweep these things under the rug, or to

243
00:42:28.500 --> 00:42:36.030
Adam Riess: You know, sort of disavow them because we don't know why yet. I think it's, you know, very important to pay attention.

244
00:42:36.810 --> 00:42:51.570
Adam Riess: So our part is to continue to improve the precision of the Hubble constant measurements. So we're hoping in the next few cycles with the Hubble Space Telescope. To do that, we're getting pretty good data so far, showing even more sexy variables. There they go.

245
00:42:53.220 --> 00:43:00.300
Adam Riess: And the next couple of waves of improvement. We're hoping to get to about 1.2% precision.

246
00:43:01.710 --> 00:43:10.680
Adam Riess: With the combination of more supernova Cepheids hosts and better Gaya data. There are other techniques that are starting to come of age, the use of gravitational waves.

247
00:43:11.160 --> 00:43:19.830
Adam Riess: From the Lego experiment to measure distances better characterization of the expansion history of the universe with new

248
00:43:20.880 --> 00:43:29.370
Adam Riess: Facilities like desi LS st W first and Euclid, you know, the better we characterize H AMP z the expansion history of the universe.

249

00:43:29.790 --> 00:43:36.240
Adam Riess: The cleaner, it will be to identify what, if anything, is the source of this tension.

250
00:43:36.840 --> 00:43:43.710
Adam Riess: And also next generation cosmic microwave background experiments might see some of the signatures. Some of the physics ideas.

251
00:43:44.010 --> 00:43:51.570
Adam Riess: That are proposed to explain the tension like early dark energy. So I would say, stay tuned to this measurements are hard.

252
00:43:52.200 --> 00:44:00.810
Adam Riess: But a lot of progress has been made, and we do sit here. Now with this interesting puzzle. So my final, final thoughts here.

253
00:44:01.710 --> 00:44:12.300
Adam Riess: I think the discrepancy at this point is around five sigma. You know, you could argue, I think, fairly it's anything as low as four or as high as six depending on which data combination you want to form.

254
00:44:13.110 --> 00:44:23.490
Adam Riess: A very simple way to say it is, I would say no late universe measurement. I've seen a credibility is lower than any early universe measurement of credibility. That's a simple statement of tension.

255
00:44:24.330 --> 00:44:35.460
Adam Riess: It appears to be robust that it requires multiple failures on experiments that seems unrelated to undo it. So that would be quite a

256
00:44:36.240 --> 00:44:43.350
Adam Riess: Bit of a conspiracy. If that uh, you know, was the case, but you know we pay attention to that. Of course, I think it's very interesting.

257
00:44:43.680 --> 00:44:53.460
Adam Riess: Unless you have a very strong Beijing prior that vanilla lambda CDN, as is. And as calibrated by the cosmic microwave background is mathematically correct

258
00:44:54.120 --> 00:45:07.650
Adam Riess: You know that not prior needs to be more than five sigma, because that's around the level of evidence of the tension or tensions. I don't know what is going on, I think, though, it's important to follow the evidence. And of course, at the same time.

259
00:45:08.760 --> 00:45:18.780
Adam Riess: Listen to the theory community as they wrestle with a possible explanations struggle with that. And, you know, never forget the universe might be more clever than we are now.

260
00:45:19.800 --> 00:45:38.850
Adam Riess: There's been times in the past, as I said, where an observational phenomenon was seen and it's taken us a long time to understand why. So I will end there with this cool cartoon that was in a symmetry magazine last year about this and happy to take any questions that you have.

261
00:45:41.400 --> 00:45:47.160
thomas rizzo: Great. That was great. Adam, thanks a lot. We're going to turn it over to rich and he'll just to throw some questions at you.

262
00:45:47.520 --> 00:45:47.910
Okay.

263
00:45:49.590 --> 00:45:57.870
Richard Partridge: Thank you. That was quite an impressive tour through this interesting problem.

264
00:45:59.160 --> 00:46:07.380
Richard Partridge: The first. So kind of number of questions here. The first question is what do reddening corrections mean

265
00:46:08.520 --> 00:46:18.900
Adam Riess: Yeah. So when we see when we look at standard candles in distant galaxies. There we have to assume there's some amount of dust between us.

266
00:46:19.230 --> 00:46:25.140
Adam Riess: And those standard candles. Usually we're worried just about the dust in the in the host galaxy because

267
00:46:25.650 --> 00:46:37.350
Adam Riess: The amount of dust in our galaxy has been well calibrated and so we look at the change in colors dust reddens the light of a standard candle and so reading correction is

268
00:46:37.770 --> 00:46:45.930

Adam Riess: Measuring the shift or change in the color relative to the mean and removing that. And so that's what a reading corrections.

269
00:46:47.010 --> 00:47:00.330
Richard Partridge: Okay. And the next question is, do we knew no I'm sorry. Do we know the luminosity versus time graph for supernova one days. How many years is there luminosity significant for

270
00:47:02.100 --> 00:47:06.660
Adam Riess: Oh, okay. So, um, so I think you're talking about actually in the explosion and show

271
00:47:07.350 --> 00:47:11.820
Adam Riess: Yes, there's a light curve that's the light history of the supernova. It takes about

272
00:47:12.000 --> 00:47:20.580
Adam Riess: Two and a half to three weeks from explosion to reach its peak luminosity usually depending on what distance. It's at astronomers can usually only see it.

273
00:47:21.540 --> 00:47:26.880
Adam Riess: Maybe a week or so before that peak luminosity, and then it decays four months.

274
00:47:27.180 --> 00:47:34.560
Adam Riess: Again, depending on the distance you might be able to see the decay for weeks or months, the nearby ones obviously much longer.

275
00:47:34.800 --> 00:47:42.090
Adam Riess: The faraway ones less most of the information we need to measure in the decay rate that correlates with the peak luminosity.

276
00:47:42.660 --> 00:47:55.140
Adam Riess: Is done by Beth three weeks. And so I would say, you know, kind of most of the information we get is a week before maximum to about three weeks after, of course, there's time dilation as well so

277
00:47:55.650 --> 00:48:08.880
Adam Riess: If it's a high redshift supernova that whole time that four week time frame is dilated or expanded by one plus z. And so it can be quite advantage when you're observing very distant supernovae that it extends the amount of time you have

278

00:48:10.860 --> 00:48:16.230
Richard Partridge: Thank you. The next question that we have from our participants is

279
00:48:17.430 --> 00:48:27.750
Richard Partridge: What's the difference between the relative and absolute distance since the Copernican principle says that our position in the universe isn't special could they be the same.

280
00:48:30.540 --> 00:48:40.140
Adam Riess: I'm, I'm not sure exactly what is meant by that. But I'll just say a you know a relative distance is to see that, you know,

281
00:48:40.860 --> 00:48:52.260
Adam Riess: One supernova Supernova A is four times fainter and supernova be of the same intrinsic type and so therefore you know that supernova as twice as far away as supernova be

282
00:48:52.590 --> 00:49:01.440
Adam Riess: At a relative statement and it can be useful, but that is different than putting an actual distance on it and say, not only that but supernova a is

283
00:49:01.740 --> 00:49:17.730
Adam Riess: 40 mega parsecs away and supernova be is 10 mega parsecs away. That's an absolute statement of distance still has the relative information in there, but often the relative information even without an absolute calibration is still very valuable.

284
00:49:19.440 --> 00:49:19.860
Richard Partridge: Okay.

285
00:49:21.240 --> 00:49:33.870
Richard Partridge: Next question is why hard astrophysical models. General relativity or lambda CPM needed now. If I would have assumed that I would need to take those into account over such large distances.

286
00:49:34.260 --> 00:49:40.770
Adam Riess: Because the distances are not large when we measure the expansion rate of the universe. We can do it extremely locally.

287
00:49:41.490 --> 00:49:49.920
Adam Riess: You know, really effectively the redshift mean redshift. I would say we're going to when we make those measurements is about point oh five.

288
00:49:50.760 --> 00:50:06.540
Adam Riess: And so it's very local. And so that's why I said you know john relativistic affects the cause module model is very small effect, you know, less than a percent. And it's because we're staying very local to make those measurements.

289
00:50:09.720 --> 00:50:12.900
Richard Partridge: The next question we have is, for parallel

290
00:50:13.920 --> 00:50:16.440
Richard Partridge: For parallax. Sorry.

291
00:50:16.800 --> 00:50:24.330
Richard Partridge: Apparently, how can we be sure that we've gotten the central have a star, especially when the stars around. It may also be

292
00:50:26.190 --> 00:50:28.770
Adam Riess: Especially when the stars around. It may also be moving

293
00:50:29.040 --> 00:50:29.970
Adam Riess: Right. Yes.

294
00:50:30.210 --> 00:50:31.470
Richard Partridge: Require binary or so.

295
00:50:31.530 --> 00:50:36.990
Adam Riess: That's correct. That's correct. So that's what we call an astro metric binary and that can certainly mess up the measurements.

296
00:50:37.680 --> 00:50:51.060
Adam Riess: So the sort of the best thing to do is measure over many years. And so you see if you can decompose emotion into simply a drifting motion, what we call proper motion and parallax. And you see no residuals, then you know

297
00:50:51.900 --> 00:51:04.290
Adam Riess: That it's not an astro metric binary. If, on the other hand, you see residuals and astronomers try to fit a an orbit or another component to that many astral metrics binaries have

298
00:51:04.890 --> 00:51:21.060

Adam Riess: Periods which don't sync up to the, the year on Earth. And so if the period of the astral metric binary is either much smaller than a year are much greater than a year and then generally it'll also have no no effect. It will just go into the drifting motion.

299
00:51:21.990 --> 00:51:32.970
Adam Riess: So, you know, it's only sort of I would say modest fraction where, you know, it's all you know order one year to year binary, in which case, you know, then you have to look at the residuals.

300
00:51:36.300 --> 00:51:37.560
Richard Partridge: And the next question is,

301
00:51:39.210 --> 00:51:48.120
Richard Partridge: Is it significant that the theory PL our 11 group phone evaluate outside the dashed line range.

302
00:51:48.450 --> 00:51:50.010
Adam Riess: PL our 11

303
00:51:52.530 --> 00:51:54.660
Adam Riess: Is that you know our 11

304
00:51:56.220 --> 00:52:03.900
Adam Riess: Um, let's see. I'm going to go into that plot where they may have been talking about that it was outside the dash range. Let me take a look

305
00:52:06.720 --> 00:52:20.460
Adam Riess: Let's see. I showed two plots. I think they could have been referring to this one. Is there something outside the dashed range. It's PL our lab in P. O. Maybe it's this one. Um,

306
00:52:21.480 --> 00:52:23.040
Adam Riess: Yes, I don't think so.

307
00:52:25.650 --> 00:52:37.260
Adam Riess: You know, it's a, you know, within a sigma this dashed range the dash rain was only by I to sort of suggest to you, everything has been around 71 to 75 they found 76 plus or minus two.

308
00:52:37.860 --> 00:52:49.470

Adam Riess: This was also the only paper here where it was a theoretical calibration of the period luminosity relationships EPI, it's not an empirical one. You know, I don't think that one is a really out of whack.

309
00:52:50.250 --> 00:52:50.610
Okay.

310
00:52:52.170 --> 00:52:55.290
Richard Partridge: How can you be a single row distance letter.

311
00:52:56.040 --> 00:53:02.700
Adam Riess: Ah, great question. So the best example I can think of our majors and so you're looking at very distant galaxy.

312
00:53:03.180 --> 00:53:15.240
Adam Riess: And in the radio you observe these major clouds with radio a mission you measured the proper motion of the major clouds across the line of sight, but you're also measured the radial

313
00:53:16.500 --> 00:53:22.050
Adam Riess: Motion, the velocity and between those two and Kepler's Law, you get a geometric distance

314
00:53:22.410 --> 00:53:35.100
Adam Riess: And that's done. If you can do it far enough out you're directly in the Hubble Flow and so you don't need any more steps of the whole goal of a distance ladder is to measure a distance and a redshift, but to do it far enough out

315
00:53:35.430 --> 00:53:46.590
Adam Riess: That the universe is expanding. And so you want to do it you know beyond a redshift of, you know, point oh two or three where the dominant source or cause of the redshift is expansion and not

316
00:53:47.370 --> 00:53:58.530
Adam Riess: What we call peculiar emotion, just, you know, like our galaxy falling towards Andromeda or Andromeda towards us, has nothing to do with the expanding universe on small scales gravity is important.

317
00:53:59.250 --> 00:54:07.170
Adam Riess: And so you want to get far enough, and there are very few techniques that can go out that far. The only one I can really think of is majors and they're just rare.

318

00:54:07.770 --> 00:54:16.980
Adam Riess: You know configurations that give you like kind of amazing. And so that's why generally to use the the best tools we have to lash them together.

319
00:54:20.310 --> 00:54:23.580
Richard Partridge: Next question I have is, what's the lithium problem.

320
00:54:24.870 --> 00:54:37.650
Adam Riess: What's the lithium problem I'm far from the world's experts from it. But basically, you try to figure out how much primordial lithium, there should be from Big Bang nuclear synthesis and then you look in I guess you look in the

321
00:54:38.340 --> 00:54:49.470
Adam Riess: Oldest or at least process stars. And there's some mismatch between them and you know it has to do with, do we understand

322
00:54:49.980 --> 00:55:01.440
Adam Riess: How stars dredge up lithium, whether it gets lost or destroyed. It's, it's some mismatch between an expectation and an observation. I don't think it relates to the other tensions have been talking about.

323
00:55:01.770 --> 00:55:08.610
Adam Riess: And at various times people have proposed solutions and I only pose it as an example of a long standing problem.

324
00:55:13.440 --> 00:55:31.140
Richard Partridge: Next question, which constraints. Can we get from the composition of the universe at different times and things like the type of dark energy. Are there any models in which dark energy and something like dark matter tell to another minimum of the vacuum expectation

325
00:55:32.100 --> 00:55:42.270
Adam Riess: Yeah, I mean I think that it's important to measure the expansion rate of the universe over as a wider range of redshift as possible because you know these different components become dominant at different times.

326
00:55:43.020 --> 00:55:54.810
Adam Riess: Certainly we saw some strange additional behavior on that could point towards weird dark energy, you know, part of the problem is what we see what the Hubble tension is it's really an end to end test, it's really

327
00:55:55.380 --> 00:56:02.190
Adam Riess: You know, shortly after the Big Bang, you're essentially measuring how fast the universe is expanding and using a model to

328
00:56:02.520 --> 00:56:11.190
Adam Riess: extrapolate that to the present. And then you're looking at it in the present. If they don't agree. It doesn't tell you right away, where the problem occurred when the problem occurred.

329
00:56:11.490 --> 00:56:18.990
Adam Riess: And so then you want to use measurements of the expansion rate over a wide range to see if you can see it showing up in some

330
00:56:19.440 --> 00:56:25.590
Adam Riess: Epic. And I would say so far, we haven't we have not really seen it showing up in a particular epic

331
00:56:26.130 --> 00:56:38.700
Adam Riess: Which is why were these days off in questioning you know what if it was baked in from the beginning, you know, with something before the cosmic microwave background is admitted. But, you know, maybe there is a more creative idea.

332
00:56:42.600 --> 00:56:52.260
Richard Partridge: The next question I have is, have there been efforts to reduce the local measurements are the value of h, not through the introduction of some new physics.

333
00:56:53.940 --> 00:56:58.710
Adam Riess: Um, you know what's tough is we use a little physics to make that measurement

334
00:56:59.340 --> 00:57:02.850
Adam Riess: You know, in the case of the classroom. Right, great background you use the physics.

335
00:57:03.090 --> 00:57:10.290
Adam Riess: You understand of the early plasma, you know, you have to start out in those calculations and say, all right, how many neutrinos are there in the universe.

336
00:57:10.500 --> 00:57:18.780

Adam Riess: Because I have to echo partition energy into radiation and particle. So you're really using physics there. The distance ladder so empirical that um

337
00:57:19.470 --> 00:57:31.320
Adam Riess: We don't you know there's there's not really any physics, we're using. I mean, you know, the geometric step is is really mostly that like parallax is just geometry. I mean Kepler's laws to measure.

338
00:57:32.790 --> 00:57:45.780
Adam Riess: Distances with lasers is not a lot of physics. And then after that, it's quite empirical, I mean it's physics motivated. I mean, we understand why type one A supernovae should be good standard candles. We understand why there's a correlation between Cepheids

339
00:57:46.320 --> 00:57:52.740
Adam Riess: A variable luminosity and their period from pulsation theory, but we don't use any of the theory it's empirical

340
00:57:53.460 --> 00:58:09.540
Adam Riess: So you'd have to come up with some physics that we're just missing or not, including you know some, you know, some wizard wizardry nearby. That's why I talked about a Local Void. That would be like physics, sort of in a way that you're missing. But that doesn't look plausible.

341
00:58:11.760 --> 00:58:12.450
Richard Partridge: Okay.

342
00:58:13.980 --> 00:58:15.420
Richard Partridge: One more question here.

343
00:58:17.730 --> 00:58:25.560
Richard Partridge: And you're asking about Slide five and asking how is the Higgs field in existence proof of lambda CDN.

344
00:58:27.030 --> 00:58:27.570
Richard Partridge: Getting it

345
00:58:29.400 --> 00:58:29.700
Richard Partridge: To you.

346
00:58:29.760 --> 00:58:31.770

Adam Riess: Yeah I know which slide. You mean, let me get back there here.

347
00:58:32.820 --> 00:58:42.060
Adam Riess: Um, the Higgs field is not an existence proof of lambda cm. It's an existence proof of static dark energy.

348
00:58:42.570 --> 00:58:53.850
Adam Riess: It's not the right scale at all for the lambda, the, the, the vacuum energy that is causing the universe to accelerate. It's a completely different energy scale, but it's an existence proof that

349
00:58:56.940 --> 00:59:02.190
Adam Riess: That there is a non zero energy in empty space.

350
00:59:06.450 --> 00:59:11.850
Richard Partridge: So, thank you. I think that's pretty much exhausted or questions.

351
00:59:11.910 --> 00:59:17.310
Adam Riess: Okay, if anybody has any more questions, wants to just email me, feel free. You

352
00:59:18.420 --> 00:59:23.820
thomas rizzo: Gonna put put all your questions on a Google Doc and make sure you have the link to it. And so you can see everything.

353
00:59:24.600 --> 00:59:25.080
Okay.

354
00:59:26.100 --> 00:59:29.610
thomas rizzo: I didn't, I didn't, I didn't check recently in case you didn't send us your slides.

355
00:59:29.730 --> 00:59:30.420
Adam Riess: I did not yet.

356
00:59:30.570 --> 00:59:32.250
Adam Riess: You do. Okay.

357
00:59:34.230 --> 00:59:34.860
thomas rizzo: Thanks a lot.

358
00:59:35.220 --> 00:59:35.520
Adam Riess: Okay.

359
00:59:35.580 --> 00:59:42.300
grzegorz madejski: Very good talk, you can send it to any, any one of us is send them to me. I'll make sure to and get them to Charlie.

360
00:59:43.200 --> 00:59:43.470
grzegorz madejski: Had a

361
00:59:43.500 --> 00:59:44.430
Great talk.

362
00:59:46.110 --> 00:59:46.680
Adam Riess: Take care.

363
00:59:49.230 --> 00:59:51.030
thomas rizzo: They're going to stop the recording now.

364
00:59:55.560 --> 01:00:00.720
thomas rizzo: And we're going to take a 15 minute or so break and then we'll start again.