WEBVTT

1
00:00:05.250 --> 00:00:05.790
Wren Suess (she/her): For having

2
00:00:07.049 --> 00:00:16.980
Wren Suess (she/her): Virtually it's nice to see some some faces that are familiar, so I'll be talking today about a few projects and galaxy evolution, hence the kind of broad title.

3
00:00:17.430 --> 00:00:27.210
Wren Suess (she/her): And this is work that's been done in collaboration with a lot of really fantastic folks, both at Berkeley and beyond. But I do, especially when I highlight my thesis advisor mariska Creek.

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00:00:28.860 --> 00:00:35.880
Wren Suess (she/her): Alright, so when we are starting to try to answer this question of how galaxies evolve over over cosmic time

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00:00:36.240 --> 00:00:44.550
Wren Suess (she/her): There's a couple different routes that we can go and of course we can start by just looking at galaxies in the local universe and taking detailed images and spectroscopy.

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00:00:44.880 --> 00:00:49.410
Wren Suess (she/her): And trying to figure out what the physical processes are that are shaping these galaxies.

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00:00:50.010 --> 00:00:58.050
Wren Suess (she/her): But the reason that I really love studying galaxy evolution is that we don't get just this kind of end snapshot of what galaxies look like today.

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00:00:58.410 --> 00:01:03.960
Wren Suess (she/her): By looking at galaxies that are far away, we're also getting a view into the distant past.

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00:01:04.800 --> 00:01:10.380
Wren Suess (she/her): And the, the universe that you know redshift two and beyond. This is just a cutout from one of the candles deep fields.

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00:01:10.860 --> 00:01:19.950

Wren Suess (she/her): The universe looked very different at those of those early times and many of these properties that we can look out of galaxies have evolved significantly since then.

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00:01:20.460 --> 00:01:26.970
Wren Suess (she/her): And in particular, galaxy sizes have grown their morphology is have changed. They've gone from these kind of clumpy

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00:01:27.540 --> 00:01:36.060
Wren Suess (she/her): Burstein things to these wells settle discs and these large quiescent elliptical galaxies that we see this high fraction of and in the local universe.

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00:01:36.960 --> 00:01:52.950
Wren Suess (she/her): And of course, the fundamental question that we're trying to answer is how we get from there to these galaxies that we see today, and in particular in this talk, I'm going to focus on to kind of sub questions of that. And so, first I'll be talking about how galaxies grow over time.

14
00:01:53.190 --> 00:01:56.910
Wren Suess (she/her): What that size evolution actually looks like and how we can do a good job of

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00:01:57.030 --> 00:02:06.780
Wren Suess (she/her): characterizing it and then I'll focus in on this question of why we see this by modality between galaxies that are forming stars and galaxies that aren't because of that.

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00:02:07.560 --> 00:02:17.790
Wren Suess (she/her): You know, of course, that that implies that there's some process that shuts down star formation and galaxies, but we still don't really have a good handle on the detailed physics that's that's causing that transformation.

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00:02:18.270 --> 00:02:26.070
Wren Suess (she/her): So the first part of my talk on mostly talk about sizes and galaxy growth and then and then get a little bit into this question question, towards the end.

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00:02:27.150 --> 00:02:34.260
Wren Suess (she/her): So just to orient you with a kind of cartoon defied version of the of the size, mass plot for galaxies.

19
00:02:34.770 --> 00:02:49.710

Wren Suess (she/her): We see that both star from and galaxies here in blue and quiescent galaxies in red lie on this fairly well. Sighs mass relation were at fixed stellar mass quiescent galaxies tend to be smaller than their star forming counterparts.

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00:02:50.850 --> 00:03:03.060
Wren Suess (she/her): And this picture. This is the relation and in the redshift zero universe and the picture looks fairly similar. If we go to higher redshift except the normalization of both of these relations just decrease. So going from Richard

21
00:03:03.960 --> 00:03:06.750
Wren Suess (she/her): Richard zero back to redshift to these things just shift down

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00:03:07.500 --> 00:03:18.120
Wren Suess (she/her): And so this, this makes sense. I think for the star form and galaxies because between redshift to and today they're continuing to form stars. So it kind of makes sense that they also might be growing

23
00:03:18.750 --> 00:03:29.100
Wren Suess (she/her): But it's a lot harder to explain for these quiescent galaxies, because of course they're not they're not forming any stars anymore. So why are we seeing this huge size growth.

24
00:03:30.000 --> 00:03:39.240
Wren Suess (she/her): And, you know, in particular, they're, they're more than doubling or tripling their sizes, which is very difficult to explain. And this was really surprising when folks first figure this out.

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00:03:39.720 --> 00:03:45.630
Wren Suess (she/her): And so there's been a lot of work trying to figure out just exactly what is causing this size growth of quiet and galaxies.

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00:03:46.440 --> 00:03:58.680
Wren Suess (she/her): And there's two kinds of explanations that have a reason to to explain this size growth. The first is that individual quiescent galaxies are growing after they've stopped forming stars.

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00:03:59.340 --> 00:04:08.100
Wren Suess (she/her): And the way that they're doing that is by undergoing these minor mergers, which are essentially just adding small amounts of mass their outskirts and puffing the galaxies up

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00:04:08.700 --> 00:04:10.800
Wren Suess (she/her): And so this is this idea of inside out growth.

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00:04:11.730 --> 00:04:15.150
Wren Suess (she/her): But you can actually go out and measure the number of minor mergers.

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00:04:15.450 --> 00:04:26.340
Wren Suess (she/her): At these redshift and you find that the the growth that you get from minor mergers is not actually sufficient to explain the full size growth that that folks are observing in the client population.

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00:04:26.850 --> 00:04:30.420
Wren Suess (she/her): And so there has to be, you know, something else that's also going on.

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00:04:31.110 --> 00:04:40.530
Wren Suess (she/her): And so another kind of competing explanation for explaining this size growth is that it's not necessarily that individual galaxies are changing their sizes.

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00:04:40.800 --> 00:04:46.260
Wren Suess (she/her): It's that we're observing some kind of change in the population of quiet galaxies over time.

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00:04:46.740 --> 00:04:51.120
Wren Suess (she/her): So if the class and galaxies that are quenching later are also larger

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00:04:51.480 --> 00:05:02.370
Wren Suess (she/her): Than you can get a change in the medium size of the client population when you look over time, not because individual galaxies are actually growing, but just because you're changing the population that you're looking at.

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00:05:03.390 --> 00:05:14.910
Wren Suess (she/her): So the field is kind of settled on on some kind of combination of both this inside out, growth and this presented or bias being responsible in in roughly equal parts for the size growth of Christ and galaxies.

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00:05:15.840 --> 00:05:28.080
Wren Suess (she/her): But the thing that I want to talk about mostly today is that almost all of these studies have been done using the light

profiles of galaxies, because of course we're astronomers and light is what we what we fairly easily have access to

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00:05:28.590 --> 00:05:42.180
Wren Suess (she/her): But unfortunately light is also a biased tracer of stellar mass. And if you have any radio variations in stellar population properties across your galaxy that creates mass to light ratio gradients.

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00:05:42.720 --> 00:05:53.280
Wren Suess (she/her): And so those are observable as as color gradients and so the situation that you want to be in when you're trying to use half light radio as a probe of how big galaxies are

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00:05:53.610 --> 00:05:59.220
Wren Suess (she/her): Is your kind of assuming that you have the same color throughout your galaxy, you have a flat mass delight ratio.

41
00:05:59.730 --> 00:06:08.490
Wren Suess (she/her): Because then your mass profile and your light profile are the same. And so when you look at your half light radius. That's a good tracer of the underlying mass distribution.

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00:06:09.390 --> 00:06:17.130
Wren Suess (she/her): But you could also fairly easily imagine that you could instead be in a case like this where the outskirts of your galaxy here are redder

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00:06:17.640 --> 00:06:26.250
Wren Suess (she/her): Either because they're older or their dustier or they have more medals and in this case, your mass profile is more extended than your light profile.

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00:06:26.670 --> 00:06:32.310
Wren Suess (she/her): And so you're not getting a good idea of how large your galaxy actually is when you're just looking at the light

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00:06:33.060 --> 00:06:39.960
Wren Suess (she/her): Or you could have, of course, the opposite where the center is redder and then your mass profile is is more compact than your light profile.

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00:06:40.830 --> 00:06:45.240
Wren Suess (she/her): And you can easily imagine kind of situations that would give you these types of

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00:06:45.540 --> 00:06:53.310
Wren Suess (she/her): Radio color gradients, like here, you know, what if you have essentially concentrated starburst that puts a lot of young stars at the center of your galaxy.

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00:06:53.670 --> 00:06:58.680
Wren Suess (she/her): Or here. What if you have something that has, say, a bulge in the center and so

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00:06:59.520 --> 00:07:07.530
Wren Suess (she/her): Accounting for these color gradients is really necessary in order to understand kind of the, the true size evolution of galaxies.

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00:07:07.890 --> 00:07:19.920
Wren Suess (she/her): Because if we're looking at just how they are half light radio are changing over time, we're kind of getting not just their size evolution, but also potential evolution and the strengths of these color gradients.

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00:07:20.970 --> 00:07:29.190
Wren Suess (she/her): And so we went out to go measure these color gradients and galaxies and kind of a systematic way for a large sample across redshift.

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00:07:29.850 --> 00:07:35.970
Wren Suess (she/her): And so our samples now quite, quite a few galaxies that at redshift less than about two and a half.

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00:07:36.510 --> 00:07:45.690
Wren Suess (she/her): And these are all things that are in these these candles deep field. So they all have multi band high resolution HST imaging. That's all involved in the same point spread function.

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00:07:46.380 --> 00:07:53.490
Wren Suess (she/her): And I'm not actually really going to talk about the methods. It's like to kind of simplify. It's we're doing spatially resolves

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00:07:53.850 --> 00:08:00.240
Wren Suess (she/her): spectral energy distribution fitting combined with some some forward modeling to account for the point spread function and

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00:08:00.780 --> 00:08:11.610

Wren Suess (she/her): I thought a lot about the details for this. And we've tested a few different methods. And so that's all in this 2019 a paper or I'm super happy to answer questions if folks have have any

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00:08:12.180 --> 00:08:21.270
Wren Suess (she/her): Towards the end about about the actual methods, but for now I kind of want to just get into what we actually found once we went out and measure these mass profiles and he's half mass radio

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00:08:22.200 --> 00:08:29.520
Wren Suess (she/her): And so the first thing that we can ask is, essentially, you know, was it worth going going through all of this trouble to measure these mass profiles.

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00:08:29.910 --> 00:08:35.670
Wren Suess (she/her): And by asking the question of whether or not it's actually affects the evolution of the size, mass relation

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00:08:36.390 --> 00:08:42.810
Wren Suess (she/her): And so here I'm showing just the strength of these color gradients as spread by like the half mass radius divided by the half light radius.

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00:08:43.110 --> 00:08:50.670
Wren Suess (she/her): So this dashed line means that the whole galaxy is the same color. This means down here means red or centers or blue or centers up here.

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00:08:51.600 --> 00:08:58.800
Wren Suess (she/her): And so what I find is that these color gradients in both star for me in Christ and galaxies are essentially flat at high redshift.

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00:08:59.220 --> 00:09:09.750
Wren Suess (she/her): And then they actually decrease quite sharply towards the render center edge of this diagram down to about redshift of one or so and then they flatten below that.

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00:09:10.350 --> 00:09:20.820
Wren Suess (she/her): And this is not really been seen before. And it's really interesting because it means that half mass radio. I actually have a different redshift evolution than half light radio. I do.

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00:09:21.420 --> 00:09:25.530

Wren Suess (she/her): And so the view that we were getting of the galaxy. Sighs mass relation before

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00:09:26.100 --> 00:09:34.980
Wren Suess (she/her): Was looking again, not just at the actual size of evolution of these galaxies, but also at this this fairly strong color gradient evolution that I'm showing here.

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00:09:35.700 --> 00:09:43.890
Wren Suess (she/her): But now that we have these you know color gradients measured, I can plot the, the actual evolution of the half mass radio over cosmic time

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00:09:44.670 --> 00:09:53.490
Wren Suess (she/her): And here I'm just going to think about the the quiescent galaxies. Because again, I was talking about this, this kind of huge growth, especially here at early times

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00:09:53.910 --> 00:10:02.160
Wren Suess (she/her): So this is just the size at fixed mass. So like one point on that, on that size, mass relation as a function of either look back time or redshift whichever you prefer.

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00:10:03.120 --> 00:10:07.530
Wren Suess (she/her): And this is the evolution of half light radio I have quiescent galaxies.

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00:10:08.460 --> 00:10:20.580
Wren Suess (she/her): And like I said you can you can predict how much you expect these galaxies to grow from minor mergers and if I put that model. This one is it. This is a model from drew Newman on on here.

72
00:10:21.240 --> 00:10:32.850
Wren Suess (she/her): We see that this minor merger model does an okay job at low redshift predicting this relatively moderate sized growth, but there's this big gap at high redshift where this model is not able to produce the full

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00:10:33.750 --> 00:10:40.890
Wren Suess (she/her): You know, kind of growth that scene and these half light radio I have clients and galaxies is about a factor of two to two shallow

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00:10:41.820 --> 00:10:52.020

Wren Suess (she/her): But when I plot the evolution of half mass radio, it actually does go right through this this this minor merger track. And so what we're saying here is that

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00:10:52.620 --> 00:11:02.820
Wren Suess (she/her): The, the size growth of classic galaxies is actually fully consistent with this model. It's just that we had to account for these these evolving color gradients.

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00:11:03.450 --> 00:11:12.870
Wren Suess (she/her): And so it doesn't seem like this progenitor bias is required to explain a large amount of the size growth of Aquarius and galaxies, at least at these ratchets

77
00:11:14.580 --> 00:11:20.730
Wren Suess (she/her): Alright, so the next thing that I kind of want to talk about is, is how we actually get quiet and galaxies.

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00:11:21.060 --> 00:11:30.480
Wren Suess (she/her): Because of course, just looking at this size evolution of the whole client population doesn't really tell us about what's shutting down star formation.

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00:11:31.290 --> 00:11:38.700
Wren Suess (she/her): And there are some clues that we can use galaxy sizes and structures to probe this question of, of what's responsible for quenching

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00:11:39.390 --> 00:11:44.700
Wren Suess (she/her): And so like I said before, our class and galaxies are smaller than their star forming counterparts.

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00:11:45.150 --> 00:11:50.880
Wren Suess (she/her): But folks have also observed before that the youngest quiescent galaxy seen even smaller.

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00:11:51.330 --> 00:11:59.790
Wren Suess (she/her): So this is a plot a few years ago from Omar armine. This is just the size, mass plane with star from and galaxies in Blue Cross and galaxies and read

83
00:12:00.240 --> 00:12:06.660
Wren Suess (she/her): And then these black points are post starburst galaxies. These are the youngest class and galaxies.

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00:12:07.350 --> 00:12:14.100
Wren Suess (she/her): And you can see here, especially at at high masses, they seem to be smaller than both star forming and quiescent galaxies.

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00:12:14.490 --> 00:12:26.610
Wren Suess (she/her): And this is telling us that something about the process that shut down star formation and these galaxies potentially really shrunk them down from there, start forming sizes and then they had to grow again along the quiescent sequence.

86
00:12:27.180 --> 00:12:34.800
Wren Suess (she/her): And and so the question that I have now is, is does this result hold when we're considering these half mass radio

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00:12:35.940 --> 00:12:43.590
Wren Suess (she/her): And in order to answer this question. You know, I don't have spectra for all of these galaxies. They're, they're all kind of, you know, photometer from candles.

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00:12:44.070 --> 00:12:51.360
Wren Suess (she/her): So I need a good way to to estimate the ages along the crescent sequence. And so I've actually used a

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00:12:51.750 --> 00:13:00.990
Wren Suess (she/her): Result from scenario from last year where he went out and took a bunch of spectra and found that you can do a good job at estimating the sizes on the Christ and sequence.

90
00:13:01.320 --> 00:13:10.410
Wren Suess (she/her): Just by where galaxies lie on this this up, Jay. Color. Color plot. So I can take his results and essentially age Date My, my whole quiescent sample.

91
00:13:11.070 --> 00:13:23.160
Wren Suess (she/her): And divide them into kind of these young quiescent galaxies or the post starburst like things versus these older price and galaxies, and then I can look at how the sizes of these two populations different

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00:13:24.270 --> 00:13:32.370
Wren Suess (she/her): So this is kind of the, the picture that I was showing before just now with my data set of how the half light radio I have these galaxies look

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00:13:32.850 --> 00:13:45.120
Wren Suess (she/her): So these are just individual points colored by their inferred age and then median bins of both the old Christ and population here and then the post starburst or young class and galaxies down here.

94
00:13:45.960 --> 00:13:54.270
Wren Suess (she/her): And so we see again, this, this, you know, gap in the in the sizes of these things as a function of age where the younger class and galaxies look smaller.

95
00:13:55.290 --> 00:14:02.790
Wren Suess (she/her): But when I plot. Instead, the half mass ready I have these galaxies that size difference again mostly disappears.

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00:14:03.330 --> 00:14:11.070
Wren Suess (she/her): So it seems like these posts starburst galaxies are not actually significantly smaller at fixed mass than their older quiescent counterparts.

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00:14:11.580 --> 00:14:22.350
Wren Suess (she/her): But the fact that the you know the picture and light sizes versus mass sizes looks different means that these two populations have to have differences in the strength of their color gradients.

98
00:14:23.310 --> 00:14:26.310
Wren Suess (she/her): Because that's essentially what's making the left and the right side, different here.

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00:14:26.940 --> 00:14:40.980
Wren Suess (she/her): So I can plot. Their, their color gradient strength. So again, this is just the dashed line means flat, the bottom half is red centers or blue centers and this time. This is a function of inferred age along the class and sequence.

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00:14:41.520 --> 00:14:46.740
Wren Suess (she/her): And these are just the individual points in my sample and three different redshift bends and then a best fit.

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00:14:47.550 --> 00:14:52.770
Wren Suess (she/her): And indeed, we see that color gradient strengths are changing along the class and sequence.

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00:14:53.250 --> 00:15:08.310

Wren Suess (she/her): And so the these posts starburst galaxies seem to have essentially flat color gradients and then they become gradually stronger towards his redder centers side as as quiescent galaxies are aging along the along the sequence.

103
00:15:08.820 --> 00:15:10.590
Ana Bonaca: And so again, this is telling us

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00:15:11.040 --> 00:15:13.350
Wren Suess (she/her): Great. And that, that these things are

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00:15:14.130 --> 00:15:18.750
Wren Suess (she/her): Are not actually really significantly smaller, they just have systematically different color gradients.

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00:15:20.040 --> 00:15:30.090
Wren Suess (she/her): And so to kind of try and put this all together into a broader picture of how these galaxies are evolving along along the class and sequence from from their structures.

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00:15:30.810 --> 00:15:42.030
Wren Suess (she/her): Here's just. This is the full mass profiles of all the galaxies in the sample. All the classic galaxies bend by their invert age and then color gradient strengthen and half mass radio

108
00:15:42.930 --> 00:15:54.270
Wren Suess (she/her): And so just kind of take you through what I'm seeing along the quiescent sequence putting this together is that as galaxies are getting older, as we're going towards the purple colors here.

109
00:15:55.020 --> 00:16:06.750
Wren Suess (she/her): They're becoming more massive. And they're also becoming larger and we can see that here. And then we can go look at these mass profiles and ask how they're building up that mass

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00:16:07.200 --> 00:16:13.320
Wren Suess (she/her): And the zoom in of their central killer parsecs shows you know all these profiles are essentially the same in the center.

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00:16:13.830 --> 00:16:20.400
Wren Suess (she/her): But the mass that they're adding these classes and galaxies as they age is being added to their outskirts out here.

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00:16:21.360 --> 00:16:29.310
Wren Suess (she/her): And then we can also look at the the strength of their color gradients, which again is going towards kind of the red or centers blue or outskirts

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00:16:29.550 --> 00:16:36.660
Wren Suess (she/her): And so that's kind of implying that the mass that's being added to these galaxies potentially is is bluer on outskirts

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00:16:37.260 --> 00:16:44.070
Wren Suess (she/her): And this seems to be all kind of consistent with this picture where these quiescent galaxies are growing inside out via minor mergers.

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00:16:44.340 --> 00:16:49.530
Wren Suess (she/her): Because again, that should be puffing up their outsides but leaving their centers essentially unchanged.

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00:16:49.950 --> 00:16:57.630
Wren Suess (she/her): And then also, you know, you're expecting that the the stars that you're adding in those murders are coming from lower mass lower metal city galaxies. They should be bluer

117
00:16:58.560 --> 00:17:02.460
Wren Suess (she/her): And then the other thing that this is telling us is that these posts starburst galaxies.

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00:17:02.730 --> 00:17:12.690
Wren Suess (she/her): Seem to be the result of a kind of a rapid quenching process that's requiring some sort of structural change because they've already built up these massive centers that are required for quiescence

119
00:17:13.350 --> 00:17:18.240
Wren Suess (she/her): But they also something has happened to flatten their color gradients out from the star forming population.

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00:17:18.960 --> 00:17:26.580
Wren Suess (she/her): And so in my last like two minutes. I want to kind of just dive a little bit more into these posts starburst galaxies as probes of quenching

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00:17:27.150 --> 00:17:35.670

Wren Suess (she/her): And talk to just super briefly about about some results where we've looked at kind of a multi wavelength study of these post starburst galaxies.

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00:17:35.970 --> 00:17:39.780
Wren Suess (she/her): To really try and figure out why they've they've shut down their star formation.

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00:17:40.410 --> 00:17:55.440
Wren Suess (she/her): And so we've looked for these post starburst galaxies at slightly lower redshift about point seven so that we can do these multi wavelength follow ups and I've, I've selected a big sample from Sloan. This is what their, their spectra look like and they look a lot like a type stars.

124
00:17:56.730 --> 00:18:04.680
Wren Suess (she/her): And like I said, we're really doing a multi wavelength follow up. This is called the squiggle survey, which is a long convoluted acronym. I figured I should

125
00:18:05.250 --> 00:18:11.340
Wren Suess (she/her): Make one of those up in order for them to actually give me a PhD, because, of course, astronomers love our convoluted acronyms.

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00:18:11.760 --> 00:18:18.960
Wren Suess (she/her): And so we're looking at a lot of different properties there kinematics there a GN fractions. A lot of a lot of things like that.

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00:18:19.260 --> 00:18:28.050
Wren Suess (she/her): But also about their molecular gas reservoirs, because of course stars are forming out of molecular gas. And so if they stopped forming stars. Maybe it's because they ran out of fuel.

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00:18:28.890 --> 00:18:36.780
Wren Suess (she/her): So just quickly on some results there. This is star formation rate versus molecular gas mask. This is essentially the kind of catchment relation

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00:18:37.230 --> 00:18:45.180
Wren Suess (she/her): And these are a bunch of normal galaxies that Richard zero or higher redshift. And we went and took all my data for some of these posts starburst things

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00:18:45.900 --> 00:18:52.740
Wren Suess (she/her): We found that they actually have significant molecular gas reservoirs. So they're really offset from this expected relation

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00:18:53.610 --> 00:18:58.860
Wren Suess (she/her): Which is really strange because, why do they have so much gas that they're not forming new stars out of

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00:18:59.610 --> 00:19:07.320
Wren Suess (she/her): And we were really surprised and excited by this. So we went and took all the data of a bunch more of these posts starburst galaxies, the next cycle.

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00:19:07.740 --> 00:19:19.500
Wren Suess (she/her): And we found four of them that again have these really significant molecular das reservoirs and gas fractions of something like 20% despite the fact that, again, they're not forming any stars out of this gas.

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00:19:20.070 --> 00:19:28.980
Wren Suess (she/her): We also got a bunch of non detections which, you know, we can see the stack of those, but there it's kind of at the edge of what you would expect from this kind of kitchenette relation

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00:19:30.090 --> 00:19:37.740
Wren Suess (she/her): And again, this is a factor of like 30 and CEO luminosity here, despite the fact that this is optically a pretty uniform sample.

136
00:19:38.070 --> 00:19:44.130
Wren Suess (she/her): So this is saying that something is happening to the the molecular gas in these galaxies on fairly short time scales.

137
00:19:44.730 --> 00:19:51.960
Wren Suess (she/her): And I've actually gone and fit all of the star formation histories of these things using prospector which of course is is developed out of, out of Harvard

138
00:19:52.380 --> 00:20:00.300
Wren Suess (she/her): And to get constraints on how long these galaxies event quenched. And it looks like this is now gas mask versus time since quenching

139
00:20:00.690 --> 00:20:12.240

Wren Suess (she/her): And it looks like the gas that we're seeing in these galaxies is there on extremely short timescales after quenching and then really just disappears at something like this kind of point to your point three year mark.

140
00:20:12.660 --> 00:20:17.940
Wren Suess (she/her): So it seems like these things cannot can quench with gas, but then it disappears on short time scales.

141
00:20:19.110 --> 00:20:29.400
Wren Suess (she/her): Alright, so I want to leave you with just, just a few main takeaway points. So first, I think we really need to account for these color gradients and their, their evolution.

142
00:20:30.270 --> 00:20:40.350
Wren Suess (she/her): Over time, when we're doing these studies of galaxy sizes and, in particular, I've showed that class and galaxies evolve much slower than you would expect from their half light radio

143
00:20:40.950 --> 00:20:45.090
Wren Suess (she/her): And actually that growth is fully consistent with this minor merger growth model.

144
00:20:45.750 --> 00:20:55.350
Wren Suess (she/her): And I've also showed that the youngest Christ and galaxies aren't actually significantly smaller than their older counterparts, they again just have systematic differences in their color gradients.

145
00:20:56.220 --> 00:21:02.160
Wren Suess (she/her): And then lastly, I talked a little bit about post starburst galaxies as these laboratories to study quenching

146
00:21:02.910 --> 00:21:18.390
Wren Suess (she/her): And we found that galaxies can quench while retaining large molecular gas reservoirs, but there's some hands that that that gas masses is correlated with the time since launching so that's all I have. Thank you so much for for your attention, and I'd be happy to take questions.

147
00:21:19.140 --> 00:21:19.860
Morgan Elowe MacLeod: Thank you.

148
00:21:28.350 --> 00:21:37.890

Morgan Elowe MacLeod: Well, thank you so much for a wonderful talk. We have a bunch of questions. And so we'll get through some right now and then they'll be time for more online.

149
00:21:38.970 --> 00:21:43.770
Morgan Elowe MacLeod: So one of the first questions is from Abby low who's asking

150
00:21:44.820 --> 00:21:51.420
Morgan Elowe MacLeod: About the non baryonic mass in in these regions. So if I understand correctly, when we're

151
00:21:52.860 --> 00:21:58.230
Morgan Elowe MacLeod: Better accounting for the colors of stars and their differences, we're still talking about the stellar

152
00:21:58.470 --> 00:22:01.860
Wren Suess (she/her): Yeah, man. I saw this is all stellar mass. Yeah, so

153
00:22:02.160 --> 00:22:08.070
Morgan Elowe MacLeod: Are there reasons that the dark matter mass would evolve in these

154
00:22:09.330 --> 00:22:17.370
Morgan Elowe MacLeod: Different cases and or is basically this region that we're probing always mostly baryonic

155
00:22:18.000 --> 00:22:31.380
Wren Suess (she/her): Yeah. So I think, I think this is all going to be mostly mostly baryonic and I don't think right now. We really have the data to test that. Because I think measuring dynamical masses is much harder than measuring stellar masses of course observation.

156
00:22:32.190 --> 00:22:45.090
Wren Suess (she/her): Um, but I do think that there's, you know, there's important things, especially with this quenching question of what's going on with with dark matter halos. And so I think there are a lot of interesting questions there. I just haven't put a lot of thought into that just yet.

157
00:22:45.480 --> 00:22:48.630
Wren Suess (she/her): But yeah, these measurements are all stellar mass. Yeah.

158

00:22:49.950 --> 00:22:51.180
Morgan Elowe MacLeod: I'm Jay Park is asking

159
00:22:52.350 --> 00:23:08.550
Morgan Elowe MacLeod: I was wondering how the gas fractions of mergers would affect the sizes of evolution of galaxies and would the fact that mergers at higher redshift tend to be gashes be part of the reason why the minor merger module does not match well with the half light radio

160
00:23:09.810 --> 00:23:11.820
Morgan Elowe MacLeod: Oh yeah, the quiescent galaxies.

161
00:23:13.230 --> 00:23:19.710
Wren Suess (she/her): Yeah. So normally when we're talking about this kind of minor merger growth there they're fairly dry mergers that we're talking about.

162
00:23:20.190 --> 00:23:34.560
Wren Suess (she/her): And, of course, that that does evolve with redshift, and I can't remember all of the details of Drew's model. But I do think that the the different tracks at different registers assume something about the the actual gas fractions.

163
00:23:35.100 --> 00:23:49.140
Wren Suess (she/her): From the measurements, but I would have to go go look at that more, but I think my my measurements are arguing that a lot of this. The reason that this model isn't fitting is is maybe because of the color gradient evolution. Interesting.

164
00:23:49.890 --> 00:23:53.100
Morgan Elowe MacLeod: Do you want to chime in. Did I miss details there that

165
00:23:54.240 --> 00:23:55.560
Morgan Elowe MacLeod: You'd like to follow up on

166
00:24:07.080 --> 00:24:09.000
Morgan Elowe MacLeod: I think you're still muted. Okay.

167
00:24:10.230 --> 00:24:11.160
Morgan Elowe MacLeod: Yeah, so

168
00:24:13.830 --> 00:24:31.020

Morgan Elowe MacLeod: Sandra is asking what's the about the sample a little bit more. So what is the completeness that have half mass size estimates and are you able to do something like a number density

169
00:24:33.930 --> 00:24:42.060
Morgan Elowe MacLeod: And measure whether the small quiescent galaxies fraction essentially evolves over time.

170
00:24:42.450 --> 00:24:54.780
Wren Suess (she/her): Yeah, that's a great question. And so, so we have had to do a cut on essentially signal to noise in order to measure color gradients. So it's kind of a cut on on F1 60

171
00:24:55.980 --> 00:25:06.360
Wren Suess (she/her): I forgot exactly what what sigma detection for for that. And so we've gone through an estimated mass completeness limits using kind of the same technique that

172
00:25:06.750 --> 00:25:17.250
Wren Suess (she/her): That Amazon is used for the AltaVista sample and but because we're putting in that signal to noise guide which kind of eventually corresponds, of course, to a to a mass cut

173
00:25:17.760 --> 00:25:27.090
Wren Suess (she/her): It's a little bit hard to do the number densities, because if you want to get an extremely like good estimate of your completeness, you're really just getting the highest mass things and the brightest things

174
00:25:27.600 --> 00:25:36.360
Wren Suess (she/her): So I've thought about doing doing number densities and just haven't gotten to it yet because it looks like we're mostly going to be doing the, the kind of high mass end

175
00:25:38.220 --> 00:25:42.570
Wren Suess (she/her): But the 90% mass completeness is something like 10 to the 10 across Russia.

176
00:25:45.540 --> 00:25:48.450
Morgan Elowe MacLeod: So I have one last question, which is, I guess.

177
00:25:49.470 --> 00:25:55.320
Morgan Elowe MacLeod: mashing together what I've been wondering about, and the question that on a pinata asked, which is

178
00:25:56.850 --> 00:25:57.510
Morgan Elowe MacLeod: Since

179
00:25:59.160 --> 00:26:06.000
Morgan Elowe MacLeod: Not myself. But a lot of the people in this call are our people who are involved in running the illustrious simulations.

180
00:26:07.170 --> 00:26:17.160
Morgan Elowe MacLeod: What can we learn from comparing to cosmological simulations of galaxy permission and, in particular, I was wondering about two things.

181
00:26:19.050 --> 00:26:23.010
Morgan Elowe MacLeod: One is this idea of the merger history.

182
00:26:24.900 --> 00:26:28.020
Morgan Elowe MacLeod: And I was wondering about

183
00:26:29.250 --> 00:26:38.610
Morgan Elowe MacLeod: Like computing the sorts of gradients that you are able to measure in the simulations and whether that's been done.

184
00:26:39.780 --> 00:26:41.670
Morgan Elowe MacLeod: And then the second thing is

185
00:26:43.320 --> 00:26:49.110
Morgan Elowe MacLeod: Do you feel just sort of as we step forward that like

186
00:26:50.370 --> 00:26:57.030
Morgan Elowe MacLeod: Directly comparing this particular observable is a useful way to distinguish between the sort of

187
00:26:58.560 --> 00:27:09.930
Morgan Elowe MacLeod: Quenching mechanisms that we have to put into the simulations essentially are the recipes like do you think that this is a good avenue towards backing out some of the physical properties of

188
00:27:11.700 --> 00:27:16.500
Wren Suess (she/her): Those for sure I do, I think, I think that in order to really make that step.

189

00:27:16.890 --> 00:27:30.090
Wren Suess (she/her): It's good to go. Kind of beyond these color gradients that I've been measuring into actually understanding whether or not these are age gradients or medalists at gradients or some combination of dust gradients that I'm not totally modeling.

190
00:27:30.180 --> 00:27:39.120
Wren Suess (she/her): Right, so I think once you get to kind of the level of looking at agent medalists at gradients. Those are actually really great to compare to theoretical predictions.

191
00:27:39.450 --> 00:27:46.230
Wren Suess (she/her): Because it's telling you something about how you're assembling your stars and where the gas that you're making those stars out of this is coming from.

192
00:27:46.680 --> 00:27:55.260
Wren Suess (she/her): And so I've actually looked a lot into kind of thinking about how to use these to kind of constrain quenching mechanisms and I think it's doable.

193
00:27:55.740 --> 00:27:59.820
Wren Suess (she/her): At least from the kind of the simulation front as something to compare to.

194
00:28:00.270 --> 00:28:06.120
Wren Suess (she/her): And then on the observational side right now of course we can. We can either kind of get that

195
00:28:06.360 --> 00:28:14.580
Wren Suess (she/her): differentiation of if their age metal city or dust by looking at, say, like if you study is where we're actually able to look at the spectral lines.

196
00:28:14.850 --> 00:28:21.540
Wren Suess (she/her): And so that's something that you can compare to for small numbers of galaxies right now. But then also, once we have this

197
00:28:21.900 --> 00:28:32.190
Wren Suess (she/her): You know, amazing a web data. And in, in the longer wavelength regime, you can start breaking those age medalists at dusty generous ease for photo metric samples as well.

198
00:28:32.520 --> 00:28:36.210

Wren Suess (she/her): And so I think that is a really promising avenue for for comparing

199
00:28:36.660 --> 00:28:52.590
Wren Suess (she/her): And I would love for you know to talk about comparing sizes. I think it's it's really difficult to do it in a uniform way between the simulations and the observations, just because a lot of times we're kind of talking about different things. And so, yeah, we'd love to chat about that more.

200
00:28:55.410 --> 00:29:02.940
Morgan Elowe MacLeod: Well, we have a couple more questions that I wasn't able to get to, but we should move on to our second speaker. But thank you so much for

201
00:29:03.180 --> 00:29:04.020
Morgan Elowe MacLeod: A really interesting

202
00:29:04.740 --> 00:29:05.610
Wren Suess (she/her): Check this slack.

203
00:29:05.640 --> 00:29:08.280
Wren Suess (she/her): Yeah. And also, if anybody wanted to meet I'm

204
00:29:08.340 --> 00:29:11.910
Morgan Elowe MacLeod: I'm around if you want to do. Absolutely. Thank you so much.

205
00:29:13.200 --> 00:29:21.960
Ana Bonaca: Okay, thanks for turn our to our next speaker. Yes, who is a professor of cosmology at the University of Manchester.

206
00:29:22.380 --> 00:29:31.740
Ana Bonaca: And he got his undergrad degree in physics, from my university of getting gambler. He studied the impact of internal cluster dynamics on the SC effect.

207
00:29:32.220 --> 00:29:47.280
Ana Bonaca: And then he moved to MPa and will we can make millions university for his PhD, where he started the spectral distortions of the CMT and 30 years he has explored a number of topics and early universe cosmology from

208
00:29:48.540 --> 00:29:58.530

Ana Bonaca: The effects are this primordial magnetic fields might have on the heating the the matter, the universe and all the way to

209
00:29:59.610 --> 00:30:17.310
Ana Bonaca: Effects off at dark matter annihilation and at the same time. He also developed. He's pieces of code that has been pretty crucial in analysis of cosmological data, especially from plunk mission and today though they're sort of going back to his original

210
00:30:18.660 --> 00:30:29.490
Ana Bonaca: Topic of sin, respectfully searches and endured will hear about some current challenges and also in the opportunities with this features. So that's taken away. Yes.

211
00:30:30.210 --> 00:30:45.690
Jens Chluba: Yeah, thanks a lot on now. Can everybody hear me and see my slides. That's all up. Okay, great. So yeah, thanks a lot for having me speak here I would, of course, I've been really happy to come and I'm happy to see many faces familiar faces in the audience.

212
00:30:46.740 --> 00:30:58.440
Jens Chluba: I'm going to try to excite you about spectral distortions and for those of you who have heard me speak about this. I hope that I will have several things that are going to be exciting and beyond what you have heard about. And then, of course,

213
00:30:58.920 --> 00:31:05.340
Jens Chluba: For those who have not heard about spectral distortion. I'm going to try to give a little bit of a flavor of what's going on so

214
00:31:06.090 --> 00:31:14.670
Jens Chluba: Let us start with I need to. Yes. So, let us start with the nice picture of the cosmic microwave background, the same be another trapeze. And the temperature

215
00:31:15.030 --> 00:31:24.900
Jens Chluba: This is something that you probably have seen many times and these tiny fluctuations here from the plank measured by the plank satellite. They have told us a great deal about cosmology and

216
00:31:25.950 --> 00:31:26.940
Jens Chluba: The universe we live in.

217
00:31:28.260 --> 00:31:38.670

Jens Chluba: Here's just a one slot summary slide basically about the cosmological control governance model. I don't want to go into details. I think we all know we have alumnus EDM cosmology that is preferred.

218
00:31:39.390 --> 00:31:49.590
Jens Chluba: precision of the parameters is extremely high. And we are we are we are we are having very good understanding of both the early phases as well as late stages of the universe.

219
00:31:50.220 --> 00:32:00.180
Jens Chluba: And of course this was not just something that came in one day there was lots of experiments which led to this and I'm here only focusing on the cosmic microwave background measurements of course there was

220
00:32:00.870 --> 00:32:09.810
Jens Chluba: Supernova data. And of course, logical structure, all these things go into this picture of the llama city and cosmology, but nevertheless great progress over many years.

221
00:32:10.080 --> 00:32:17.190
Jens Chluba: And a lot of things to look forward to, as well with the upcoming upcoming measurements of the primordial remotes

222
00:32:17.700 --> 00:32:20.790
Jens Chluba: Which are which are going to tell us more about the cosmological of them.

223
00:32:21.300 --> 00:32:28.710
Jens Chluba: But I'm not going to talk about the CD another trapeze. I just wanted to remind everybody the same bananas drop is a great and have been really, really.

224
00:32:29.100 --> 00:32:33.840
Jens Chluba: Extremely useful. But there's a second part of the cosmic microwave background which we can look at

225
00:32:34.320 --> 00:32:45.180
Jens Chluba: And that is the average sky spectrum. So we're no longer looking at different comparing temperatures in different directions, but we're basically taking the average sky and we're looking at the differences in frequency

226
00:32:45.480 --> 00:32:52.560

Jens Chluba: So the real frequency dependence of the microwave background emission and we know that that is given by a black body to extremely high precision.

227
00:32:53.160 --> 00:32:58.080
Jens Chluba: And this we know since the measurements by Colby fire us many, many years ago.

228
00:32:58.680 --> 00:33:07.710
Jens Chluba: And when I'm talking about spectral distortions. I'm talking about small departures from this average black bodies spectrum that we normally refer to as the you know best.

229
00:33:08.190 --> 00:33:15.360
Jens Chluba: Most perfect black body that we have in the universe, and he's small departures. That's what spectral distortions are so departures from black body shape.

230
00:33:16.260 --> 00:33:27.330
Jens Chluba: How can these be created. Well, if we have something like energy release or injection of photons or particles, something that preserves the equilibrium between matter and radiation. You can create it as a spectrum distortion.

231
00:33:27.840 --> 00:33:34.680
Jens Chluba: One typical spectrum distortion. Here are some nice figures from original papers from the sheet and and salvage

232
00:33:36.150 --> 00:33:46.800
Jens Chluba: The. These are the most commonly known one is these so called white type distortion, which is also connected in connection with clusters. We all have probably heard about this idea of soda which effect.

233
00:33:47.040 --> 00:33:51.120
Jens Chluba: So you have the CB photons coming through what medium and you get an app scattering of photons.

234
00:33:51.540 --> 00:34:03.420
Jens Chluba: Where you move the intrinsic black body, you just it differentially move photons upwards and basically get an app scattering effect that is a distortion that is introduced at low wretches which means for me below 50,000

235
00:34:03.810 --> 00:34:17.190

Jens Chluba: So obviously people who are working on galaxies are laughing Yes So 50,000 that is the time when customization starts being inefficient. And if you go into earlier wretches so the high rates of

236
00:34:17.640 --> 00:34:25.680
Jens Chluba: Universe, then you have actually many interactions with the electrons, protons and electrons can equilibrate and you get the so called chemical potential that distortion.

237
00:34:25.950 --> 00:34:35.220
Jens Chluba: It's basically a vehicle lithium on the black body which is not having the perfect match of number and energy density. So these two types of distortions are the characteristic

238
00:34:35.610 --> 00:34:43.860
Jens Chluba: Classical distortions that we normally think about and the mu distortion is something that can only be created in the early universe. So this is really an important point to keep in mind.

239
00:34:44.610 --> 00:34:50.580
Jens Chluba: Okay, so let's go. Here's a nice picture of the evolution of the universe. We have probably all seen this in one or the other way.

240
00:34:51.060 --> 00:35:00.780
Jens Chluba: Where we think about the Big Bang and inflation setting up initial conditions and then the universe expands cools down all the all the interesting things happening. One of the most important areas.

241
00:35:01.650 --> 00:35:10.170
Jens Chluba: Or very important areas is the combination era where we start seeing the CB another trapeze. And then there's all the fun things happening at low wretches with galaxies and so

242
00:35:11.040 --> 00:35:22.500
Jens Chluba: Okay, Cindy and as a trapeze are literally what we are studying to learn about the initial conditions. And then of course there's interesting things being introduced by by the large scale structure in the later phases as well.

243
00:35:22.890 --> 00:35:29.760
Jens Chluba: And but when we're talking about spectral distortions, we actually talking about the thermal history of the universe and spectral distortions probe.

244
00:35:30.210 --> 00:35:32.790

Jens Chluba: The thermal history of the universe over a

245
00:35:33.390 --> 00:35:44.670
Jens Chluba: Wide range of times and starting a couple of months after the big bang until today. So if you have some energy release injection, you get a distortion, as I said, we invite type distortions. That's the classical kind of

246
00:35:44.940 --> 00:35:49.620
Jens Chluba: Thing, you're thinking about and you're learning something about a vast range of of

247
00:35:50.490 --> 00:35:58.410
Jens Chluba: Times. And you have also the premier combination injection that can give you some information about stuff happening before the last scattering surface.

248
00:35:59.010 --> 00:36:05.250
Jens Chluba: So this is a new window to the universe. And there's a lot of discovery space. I'm going to try to allude to that. So here's

249
00:36:05.970 --> 00:36:12.780
Jens Chluba: Another sketch showing the classical pictures or the meter distortion in the early phases and the wider distortion and Lake phases.

250
00:36:13.440 --> 00:36:24.480
Jens Chluba: And so the average and and she turned out here. And then there's also the so called temperature era, because you have feminization being extremely efficient and you're basically able to thumb lies any distortion, you will be created.

251
00:36:25.320 --> 00:36:34.800
Jens Chluba: So that's the classical picture. But since a couple of years, we have now understood that there's actually an intermediate phase between the moon, why era which doesn't make this transition between reason why just abrupt

252
00:36:35.010 --> 00:36:43.200
Jens Chluba: But it's actually a gradual transition and there's kind of an information, you can actually hope to get because these the spectra in the transition era.

253
00:36:43.740 --> 00:36:51.360

Jens Chluba: Are not just given by the superposition of the three extreme cases. So this gives you time to been information which is really interesting. And one of the things that has

254
00:36:51.900 --> 00:36:58.770
Jens Chluba: Been reasonably understood more and then there's also something happening with hydrogen and helium recommendation which I will get to hopefully at the end.

255
00:37:00.030 --> 00:37:10.500
Jens Chluba: Okay, and then we can also talk not about energy needs. But we can also talk about injection of photons. And in that case, you actually get distortions in particular in the late phases like the wild type era.

256
00:37:10.830 --> 00:37:17.430
Jens Chluba: And you actually get distortions which can be much much richer and I will come back to that hopefully at the end of the talk, but

257
00:37:17.730 --> 00:37:24.030
Jens Chluba: It is not the standard me and white type distortions which you're getting there. But you can actually formalize and compromise.

258
00:37:24.330 --> 00:37:30.480
Jens Chluba: The distribution function. So you get actually really interesting signals and they can tell you something about the nature of the injection process. For example,

259
00:37:31.350 --> 00:37:41.280
Jens Chluba: We also understand the fundamental processes, really, really well. Now companies getting I mentioned already, there's the other thing which you need to do is adjust the photo number

260
00:37:41.880 --> 00:37:50.760
Jens Chluba: That is branch trunk, which is which. Everybody knows about. And then there's the so called double counting process. I don't want to go into details, but we can now calculate is really, really accurately and and

261
00:37:51.030 --> 00:37:58.260
Jens Chluba: There has been actually recent work which which really made this now very precise although these are very classical processes. There was no way

262
00:37:58.890 --> 00:38:09.720

Jens Chluba: A simple way to just include this calculation in an efficient and quick way. And now we are we are able to do this. Okay, so let's go back to this, this

263
00:38:10.560 --> 00:38:19.050
Jens Chluba: Spectrum the measurement of virus. Here's these numbers mean why so I introduced you and why, but I didn't mention them before we see that these numbers are extremely small.

264
00:38:19.440 --> 00:38:32.460
Jens Chluba: So why is this interesting at all. Well, the numbers are very, very small. But there's of course a lot of experimental progress that we know has happened and see me as a trapeze. You know, from Colby to plank. Lots of sensitivity and

265
00:38:33.240 --> 00:38:34.680
Jens Chluba: Resolution improvement.

266
00:38:35.160 --> 00:38:46.140
Jens Chluba: And in, in the spectral distortion domain. We're still 25 years behind where basically still talking about Coby fire as being the state of the art which is which is really outstanding achievement of copy fires, but

267
00:38:46.350 --> 00:38:50.100
Jens Chluba: Of course, we understand that there's possibilities. Got to go beyond and

268
00:38:51.000 --> 00:38:55.680
Jens Chluba: You probably have heard about Pixie as one of the concepts that has been pushed forward in this direction.

269
00:38:56.070 --> 00:39:06.240
Jens Chluba: And this is something that people have talked about it, both in connection with the primordial Deimos as well as spectral distortions, where the hope is to improve the spectrum distortion measurements by a factor of

270
00:39:07.650 --> 00:39:08.610
Jens Chluba: Basically 1000

271
00:39:09.660 --> 00:39:14.040
Jens Chluba: So I don't want to go into the experimental details here, but this is not the only idea.

272
00:39:14.460 --> 00:39:26.370
Jens Chluba: Because since then there have been several ideas put put forward. So for example, let's see. Sarah experiment which is the ground based bolometer array which might be looking at for the low frequency recommendation lines.

273
00:39:26.640 --> 00:39:36.180
Jens Chluba: And it's basically just above the 21 centimeter lines of our of our galaxy. So in the two to six gigahertz regime so very low frequency measurements.

274
00:39:36.570 --> 00:39:46.020
Jens Chluba: And I just spoke to Robbie Subramanian and he's now moved to Australia and he's actually going to pick up this kind of thing again and now put some prototype development and

275
00:39:46.830 --> 00:39:56.850
Jens Chluba: And there's also initiatives with the Italian colleagues, which are trying to measure the me the white of distortion from the ground because my dorm see using the facilities that have

276
00:39:57.510 --> 00:40:04.680
Jens Chluba: The Concordia station that don't see. And this is not just an idea. This is actually happening. So here's the deal, but the study

277
00:40:04.920 --> 00:40:14.190
Jens Chluba: Putting together some of the Christ that Sylvia Massey is here and and Paolo divine others. These are the folks, which are really pushing this forward and it's really exciting to see that this is real, right.

278
00:40:14.730 --> 00:40:25.200
Jens Chluba: We also have had many activities. Here is a workshop that we organized a couple of years ago at CERN a sheet here in the front. Very happy. Super soccer as well and

279
00:40:25.770 --> 00:40:35.610
Jens Chluba: Mark is somewhere in the back. And here's our cohort. And we're all discussing, you know, what are the interesting things. Want to do and what are the experimental things that we have to

280
00:40:35.850 --> 00:40:50.700
Jens Chluba: How can we get this really happening. And he was also talking about ideas to go even to the moon. And luckily, my camera was

not having you know something was going wrong with this. But yeah, this is one of the ideas that was was being put forward there as well.

281
00:40:51.810 --> 00:41:00.690
Jens Chluba: Okay. And then, of course, also in general we know there's the Decatur review, we have been putting forward white papers and that we have actually proposed to confess

282
00:41:00.870 --> 00:41:08.430
Jens Chluba: Several concepts of, you know, going for spectrum distortions and this is all something that is actually looking like it's, you know, there's many, many

283
00:41:09.120 --> 00:41:21.180
Jens Chluba: Promising avenues. And then last but not least, boys 2015 is the big call from the ISA from from the European Space Agency to actually ask for what is the kind of experimental possibilities. One would

284
00:41:21.570 --> 00:41:29.670
Jens Chluba: Be looking at and there we again have put forward some white papers explaining what is really interesting about this. So lots of activity and

285
00:41:30.780 --> 00:41:37.770
Jens Chluba: I want to put into perspective now several signals and which I think will be very helpful. So here's

286
00:41:38.220 --> 00:41:48.930
Jens Chluba: Basically redshift. And here you heard about the reason why type distortion. So the meeting type distortion in the early phases and then the white type distortion in the late phases and here. Think of this

287
00:41:49.140 --> 00:41:57.210
Jens Chluba: Vertical Axis signals level. And here's a couple of experimental concept. So I was in the scale is up here then zoo as balloon.

288
00:41:58.290 --> 00:42:05.220
Jens Chluba: Is probably going to reach somewhere there. And then as you see here, and more and more ambitious experimental concepts which have been discussed

289
00:42:05.730 --> 00:42:09.750
Jens Chluba: So let's, let's put a pull up the sun that signals that we expect

290
00:42:10.710 --> 00:42:21.660
Jens Chluba: These are coming from the lower Richard universe, the largest signals are coming actually from a Z clusters. The calculate the flux of A, Z clusters. Basically, the app scattering of the CD photons and their relativistic correction.

291
00:42:22.710 --> 00:42:31.830
Jens Chluba: Intensity mapping and landscaping signals. These are things that you can and principal be looking at, at the larger scales was lower resolution absolute spectroscopy.

292
00:42:32.640 --> 00:42:41.340
Jens Chluba: And then the other expected signals. As you can see several orders of magnitudes in sensitivity. You have many, many

293
00:42:41.640 --> 00:42:50.190
Jens Chluba: Orders of magnitude of gains that you need in order to tap the signals. So one of the most promising and interesting signals in terms of cosmology is the damping signal.

294
00:42:50.700 --> 00:43:01.560
Jens Chluba: From the damping of acoustic modes at small scales. And then there's the recommendation lines which are also extremely interesting. I will probably try to skim over them, if I have enough time.

295
00:43:02.310 --> 00:43:14.280
Jens Chluba: And so these are the guaranteed signals and you can in principle design your experiments to get them. And as you can tell, here from the scale things like super Pixie and virus 2015 very ambitious experiments they might actually be able to get there.

296
00:43:15.120 --> 00:43:21.000
Jens Chluba: Okay, but then even if you don't reach to these levels of precision, there's still a huge

297
00:43:21.570 --> 00:43:27.750
Jens Chluba: Amount of discovery space, we can actually, you know, by just reducing the limits on the new parameter we can actually probe.

298
00:43:27.930 --> 00:43:39.510
Jens Chluba: Many, many processes. And this is, of course, extremely interesting. In particular, when you think about non standard physics which we have, you know, heard about many, many occasions like annihilation decaying particles.

299
00:43:40.140 --> 00:43:47.790
Jens Chluba: Primordial black holes magnetic fields and even small scale enhancement of the perspective. So this is really exciting and

300
00:43:48.840 --> 00:43:55.230
Jens Chluba: I think there will be lots of progress in this direction and more understanding of what's going on and I'm really glad that I have a big team.

301
00:43:55.470 --> 00:44:01.320
Jens Chluba: In Manchester now helping me with with this big challenge not only doing the theoretical calculations, but also

302
00:44:01.830 --> 00:44:07.800
Jens Chluba: Looking at the at the experimental possibilities and optimizing designs of experiments and so on. There's a long way to go.

303
00:44:08.700 --> 00:44:24.120
Jens Chluba: Okay, I want to go quickly through a couple of cases in more detail. So here's the white distortion from the accumulated flux of clusters in the universe, and I will just mention this as as a booming signal, this will be guaranteed.

304
00:44:24.630 --> 00:44:31.890
Jens Chluba: Detection even with former Monday marginalization, we have very little doubt that this could be reachable from from space for sure.

305
00:44:32.280 --> 00:44:44.040
Jens Chluba: And it's it's white hat distortion of the auto tend to my six. So here's the negative branch. He has the now at 278 gigahertz. And this is the positive France, where you have the app scattering of photons and then you have here the relativistic reaction to it.

306
00:44:44.280 --> 00:44:51.330
Jens Chluba: Because the clusters are hot. They have several kV temperature. So you actually need to take into account that they have relativistic at high

307
00:44:51.690 --> 00:44:59.610
Jens Chluba: Speeds the electrons in the, in the medium and therefore you get rid of the corrections if you measure both of these parts you can actually look at

308

00:45:01.110 --> 00:45:13.680
Jens Chluba: And you can actually constrain here in the y versus relativistic temperature plane, you can actually constrain Feedback models and things like that. So you can learn something about the late universe and formation of universe and in

309
00:45:14.400 --> 00:45:15.120
Jens Chluba: 12 seconds.

310
00:45:16.050 --> 00:45:18.330
Jens Chluba: Okay, I was predicting but okay.

311
00:45:19.140 --> 00:45:30.870
Jens Chluba: Good. Let's move on to the acoustic modes, the acoustic modes are really one of the things that the cosmologists I'm most excited about. So you have the small scale perturbations and the universe and they are dumping away by South tapping

312
00:45:31.260 --> 00:45:35.730
Jens Chluba: And that so sampling process is actually the equivalent of an energy release process because when you take

313
00:45:36.030 --> 00:45:43.950
Jens Chluba: black bodies of different temperatures. So here a picture was to temperatures and you just take the sum of their spectra, you don't get the black body anymore.

314
00:45:44.160 --> 00:45:51.840
Jens Chluba: And taking the summer spectra is the mixing process and the mixing process is nothing else than Thompson scattering swelling up the medium making everything uniform

315
00:45:52.230 --> 00:46:01.770
Jens Chluba: So this creates initially a wider distortion and then through customization, you get the mood type distortion. So this is one of the predicted signals just coming from the small scale extrapolation of the

316
00:46:02.130 --> 00:46:15.360
Jens Chluba: Acoustic modes from scale up perturbations and this is here the calculation that predicts that the sun that extra extrapolated power from plank should be giving a new type distortion of two times 10 minus eight.

317
00:46:15.780 --> 00:46:22.650

Jens Chluba: And they are about. It's coming from the uncertainties in the parameters predicting the or describing the power spectrum of the of the models.

318
00:46:23.040 --> 00:46:32.730
Jens Chluba: So which modes are important for plunk we're looking at, you know, scales of k of tend to minus four to 10 to, let's say, one for large scale structure and plank and so on.

319
00:46:33.000 --> 00:46:40.080
Jens Chluba: And then we have many, many modes at small scales as well, in principle, one would expect a flat power spectrum. If you think about inflation.

320
00:46:40.530 --> 00:46:52.680
Jens Chluba: But we have only prob these and there's upper limit of course a very small scales spectral distortions will prob modes at the rate in the range of one inverse to a few times 10 to the four and verse makeup.

321
00:46:52.770 --> 00:46:53.220
Morgan Elowe MacLeod: Sex.

322
00:46:53.340 --> 00:46:56.250
Jens Chluba: So very small scales. And if you actually make the numbers.

323
00:46:56.250 --> 00:47:04.350
Jens Chluba: From Tyrus then you can say Simon Says already ruled out power in excess of order temperaments five and the perturbations scale up perturbations.

324
00:47:04.590 --> 00:47:15.120
Jens Chluba: And with Pixie with a pixie tab experiment after foreign marginalization. You even you would be pushing this down. And of course, if you go super Pixie and boys 2050. You could even reach down to the level of

325
00:47:15.720 --> 00:47:22.980
Jens Chluba: The prediction predicted extrapolated power. So this is a guaranteed signal if you believe lameness EDM and

326
00:47:23.310 --> 00:47:29.460
Jens Chluba: The standard slow roll paradigm, but there's nobody telling you at this point that this is of course going to work.

327
00:47:29.640 --> 00:47:34.110
Jens Chluba: And we know that there's indications for things like primordial black holes, maybe being present. That means

328
00:47:34.290 --> 00:47:43.620
Jens Chluba: We need to have at smaller scale some enhancement of power and if you have some enhancement here, then you need to go to low power there. That means you have some intermediate

329
00:47:43.890 --> 00:47:49.950
Jens Chluba: Range, where you have some increase of power. That means there is a way to probe these kind of scenarios in a very similar way.

330
00:47:50.280 --> 00:47:58.530
Jens Chluba: You can think about small scales being suppressed. For example, we know about the missing satellite problem and too big to fail or these small steps crisis.

331
00:47:58.650 --> 00:48:13.200
Jens Chluba: If there is a primordial origin of that indeed the power spectrum is actually suppressed, then you would predict that the distortion has to be zero or very small so there's basically ways all this signifies is you have ways to approach this Mosca power spectrum.

332
00:48:14.220 --> 00:48:19.800
Jens Chluba: And I'm very excited to also say a few words about gravitational waves which can be proof with with

333
00:48:20.250 --> 00:48:32.220
Jens Chluba: Spectral distortions, because these gravitational waves. They also induce acoustic modes and those acoustic modes dissipate and if you hear, look at you know the gravitational wave power spectrum, basically.

334
00:48:32.850 --> 00:48:37.800
Jens Chluba: And you can see light bird and things like that, through measurements of our that can measure the large scales.

335
00:48:38.070 --> 00:48:45.180
Jens Chluba: And the small scales are appropriate. Many, many experiments spectral distortions would be probing regimes right in the middle between these two.

336
00:48:45.660 --> 00:48:54.870

Jens Chluba: And this is work that Tom kite and Andrea have any I've just completed. This is the details on the archive and it was really interesting because bridging the gap between the two.

337
00:48:55.530 --> 00:49:01.680
Jens Chluba: regimes and you can think about things like phase transitions non standard physics. So this is exciting and interesting

338
00:49:02.220 --> 00:49:08.310
Jens Chluba: I don't have much time left but I want to just very briefly mentioned, if you have I mentioned the photon injection cases.

339
00:49:08.640 --> 00:49:14.190
Jens Chluba: But that was single injections. So these are the signals that were calculated. But if you now do the cane particles.

340
00:49:14.430 --> 00:49:24.000
Jens Chluba: You actually think of photons being injected, you can get a wide range of spectra and wide range of signals and I don't have time to go into details here, but this is work that I'm doing with forest, but yeah.

341
00:49:24.330 --> 00:49:33.840
Jens Chluba: I'm was just moved to to Columbia University and we are actually using this to constrain the lifetime and the energy of the particles that could be injecting

342
00:49:34.260 --> 00:49:45.990
Jens Chluba: Energy and we're talking here about very small muscles of articles or excited states of that matter and using virus and state that this is a paper that we're about to finish, I hope. Next week, maybe it will come out.

343
00:49:46.770 --> 00:50:02.310
Jens Chluba: Okay, I have 14 minutes 50 seconds. And I want to talk about the forums, very quickly. But I also want to mention the recommendation lines we have now with Luke heart and forecast for this I will be very happy to hear to have questions on this and use my 30 seconds.

344
00:50:02.730 --> 00:50:14.430
Jens Chluba: To talk about the foreground problem, the elephant in the room is that we have glossed over forums, because the signals are tiny. And there's lots of things in the middle.

345
00:50:14.970 --> 00:50:23.700

Jens Chluba: Thermal dust. We know this from from plank and so on. And, but I'm lucky to have material them as a and also the god and my team, we're both

346
00:50:24.270 --> 00:50:33.600
Jens Chluba: Really they understand the challenge and they can deal with all this data I'm I'm without them I wouldn't be able to do any of these calculations.

347
00:50:34.020 --> 00:50:41.850
Jens Chluba: So the nice thing is that we are dealing with it and we're looking at it and we're trying to really estimate what is the challenges with forums.

348
00:50:42.090 --> 00:50:47.670
Jens Chluba: And here's the work that I have done a little bit earlier with Max rabbit bowl and Colin hill.

349
00:50:48.090 --> 00:51:00.630
Jens Chluba: And where we did official forecast, including all kinds of forums and showing what levels of precision, we can get. And this was then picked up and refined by a teacher to use this as forecast for the voice 2050

350
00:51:01.560 --> 00:51:06.960
Jens Chluba: Concepts and you can see here the recommendation lines are basically at the very, very small level here and

351
00:51:07.500 --> 00:51:15.990
Jens Chluba: The signals that we're looking at are very small in comparison to the forefront. So you need to really be measuring very precisely at many, many frequencies and use all the information

352
00:51:16.410 --> 00:51:23.910
Jens Chluba: And we are also now moving beyond the official forecasts. I'm nearly done really taking into account spatial variations and things like that.

353
00:51:24.600 --> 00:51:34.110
Jens Chluba: There's a nice paper that Dita published a couple of months ago now and we're working now on a real detailed forecast, including spatial variations and everything. And it's obvious.

354
00:51:34.350 --> 00:51:38.340

Jens Chluba: That there's many challenges to tackle. How do you include averaging processes.

355
00:51:38.610 --> 00:51:52.440
Jens Chluba: And in fact, when you really want to deal with the problem. It's much better to not use parametric methods, but actually go for a blind methods which are basically ignorant or as ignorant as possible about the forums and the challenges so that you actually end up with

356
00:51:52.980 --> 00:52:04.320
Jens Chluba: Your targeting the signals, rather than trying to reconstruct the four rounds. And then how do we use external information, we will have so many measurements with galaxy catalogs and so on. All this has to be still worked out and I

357
00:52:04.770 --> 00:52:19.200
Jens Chluba: There's a few more bullets here, of course, but I think I should really finish here and just wrap up. There's really exciting avenues forward. I think what spectral distortions. There's guaranteed signals. But there's also predicted unexpected signals or

358
00:52:20.370 --> 00:52:28.440
Jens Chluba: Discovery space you can really learn something about the universe physics and particle physics. So this is really, really interesting and I think

359
00:52:29.310 --> 00:52:41.310
Jens Chluba: We are having the hope that there is maybe going to be some improvements over Coby fire us in the next decades to come, obviously, is very challenging, but it's extremely interesting, I think, thank you. Sorry for being able to walk down

360
00:52:44.400 --> 00:52:44.910
Morgan Elowe MacLeod: Thank you.

361
00:52:45.630 --> 00:52:46.290
Jens Chluba: Very. Thank you.

362
00:52:48.660 --> 00:52:49.830
Jens Chluba: And I take questions, obviously.

363
00:52:49.890 --> 00:53:08.880
Morgan Elowe MacLeod: Yeah. So we have a couple questions that all sort of wrap all into one and maybe we can dig into more of the details later

on. But I think people are wondering, including on and Avi about the nature of the four backgrounds, in particular, and where you think

364
00:53:10.290 --> 00:53:18.150
Morgan Elowe MacLeod: Which foreground, do you think will be easy to deal with. So, and which you think will be the most challenging and if you can elaborate on that.

365
00:53:19.740 --> 00:53:32.580
Jens Chluba: So no foreground will be easy to deal with. And I'm pretty sure it's very, it's a huge dynamic range. We're talking basically several orders of magnitude excess of forums vs vs signal but

366
00:53:33.750 --> 00:53:46.530
Jens Chluba: We can benefit of course from from the Multi Frequency coverage and then that way, really, really help cleaning things and then even low resolution will still be helping you with some of the spatial information that you can have

367
00:53:47.370 --> 00:53:52.680
Jens Chluba: What we found in our work with with Max was that low frequency four rounds in particular.

368
00:53:53.520 --> 00:54:01.290
Jens Chluba: And the coverage at low frequencies was very, very important for detection of me because the signal and the novel is

369
00:54:01.590 --> 00:54:13.590
Jens Chluba: Shifted with respect to the mouth of the wider distortion, the wider distortion has another 278 gigahertz, and the mood distortion has a 230 regards 130 years, excuse me, and

370
00:54:14.670 --> 00:54:24.990
Jens Chluba: This the shift it makes the loo distortion be slightly more degenerate with, for example, the temperature of the monopole and the small uncertainty in the monopole there is just

371
00:54:25.470 --> 00:54:34.590
Jens Chluba: It seems that a lot of information is gleaned and in fact from the low frequency part so wipe distortions, if we if we, for example, take away

372
00:54:35.040 --> 00:54:47.280

Jens Chluba: Low Frequency coverage than the meetup distortion is just starting to become harder to detect and so I think low frequency four rounds are our challenge and they are we have things like the Amy.

373
00:54:47.730 --> 00:54:56.550
Jens Chluba: The anomalous microwave permission. We also have right in the middle here the integrated CO2 emission, which obviously has also been, I've been working on and

374
00:54:56.880 --> 00:55:01.020
Jens Chluba: In this context, and showing that it is of course a signal, one should worry about

375
00:55:01.680 --> 00:55:13.740
Jens Chluba: But luckily, this is again where the synergistic aspect might be coming into play. We are hoping that we will have tons of galaxy cutter looks at that at some point as well and we will maybe be able to even, you know, to some extent.

376
00:55:14.370 --> 00:55:24.000
Jens Chluba: Model in some way, at least part of this, this kind of signal. And then we also can hope for low frequency coverage, maybe even being being done or

377
00:55:24.570 --> 00:55:37.830
Jens Chluba: Permitted, at least in terms of another trapeze from the ground with things like CBS and and there's there's many there's several experiments which are also relevant to the remote services, of course, and seeing being so

378
00:55:39.510 --> 00:55:50.880
Jens Chluba: Then, then I want to say immediately. A few things to the the dust and Civ, of course, they are not single temperature modified, Back, Body spectra and that's where, for example.

379
00:55:51.750 --> 00:56:02.040
Jens Chluba: Things like blind methods will come in. You want to not put in absolute parametric fits and then realize that you're having big residuals, which you're not going to get

380
00:56:02.610 --> 00:56:09.870
Jens Chluba: Not come to capture and but you will reduce them, of course, and but if you think about semi blind methods.

381
00:56:10.350 --> 00:56:16.200

Jens Chluba: Where you actually do something like the IOC methods in CB analysis where you actually include some

382
00:56:16.830 --> 00:56:21.990
Jens Chluba: Knowledge about the signal. So for example in CB the spectrum of the same either the temperature derivative

383
00:56:22.950 --> 00:56:32.340
Jens Chluba: Or the white type distortion or the meetup distortion, those would be signal constraints, but you can then also put constraints on things like the dust and dust.

384
00:56:33.000 --> 00:56:42.450
Jens Chluba: And also it spectral index and things like that. So these are moments of the distribution functions which are literally capturing averaging effects. So we are hoping that by

385
00:56:42.960 --> 00:56:46.560
Jens Chluba: Subsequently, adding more and more constraints which also costs, of course.

386
00:56:47.370 --> 00:56:54.030
Jens Chluba: Signal to noise that one can actually get a, get rid of layer by layer these signals and the projections

387
00:56:54.330 --> 00:57:03.780
Jens Chluba: On on to each other are, of course, getting more and more small and they're wonderful. By the way, say, although this white this distortion from recommendation is very, very low.

388
00:57:04.200 --> 00:57:19.380
Jens Chluba: On the scale. You can see it's lower even of order one 110 times lower than the view distortion, because it has many spectral beta features is actually is somehow easier to detect and disentangle from from four rounds, because it has many, many features.

389
00:57:21.030 --> 00:57:31.560
Jens Chluba: Yeah so low frequency forums for me distortion are definitely a big challenge of but but obviously everywhere. We are talking about many orders of layers of peeling off. But I'm always thinking

390
00:57:31.770 --> 00:57:39.120

Jens Chluba: About the analogy of gravitational wave detection, where you have to you know make sure that everything is isolated and no tend to minus nine.

391
00:57:39.570 --> 00:57:48.690
Jens Chluba: Whatever effects get propagated to the final signal so i i think i think with obviously enough data and creative methods we might be getting there.

392
00:57:49.950 --> 00:58:05.070
Morgan Elowe MacLeod: I mean a lot of sense. And also your comments on the spectral features makes a lot of sense and how we can use them because I mean I think about even like transiting planet detections. We don't need stable for telemetry over long times, but you can still detect those features.

393
00:58:05.070 --> 00:58:05.730
Morgan Elowe MacLeod: Right, right.

394
00:58:05.820 --> 00:58:10.980
Morgan Elowe MacLeod: Yep. Yeah, maximizing those noodles and that sort of thing seems really interesting forward.

395
00:58:12.570 --> 00:58:20.340
Morgan Elowe MacLeod: I wondered if Julian minutes. Do you want to unmute yourself and pick one of the questions that you asked to ask live

396
00:58:20.910 --> 00:58:32.400
Julian Munoz: Yeah, sure. I mean, I was wondering, yes, we have this big why distortion from clusters. But this this other new physics processes might be there. How can you distinguish between the moon frequency signal is about the same.

397
00:58:33.240 --> 00:58:34.140
Jens Chluba: Yeah, so, so

398
00:58:35.250 --> 00:58:42.090
Jens Chluba: This is a great question. So the wipe distortion. This is one of the things that I mentioned very big at the very beginning can be formed.

399
00:58:42.330 --> 00:58:49.410
Jens Chluba: Both from very low righteous by clusters as Julian Assange and that's the dominant signal, but we can, in principle, have a wider distortion also formed

400
00:58:50.280 --> 00:58:53.160
Jens Chluba: Around recommendation, just by heating of the electrons.

401
00:58:53.760 --> 00:59:08.820
Jens Chluba: In that case, you wouldn't be talking about million Calvin electrons up scattering photons, we normally would normally talk about just like a small temperature difference between electrons and protons and those processes a priori cannot be directly distinguished however again.

402
00:59:09.870 --> 00:59:22.620
Jens Chluba: clusters of galaxies is one of those things. And somehow, people often think of this as a you know a reason why spectral distortions might not be as interesting in the sense of for the cluster physics you have

403
00:59:23.100 --> 00:59:30.150
Jens Chluba: You will have many, many measurements of all I did, yes. Here you will have many measurements from X rays.

404
00:59:30.540 --> 00:59:37.260
Jens Chluba: You will have many measurements even logical structure measurements and that way you can actually model, or at least resolve and

405
00:59:37.950 --> 00:59:44.760
Jens Chluba: large fraction of the of the population of clusters that will contribute. Now this is here. Basically, the relative contribution as a

406
00:59:45.540 --> 00:59:53.340
Jens Chluba: Mass of the system and spectrum distortions get, you get you're still 20% more systems. So it's not like everything is totally

407
00:59:53.670 --> 01:00:03.480
Jens Chluba: The same. But in principle you could hope for taking these clusters and actually reducing at least the the contribution by some significant fraction and potentially

408
01:00:03.990 --> 01:00:15.750
Jens Chluba: Through cross correlations. You can maybe even, you know, take some additional layers or so this might be allowing you to push this you know detection limit. Let's say for primordial why distortions to

409

01:00:16.050 --> 01:00:26.190
Jens Chluba: Maybe a little bit lower, maybe a factor of 10 maybe even dreaming, a factor of Android lower. So to 1% precision. Let's say we can maybe take away some of this.

410
01:00:26.370 --> 01:00:29.100
Abraham Loeb: You still have randomization. In addition to cluster.

411
01:00:29.130 --> 01:00:36.690
Jens Chluba: Correct. And I was about saying the realization. One is something that you want to actually measure as well. And that's roughly one order of magnitude.

412
01:00:37.050 --> 01:00:43.380
Jens Chluba: You know, depending on if you take the oversea quite square terms into account two orders of magnitude. That's where these signals are

413
01:00:44.010 --> 01:00:55.170
Jens Chluba: And you want to measure them as well. So if you had a factor of 10 reduction, you actually start seeing those yes I agree with it. That's very important point. Yes, thank you. And then there is also some interesting

414
01:00:56.460 --> 01:01:05.760
Jens Chluba: Atomic Physics that allows you to principal distinguish tree recombination wine stores and some post recombination why distortions, because if the CB is actually a distorted.

415
01:01:06.030 --> 01:01:10.980
Jens Chluba: Then the spectrum that we would be calculating with the recommendation lines does not look

416
01:01:11.640 --> 01:01:18.330
Jens Chluba: Like this spectrum, but there will be small changes in the in the features and even you can even have cases where you can get

417
01:01:18.900 --> 01:01:29.070
Jens Chluba: A strong changes in the features, depending on how much distortion in the pre recommendation University already have presence and I'm now working on a very detailed paper in that direction.

418
01:01:29.340 --> 01:01:39.720

Jens Chluba: And that would be telling you. Oh, there's actually a why distortion type introduced that earlier times, and that would be another way of labeling things. But yeah, this is this is definitely

419
01:01:40.350 --> 01:01:49.980
Jens Chluba: Important. So why that part cannot be used to constrain new physics as easily. But the mu time part is something that's unique to the early universe.

420
01:01:52.290 --> 01:01:53.040
Julian Munoz: That's great. Thanks again.

421
01:01:55.020 --> 01:02:03.900
Morgan Elowe MacLeod: Thank you so much. I think we should probably close there and but there are more questions than I was able to ask live online and yeah

422
01:02:03.960 --> 01:02:17.220
Morgan Elowe MacLeod: That's all, thank both of our speakers. Again, we're really grateful for you taking the time and and balancing the time zones to be here with us during a time of a lot of challenges. So thank you so much.

423
01:02:17.550 --> 01:02:21.480
Jens Chluba: Thank you. Thanks a lot. Yeah. Um, so on Slack. There is more questions, I will. That's

424
01:02:21.480 --> 01:02:22.290
Morgan Elowe MacLeod: Right, yeah.

425
01:02:22.410 --> 01:02:23.010
Jens Chluba: Yeah, great.

426
01:02:23.190 --> 01:02:23.670
Morgan Elowe MacLeod: Okay, thanks.

427
01:02:23.910 --> 01:02:25.320
Jens Chluba: A lot everybody. Yep.

428
01:02:25.830 --> 01:02:26.310
Morgan Elowe MacLeod: Thank you.

429
01:02:26.400 --> 01:02:26.700

Then

430
01:02:28.770 --> 01:02:29.790
Wren Suess (she/her): Again for organizing

431
01:02:30.150 --> 01:02:30.810
Morgan Elowe MacLeod: Really, yeah.

432
01:02:30.870 --> 01:02:32.130
Jens Chluba: Exactly. Thanks a lot. Yeah.

433
01:02:33.270 --> 01:02:34.230
Ana Bonaca: I'm happy to have you.

434
01:02:47.550 --> 01:02:49.770
Morgan Elowe MacLeod: Do you want to

435
01:02:52.170 --> 01:02:56.520
Morgan Elowe MacLeod: switch to another channel. And maybe you can end the recording.